Working group on water issues of the

Federal States and the Federal Government

Group of Experts on "Impacts of Climate Change on Water Management"

&

Permanent Committee "Climate Change" (LAWA AK)

Impacts of Climate Change on Water Management

Stocktaking, scope for action and strategic fields of action

2020

Adopted by LAWA by circular letter 12/2020 on 22 December 2020

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Publication data

Impacts of Climate Change on Water Management - Stocktaking, scope for action, and strategic fields of action 2020 (LAWA Climate Change Report 2020)

Publisher:

German Working Group on Water Issues of the Federal States and the Federal Government (LAWA)

Bavarian State Ministry of the Environment and Consumer Protection (StMUV)

Rosenkavalierplatz 2

81925 Munich

This publication is available for download from the LAWA website (www.lawa.de).

Drafted/copy-edited/designed by:

Group of Experts on "Impacts of Climate Change on Water Management" of the LAWA Permanent Committee "Climate Change"

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Image credits:

Image p. 58, Example 7:	Judith Sprenger
Image p. 67, Example 11:	ecolo GmbH & Co. KG im Auftrag des Projektes KLAS (http://www.klas-bremen.de)
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Image p. 132, Example 35:	State Reservoir Administration of Saxony
Image p. 137, Example 37:	Government of Lower Franconia
Image p. 139, Example 38:	Government of Lower Franconia

Available online at:

https://www.lawa.de/Publikationen-363-Anpassung-an-den-Klimawandel.html

Last updated:

2 December 2020

Proposed citation:

LAWA (2020): Impacts of Climate Change on Water Management - Stocktaking, scope for action, and strategic fields of action 2020 (short form: LAWA Climate Change Report 2020). German Working Group on Water Issues of the Federal States and the Federal Government (LAWA).

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Foreword

Dear Readers,

Climate change is indisputable. Despite all mitigation actions taken, greenhouse gas emissions are continuing to rise worldwide and are causing global warming. Even if the goals established at the Paris Climate Conference (COP 21) are met, climate change can not be halted. Precautionary environmental policy now demands that comprehensive action is taken to prevent harm to humankind and the natural environment.

The Conference of German Environment Ministers, at its 86th session on 17 June 2016, therefore commissioned the German Working Group on Water Issues of the Federal States and the Federal Government (LAWA) to appraise the impacts of climate change on water resources management and to identify the need for water management responses.

Consequently, after seeking input from all stakeholder groups, LAWA prepared a comprehensive report in 2017 on the concerns, potential responses and strategic fields of action in water resources management and updated the report in 2020. This report is designed to provide guidance for practitioners and is therefore intentionally application-oriented. For, even today, climate change must be kept in mind when performing ongoing water management tasks. The goal should be to make water management measures climate-resilient and thus minimise the future costs of adaptation. This report advances that goal by assisting water management administrations, local authorities and planners in implementing the relevant plans and directives such as the EU Water Framework and Floods Directives. The report moreover presents to the interested professional community examples of best practice and fundamental decision-making aids for integrating climate adaptation measures in their day-to-day water management activities.

Climate change presents a major challenge to society. To cope with this task, it is essential to have a well-equipped water administration that is capable of operating in a forward-looking and interdisciplinary manner. This will require a firmer focus on planning processes, with consideration of what-if scenarios. This approach depends crucially on the fundamental data provided by hydrological services and on long-term monitoring of both climate impacts and the outcomes of adaptation measures.

At the same time, we must not lose sight of the fact that climate change is currently the most discussed phenomenon of the Anthropocene age, but it is far from being the only one.

Even without climate change, the challenges for water management are becoming more formidable. At what point will the resilience of our ecosystems be exhausted? The increase in chemicals (e.g. trace substances, increasing use of pharmaceuticals) is a concern for water quality. Overall, these effects will demand more of us than ever before.

LAWA is aware of its particular responsibility in this regard and invites the other sectors to engage in professional dialogue in order to maintain an overview of the challenges, resolve conflicts in goals and jointly use synergies. The challenges of the Anthropocene age and particularly climate change can only be met through concerted action.

My thanks go to all those who have contributed to the successful production of this report and its update.

Prof. Dr-Ing. Martin Grambow

Chair of German Working Group on Water Issues of the Federal States and the Federal Government (LAWA)
Bavarian State Ministry of the Environment and Consumer Protection

Note

In the present report "Impacts of Climate Change on Water Management 2020", the following chapters have been updated since the 2017 report:

Foreword

2 Introduction

3 Climate change in Germany

3.2 Climate modelling, uncertainties and ranges

3.2 Observed regional climatic changes

3.3 Future regional climatic changes

3.4 Extreme events

4 Water – impacts of climate change

Introduction chapter 4

4.1 Surface waters

4.2 Groundwater

4.2.2 Groundwater quality and temperature

4.3.1 Sea level

5 Concerns, climate adaptation measures and practical examples

Introduction chapter 5

5.2.1 Concerns

5.2.2 Climate adaptation measures

Additionally, several practical examples in chapter 5 were updated to reflect current situation.

6 Strategic fields of action

6.1 Introduction

6.2 Concerns – understanding and describing climate change

Annex I: List of references and links to web content published by the federal states (Länder) and the federal government

Climate adaptation measures and options for action

In addition, formulations were changed, terms were corrected (e.g. stringent use of the terms "climate adaptation measure" and "option for action") and spelling mistakes were corrected, all of which have no bearing of the content of the report.

1 Abstract (German / English / French)

Die Erwärmung des globalen Klimasystems ist eindeutig, entsprechende Veränderungen können auch in Deutschland beobachtet werden. Im langzeitigen linearen Trend steigen sowohl die mittlere Jahrestemperatur als auch die jährliche Niederschlagshöhe in Deutschland an, wobei es v. a. bei der jährlichen Niederschlagshöhe regionale Unterschiede gibt. Dies hat Auswirkungen auf verschiedene Komponenten des Wasserhaushalts und der Gewässer.

Der Klimawandel stellt eine zentrale Herausforderung für die Gesellschaft dar, mit vielfältigen Auswirkungen auch auf die Wasserwirtschaft. Die LAWA-Vollversammlung hat im Mai 2016 eine Expertengruppe damit beauftragt, das aus dem Jahr 2010 stammende Strategiepapier „Auswirkungen des Klimawandels auf die Wasserwirtschaft – Bestandsaufnahme und Handlungsempfehlungen" unter Berücksichtigung der neu gewonnenen Erkenntnisse und Aktivitäten der Länder und des Bundes zu überprüfen und weiterzuentwickeln. Dabei soll der Inhalt aktualisiert, erweitert und konkretisiert sowie mögliche Anpassungsmaßnahmen in den wasserwirtschaftlichen Handlungsfeldern definiert werden. Die Aufgabenstellung zielt dabei nicht auf den Klimaschutz, sondern auf die Bewältigung der nicht mehr aufzuhaltenden Folgen des Klimawandels für die Wasserwirtschaft.

Der anwendungsorientierte Bericht schildert knapp, wie sich die Änderung der Klimaelemente (Temperatur, Niederschlag, Wind, etc.) auf Oberflächengewässer, Grundwasser sowie die Ökologie der Gewässer auswirkt. Betrachtet werden dabei der oberirdische Abfluss (Abflussregime, Niedrigwasser, Hochwasser, Sturzfluten), Gewässer- und Meeresökologie, Grundwasser (Grundwasserneubildung, Grundwasserbeschaffenheit und -temperatur) sowie Küstengewässer und Ästuare (Meeresspiegel, Sturmfluten, Seegang und morphologische Änderungen). Zunehmende Hitzeperioden, häufigere und stärkere lokale Starkregenereignisse oder ein beschleunigter Meeresspiegelanstieg sind nur einige der diskutierten Auswirkungen des Klimawandels, die hier zu nennen sind.

Der Bericht geht dann ausführlicher auf die Betroffenheit folgender 15 wasserwirtschaftlichen Handlungsfelder ein:

- Binnenhochwasserschutz und Schutz vor hohen Grundwasserständen,
- Küstenschutz,
- Siedlungsentwässerung und Abwasserreinigung,
- Überflutungsschutz: Starkregen und Sturzfluten,
- Niederungsentwässerung an der Küste,
- Meeresschutz,
- Gewässerökosystemschutz,
- Grundwasserschutz und Grundwassernutzung,
- Öffentliche Wasserversorgung,
- Kühlwasserverfügbarkeit,
- Wasserkraftnutzung,
- Schiffbarkeit,
- Wasserentnahme zur Bewässerung in der Landwirtschaft,
- Talsperren- und Speichermanagement,
- Niedrigwassermanagement in Fließgewässern.

Zu jedem dieser 15 Handlungsfelder werden exemplarisch zwei bis drei Praxisbeispiele vorgestellt. Insgesamt enthält der Bericht 38 Praxisbeispiele mit Kurzbeschreibung und Angaben zu Zielen, Zeitraum der Umsetzung, Finanzierung, Beteiligten, Herausforderungen, Lösungen und Erfolgen sowie Ansprechpartnern. Die zu den Handlungsfeldern identifizierten möglichen Klimaanpassungs-

maßnahmen und Handlungsoptionen sind im Anhang in 110 Tabellen dargestellt. Zu jeder Klimaanpassungsmaßnahme werden – soweit möglich – Ziele, Anlass, Umsetzung, Entscheidungsgrundlagen, zuständige Akteure, Synergien, Abwägungsbedarf und – falls bekannt – auch einige Praxisbespiele benannt. Auf Quervernetzungen in den wasserwirtschaftlichen Handlungsfeldern wird hingewiesen.

Insbesondere für politische Entscheidungsträger werden strategische Handlungsfelder beschrieben und Zielkonflikte benannt. Entsprechend des zyklischen Ansatzes der Deutschen Anpassungsstrategie an den Klimawandel (DAS) wird die zwingend erforderliche Aufrechterhaltung und der Ausbau des Monitorings hervorgehoben (Betroffenheit – Klimawandel verstehen und beschreiben) und die Struktur der Vulnerabilitätsanalyse vorgestellt (Gefährdung – Gefahren erkennen und bewerten). Es werden Hinweise für die Entwicklung und Planung von Maßnahmen gegeben und nachdrücklich auf die Notwendigkeit von Monitoring anhand geeigneter Klimaindikatoren und deren Evaluation hingewiesen. Die anschließend geschilderten Zielkonflikte bei der Umsetzung von Klimaanpassungsmaßnahmen mit den Belangen der Land- und Forstwirtschaft, der Fischerei, der Energiegewinnung, des Tourismus und der Globalisierung werden nur knapp angerissen. Die vertiefte Betrachtung der sektorübergreifenden Herausforderungen bei der Anpassung an den Klimawandel bleibt der Arbeit weiterer spezifisch zusammengesetzter Arbeitsgruppen vorbehalten.

Zukünftige Aufgabenschwerpunkte werden beispielsweise bei Niedrigwassermanagement / Bewässerung, Stadtentwässerung / Stadtklima und Meeresspiegelanstieg und seinen Auswirkungen auf Flusssysteme bzw. Ästuare gesehen.

Abschließend wird zu folgenden Schwerpunkten des Forschungs- und Entwicklungsbedarfs (F+E) berichtet:

- Allgemeiner und übergeordneter F+E-Bedarf,
- Einfluss des Klimawandels auf Zielgrößen der Gewässergüte,
- F+E-Bedarf Modellrechnung, Werkzeuge und Anwendungen,
- räumliche Verteilung und zeitliche Veränderung von Starkregenereignissen,
- Beispiele für die Anpassungsforschung (Elemente der Regenwasserbewirtschaftung weiterentwickeln, Land- und Forstwirtschaftliche Praxis wasserwirtschaftsgerecht weiterentwickeln).

Ein umfangreiches Literaturverzeichnis, ein Abkürzungsverzeichnis sowie die Anhänge „Klimaanpassungsmaßnahmen und Handlungsoptionen“ und „Literatur- und Linkzusammenstellung der Länder und des Bundes“ runden den Bericht ab.

Abstract

The warming of the global climate system is unambiguous, and accordant changes can also be observed in Germany. In the long term, mean annual temperature as well as annual rainfall show increasing trends, with regional differences, especially in the amount of annual precipitation. This implies impacts on various components of the water balance and on water bodies.

Climate change is a key challenge for society, with manifold implications also for water management. In May 2016, the LAWA General Assembly commissioned a group of experts to review and further extend the strategy paper “Impacts of Climate Change on Water Management - Stocktaking and Recommendations for Action” from 2010 in accordance with newly acquired knowledge and recent activities of the federal states and the federal government. In addition to the update, extension and concretisation of the content, possible adaptation measures in various fields of water management were to be defined in the report. The task is not aimed at climate protection, but at tackling the unstoppable impacts of climate change on water management.

The application-oriented report briefly describes how changes in climate elements (temperature, precipitation, wind, etc.) affect surface water, groundwater and the ecology of water bodies. It considers the above-ground run-off (run-off regime, low water, floods, flash floods), aquatic and marine ecology, groundwater (groundwater recharge, groundwater quality and temperature) and coastal waters and estuaries (sea level, storm surges, swell and morphological changes). Increasing heat periods, more frequent and stronger local heavy rain events or accelerated sea level rise are just some of the discussed impacts of climate change.

The report then details the concerns for the following 15 fields of water management:

- Inland flood protection and protection against high groundwater levels
- Coastal protection
- Urban drainage and wastewater treatment
- Flood protection: heavy rainfall and flash floods
- Drainage of low-lying coastal areas
- Marine protection
- Conservation of aquatic ecosystems
- Groundwater protection and groundwater use
- Public water supply
- Cooling water availability
- Hydropowergeneration
- Navigability
- Water abstraction for irrigation in agriculture
- Dam and reservoir management
- Low water management in watercourses

For each of these fields of action, 2-3 practical examples are presented. In total, the report contains 38 practical examples with brief descriptions of the example as well as indications of targets, the period of implementation, funding, participants, obstacles, solutions and achievements and contact persons. The possible climate adaptation measures (options for action) which have been identified in these fields are contained in Appendix II in 110 tables. As far as possible, objectives, causes, forms of implementation, basis of decision-making, responsible actors, synergies, the need for consideration and, if known, some practical examples are named for each option. Cross-links between the different fields of water management are mentioned.

To address specifically political decision makers, strategic fields of action are described and conflicts of aims are named. In accordance with the cyclical approach of the German Adaptation Strategy to Climate Change (DAS), the absolutely necessary continuation and enhancement of monitoring are emphasized (concern - understanding and describing climate change) and the structure for vulnerability analysis (hazard - identifying and assessing risks) is presented. Hints for the development and planning of measures are given and the need for monitoring by means of suitable climate indicators and their evaluation is stressed. The conflicts, which may arise when climate change adaptation interferes with concerns of agriculture and forestry, fisheries, energy, tourism and globalisation, can only marginally be addressed. An in-depth examination of such cross-sector challenges in climate change adaptation could prospectively be addressed by specifically composed working groups.

The focus of future work could for example be on low water management / irrigation, urban drainage / urban climate and sea level rise and its effects on river systems and estuaries.

Eventually, research and development needs (R & D) are described by focusing on the following aspects:

- General and overall R & D needs
- Impact of climate change on target parameters for water quality
- R & D needs in modelling, tools and applications
- Spatial distribution and temporal change of heavy rainfall events
- Examples of adaptation research (development of elements of rainwater management, development of agricultural and forestry practices in accordance with water management)

A comprehensive bibliography, a list of abbreviations and the appendices “Options for Action” and “Literature and Link Compilation of the Federal States and the Federal Government” complete the report.

Résumé

Le réchauffement du système climatique mondial est évident et des changements significatifs peuvent également être observés en Allemagne. Dans la tendance linéaire à long terme, la température annuelle moyenne et la précipitation annuelle augmentent en Allemagne, avec des différences régionales, en particulier dans la quantité de précipitations annuelles. Cela affecte divers composants du bilan hydrologique et des eaux.

Le changement climatique est un défi majeur pour la société, avec de nombreuses implications pour la gestion de l'eau. En mai 2016, l'Assemblée générale de LAWA a chargé un groupe d'experts de vérifier et de continuer à développer le document stratégique «effets du changement climatique sur la gestion de l'eau – état des lieux et mesures d'adaptation» de 2010 en tenant compte des nouvelles connaissances et des activités des états fédéraux et du gouvernement fédéral. Le contenu du rapport doit être mis à jour, élargi et spécifié et les mesures d'adaptation possibles dans les champs d'action de gestion de l'eau sont à définir. Le sujet du rapport ne vise pas à la protection du climat, mais à la lutte contre les conséquences désormais inévitables du changement climatique.

Le rapport décrit brièvement comment les changements des éléments climatiques (température, précipitations, vent, etc.) affectent les eaux de surface, les eaux souterraines et l'écologie des eaux. Elle prend en compte les écoulements en surface (régime d'écoulement, débit d'étiage, débit de crue, crues soudaines), l'écologie aquatique et marine, les eaux souterraines (recharge des nappes phréatiques, qualité et température des eaux souterraines), les eaux côtières et les estuaires. Les périodes de chaleur croissantes, les pluies fortes locales plus fréquentes et plus marqués ou l'élévation du niveau de la mer ne sont que quelques-uns des effets du changement climatique.

Le rapport aborde ensuite plus en détail les sensibilités au changement climatique des 15 champs d'action suivants liés à la gestion de l'eau:

- la protection contre les inondations à l'intérieur du pays et la protection contre les niveaux élevés d'eau souterraine,
- la protection du littoral,
- le drainage urbain et le traitement des eaux usées,
- la protection contre les inondations : fortes pluies et crues soudaines,
- le drainage des plaines côtières,
- la protection du milieu marin,
- la protection des écosystèmes d'eau,
- la protection des eaux souterraines et l'utilisation de l'eau souterraine,
- l'approvisionnement public en eau,
- la disponibilité d'eau de refroidissement,
- l'utilisation de l'énergie hydraulique,
- la navigabilité,
- les prélèvements en eau pour l'irrigation dans l'agriculture,
- la gestion des barrages et du stockage,
- la gestion des débits d'étiage dans les rivières.

Deux à trois exemples pratiques sont présentés pour chacun de ces 15 champs d'action. Au total, le rapport contient 38 exemples avec une brève description et une indication des objectifs, le temps de mise en œuvre, le financement, les parties prenantes, les obstacles, les conseils et les solutions, et les contacts. Les mesures possibles d'adaptation au climat (options d'action) identifiées dans les champs d'action sont présentées dans un annexe de 110 tableaux. Dans la mesure du possible, les objectifs, le motif, la mise en œuvre, les principes de prise de décision, les acteurs responsables, les synergies, le

besoin de considération et, si connus, quelques exemples pratiques sont nommés pour chaque option. Il est fait référence à la réticulation dans les champs d'action liés à la gestion de l'eau.

Les champs d'action stratégiques sont décrits en particulier pour les décideurs politiques et les objectifs contradictoires sont nommés. Selon l'approche cyclique de la stratégie allemande pour l'adaptation au changement climatique (DAS), l'entretien obligatoire et l'expansion du suivi est mis en évidence (sensibilité - comprendre et décrire les changements climatiques) et la structure de l'analyse de la vulnérabilité est présenté (risque - reconnaître et évaluer les dangers). Des orientations sont données pour le développement et la planification des mesures. La nécessité d'un suivi fondé sur des indicateurs climatiques appropriés et leur évaluation est soulignée. Les conflits cibles décrits ensuite dans la mise en œuvre des mesures d'adaptation au changement climatique avec les intérêts de l'agriculture et de la foresterie, de la pêche, de la production d'énergie, du tourisme et de la mondialisation sont à peine abordés. Un examen approfondi des défis intersectoriels en matière d'adaptation au changement climatique reste réservé au travail d'autres groupes de travail spécifiquement composés.

Les domaines d'intérêt futurs comprennent en outre la gestion des débits d'étiage / irrigation, le drainage urbain / climat urbain et l'élévation du niveau de la mer et ses effets sur les systèmes fluviaux et les estuaires.

Enfin, les points focaux suivants des besoins en recherche et développement (R & D) sont rapportés :

- les besoins généraux et globaux de R & D,
- l'influence du changement climatique sur les paramètres cibles de la qualité de l'eau,
- les besoins en R & D pour le calcul des modèles, les outils et les applications,
- la distribution spatiale et le changement temporel des fortes pluies,
- les exemples de recherche sur l'adaptation (poursuite de développement des éléments de la gestion des eaux pluviales et poursuite de développement des pratiques agricoles et forestières conformément à la gestion de l'eau).

Une vaste bibliographie, une liste d'abréviations et les annexes «options pour l'action» et «compilation de littérature et de liens des états fédéraux et du gouvernement fédéral» complètent le rapport.

2 Introduction

Climate change is one of the principal challenges facing environmental policy today. Despite the many measures being carried out to mitigate climate change, anthropogenic greenhouse emissions are increasing globally, ensuring continuation of the global warming process. Along with mitigation efforts to reduce emissions and thus limit the temperature increase, society, along with water management, must prepare for the possible consequences of climate changes and pursue approaches for adapting to them. Increased frequency of heavy rainfall events, severe flash flooding, river flooding, melting of glaciers and ice sheets, shifting values of typical hydrological regime parameters, and rising sea level are just a few examples. The most important goal must be to confront the many risks of climate change in a timely manner, in order to limit the damage for the collective good and for the national economy as far as possible, and to recognise opportunities for the future.

As early as 2010 the German Working Group on Water Issues of the Federal States and the Federal Government (LAWA) published the strategy paper “Impacts of Climate Change on Water Management – A Review and Policy Recommendations” (LAWA 2010). Since then, not only have significant advances in the understanding of climate change, its consequences, and possible countermeasures and adaptive measures been achieved, but international and national-level developments in climate politics have also produced some early results. Based on the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2014; IPCC-DE 2016) the international community set goals for climate change mitigation and adaptation to its inevitable consequences at the 2015 Paris climate summit.

In the same time frame, in 2013, the European Commission developed an adaptation strategy[1], while the German Strategy for Adaptation to Climate Change (DAS, Bundesregierung 2008) was published at federal level in coordination with the federal states (Länder) and updated with the Adaptation Action Plan (APA, Bundesregierung 2011). In 2015, the German Strategy for Adaptation to Climate Change and the second Adaptation Action Plan (APA II, Bundesregierung 2015) were updated and established as long-term tasks. The second progress report was published in autumn 2020 (Bundesregierung 2020). In addition, Germany's federal states have developed numerous activities on their own and devised climate adaptation strategies tailored to their specific concerns.

At its plenary session in Kressbronn-Gohren on 31 May 2016, the LAWA General Assembly decided to review and refine the 2010 strategy paper in light of the latest findings and activities of the federal states and the federal government. In particular, besides the thematic expansion of content, possible adaptation measures in the various climate-sensitive water-management fields of action were to be identified and further needs for coordination and research were to be specified.

The aim of the present report is to respond to the challenges of climate change that have already been observed and those that are projected, and to make a contribution to sustainable water management that is both environmentally sound and sustainable. As an appraisal and overview of climate adaptation measures and options for action, the paper is application-oriented and is intended to serve as a guide not only for water-management administrators, but also for the interested professional community.

The impacts of climate change on water management in Germany must be taken seriously as they present new challenges and obligations. Presumably, many of the consequences described here will be regionally or temporally limited, or will not be observed until a few decades from now. Usage demands and environmental policy objectives have also changed in recent years (e.g. as a result of demographic change). Future changes in the hydrological regime represent additional challenges for other sectors. A sectoral water management approach alone is insufficient in view of the complex direct and indirect

[1] The Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on an EU strategy on adaptation to climate change (COM(2013) 216 final) is not legally binding.

impacts of climate change, and with regard to the expected adaptations in other sectors such as energy, urban and regional planning, forestry and agriculture, transportation, etc.

Raising awareness among those affected and maintaining dialogue with the stakeholders involved is essential. This must be underpinned at political level by the provision of necessary resources for advancing knowledge and developing and implementing innovative approaches, so that planners and decision-makers at the operational level, for example, can be regularly provided with up-to-date and nationally recognised forecast and projection data on the relevant climate-influencing parameters, or that pilot projects can be developed and implemented.

In this paper, Chapter 3 presents the current state of knowledge with respect to changes in the atmospheric elements of temperature, precipitation and wind from a climatological perspective.

Chapter 4 builds on this by explaining the effects these possible changes could have on the various components of the water cycle and water bodies, or on the parameters that define them.

Chapter 5 identifies the various fields of action in water management for which the public administration is responsible. In light of the expected changes in water-management parameters, the concerns of the various sectors are examined. In addition, climate adaptation measures are identified and presented using practical examples. The discussion of climate adaptation measures is neither complete in its scope, nor does the selection of examples imply any priority or weighting.

Based on damage potential and the risks accepted by society today, and considering the ranges of possible future developments, Chapter 6 describes a set of steps for an efficient response to climate change. In addition, conflicting objectives related to the requirements of other sectors are presented here.

Chapter 7 outlines the extent to which the scientific basis and the design of adaptation measures require further research and development.

The Annex contains a list of references and links to web content published by the federal states and federal government as well as a systematic compilation of climate adaptation measures and options for action for all 15 water-management fields of action.

This report identifies numerous climate adaptation measures and options for actions considered to be useful for adapting to climate change. Some of these climate adaptation measures are already being applied as measures within the existing framework of statutory requirements. The designation as a climate adaptation measure in this report, however, has no formal implication in terms of existing legal requirements.

The report is meant to be a technical reference work for the stakeholders in water management and interrelated fields of action. It can only provide a momentary snapshot of the complex field of climate change adaptation, which is rapidly developing with new research findings, new tools and experiences in climate and climate-impact research, and through expanding practical experience. Regular updates of this report will therefore be necessary, taking into account recent scientific and political developments for dealing with uncertainties and risks, as well as other current issues.

Statutory framework under federal law

Water bodies are subject to public usage laws and shall be protected through sustainable water management as an element of the natural balance, as a basis for human life, as a habitat for animals and plants, and as a beneficial asset. In view of this objective of the Federal Water Act (WHG - Wasserhaushaltsgesetz), under which the requirements of the pertinent European framework directives are also transposed into federal law, the following discussion is limited to the provisions and stipulations of the WHG as they relate to climate change, since the effects of climate change on water management are considered in the LAWA strategy paper at national level without appraising state-specific features.

When water bodies are utilised, provisions of water law are applied that include the consideration of climatic effects on the hydrological regime. Thus, everyone is under an obligation to use water sparingly in accordance with the hydrological regime, and to refrain from causing an increase or acceleration in water run-off (Article 5 para 1 WHG). With the exception of communal and residential use, the utilisation of water bodies requires a permit or authorisation, which may be granted if expected changes to the water bodies are not detrimental or contrary to public legal regulations (Art. 12 para 1 WHG). In this context, for example, the damming of a surface water body or the withdrawal or diversion of water from surface waters in accordance with Art. 33 of the WHG is only permissible if the flow rate for the water body and associated waters is maintained to comply with the objectives of sustainable water management and the management objectives in accordance with Articles 27 to 31 of the WHG. In the case of groundwater withdrawal, the water body deterioration prohibition and the target achievement requirement regarding the good volume status of the water body must be observed in accordance with Art. 47 para 1 of the WHG. Furthermore, there is no guarantee that a permit or authorisation will be granted; the competent authority must exercise management discretion (Art. 12 para 2 WHG).

Waters are to be managed in a sustainable manner. One of the principles of sustainable water management is to anticipate the possible consequences of climate change and, as far as possible, to ensure natural and harmless run-off conditions in surface waters (Art. 6 para 1 WHG). Climate change also has a significant impact on efforts to retain and improve the functionality and performance of water bodies as part of the natural balance and as a habitat for animals and plants, and so must be taken into account in the management of such water bodies.

Maintenance of water bodies is especially important for the run-off conditions in a catchment area. Aside from the maintenance and development of good ecological status, the requirements for proper water maintenance according to Article 39 para 1 of the WHG also include specifically:

- Maintenance of the river bed to ensure proper water run-off,
- Keeping the banks clear for water run-off,
- The maintenance of water bodies so as to meet water-management requirements with regard to the discharge or retention of water, bedload, suspended matter and ice.

According to Article 40 para 1 sentence 1 of the WHG, the owner of a water body is responsible for its maintenance unless this function has been transferred to municipalities, water and soil associations, special-purpose associations or other public law bodies. As part of their water pollution control duties, water authorities have to monitor the water status in compliance with Article 100 para 1 of the WHG and, if necessary, to make the necessary provisions to establish proper conditions. An important practical instrument for this are the water inspections or professional inspections, which, although not prescribed by federal law, are partly stipulated by state law and regulated with respect to the group of participants.

Another important aspect is the management of rainwater where local infiltration is not possible (Art. 55 para 2 WHG). The appropriate wastewater disposal company is responsible for the safe disposal of the effluent, and must construct and operate the necessary wastewater systems in accordance with generally accepted technical standards. To adapt to the consequences of climate change, it is especially important to ensure sewage system dimensions are adequate and relief is provided through rain retention basins (DWA - M 119 2016). Moreover, in the case of heavy rainfall events exceeding the design event, there is a collective need for municipal players to take action.

Every person who may be affected by floods is obliged, within their possible and reasonable limits, to take appropriate preventive measures to protect against adverse flood consequences, to mitigate damage, and especially to adapt land use to alleviate the possible damaging consequences of flooding for people, the environment or property (Art. 5 para 2 WHG, Flood Protection Act II 2017). The concept of flooding as defined by the WHG also refers to the uncontrolled wild flow of surface water. Flood prevention takes place, on the one hand, through the construction and maintenance of flood-control facilities and the preservation and restoration of retention areas. On the other hand, flood-risk management is carried out through risk-management plans that are obligatory for the authorities. According to Article 9 No. 16 of the Federal Building Code (BauGB-neu), future development plans may specify areas on a property that must remain unsealed for the natural infiltration of rainwater to prevent flooding damage, including possible damage caused by heavy rainfall.

The protection of special areas through restrictions in usage is an important legal instrument of the WHG. According to Article 77 of the WHG, these areas can be natural retention sites that are subject to a preservation and restoration obligation. They can also, however, be flood plains in which the special protection provisions of Article 78 of the WHG are applicable after preliminary procurement or designation. In addition, the federal states may designate flood formation areas (see Art. 78d of the WHG, which entered into force on 5 January 2018).

3 Climate change in Germany

Warming of the global climate system is indisputable, and it is highly probable that human activity has been the main cause of the warming observed since the mid-20th century (BMUB, BMBF, DE-IPCC & UBA 2013). It is primarily generated by the human-induced increase in greenhouse gas concentrations, combined with other human impact factors. This is the basic finding of current global climate research, which is set out in the 5th Assessment Report (AR 5) of the Intergovernmental Panel on Climate Change (IPCC) of 2013/2014. On 4 November 2016, the Paris Agreement, an international climate agreement negotiated at the UN Framework Convention on Climate Change's 21st Conference of the Parties (COP21) held in Paris in December 2015, entered into force. With this agreement, the international community has committed to limiting global warming to well below 2 °C, if possible to below 1.5 °C, above pre-industrial levels.

3.1 Climate modelling, uncertainties and ranges

Knowledge of the present climate and of the observed change in climate is based on evaluations of long measurement series (observation data). Assessments of future climate change, which will be strongly influenced by the present and future activities of humankind, are only possible through projections assisted by climate models based on scenarios of the future.

For this modelling, the atmosphere and Earth's oceans are overlaid by a three-dimensional grid. The resolution (grid-point spacing) for global climate models is very coarse due to the necessity of acceptable timeframes to compute models covering relatively long periods of time. Although these models do adequately describe the fundamental large-scale variability of the climate, the resolution is not sufficient to depict detailed differences in the character of climate change for a particular region on Earth (e.g. Germany). For this purpose, higher-resolution, regional climate models must be applied.

For this report, the results of all the latest generation of regional climate simulations available from the German National Meteorological Service (DWD - as of autumn 2016), covering the period from 1971 to 2100, are used for assessments of temperature and precipitation. Most of the regional climate projections are produced and provided within the framework of the EURO-CORDEX Project[2] .

This ensemble is based on various global forcing models, three different emission scenarios (RCP2.6, RCP4.5 and RCP8.5) and a number of regional climate models. The following time slices are used to evaluate the change signals in the climate-model ensemble.

- Reference: 1971–2000
- Near future: 2031–2060
- Distant future: 2071–2100

The scenarios used in Assessment Report 5 of the Intergovernmental Panel on Climate Change, published in 2013, describe representative pathways of radiative forcing in W/m² (Representative Concentration Pathways, RCP) coupled with the concentration of greenhouse gases in the atmosphere.

These RCP scenarios were determined for the period from 2005 to 2100 using coupled energy-economy-climate land-use ocean models, using the radiative forcing factor for the end of the century. The RCP4.5 scenario thus, for example, represents a global average radiative forcing of 4.5 W/m² in the year 2100 as compared to 1850. The present radiative forcing is near 2.0 W/m².

It is projected (Fig. 1) that the increase in mean Earth-surface temperature for 2081–2100 relative to 1986–2005 will probably be in the range of 2.6 °C to 4.8 °C using RCP8.5 and 0.3 °C to 1.7 °C with RCP2.6.

The RCP8.5 scenario reflects a world where no climate change mitigation measures are taken at all, and economic growth continues to depend on the combustion of fossil fuels. RCP4.5 reflects moderate,

[2] http://euro-cordex.net

resource-saving development. RCP2.6 represents an optimal picture, whose emission path can only be achieved by a rapid and significant reduction of all greenhouse gas emissions, and which corresponds approximately to the 2-degree target of the Paris agreement.

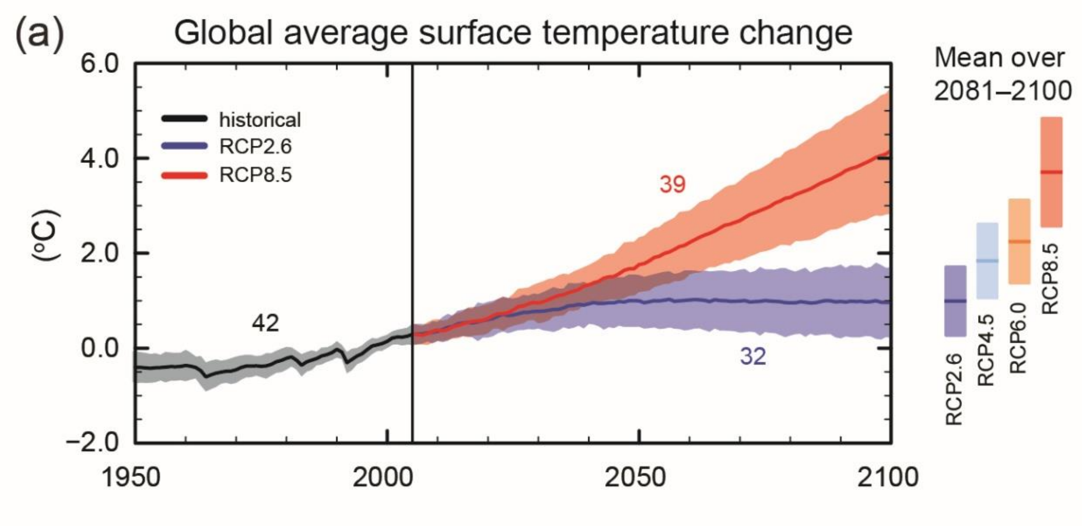


Fig. 1: Coupled Model Intercomparison Project Phase 5 (CMIP5). Multi-model simulated time series from 1950 to 2100 for the change in global mean Earth-surface temperature relative to 1986–2005. The time series of the projections and a measure of uncertainty (shading) are shown for the scenarios RCP2.6 (blue) and RCP8.5 (red). Black (grey shading) is the modelled historical development derived from historically reconstructed forcings. The means and corresponding uncertainty areas calculated for the period from 2081 to 2100 are illustrated as coloured vertical bars for all RCP scenarios. The number of CMIP5 models used to calculate the multi-model mean is indicated (source: IPCC 2013, Fig. SPM.7a).

Presently available regional climate projections represent a range of possible climatic developments in Germany. The range of projections is accounted for by the variety of assumptions and approaches that have been used in the model chain (RCP scenarios, global or regional climate models) and in the models employed. In dealing with these model chains various factors, briefly explained below, need to be considered. Additional details can be found in the "Guidelines for the interpretation of regional climate-model data" from the federal-Länder technical discussion on "Interpretation of regional climate-model data" (Linke et al. 2017).

Uncertainties and ranges

The findings of climate-projection calculations are subject to a series of assumptions (scenarios) and uncertainties. Thus, a precise prediction of future climatic conditions is not possible. Climate researchers therefore do not consider their results to be climate predictions, but rather climate projections. Some of the uncertainties are system-inherent and as such, in principle, are unavoidable. Furthermore, in the model chain an accumulation of uncertainties in the results must be expected. Overall, uncertainties can be identified as a result of the following factors:

- Selection of the climate scenarios
- Limitation of model accuracy
- Internal variability of climate
- Inaccuracy in the model cascade

The aforementioned limitations produce a range in the results of various climate models. To be able to estimate the uncertainty of future climatic changes, and to derive the most robust results possible regarding the possible climate future, the use of climate-model ensembles has become widely established. Ensembles can be generated, for example, through the combination of several different global and regional climate models (called multi-model ensembles).

Systematic model bias

In spite of many recent improvements, climate models can only reflect natural processes to a limited extent, and are therefore subject to systematic bias. An important requirement for the interpretation of climate-model data is minimisation of this bias through the application of appropriate statistical correction techniques using observation data sets. This is true for analysing changes in absolute climate parameters, for example, as well as their use in climate impact modelling.

Generally, the change signals in time slices of the scenario run when compared to those of the historical course are considered to be more robust than the absolute climate values from the scenarios. Many causal models are designed for forcing by absolute meteorological values (usually measured values).

If causal models are driven by the results of climate projections, the absolute values must also be used as model input variables rather than the more robust change signals, which can lead to discrepancies. There are bias-correction procedures of varying complexity available for dealing with this problem, ranging from a simple scaling approach to an adaptation of the distribution function of individual variables, or using multivariate approaches.

Ensemble reduction

Furthermore, the next modelling step - the implementation of modelled climatic parameters as input for, for example, hydrological regime models for the calculation of run-off parameters (impact modelling) - raises a question related to the selection of robust and plausible data sets.

A further aspect is that the great number of available projections for subsequent impact modelling can involve substantial effort. It is therefore often desirable to have a selection of projections for the further processing. The climate models have varying degrees of similarity, thus forming model families and effectively reducing the size of the ensemble.

There are a number of possibilities for ensemble reduction, such as expert support in selection of the projections considered based on application-specific target values (e.g. discharge at a certain level as in the KLIWAS project[3], generation of ranking using objective methods, see also Bavarian Climate Audit in BI-KLIM 2014), or statistical procedures with multivariate consideration of the most important

[3] KLIWAS was a research programme of the BMVI on the impacts of climate change on waterways and shipping in Germany, www.kliwas.de

parameters. The latter was investigated more closely by DWD and a core ensemble was defined for it.(Dalelane et al. 2018; DWD 2019a).

3.2 Observed regional climatic changes

The following results are based on the work of the German Meteorological Service (DWD) and of the individual federal states of Germany. More in-depth research is being carried out at various universities and research institutions. A synopsis of all results (see also e.g. National Climate Report (DWD 2017a)), a periodic update, and a summary of the results for Germany are carried out by DWD. The following information is based on the processing of the measurement series from 1881 to 2018.

Air temperature

The mean annual temperature for Germany (reference period: 1961–1990) is around 8.2 °C; from 1881 to 2015 it rose by an average of around 1.5°C (see Fig. 2), which is greater than the global average increase of about 1 °C. The increase in recent decades was particularly sharp (Kaspar & Friedrich 2020). The rate of warming for the period from 1969 to 2018 is 0.36 K (Kelvin) per decade, whereas this figure was only 0.06 K per decade for the period from 1881 to 1968. This increase is attributed to above average mean annual temperatures in recent years. 2018 was the warmest year observed (10.5 °C) in Germany since 1881. In the period from 1881 to 2018, 9 of the 10 warmest years were recorded in the 21st century.

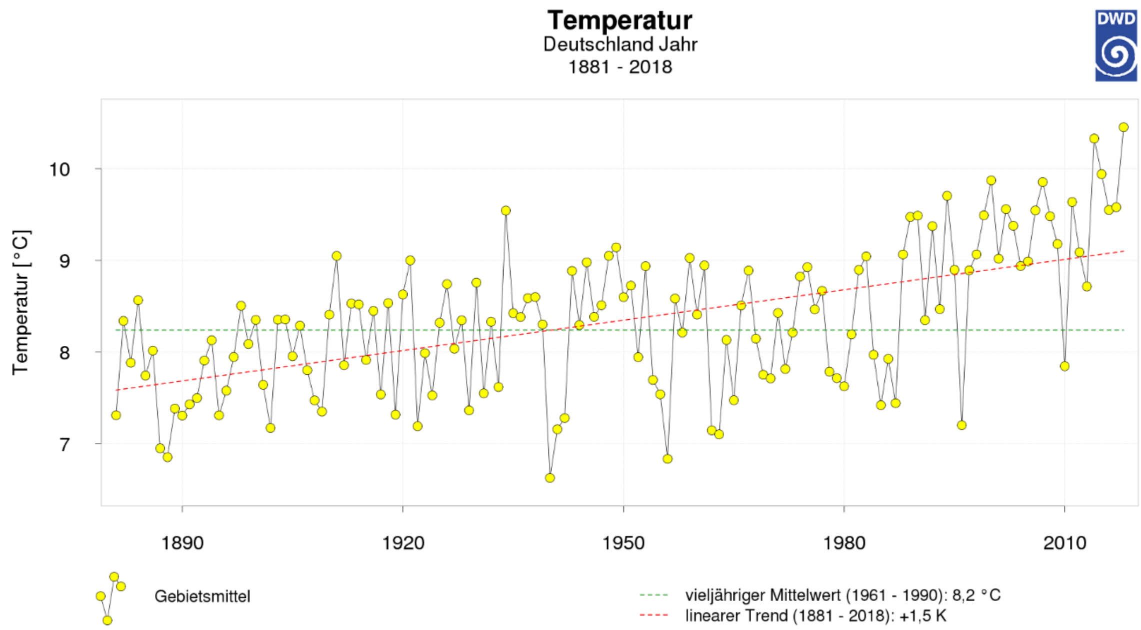


Fig. 2: Change in the average annual temperature and the corresponding linear trend in Germany from 1881 to 2018 (source: DWD 2019a)

Precipitation

Germany has an annual average precipitation rate of 789 mm per year (1961–1990). In the northeast and central parts of Germany the annual precipitation rates are commonly below 600 mm, while in the higher regions of the Alps and Black Forest values above 1,500 mm are normal.

Nationwide, the annual amounts of precipitation in Germany increased by 69 mm from 1881 to 2018, or by 9 percent of the average value of the 1961–1990 reference period (see Fig. 3). The year-to-year variability during the period and the regional differences in the trends, however, are very pronounced. Assessments of the distribution of precipitation between the summer and winter periods, or among the seasons, indicate that the average levels of precipitation in the winter have significantly increased by about 25 percent while they have remained constant or slightly decreased in the summer.

One cause for this is thought to be a change in the occurrence of large-scale weather patterns. Because of the large spatial and temporal differences in precipitation, the seasonal and local trends are variably pronounced. In eastern Germany, trends in annual precipitation and in the winter are lower than in the rest of Germany.

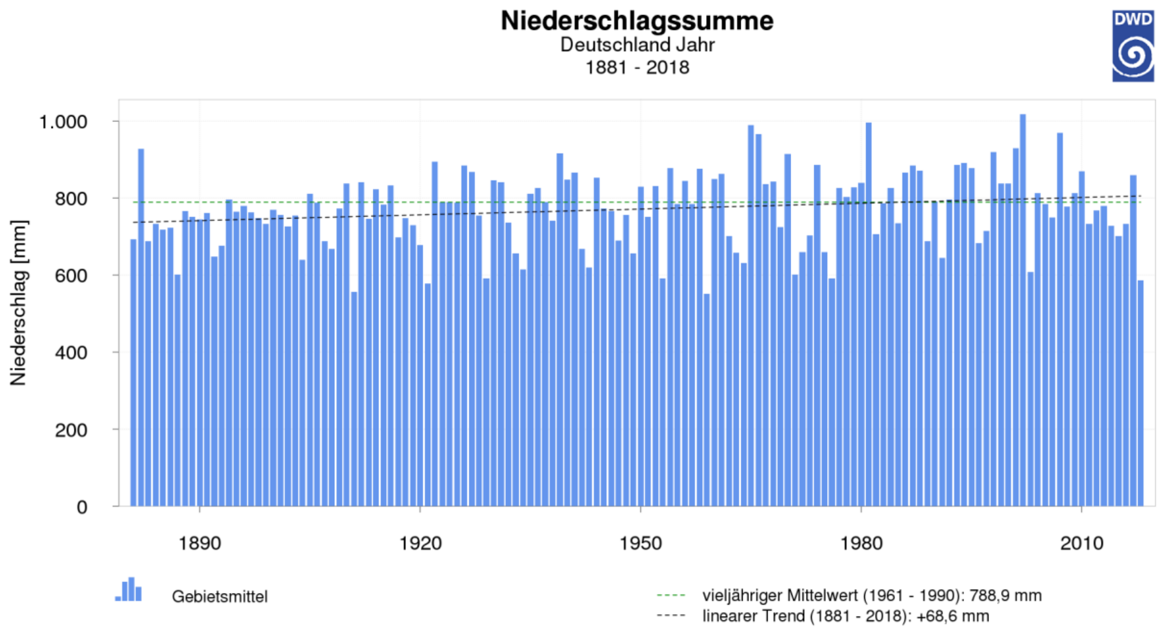


Fig. 3: Changes in mean annual precipitation and the corresponding linear trend in Germany from 1881 to 2016 (source: DWD 2019a).

3.3 Future regional climatic changes

The following results are based on the DWD reference ensemble v2018 (DWD 2019a).

Air temperature

Across Germany an average warming of 1-2 °C compared to 1971–2000 is projected for the near future (2031–2060). Then, to 2100, there are significant differences between the scenarios: Under RCP2.6 (optimal development, see explanation in 3.1) warming stabilises at about 1-2 °C. Under RCP8.5 (no measures taken for climate change mitigation, continued use of fossil fuels) a nationwide average warming in Germany of 3.5-4.5 °C is projected (Fig. 4). Generally, the model calculations show progressive warming from the northwest to the southeast.

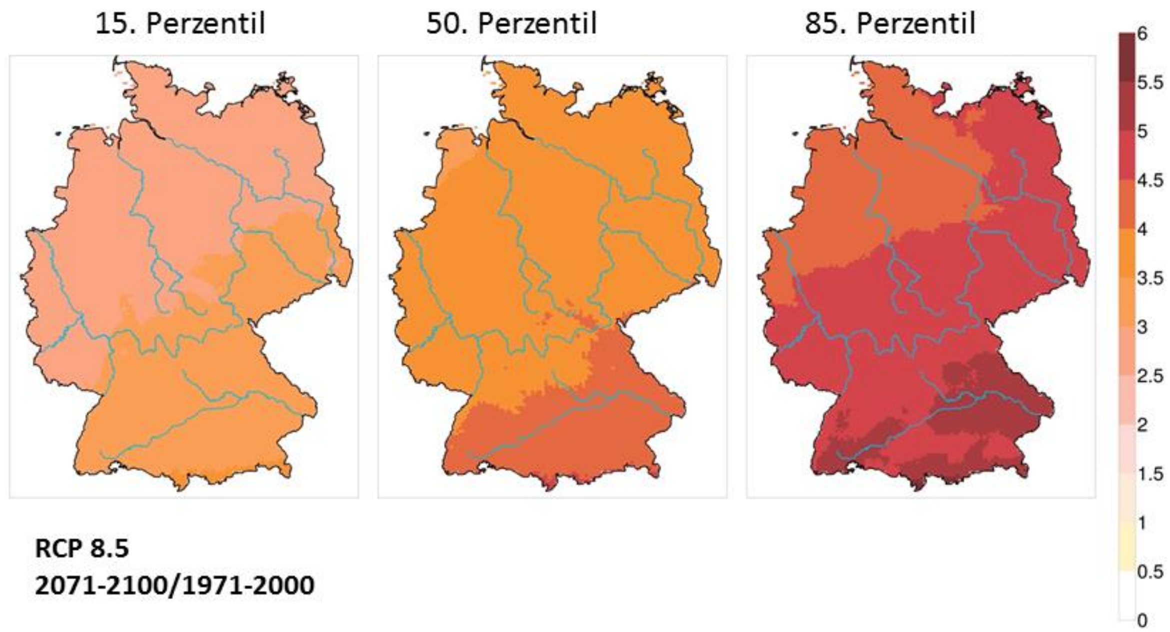


Fig. 4: Projected changes in annual mean air temperature during the 2071–2100 projection period in relation to the 1971–2000 reference period based on the RCP8.5 scenario. The average of the ensemble corresponds to the 50th percentile, the 15th and 85th percentiles represent the range (source: German Meteorological Service, DWD).

Precipitation

By the middle of the century, the projected change in the mean annual total of average precipitation in Germany is 0 to 10 percent. For the more distant future, the climate calculations show an increase in annual precipitation of up to 15 percent, whereby regional differences are expected. For the winter months, both time horizons show a tendency towards an increase in the amounts of precipitation, with average increases of 5 to 20 percent to be expected (Fig. 5) for the near future (2031–2060). A trend for the summer is not clear for the near future, but there is a tendency toward dry summers in the distant future (2071–2100).

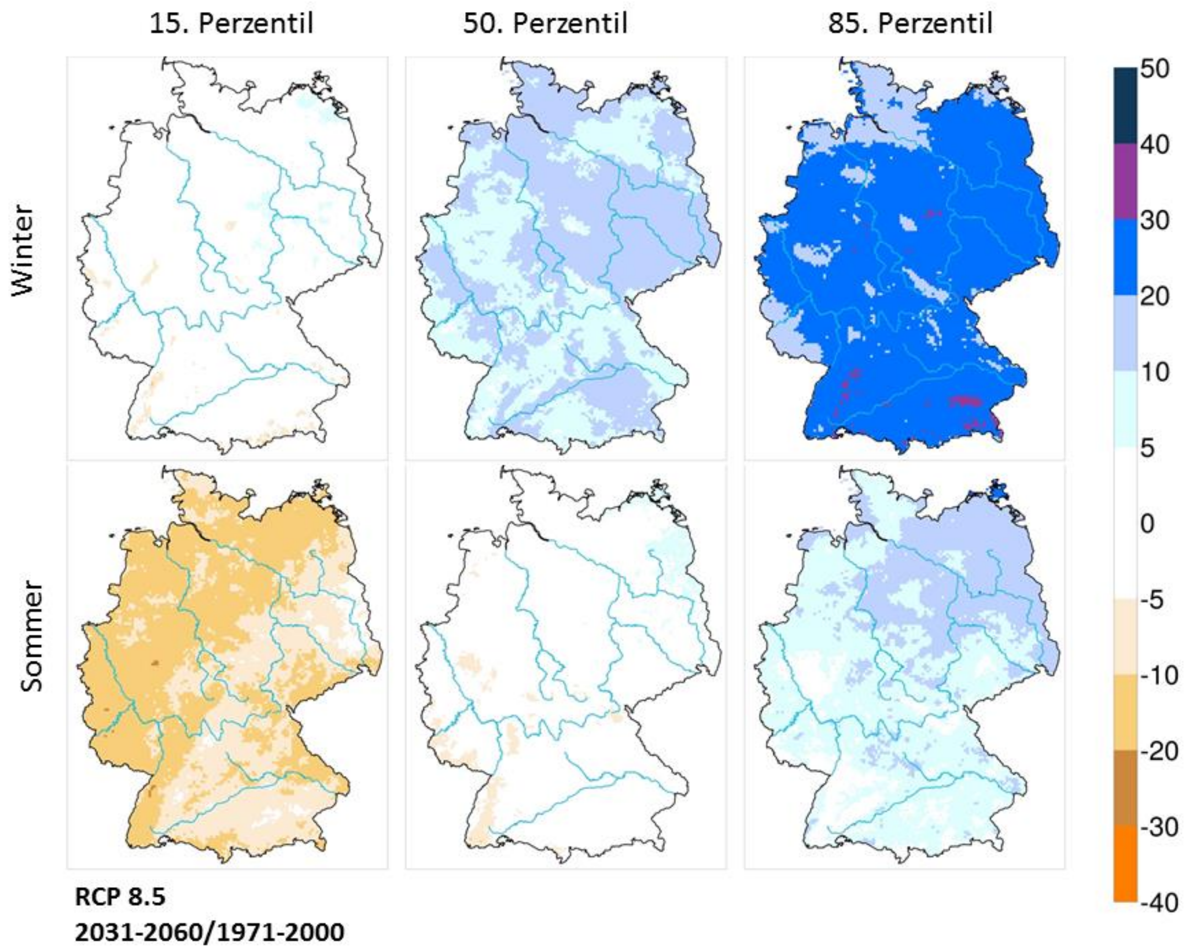


Fig. 5: Projected relative percentage change in average winter precipitation (DJF, above) and summer precipitation (JJA, below), average of the 2031–2060 projection period based on the RCP8.5 scenario relating to the reference period 1971–2000. The average of the ensemble corresponds to the 50th percentile, the 15th and 85th percentiles represent the range (source: German Meteorological Service, DWD).

3.4 Extreme events

Extreme events are very rare events that deviate strongly from the average conditions. There are various reasons why an event can be designated an extreme event. It can be an event that happens on a single day, such as a hurricane, a longer-term event such as a long-lasting drought, or an event that is very atypical for the time of year.

Extremes are integral parts of the weather and climate in the past and future. Known examples from the distant past include the St. Mary Magdalene's flood of 1342, which affected numerous rivers in central Europe, and an eruption of the Mount Tambora volcano that was followed in 1816 by the "year without summer".

We have also observed extreme events in the more recent past. Examples include the high waters on the Elbe, Danube and Inn Rivers in 2002 and 2013, triggered in both years by very high levels of precipitation, the heavy rain events in Münster in 2014, and in Braunsbach and Simbach in 2016, the heat wave in 2003, the low water years of 2003 and 2015, and the storms Lothar in 1999 and Kyrill in 2007.

Analyses of the intensity and frequency of the occurrence of such extreme weather events are a major focus of current climate research because of the obvious concern of how extreme conditions change within the fluctuations of climate. Because extremes are by definition very rare events, statistical analyses are difficult and less robust than for average values.

Air temperature

The average air temperature has increased significantly in recent decades. As a consequence, there have also been more days with unusually high temperatures and more heat spells. An example of this is the new temperature record for Germany of 42.6 °C, which was measured twice during the summer of 2015 in Lingen in Emsland.

It is also apparent that more frequent extreme heat waves (periods of 14 days in which very high average daily maximum temperatures (≥ 30 °C) are registered) have occurred since the 1990s. For example, from 1950 to 1993 no events of this kind were recorded in Hamburg, but since 1994 there have been five significant heat waves.

Because of the present and continuing warming, it is very probable that such high temperatures will become more frequent and will often be combined with longer-lasting hot periods. The results of regional climate projections provide clear indications for this. As yet, however, no robust estimates are available for the peak temperatures that may be recorded in the future.

Precipitation

The precipitation events relevant for various applications can occur either as local strong rainfall of short duration and high intensity, or as sustained periods of rainfall with precipitation lasting several hours or days with substantial total amounts of rain. The German Meteorological Service (DWD) has three warning levels for strong rainfall when the predicted amounts exceed the following threshold values (DWD 2017b):

- Rain volumes from 15 to 25 l/m^2 in 1 hour, or 20 to 35 l/m^2 in 6 hours (Significant Weather Warning)
- Rain volumes > 25 l/m^2 in 1 hour or > 35 l/m^2 in 6 hours (Storm Warning)
- Rain volumes > 40 l/m^2 in 1 hour or > 60 l/m^2 in 6 hours (Extreme Storm Warning)
- There are also three warning levels for sustained rainfall:
- Rain volumes from 25 to 40 l/m^2 in 12 hours, 30 to 50 l/m^2 in 24 hours, 40 to 60 l/m^2 in 48 hours or 60 to 90 l/m^2 in 72 hours (Significant Weather Warning)
- Rain volumes > 40 l/m^2 in 12 hours, > 50 l/m^2 in 24 hours, > 60 l/m^2 in 48 hours or > 90 l/m^2 in 72 hours (Storm Warning)
- Rain volumes > 70 l/m^2 in 12 hours, > 80 l/m^2 in 24 hours, > 90 l/m^2 in 48 hours or > 120 l/m^2 in 72 hours (Extreme Storm Warning)

Extended series of precipitation measurements are available for many locations in Germany based on daily values, for which diverse extreme-value and trend studies have already been carried out. Based on a variety of precipitation threshold values (called quantiles), trends for the frequency of rare events within the scope of daily precipitation were analysed. It is evident that for the winter half-year the frequency of high daily rainfall increased by about 25 percent during the study period (1951-2016). In the summer half-year, by contrast, there is no recognisable trend (Becker et al. 2016; DWD 2019b).

For analyses of precipitation events lasting less than 24 hours (convective severe rainfall events), the data foundation is generally much worse (shorter time series, more limited spatial coverage). Alternative analyses of radar data available in Germany since the start of 2011 indicate regional increases in severe short-term precipitation. Because of the relatively short timeframe of this series, however, these results are not very meaningful from a climatological perspective, and could be the result of short- or intermediate-term variations. These radar data can already be used effectively today to supplement analyses based on station data.

With climate change and the warming projected for the future, the potential for higher volumes of precipitation increases inherently, and thus also does the risk of more frequent and extreme precipitation events. There are also meteorological factors, however, that can counteract an increase in the average as well as the extreme amounts of precipitation such as, for example, a change in the general weather conditions. Additional influencing factors, some of them quite significant such as local topography and vegetation or the formation of precipitation, are responsible for an overall heterogeneous pattern throughout Germany.

According to the projections of regional climate models, it can be assumed for the present situation that, in Germany, the increase in severe precipitation at the sustained level of 24 hours (99% quantile) as outlined above will continue in the winter half-year through to 2100 (by up to 41% under RCP2.6 and up to 160% under RCP8.5, DWD 2019b). The climate models show increases for the summer months of 23% under RCP2.6 and 59% under RCP8.5. For a meaningful comparison with heavy precipitation at short duration levels, simulations by convection-permitting models must absolutely be applied. Although initial projections of this kind already exist for spatially limited areas, the data foundation for large-scale ensemble analyses is only just being successively created. There is a need for further research in this area.

<u>Wind</u>

Observed changes in the winter storm climate on the German coasts are especially significant because of the associated changes in flood-water levels. The North German Climate Monitor[4] provides comprehensive information for the North German region. The development of storm intensity (maximum value of the wind vector at 10 m above the surface) is illustrated in Fig. 6. Each point in the time series represents the difference with respect to the climate of the climate-normal period of 1961–1990. The level of today's climate (1986–2015) compared to the climate-normal period is indicated in the diagram by the blue line. According to this figure, purely mathematically, storm intensity during the 1986–2015 period is only around 1 percent higher than during the climate-normal period of 1961-1990, and so cannot be interpreted as a significant increase in storm activity. The increase was somewhat stronger for the North Sea coast and somewhat lower for the Baltic Sea coast. Furthermore, Fig. 6 clearly illustrates that the development is not of a linear nature. Up until the 1990s the storm intensity increased, and thereafter a moderate abatement is observed. The yellow line in the diagram shows the non-significant trend for the past 55 years (1961-2015), which amounts to +0.06 m/s per decade for the region of North Germany. It is also evident from longer time series that, because of the high year-to-year and (multi-) decadal variability, no long-term significant trend in storm intensity can be identified (e.g., Fig. 6 in Stendel et al. 2016).

The North German Climate Atlas[5] provides projections for 30-year time slices through the year 2100. Subsequently, as an example, a description is given for the possible development of a storm climate as it relates to coastal protection. Based on the current state of research, the changes in winter storm intensity in northern Germany to the end of the 21st century (2071–2100), compared to today (1961-1990), are not clear. Some models indicate an increase, others a decrease, with the range of possible change lying between -8 percent and +10 percent (Fig. 7, right).

As illustrated by the example climate calculation shown in Fig. 7 (corresponding to the average of all calculations) the mean possible change is +3 percent. The possible mean change is no more probable than other values within the range. Because of the high year-to-year and (multi-) decadal variability, these changes are not statistically significant. Other investigations, such as those in the framework of the KLIWAS Project, also show great variability in wind strengths, and only minor changes of statistical significance (Ganske et al. 2016).

[4] The North German Climate Monitor is an information product of the North German Climate Office of the Helmholtz Centre in Geesthacht and the Hamburg regional climate office of the German Meteorological Service http://www.norddeutscher-klimamonitor.de/, Meinke et al. (2014)

[5] The North German Climate Atlas is an information product of the North German Climate Office of the Helmholtz Centre in Geesthacht, http://www.norddeutscher-klimaatlas.de/, Meinke & Gerstner (2009).

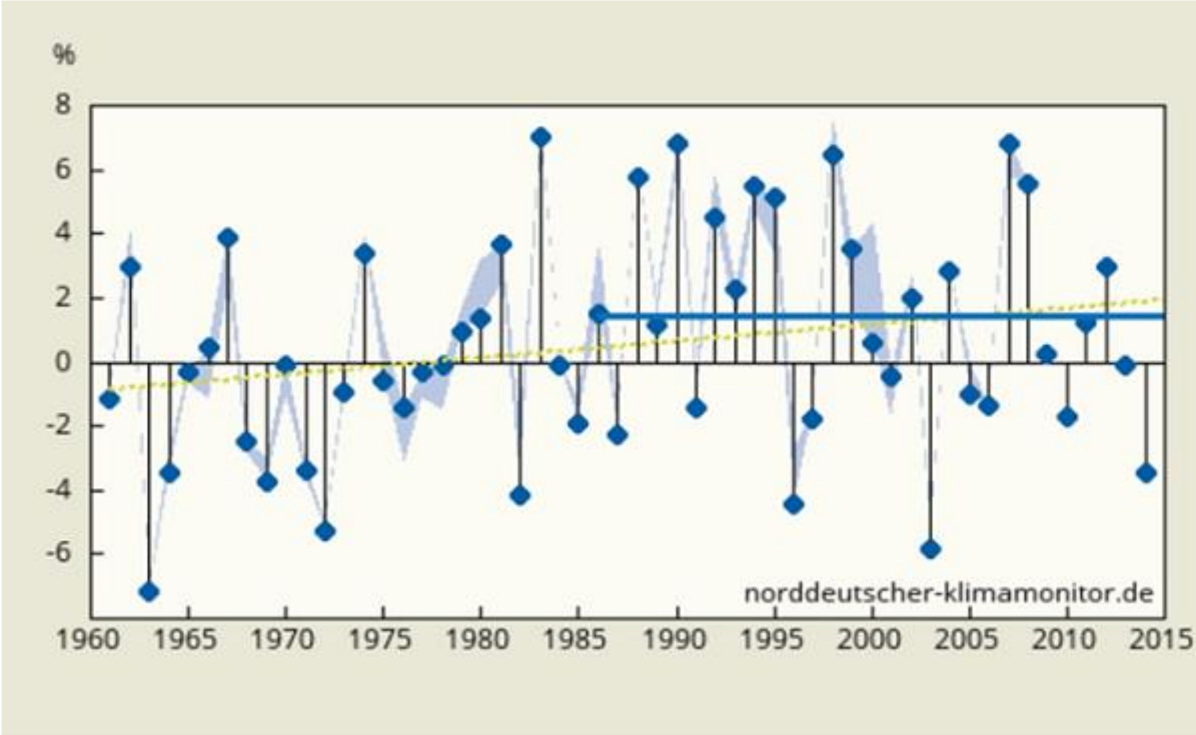


Fig. 6: Storm intensity (maximum value of the wind vector at 10 metres above ground) from 1960 to 2015 based on COSMO-CLM reanalyses (coastDat-2). The blue line represents the level of today's climate (1986–2015) and the yellow line represents the linear trend (1961- 2015, not significant). (Graph: I. Meinke, HZG).

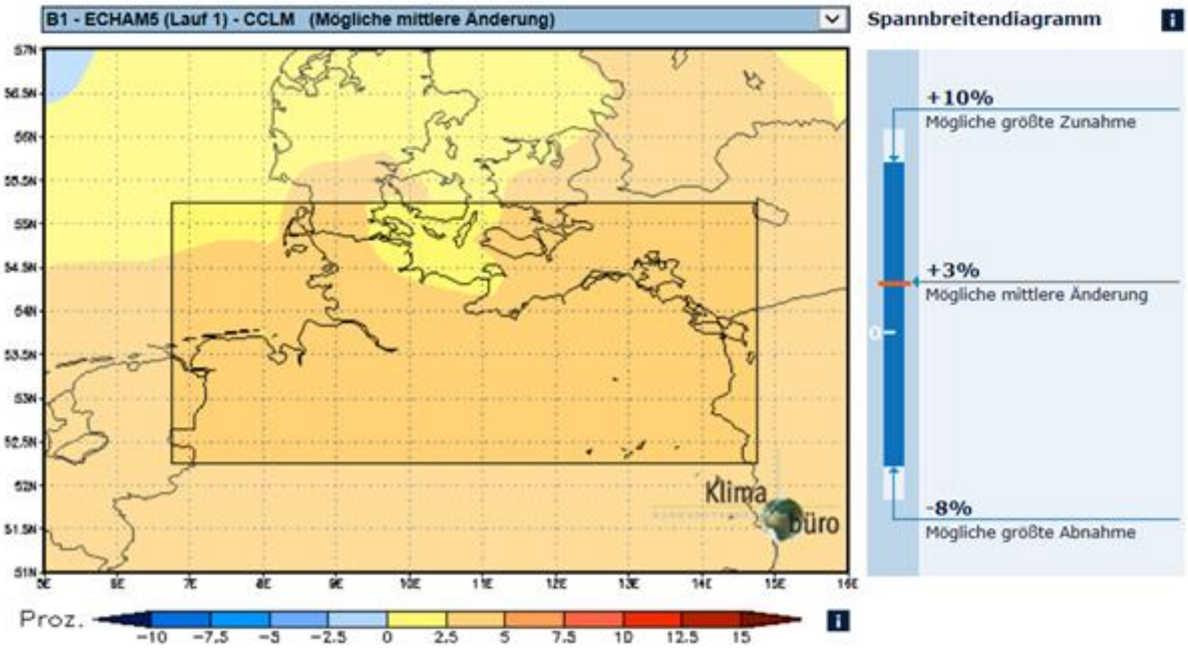


Fig. 7: Change in winter storm intensity in North Germany to the end of the 21st century (2071–2100) compared to today (1961-1990) in percent; an example of ECHAM5-CCLM with B1 SRES forcing. Right: range of all investigated climate projections for this parameter. (Graph: I. Meinke, HZG).

4 Water – impacts of climate change

The changes in climatic elements (temperature, precipitation, wind, etc.) have an impact on water resources management variables and parameters. The extent of impact is complex, and is related to processes that depend on the climatic region as well as the size and other characteristics of the catchment area. These impacts can be quantified with the aid of causal models (e.g. hydrological regime, groundwater, water-quality, and habitat models). In this procedure, an ensemble of climate scenarios produces a corresponding ensemble of possible effects, whereby different scenarios and differently composed ensembles can also produce correspondingly diverse resulting ensembles. In a subsequent step, simulation results for the future are compared to, and statistically evaluated with regard to the corresponding simulation calculations for the current state (reference period) in order to numerically represent change signals if appropriate.

The Federal Government 2020 progress report on the German Strategy for Adaptation to Climate Change (DAS) determined that changes in the hydrological regime often have cascading impacts on other fields of action (Bundesregierung 2020). Therefore, the impacts of climate change on fields of action affected by changes in the hydrological regime should be looked at case-by-case. This pertains to both the analyses of results (e.g. shift in mean values or frequencies, extreme values) and the spatial and temporal scales considered. Only in this way is it possible to describe impacts on the fields of action that often need to be assessed locally. In recent years, therefore, the number of investigations by the various federal, state and local public services authorities has continually increased.

4.1 Surface waters

4.1.1 Surface run-off

The following statements on different run-off parameters are based on the “business as usual” scenario. This is due to the fact that real developments are likely closest aligned with this scenario and most climate projections are therefore based on this scenario. As more and more current studies regarding the newest generation of emission scenarios are being published, this report contains results based on different scenarios. Older results are based on SRES A1B, newer on RCP8.5. Similarly, the reference periods have been shifted in the update of this report. Older results are based on the reference period 1961–1990 and the “near future” refers to 2021–2050, while for the newer results both periods have been pushed forward, generally by 10 years, i.e. 1971–2000 and 2031–2060. The “distant future” in both cases refers to the period 2071–2100. This means that not all signals are directly comparable as the reference periods and climate model generation used have changed.

4.1.1.1 Mean run-off and run-off regime

The mean run-off (MQ) is a statistical value of the hydrological regime of running waters. It specifies the multiannual average run-off at one point of the body of running water, usually at a gauging station.

Mean run-off is, therefore, the integral response of the catchment area to precipitation. With respect to the regime equation (run-off = precipitation minus evaporation, cf. background maps in Fig. 9, Fig. 14 and Fig. 16), it is thus an important indicator for the impact of climate change on the hydrological regime.

Due to the increase in average air temperature, which has already been confirmed in connection with climate change and is expected to continue in the future, the rates of evaporation are also generally increasing. This leaves less water for groundwater recharge and for run-off on the surface. In addition, the temporal distribution of run-off through the year can change, for example due to a shift in precipitation from the summer to the winter half-year or an increase in heavy precipitation during the summer or, in some cases, through changes in accumulation and melting processes of the winter snow reserves or shifts in the start and end of growing seasons.

In accordance with the general central European climate gradient, total annual precipitation in southern and western Germany (e.g. Rhine, Danube) is significantly higher than in the east (e.g. Elbe). This results in significantly lower specific run-offs and thus potentially greater vulnerability in the east, even though evaporation here is only slightly lower than in the west.

Many of the consequences of climate change can affect mean run-off, either jointly or in opposition to one another, especially the changes in precipitation and evaporation. In North-Rhine Westphalia, for example, within the framework of climate impact monitoring (LANUV NRW 2016), run-off data from 14 gauging stations were evaluated, which, as far as possible, exhibited no anthropogenic influence or usage changes in the near vicinity. 13 of the stations showed decreases in mean run-off for the period 1951–2014 (significant in six of them), and this in spite of the highly significant trend of increasing average annual precipitation levels nationwide. Essentially, this distinctive phenomenon can only be explained by a strong increase in evaporation rates. One cause for the increasing evaporation rates is certainly the undeniable warming trend. Due to other climatic and orographic catchment area characteristics in the 1901–2000 period, the gauging stations on the Rhine show significant and statistically significant increases downstream of the Kaub gauging station (Belz et al. 2007).

Not all changes, however, are recognisable by looking at average values. Therefore, the change in the run-off regime, i.e. the intraannual distribution of run-off expressed by the Pardé Coefficients (Pardé 1933), is also important. This relates the average multiannual mean monthly run-off for a given month to the multiannual mean annual run-off (Fig. 8). Alternatively, the distinctions between the hydrological summer (May to October) and winter (November to April) half-years, as well as the quarters of the years (the months DJF, MAM, JJA, SON) also provide an impression of possible shifts from the summer into winter. In many places, these shifts result from the projected increase in winter precipitation and decreased precipitation in the summer months contemporaneously with elevated evaporation potential, as well as an early onset of snow melting related to warming. The diverse effects produce a variety of combinations depending on geographic location, climatic zone and the size of the catchment area. It is thus not possible to interpret changes comprehensively; they must be determined individually for particular levels using measurement-data evaluations or model simulations. The changes can be roughly classified according to the run-off regimes (see Fig. 8).

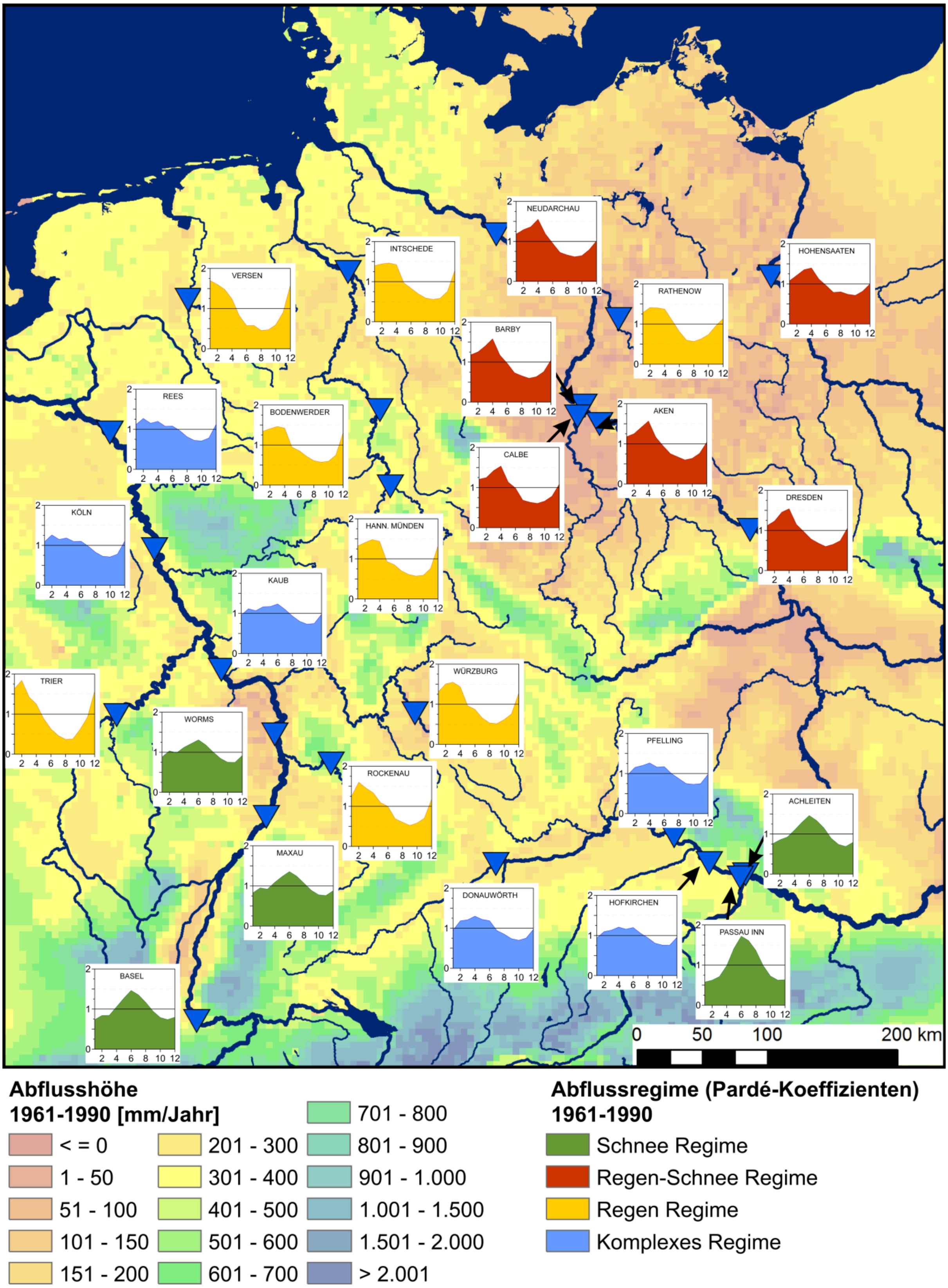


Fig. 8: Run-off regimes and run-off levels in Central Europe (adapted from Nilson et al. 2013). The inset diagrams show the Pardé Coefficients averaged over the years 1961 to 1990 for selected stations determined on the basis of observations, with the colours indicating the type of run-off regime. The background map represents average run-off levels within the same timeframe (BMU 2003, extended outside Germany according to BfG 2017).

The snow regime (nival) is characterised by high run-off during the months of May to August and low run-off from November to February. It is presently found in areas where the influence of the Alps is pronounced (Upper Rhine, Danube downstream of the Inn). Climate warming generally produces a shift of the snow regimes more toward rain regimes (pluvialisation). In regimes that were previously snow-dominated, therefore, run-off becomes more evenly distributed throughout the year due to increased run-off in the winter and spring and decreased run-off in the summer and autumn (Fig. 9).

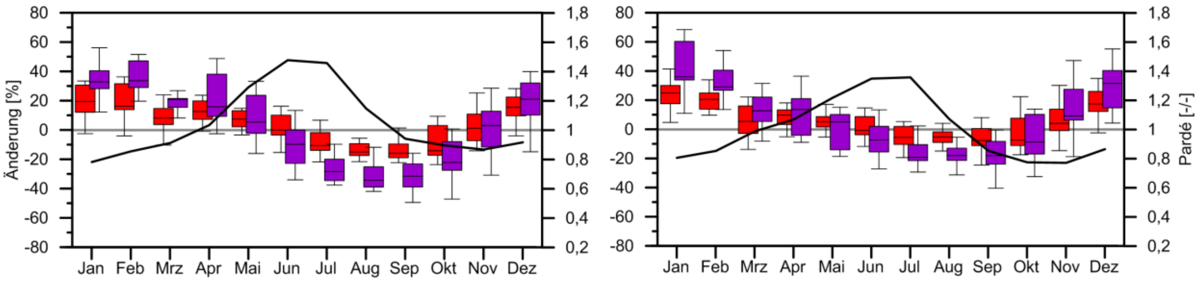


Fig. 9: Examples of the snow regime: Basel/Rhine station (left) and Achleiten/Danube station (right). Black: Pardé Coefficient, average of the years 1971–2000, determined on the basis of observations. Coloured: analysis from an ensemble of 16 future projections (respectively) of the change signals of the multiannual averaged monthly mean water run-offs for the near (2031–2060, red) and distant (2071–2100, purple) future with respect to the reference period of 1971–2000 based on the “business as usual” scenario (RCP8.5), depicted as box-and-whisker plots; the middle 50 percent of all values lies within the box (interquartile distance), within which the median is marked, the ends of the whiskers indicate the total range of the ensemble. The monthly multiplication of the change signals by the Pardé Coefficient yields the future change (with respect to the averaged multiannual annual run-off of the reference period 1971–2000). Data: Nilson et al. (2020).

Rivers from Germany's lower mountains, by contrast, typically reflect a rain regime (pluvial) coupled with high run-off between the months of December and March and lower run-off between June and September. Here, amplification of the present unequal distribution can be expected. The reasons for this are projected increases in winter precipitation in many places and the projected decreases in some places in the amounts of precipitation in the summer months with a contemporaneous higher evaporation potential due to warming (see Fig. 5 and Fig. 6).

Between these two is the rain-snow regime, characterised by higher run-off between the months of March and May and lower run-off between July and November. It can be observed at many gauging stations on the Elbe and varies depending on the particular local conditions. The increase in precipitation in winter has a significant effect on run-off, in some places causing an early onset of snow melting (Fig. 10).

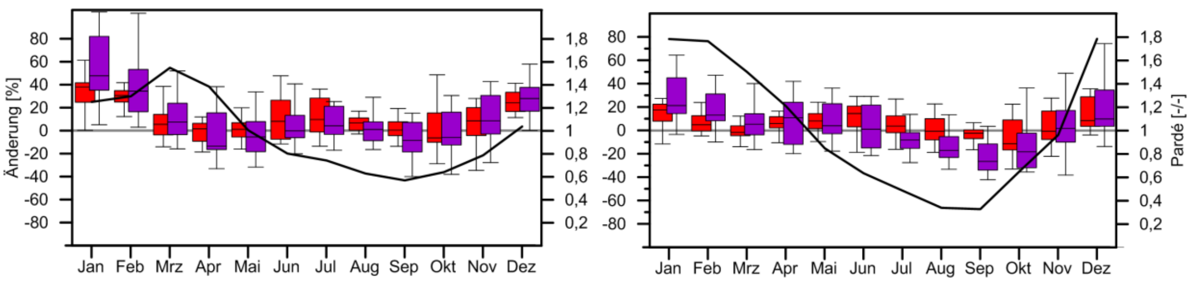


Fig. 10: Example of the rain-snow regime: Barby/Elbe station (left). Example of the rain regime: Trier/Mosel station (right). Black: Pardé Coefficient, average of the years 1971–2000, determined on the basis of observations. Coloured: analysis from an ensemble of 16 future projections (respectively) of the change signals of the multiannual averaged monthly mean water run-offs for the near (2031–2060, red) and distant (2071–2100, purple) future with respect to the reference period of 1971–2000 assuming the "business as usual" scenario (RCP8.5), depicted as box-and-whisker plots; the middle 50 percent of all values lies within the box (interquartile distance), within which the median is marked, the ends of the whiskers indicate the total range of the ensemble. The monthly multiplication of the change signals by the Pardé Coefficient yields the future change (with respect to the averaged multiannual annual run-off of the reference period 1971–2000). Data: Nilson et al. (2020).

Complex regimes are formed when the run-off from snow-dominated regimes combines with run-off from sufficiently large areas dominated by rain. Downstream from such a confluence, the annual progression of run-off can exhibit multiple peaks, but there may also be an equalisation of the annual run-off. For example, the seasonal differences on the Rhine downstream from the Main River mouth or on the Danube upstream from the Inn River mouth are less pronounced compared to the other regimes. Increasing pluvialisation of the run-off in the complex regime of the Rhine leads to the downstream annual run-off pattern becoming more uneven (Fig. 11). In the second half of the 21st century, the absence of run-off from glaciers in the summer months could mean this effect becomes more pronounced (IPCC 2019a).

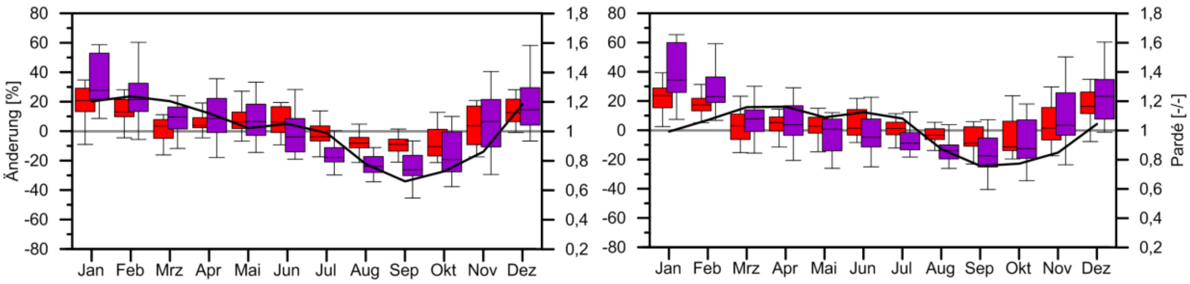


Fig. 11: Examples of the complex regime: Rees/Rhine station (left) and Hofkirchen/Danube (right). Black: Pardé Coefficient, average of the years 1971–2000, determined on the basis of observations. Coloured: analysis from an ensemble of 16 future projections (respectively) of the change signals of the multiannual averaged monthly mean water run-offs for the near (2031–2060, red) and distant (2071–2100, purple) future with respect to the reference period of 1971–2000 assuming the "business as usual" scenario (RCP8.5), depicted as box-and-whisker plots; the middle 50 percent of all values lies within the box (interquartile distance), within which the median is marked, the ends of the whiskers indicate the total range of the ensemble. The monthly multiplication of the change signals by the Pardé Coefficient yields the future change (with respect to the averaged multiannual yearly run-off of the reference period 1971–2000). Data: Nilson et al. (2020).

Very generally it can be said that, according to the projections, the effects will be more pronounced on average for the distant future (2071–2100) than for the near future (2031–2060), whereby the ranges of the changes for the two time periods overlap in part, and almost always at least meet.

For the gauging stations on the large rivers Rhine, Elbe and Danube, earlier findings of the KLIWAS research programme (BfG, DWD, BSH & BAW 2015) were confirmed by research conducted more recently (Nilson et al. 2019), with the exception of the Elbe. Changes compared to the reference period (here: 1971–2000) can be summarised as follows for the "business as usual" scenario:

For the Rhine, the majority of the projections for the near future (2031–2060) showed indifferent to increasing average annual run-off, with slight decreases in the summer half-year and increases during the winter half-year.

In the distant future (2071–2100) the difference between summer and winter half-year becomes more pronounced on the Rhine, while for the annual average, depending on the section of river, slight decreases (Upper Rhine) and increases (Middle and Lower Rhine) are projected.

Similar developments to those in the pluvially characterised catchment areas of the Rhine are projected in the Weser and Ems catchment areas. Average annual run-off for the near future (2031–2060) show indifferent to slightly increasing signals. The distant future (2071–2100) mainly shows more significant increases resulting from high winter increases and comparably moderate decreases in summer.

On the Elbe, there are slight increases in average annual run-off, mainly in the winter half-year, in the near and distant future. Downward trends are only recorded in some summer months in the distant future.

On the German section of the Danube there is hardly any change in the average run-off in the near future. Considering summer and winter separately, predominantly irregular changes are projected for the summer half-year with exceptions of the Inn and Danube downstream from the Inn mouth, where projections indicate decreasing run-off. In the winter half-year a general tendency toward increasing run-off is apparent.

In the distant future, the difference between summer and winter half-years is intensified for the Elbe, with increases more prominent in the annual average.

4.1.1.2 Low water

For the gauging stations in large catchment areas on the rivers Rhine, Elbe and Danube, the current research findings based on 16 future projections for the "business as usual" scenario (RCP8.5 e.g. Nilson et al. 2020) are shown in Fig. 13 and summarised below:

- In the near future, large stretches of the Rhine and its tributaries initially show no significant changes in low water run-off. Some significant decreases are projected by the end of the century.
- Similar to the Rhine, the Elbe, Weser and Ems show no predominant trend for the near future with respect to the occurrence of low water run-off. Projections indicating decreasing low water run-off become more prominent towards the end of the century.
- The German Danube shows a regionally varied picture. Sections of river upstream from the Inn River mouth, i.e. with complex run-off regimes, show change signals indicated for large parts of the Rhine end Elbe rivers, namely significant decreases in low water run-off only towards the end of the 21st century. However, water bodies characterised by nival such as the Inn River and the gauging stations influenced by the Inn River show a significant decrease in low water situations accompanied by the regime change (pluvialisation) described above.
- A projected decrease in low water run-off is generally accompanied by more frequent and longer-lasting low water situations.

As an example representing very many smaller river areas, Fig. 12 shows the range of possible changes in annual patterns of multiannual average monthly low water run-offs at the Heitzenhofen/Naab gauging station, a left, or northern tributary of the Danube. The possible development trends of the low water run-off of the Naab, a river without a strong nival influence, are irregular, similar to the neighbouring Elbe region. The range of future projections, however, is significantly greater for the relatively small Naab area. It should be noted here that the range of future projections depends on the ensemble being assessed and the climate scenarios used.

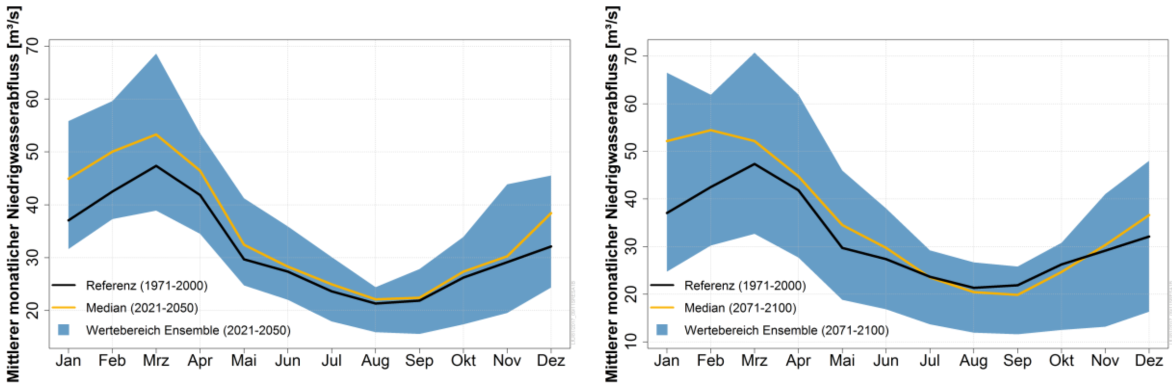


Fig. 12: Annual pattern of multiannual averaged monthly low water run-off at the Heitzenhofen/Naab gauging station. Black: average for the reference period (from observations, 1971–2000); orange and blue: median and range of two ensembles of future run-offs determined as the product of the change signal of the run-off projections and the reference. Left: near future (2021–2050), 11 ensemble members, right: distant future (2071–2100), 8 ensemble members (LfU BY/KLIWA 2017; LfU BY in preparation).

With a view to practical actions, the ICPR (2015) has compiled in a technical document "low water sensitivity guiding values" for the Rhine as a guideline for discussions on possible adaptation measures, which will be updated based on the knowledge gained in the future. This presents a range of relative changes from -10% to +10% for the multiannual arithmetic mean of the NM7Q values of the individual hydrological summer half-years (May to October) (NM7Q: lowest arithmetic mean of the run-offs on 7 consecutive days in a reference period).

After all the Alpine glaciers have melted, an additional reduction in low water discharge is to be expected in the long term. A continuation of the completed KHR project "The snow- and glacier-melt components of streamflow of the river Rhine and its tributaries considering the influence of climate change" (ASG)[6] is currently being planned and designed. The project will examine more closely the impacts of changed run-off components of glaciers and snow in the Rhine region during the 21st century (ASGII).

In long-term analyses of low water parameters determined by measurements, it is absolutely necessary to take into account that the run-off in low water areas reacts very sensitively to commercial usage and management of the water bodies. Furthermore, the gauges are designed for measurements of the total run-off spectrum, so the measurement uncertainty can be large for low run-offs and shallow water depths. A distinct separation of anthropogenic water management and climatic influences under low water conditions requires complex modelling. This should be taken into account for the interpretation of measured time series as well as in the results of calculations.

[6] http://www.chr-khr.org/de/projekt/schnee-und-gletscherschmelze

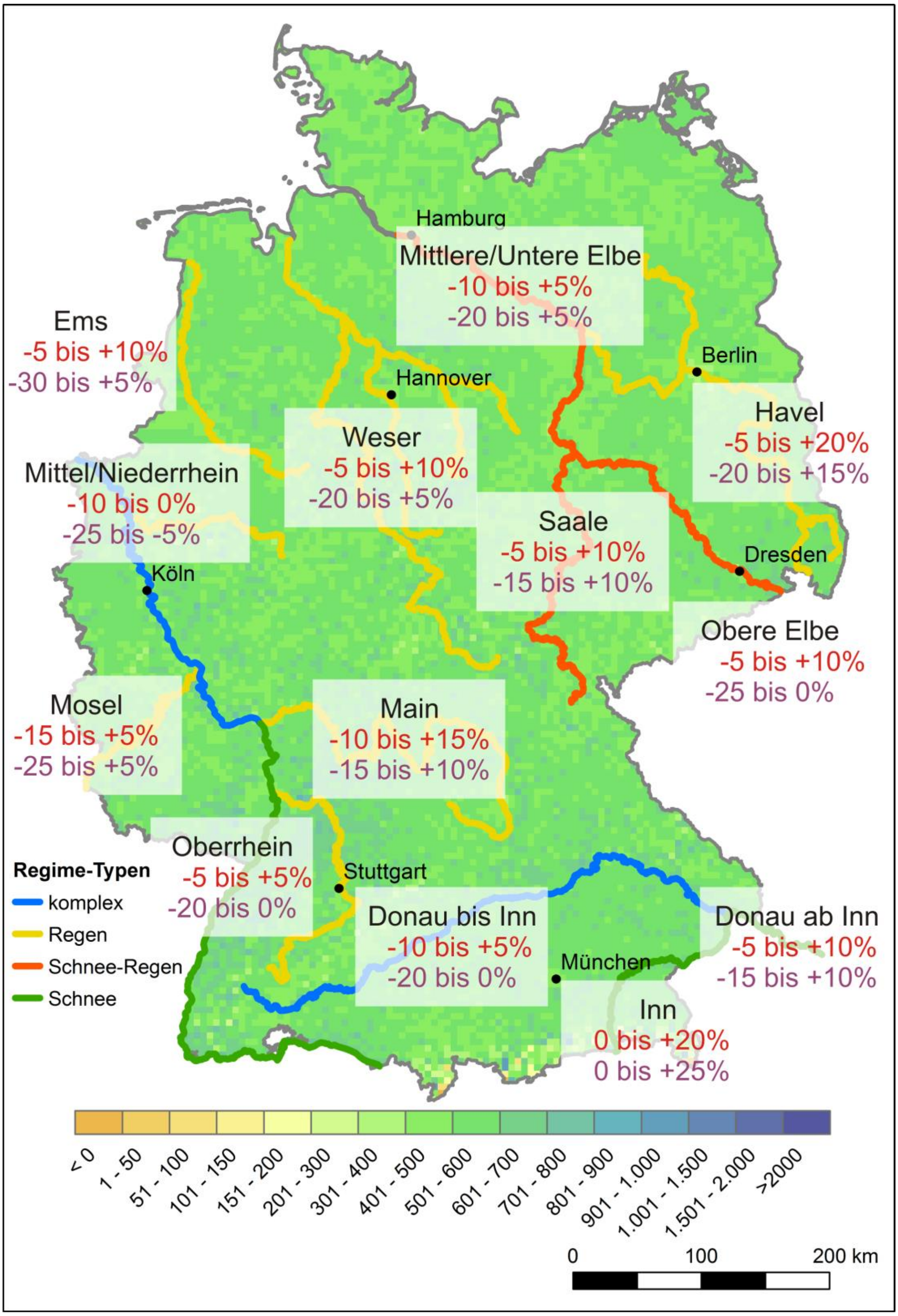


Fig. 13: Regional generalised change in the multiannual averaged low water run-off (parameter NM7Q) on the large rivers; near (2031–2060, red) and distant (2071–2100, purple) future compared to the reference period 1971–2000 based on an ensemble of 18 run-off projections assuming the business as usual scenario (RCP8.5 Nilson et al. 2020, amended, cf. Nilson et al. 2014, AG WRRL BLMP 2007 and BfG, DWD, BSH & BAW 2015). The type of run-off regime in a river course is indicated by a coloured line. The background map shows the evaporation level (BMU 2003); average of the years 1961–1990.

4.1.1.3 High water

High water run-offs according to the EU Floods Directive

A major remaining challenge is to address the question of whether more unfavourable high water peaks occur as a result of changes in low pressure area paths, more frequent large-scale weather patterns and thus precipitation patterns and intensities and/or due to a seasonal shift in the controlling run-off processes due to changes in snow conditions. Presently available climate models still provide highly variable precipitation amounts and distributions, which are more pronounced in the context of extreme precipitation than under average precipitation rates. On top of this, irrespective of climate change, are the uncertainties of hydrological models and with regard to the statistical evaluation, the uncertainty that increases each year in estimating the corresponding run-off based on a relatively short time series (generally, periods of 30 years are observed). When determining a climate signal from extreme high water values of two periods determined in this way, this alone can lead to considerable fluctuations. Ranges for estimates of the change signals of extreme high water are accordingly very great and can vary by as much as 40 percent or more, depending on the projections and methods used as well as the region and size of catchment area. It should be noted that such ranges correspond to a shift in annuality by an order of magnitude of a power of ten (rule of thumb $HQ_{1000} \sim 1.3\ HQ_{100}$ and $HQ_{100} \sim 1.3\ HQ_{10}$). Accordingly, the possibility of considerably higher extreme flows of a given annuality has to be expected in future.

A new method described in Nilson et al. (2020) analyses the combination of a number of current run-off projections considered plausible for different gauging stations on the Rhine and its tributaries into a single long time series (the so-called grand sample). This results predominantly in increases in extreme high water run-offs in the Rhine region, however, these are lower in some cases in the distant future than in the near future. Corresponding research will be continued and intensified.

For individual regions, this large uncertainty is attributed, in particular, to our incomplete knowledge of the future development of large weather patterns and of the paths of low-pressure areas. Projects like the one funded by Germany, Austria and Bavaria, "WEather Patterns, CycloneTRAcks and related precipitation eXtremes – impacts of climate change on large-area heavy precipitation in South Germany and Austria: Analysis of the changes in tracks and large weather patterns" (WETRAX)[7], have not achieved any appreciable improvement in this area as yet. There are plans to continue this research (WETRAX+).

Since 1999, the KLIWA cooperative project[8], with its partners Bavaria, Baden-Württemberg, Rhineland-Palatinate and the DWD, has been intensively involved with the topic of "climate change and its consequences for water management". KLIWA concluded that there will be more high water events in the future, especially associated with increasing high water run-off in the winter. In practice, for example, climate markups have been introduced in the states of Bavaria and Baden-Württemberg for the design of new flood-defence structures. Thus the expected impacts of climate change are already being taken into account in the planning and construction of new high water protection measures.

ICPR (2015) compiled "flood sensitivity guidance values" for the Rhine as reference parameters for discussions on possible adaptation measures, which are to be updated based on knowledge gained in the future. These refer to the ranges of relative changes, for example, 0 to +20 percent for a HQ_{100} at the Cologne gauging station.

Mean high water run-off

The mean high water run-off (MHQ) is the arithmetic mean of the highest run-off of each year for all the years of the observation period. Due to the magnitude of this figure (usually annualities between one

[7] https://www.zamg.ac.at/cms/de/klima/forschung/klima/zeitliche-klimaanalyse/wetrax

[8] "Climate change and the consequences for water management" is a cooperative project of the German states of Baden-Württemberg, Bavaria and Rhineland-Palatinate with the National Meteorological Service which investigates the changes in the hydrological regime due to climate change, http://www.kliwa.de

and three) and the statistical derivation (averaging), conclusions regarding multiannual average annual high water run-offs are more robust than the rarer and more extreme high water events. For the gauging stations on the large rivers Rhine, Elbe and Danube, the current research findings based on 16 future projections for the "business as usual" scenario (RCP8.5 e.g. Nilson et al. 2020) are shown in Fig. 15 and summarised below:

- On the Rhine and German Danube, many projections already show rising annual high water run-offs in the near future. The increase will continue over the course of the century at a considerably slower rate.
- The annual high water run-offs on the Elbe, Weser and Ems rivers show mainly the same trends as the Rhine, however the overall uncertainty margin is greater.
- A projected decrease in high water run-offs is generally accompanied by more frequent and longer-lasting exceedance of critical threshold values.

Using the Heitzenhofen/Naab gauging station (a left, or northerly tributary of the Danube) as an example for river areas of one to two orders of magnitude smaller than the large rivers, Fig. 14 shows the possible changes in the annual patterns of multiannual average monthly high water run-off. Analogous to the low water run-offs, the possible development trends of the small flood run-offs of the Naab, a river without a strong nival influence, are irregular, similar to the neighbouring Elbe region. The range of future projections in the relatively small Naab region is also significantly wider for average high water run-offs. This is typical for small catchment areas. But the range of future projections depends on the ensembles considered and the underlying climate projections.

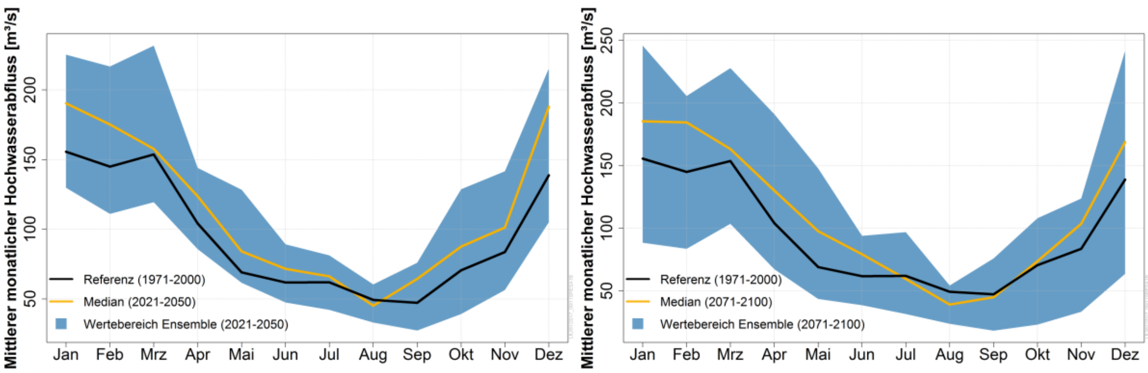


Fig. 14: Annual trend of long-term average monthly high water run-off at the Heitzenhofen/Naab gauging station. Black: average for the reference period (from observations, 1971–2000); orange and blue: median and range of two ensembles of future run-offs determined as the product of the change signal of the run-off projections and the reference. Left: near future (2021–2050), 11 ensemble members, right: distant future (2071–2100), 8 ensemble members (LfU BY/KLIWA 2017; LfU BY in preparation).

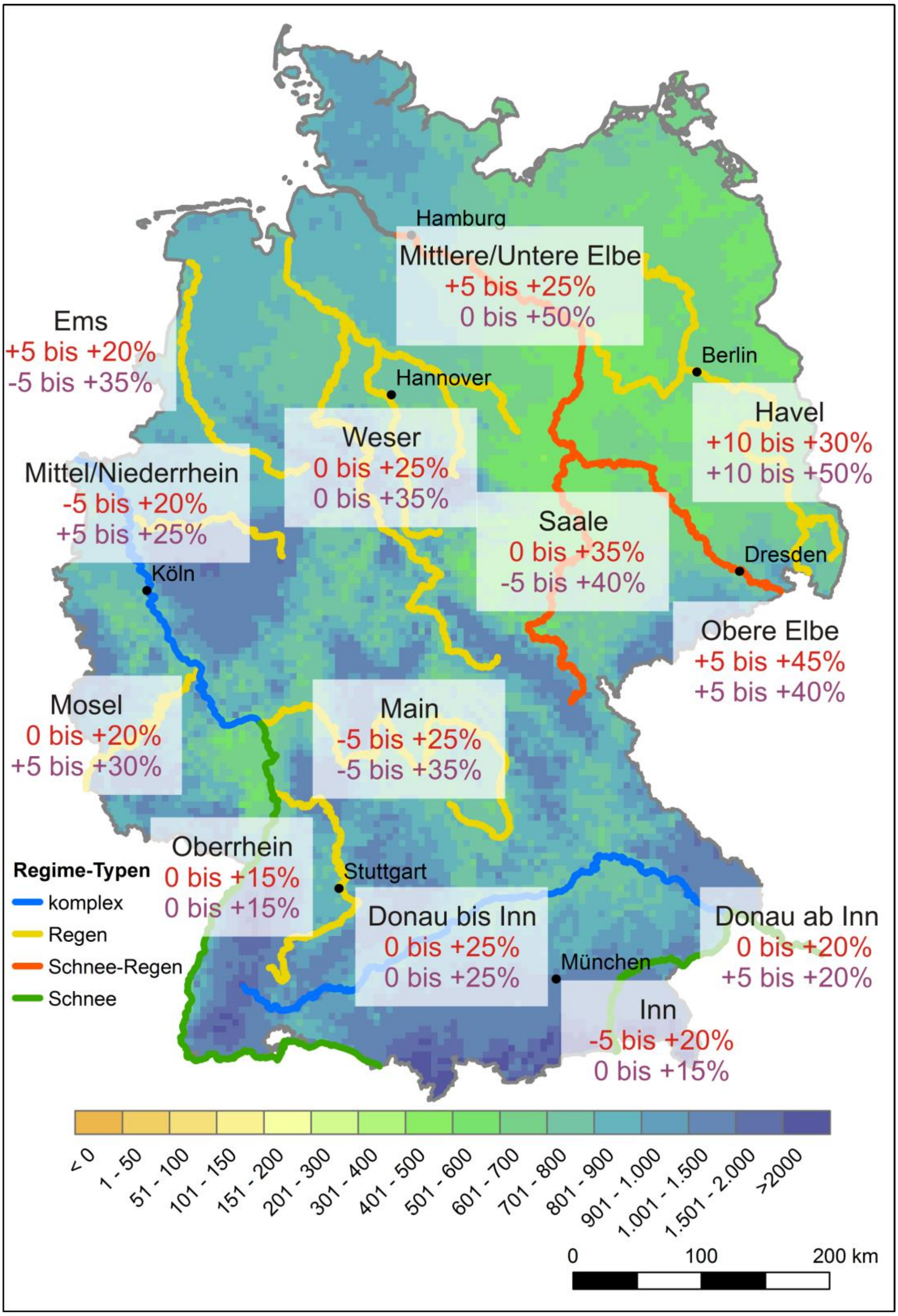


Fig. 15: Regional generalised change in the multiannual averaged high water run-off (parameter MHQ) on the large rivers; near (2031–2060, red) and distant (2071–2100, purple) future compared to the reference period 1971–2000 based on an ensemble of 18 run-off projections assuming the business as usual scenario (RCP8.5; Nilson et al. 2020, amended, cf. Nilson et al. 2014 and BfG, DWD, BSH & BAW 2015). The type of run-off regime in a river course is indicated by a coloured line. The background map shows the precipitation level (BMU 2003); average of the years 1961–1990.

4.1.1.4 Flash floods

Against the backdrop of climate change an increase in heavy-rain events, including flash floods, and thus an increase in the associated risks, is probable. Projections of rare extreme events are fraught with great uncertainty and at present are not robust enough. For this reason quantitative predictions of changes in local flash flood patterns are not possible. However, some qualitative statements can be made purely on a physical basis: with increasing temperatures the amount of precipitation will likely also increase because warmer air can hold more water vapour than colder air.

Under conditions of constant relative humidity, therefore, more precipitation would be expected. Furthermore, cloud- and precipitation-forming processes will presumably intensify due to the changed meteorological conditions. Additional influencing factors, some of them quite significant such as local topography and vegetation or the formation of precipitation, are responsible for an overall heterogeneous pattern throughout Germany.

In connection with the convective heavy rainfall events being primarily considered here, and which can often be quite destructive in Germany, empirical conclusions are not yet possible. Because of their relatively small scale, the events are often not recorded by gauging stations. Comprehensive radar data has been available since the start of 2001, but this is too short a timeframe to establish meaningful trends. However, analyses of this measurement data show that there was an increase in heavy precipitation also of shorter durations, at least regionally (Becker et al. 2016).

With regional climate modelling, no clear conclusions can be drawn regarding heavy local precipitation in Germany. The projections simply match the predictions that the proportion of strong precipitation within total annual precipitation will increase in the future. But it still remains unclear how this rise will be distributed across the increased frequencies and intensities of heavy precipitation (Becker et al. 2016; Deutschländer & Dalelane 2012; DWD 2019b). Latest research reveals that based on the business as usual scenario (RCP8.5), particularly heavy precipitation (99.9th percentile) will become relatively more frequent than lower levels of precipitation (90th percentile, see Rauthe et al. 2019).

There are thus some indications for an increase in the frequency of convective heavy rainfall events in connection with the temperature increase related to climate change. In addition, there are indications that the overall weather situation “Central Europe”, which is favourable for heavy rainfall events (e.g. predominant weather situation in first half of 2016), will become a more frequent occurrence as a result of climate change (Riediger 2012).

In this respect, conditions now exist for the possibility of more frequent occurrences of flash floods in the future.

More detail on the topic of heavy rainfall can be found under LAWA (2018).

4.1.2 Ecology of surface water bodies

Natural and semi-natural watercourses are, due to the diversity of their structure, significantly more stable and resistant to changes in the hydrological regime than severely modified stretches of watercourses(UBA 2015a). Thus watercourses with slower flow and long calm stretches, with old branches or other retention areas, can protect against heavy flooding. Permeable waterway beds permit a better exchange between the surface water and groundwater, which can help to buffer against the negative consequences of extended dry periods.

Irrespective of this, according to Article 4 (1) of the EU Water Framework Directive (WFD), as well under national law, surface water bodies must achieve good ecological status or good ecological potential (WFD 2000; German Federal Water Act (WHG)). The ecological status or the ecological potential is arrived at through investigations of the biological quality components (e.g. fish, macrozoobenthos, phytoplankton). To aid in assessment of the status, the "water-body structure" parameter is used.

4.1.2.1 Water-body ecology

Besides the amount of water, water flow velocity, quality and habitat diversity on banks, surrounding areas and the river bed, including the ecological functionality of sediment voids, important abiotic factors for habitation of running waters include the temperature and incoming solar radiation. Depending on the eco-region, the different features of geologically determined substrates, valley floor gradients, retention periods and water temperature, a zonation and water body type is produced with various habitats from the source to the mouth, in which different species occur preferentially and are reflected in the designations of running and transitional waters. The water temperatures, particularly the changes in temperature, play a large ecological role (e.g. in reproduction of fish and invertebrate fauna). As an example, salmonids prefer cooler, oxygen-rich sections of running waters, while barbels prefer warmer, nutrient-rich waters.

Changes in air temperature and the distribution of precipitation affect water temperature, the amount of water and the chemical composition of a water body. These are therefore key parameters for numerous physicochemical and biological processes in the aquatic habitat.

The result is a series of processes that can ultimately affect plants and animals in the water: some species become less abundant or extinct, while other species that migrate from warmer regions can reproduce and establish themselves in the ecosystem. Species diversity can decline in the medium term. The aquatic biocoenoses and the functional patterns of the natural environment change. But not all bodies of water react to changes in the same way. For example, fast-flowing streams in mountainous areas are less subject to oxygen deficits than slow-flowing middle or lower river courses in lowland areas or lakes.

Some aquatic habitats will shift or change their spatial expanse as a result of climate change. For instance, a shift in fishing regions within a waterway toward the source is expected. Other direct responses to increasing water temperatures and their consequences may include shifts in migration and spawning seasons of fish, emigration of water-body-specific species or disruptions to the nutrient chain.

Even short-term extreme temperatures, which lead to physiological stress and increased metabolic rates can have negative effects on fish populations. A concentration of nutrients and pollutants as a result of dry periods can also create heightened stress for aquatic organisms.

Longitudinal propagation is also expected for invertebrate fauna. Due to warming, organisms in cooler areas will migrate upstream. In smaller waterways, periods of low water in future may be accompanied by an increased risk of dried-out bank and bed segments. The loss of space and resulting high density of individuals will lead to a decline in species diversity. If the continuity of the water is interrupted by dry segments, the migratory behaviour of some fish species will be impeded. On the other hand, during times of extremely heavy storm run-off, the redistribution of gravel creates new aquatic habitats. With increased precipitation, especially in combination with land use changes, more fine sediments can be transported from the land surface into the water and fill the sediment pore spaces during the flood wave. This can impair the ecological functionality of the water body.

In lakes, depending on the hydromorphological and hydrological conditions, climate-related changes in temperature, wind and precipitation events can impact the overall lake ecosystem significantly. The thickness and duration of temperature stratification and thus the total mixing behaviour of the water body changes, thereby affecting the oxygen supply to deeper waters, material balance, and eventually the biocoenoses. A lack of ice cover will, for instance, affect the onset of spring algal bloom. Without stages of clear water, aquatic plants cannot be established and the development of summer plankton will be affected. Immigrating species can develop in masses (e.g. the quagga mussel) and displace native species (large freshwater mussels). Depending on trophic levels, high surface temperatures can lead to an increase or decrease in plankton e.g. mass development of cyanobacteria after nutrient redissolution from anaerobic sediments. Overall, both the chemical and biological conditions can change, which, in addition to the ecological effects, can also compromise the human usage of lakes. Transitional waters respond differently to low water periods caused by climate change than inland waters, because the water levels there are controlled primarily by tides. However, long-lasting periods of low upstream run-off can lead to a shift of the brackish-water boundary, which also affects the composition of the biocoenoses. This phenomenon can also impose limitations on present water uses.

4.1.2.2 Marine ecology

The North and Baltic Seas, and their coastal areas in particular, are relatively susceptible to the impacts of climate change. In 2019, the IPCC published a special report on the Ocean and Cryosphere which describes in detail the impacts of climate change, including on coastal areas (IPCC 2019b).

Higher temperatures in the seas will significantly alter the areas inhabited by species and whole habitat types. The displacement of many native species and thus consequences for ecosystem functions and services are to be expected. Changes in air temperatures are perceptible within a relatively short time for some species, such as those in the shallow Wadden Sea and the salt-marsh landscape.

Due to the removal of CO_2 from the atmosphere, CO_2 and therefore also hydrogen ion concentrations in the upper ocean layers are rising and leading to the acidification of seawater. This is especially detrimental to calcareous organisms. Carbon can no longer be stored at levels done so to date as the absorption capacity of the sea is declining over time. This process will presumably cause global warming to accelerate. The consequences will probably impact the entire marine food web.

Global sea-level rise, depending on its speed and height, can also influence marine ecosystems. For instance, if sea levels rise too rapidly there will not be sufficient input of sediment for the Wadden Sea to grow along with it. The tidal flat will be permanently flooded and lose its characteristic species and functions.

In addition to this, sea state and storm surges are decisive factors for the sediment structures, and influence the species that are dependent on them. Changes in intensities and frequencies are to be expected as a consequence of climate change. Changes in the catchment areas of large rivers could also lead to changes in nutrient and pollutant inputs into coastal and marine waters.

The German federal states and the federal government have undertaken a series of activities to identify the interrelationships in the North and Baltic Seas and to effectively protect the ecosystems of the two seas. All of these activities are based on the monitoring programmes through which the direct consequences of rises in temperature and sea-levels can be measured and assessed.

4.2 Groundwater

As a result of climate change, exceptional impacts on groundwater recharge, as well as on the available groundwater and groundwater levels can be expected. Similarly, groundwater quality and temperature can also be influenced. It is also possible that there will be an increased exploitation of groundwater reserves as a result of climate change. Although the observed effects so far have been moderate, groundwater should be comprehensively examined as early as possible due to its great importance with for public water supply, industrial use, because of its close interaction with surface waters, and because of groundwater-dependent ecosystems. This was shown clearly in 2018, a particularly dry year, in which the effects on groundwater were significantly more pronounced than in previous dry periods (NLWKN 2019; LUBW 2019).

4.2.1 Groundwater recharge

Climatically induced changes in the intraannual distribution of precipitation, as well as rising air temperatures and the associated increases in potential evaporation, can increasingly influence groundwater recharge and groundwater levels. At regional level, changes in the seasonal patterns as well as an increase or decrease in annual groundwater recharge are possible (DWA 2011; KLIWA 2012b; Hänsel et al. 2013; Herrmann et al. 2013).

A possible increase in the amount of precipitation during the hydrological winter half-year would enhance groundwater recharge. This effect, however, would be counteracted by a later end, and an earlier start to the growing season. A lack of increased precipitation during the winter half-year, or perhaps even a decrease, would result in reduced groundwater recharge. There have already been indications of this in recent years in large areas of Germany (LUBW 2019).

For the hydrological summer half-year, there are more considerable uncertainties in projections of the amounts of precipitation to be expected as well as in the spatial and temporal distributions of precipitation. A decline in summer precipitation combined with higher evaporation rates would create greater demands on the subsurface water reserves and result in a drop in the climatic hydrological regime This effect could also be reinforced by an increasingly earlier start to the growing season and the resulting longer growing period. Higher expected occurrences of intense rainfall events with unchanged total amounts of precipitation during the summer months would instead likely increase the surface run-off, allowing only limited groundwater and bottom water recharge.

Today, the more intensive use of groundwater reserves to cover the peak demands on drinking water supplies and increased irrigation requirements in agricultural areas is already evident. This trend could be exacerbated during periods of prolonged drought and heat. For the future, it is very likely that the groundwater reserves formed during the winter half-year will be subject to higher demand during the summer months, resulting in more frequently observed phases of low groundwater level (SMUL 2019).

Because of the uncertain status of information related to precipitation trends, and considering the complex interactions with other causative factors (e.g. soil, vegetation, land use, surface sealing), projections of the future development of annual groundwater recharge are still fraught with great uncertainty. In general, rather moderate changes in the annual regeneration of groundwater are projected up to the middle of the century. However, regional and local developments of this kind can vary in intensity, which is why water resources management should be prepared for an intensification of the decline in groundwater recharge. A high level of impact may be expected, especially in those areas that are already among the drier and low-precipitation areas in Germany (GERICS 2017). With the help of hydrological regime models, groundwater recharge can be estimated and regionally differentiated, even under changing climatic conditions (Herrmann et al. 2013; Herrmann et al. 2017).

In addition to annual groundwater recharge rates, the expected changes in seasonal recharge patterns and the resulting variations in the monthly hydrological regime should be kept in mind, including changes in the withdrawal amounts (e.g. drinking water and irrigation requirements). The increasing fluctuation ranges between low and high groundwater levels accompanying these patterns, as well as the spring discharge levels in connection with simultaneously occurring water-supply minima and water-demand maxima, will increasingly present water resources management with new challenges. This will particularly be the case when there is a higher frequency of successive wet or dry years. While larger groundwater reservoirs should be less susceptible to the changes described here, the probability of medium-term water shortages can no longer be ruled out in smaller reservoirs (near-surface groundwater bodies with low yield and modest thickness), which react more rapidly to changes in groundwater recharge. Groundwater-dependent ecosystems could also be subject to great changes in the future under these conditions.

4.2.2 Groundwater quality and temperature

The effects of climate change on groundwater quality are presently difficult to assess clearly. It can now be assumed fairly certainly that the increase in air and ground temperatures will also lead to a delayed increase in the near-surface groundwater temperatures (Menberg et al. 2013; Meier 2017). This could be accompanied by changes in a number of chemical, physical and biological processes such as material transport and turnover (DWA 2011). For example, it is possible that more humus could be broken down, more nitrogen mineralised, and more nitrate washed out of the groundwater. Forecasts for mineral soils show no clear trend in the development of humus content and reserves, due to the partly overlapping influences of temperature rise, increased CO_2 concentrations, and changes in precipitation and groundwater properties. The soils in regions with rising average winter temperatures could be particularly affected by the breakdown of humus. The groundwater fauna (stygofauna), a field that has not yet been extensively studied, could also be subject to changes in their species distributions.

If the amount of precipitation increases in the winter or outside of the growing season, it could lead to increased transport of materials out of the soil zone (washing out of nutrients, crop protection substances, metals and salts). Intensified agricultural activity with multiple harvests within the extended growing season could contribute to greater nutrient removal. If this is accompanied by an increase in the use of fertilisers and pesticides, however, this could lead to additional pollution of the groundwater. Enhanced irrigation can also contribute to greater leaching of the soil and washing out of nutrients and salts from the groundwater.

In coastal and estuarine areas the groundwater flow is strongly influenced by the tides and alternates between influent and effluent conditions. Higher seawater levels alter the gradients between the river or coastal waters and the groundwater, whereby there is an intensified freshwater/saltwater exchange in the mixing zone, between inflowing groundwater from the land and bank filtrate with riverine/coastal origins. In this area there will be a hydrochemical change in the groundwater (esp. increased salinification) (LLUR SH 2012).

A local increase in inland salinification is also possible. Falling groundwater levels as a result of decreasing recharge or increased groundwater abstraction to address growing water requirements can lead to a change in the pressure potentials in aquifers. Under unfavourable subsurface geological conditions, deep saline waters can then locally rise up into the near-surface groundwater areas. Areas in northeast Germany in particular could be affected by this. Overuse of near-surface aquifers can lead to increased abstraction of deeper groundwater thus increasing the risk of saltwater intrusion (Nillert et al. 2008).

4.3 Coastal waters and estuaries

Possible changes in the hydrological parameters of sea level, storm surges and sea state caused by climate change are relevant on German coasts (IPCC 2019b). Morphological changes can be expected as a consequence of hydrological changes. These hydrological and morphological changes are important not only with regard to coastal protection (flood and erosion protection), they can also influence the drainage of coastal lowlands. It should be pointed out, however, that the effects of climate change on the coasts cannot be applied one to one to the estuaries. In estuaries, the tidal or hydromorphological parameters are influenced by climate change in different ways, both from the sea side and upstream. Assessments of the effects of climate change on the large rivers and estuaries can be found in the KLIWAS reports (Nilson et al. 2014).

4.3.1 Sea level

The future development of sea-level rise as a result of human-induced climate change is an issue that is receiving considerable public and media attention. Projection of sea-level rise is an important aspect of climate research. According to the climate report “IPCC Special Report on the Ocean and Cryosphere in a Changing Climate” (IPCC 2019b), significant acceleration of sea-level rise is expected. For precautionary reasons, the federal government and the federal states agreed to apply the RCP8.5 scenario which assumes the greatest need for adaptation. In this scenario, the probable range of expected global average sea-level rise in this century is between 0.61m and 1.10m (median value 0.84m) Although according to (IPCC 2019b) regional deviations of up to ±30% from the global average are possible, according to Dangendorf et al. (2019) and Le Bars et al. (2019), significant deviations are not expected on Germany’s coasts. Sea levels will continue to rise far beyond the year 2100, by several metres in the RCP8.5 scenario. Local processes such as land subsidence will ultimately influence the actual extent of sea-level rise on the German coasts.

4.3.2 Storm surges

With regard to future storm surge water levels, it can be confidently stated that they will essentially increase in line with the average sea-level rise (see above). Additional changes could ensue from changes in the storm climate (see chapter 3.4) or by wind-forced water build-up (wind set-up). Strong landward-blowing winds can transport water toward the coast and result in a rise in the water level (locally up to 4.0 m). As discussed in chapter 3.4, according to the present state of knowledge significant changes in the storm climate and the associated wind set-up are not expected on the German coasts. Accordingly, it can be assumed that changes in the storm-flood levels on the German coasts will develop in a manner similar to changes in mean sea level.

4.3.3 Sea state

The mean and maximum sea state are, like wind set-up, primarily controlled by the wind conditions (wind strength, direction and duration) and coastal topography. According to Quante & Colijn (2016), available model studies indicate that an increase in the average and maximum wave heights on the German North Sea coast can be expected through to the end of the century. The projected increases, however, are very small and lie within the range of past natural variability. Similar developments are projected for wind conditions in the Baltic Sea (BACC II Author Team 2015), which means comparable changes in the future sea state can be assumed there.

4.3.4 Morphological changes

Due to projected hydrological changes, substantial morphological changes can be expected on the sandy German coasts. Because of sea-level rise, an acceleration of the current coastal degradation in Mecklenburg-West Pomerania is expected. More frequent undercutting and collapse could occur on cliffed coasts, and there could be increased shortages of sand on the flatter coasts (MWAT MV 2010). A similar situation is expected in Schleswig-Holstein. Because increasing coastal collapse is a fundamental consequence of increasing rates of sea-level rise, mid- to long-term intensification of coastal erosion is assumed, even at locations that are relatively stable today (MELUND 2013). For Lower Saxony's Wadden Sea, whose sediments are primarily non-cohesive, a variety of consequences is also expected. These include the steepening of foreshores, retarded growth of the tidal flats and enlargement of the inlets, as well as intensified erosion of the reef arcs and adjacent island beaches (MUEK NI 2012). Schleswig-Holstein is also facing serious issues regarding the stability of its Wadden Sea with the accelerating rise of sea levels, which will ultimately lead to a more rapid diminishing of the tidal flats and salt marshes in the Wadden Sea (MELUND SH 2015).

5 Concerns, climate adaptation measures and practical examples

In the following section, concerns related to expected changes in water management parameters are described for the water management fields of action. These concerns lead to the subsequently presented climate adaptation measures, which can help toward adapting to the consequences of climate change. Additionally, practical examples of climate adaptation measures are presented in the form of standardised profiles for each field of action. The practical examples broadly cover the regions, concerns and stakeholders in Germany's water resources management, yet merely provide an example of each field of action. The profiles contain information on the objectives of the measures, a description of implementation steps, as well as the names of contact persons and references for further information. A comprehensive overview of the climate adaptation measures and options for action can be found in the annex.

The sequence of fields of action in chapter 5 does not imply a priority order. Prioritisation of the fields of action is only possible through more extensive investigations. More information on this is given in section 6.3.

5.1 Inland flood protection and protection against high groundwater levels

5.1.1 Concerns relating to inland flood protection

Flood protection for inland waters is influenced by changes in various climatic parameters. Because flood events are heavily dependent on the character of precipitation, the most significant factors to be addressed are possible increases in intense summer rainfall and in general winter precipitation. In catchment areas characterised by snow and glaciers, high water levels can also be influenced by temperature increases with the resulting depletion of temporary storage as snow, or through intensified ice melting. Changes in wind intensity also impact wave intensity and wind set-up, and can therefore have an influence on some flood-defence structures, such as dams (MUKE BW 2013; UBA KomPass 2011).

<u>Flood-protection levels of existing structures</u>

If the frequency, height or duration of high water events increases in the future, the objects of protection under the European Union Floods Directive (i.e. human health, the environment, cultural heritage and economic activities) could be more severely impacted by flooding than previously (MUKE BW 2013). Water management structures and high water protection infrastructures are commonly designed to hold up against high waters with a defined recurrence interval (e.g. HQ_{100}). Due to changes in the patterns of high water events, however, the former design-based flood could occur more often or be exceeded in height. The level of protection afforded by existing structures would thus be reduced (MUKE BW 2013).

Likewise, higher wind speeds, which have not been considered thus far with regard to the amount of freeboard designed into protective structures, could lead to greater wave strength and wind set-up. This could also impair the existing level of protection, especially for large-scale water-protection structures or lakes exposed to the wind.

Designing flood protection

Design procedures are also affected by the possible changes in high water patterns and wind impact. The impacts of climate change are to be taken into account in the design of new structures, as well as the adaptation of existing structures, in order to maintain the desired level of protection in response to the expected changes.

Expected changes in the design parameters (often defined by annuality, e.g., 100 a for HQ_{100}) are crucial for high water design questions. Climate-change studies generally provide information on the possible changes in primary statistical parameters such as MHQ. Results describing possible changes in the occurrence of relatively rare extreme events are less readily available, and at the same time are associated with greater uncertainty. However, it is precisely these rare events that are required as extreme-value analysis parameters for designing the flood-protection structures. Information about their possible development, or procedures that consider the uncertainty would also be helpful for specific adaptations of the structures with respect to climate change.

Small and urban-dominated catchment areas

Primarily small and/or urban-dominated catchment areas are particularly affected by the possible intensification and increased frequency of small-scale heavy rainfall events. These can result in an increased incidence of flash flooding, as discussed in section 4.1.1.4. Thus, the high water protection structures along water bodies with small or urban-dominated catchment areas would also be affected.

In land areas with large coverage of sealed surfaces and thus a low retention capacity, changes in precipitation patterns can have a more direct effect on run-off than in catchment areas with a greater proportion of unpaved surfaces and correspondingly greater retention capacity, i. e. with less concentrated surface run-off. Particularly in areas with a high level of sealed surfaces that have rarely been affected by flooding in the past, it cannot be ruled out that the flood risk will increase in the future (MUEK NI 2012). As a result of small-scale convective precipitation events, small catchment areas subjected to blanketing rainfall can also respond very drastically. As a result, the risk of flooding in smaller water bodies can significantly increase. The total damage caused by small and moderate floods in tributaries can be greater than those caused by high waters in larger water bodies (MUEK NI 2012). A critical evaluation of flood protection measures for smaller and/or urban-dominated water bodies is therefore crucial.

Critical infrastructures

Critical infrastructures (e.g. transportation connections, water and energy utilities, and wastewater infrastructure) that previously were not significantly threatened by high waters could be affected in the future, especially due to the increasing threat of high water in smaller or urban-dominated waters (MUKE BW 2013). During flooding, certain infrastructures (e.g. sewage treatment plants, industrial and commercial complexes that store hazardous materials, oil tanks or pipelines that transport dangerous substances) can represent a serious potential threat to the quality of water bodies (MUEV SL 2011). Hence, a review of the flood hazards and flood protection related to critical infrastructures would also appear to be expedient.

Alpine catchment areas

Due to a lack of, or the presence of only small retention areas, flood protection in the Alps would be especially severely affected by changing precipitation patterns (BMU, no year given). Furthermore, changes in snow accumulation here could result in very serious changes in winter high water conditions. It can also be assumed that an increase in heavy precipitation in the winter (as rain rather than snow), in addition to flooding, could also have other serious consequences such as mud flows (StMUV BY 2016).

5.1.2 Concerns relating to high groundwater levels

Temporally constrained but substantially elevated groundwater levels, caused by rising river conditions, for example, can result in significant damage. Flooding by groundwater can occur in areas with shallow water tables such as floodplains, former floodplains and depressions in the land surface. This could occur as an actual emergence of groundwater at the surface or it could accumulate as precipitation that cannot be effectively absorbed because of the shallow water table (MUKE BW 2013). Climate change, through altered precipitation patterns (particularly increases in winter precipitation) as well as changes in the evaporation regime, can thus have an influence on protection against high groundwater levels.

<u>High water-table levels due to elevated river levels</u>

Usually, groundwater flows from beneath the surface into the surface waters (effluent conditions). During periods of high water in a river, surface-water levels can become so high that the direction of flow reverses and water from the surface bodies flows into the aquifer (influent conditions). The water table thus rises in the vicinity of the stream or river. In addition, if there is simultaneous surface flooding it could lead to strong infiltration. High groundwater levels, which occur as a result of and in combination with river floods, are thus affected by climate change in a similar way as inland flooding. In contrast to river floods, elevated groundwater levels persist, as a rule, for significantly longer time periods, and are thus potentially much more damaging. For reservoirs in watercourses this effect can be amplified because the aquifer empties more slowly in response to the level of the water table.

<u>Concerns relating to physical structures, agricultural and forestry lands</u>

Potentially more frequent occurrences of high water-table levels due to climate change give rise to a greater potential for damage. These primarily affect physical structures, agricultural lands and forestry areas. Increased waterlogging can restrict the normal use of buildings and property. Damage to buildings caused by high groundwater levels include:

- Damage to building material and facilities due to groundwater infiltration
- Penetration of moisture into basement floors and walls as a result of rising groundwater levels
- Contamination of building elements through leaking hazardous substances caused by rising groundwater
- Destruction of or damage to buildings due to unstable foundation with insufficient building load ("floating" or hydraulic failure)
- Indirect damage due to loss of building use

Rising water tables can also lead to water-logged farmlands and forest areas. The waterlogging of agricultural lands can result in spoiled seeds and damage to winter and permanent crops (UBA 2015e; MUKE BW 2013). A delay in planting could also be caused, for example, by difficulties in driving farm equipment on the soil. It is also possible that nitrates, pesticides, herbicides and other materials could be washed out of the soil.

5.1.3 Climate adaptation measures (Annex Tab. A. 1 - Tab. A. 12)

In many regions with a possible future increased risk of flooding, existing measures for flood protection may have to be expanded and supplemented by additional measures. The most appropriate measures will have to be decided on a case-by-case basis.

It is important that, as far as possible, the effects of climate change are considered early during the design phase of a structure. North Rhine-Westphalia therefore recommends evaluating the sensitivity of structures with respect to changes in basic data or design parameters. In Baden-Württemberg and Bavaria, climate change is taken into consideration in the planning of new flood-protection structures by adding a climate-change factor to the run-off parameters used, which can be determined using various methods (KLIWA 2012a). In Baden-Württemberg, the results of an economic feasibility analysis for a planned structure are used to determine whether the changes indicated by the added climate markup should be carried out directly during the construction of the new facility, or conditions enabling an efficient future retrofitting should simply be ensured. In Bavaria the uncertainty is counteracted by a flat-rate climate-change factor of 15 %.

Based on the changed design criteria, a technical measure for flood protection can be implemented, i.e., a permanent or mobile protection structure such as a dike, dwelling mound, or mobile bulkhead gate, whose design height may have to be adapted to take account of changing run-off statistics (see section 5.1.1). The retention of water in natural flooding areas such as floodplains or in artificial floodwater-retention basins may serve as a protection against flooding and also generally has the effect of buffering run-off. Such protection measures often require large areas of land at specific locations, so judicious planning must include guarantees to secure the areas and keep them free for the purpose of flood protection. Prerequisites for the planning of specific measures are the determination of flooding areas (areas that are flooded in the event of a hundred-year flood) and flood-threatened areas (areas that would be flooded by water higher than a hundred-year flood, or that could be flooded due to the failure of dikes or other flood-protection structures) and included these in flood hazard maps pursuant to the Floods Directive. For Bavaria, for example, the IÜG information system for flood hazard areas (Informationssystem Überschwemmungsgefärdete Gebiete) provides relevant hazard maps. Other German federal states also offer this information in their environment portals. As far as possible, settlements, infrastructures and cultural assets with high risk of being damaged should not be located in flood zones.

For high groundwater levels, a determination of areas vulnerable to waterlogging should also be carried out. For the protection of buildings in these vulnerable areas a variety of structural additions could be undertaken.

In order to devise the most efficient flood protection possible in a river basin, cooperation among the local communities in flood partnerships – crossing state and national borders, where appropriate, can be beneficial as the implementation of measures, public awareness-raising activities and disaster preparedness can be better coordinated at this level. This has been a common practice in Baden-Württemberg for many years (see practical example 2). Within the framework of the national flood protection programme (Nationales Hochwasserschutzprogramm - NHWSP), which particularly supports projects operating nationwide, cooperation for the creation and optimising of flood polders across state borders has already been initiated and intensified.

Links with other fields of action	Coastal protection, urban drainage and wastewater treatment, flood protection: heavy rainfall and flash floods, drainage of low-lying areas, conservation of aquatic ecosystems, groundwater protection, public water supply, hydropower generation, navigability, dam and reservoir management, low water management in watercourses

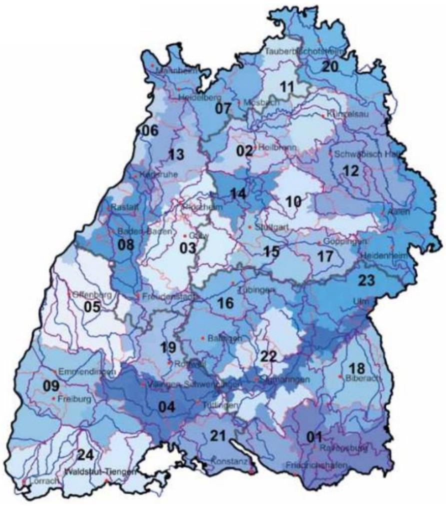
5.1.4 Profiles of practical examples

Example 1: Field of action - Inland flood protection and protection against high groundwater levels: Werse intercommunity development plan - flood protection and ecological development

Field of action	Inland flood protection (and conservation of aquatic ecosystems)
Example	**Werse intercommunity development plan - flood protection and ecological development**
Climate adaptation measures	Restoration of floodplains (Tab. A. 3), Alteration of hydromorphological structures (Tab. A. 48), Improvement of watercourse continuity (Tab. A. 47), Activation of additional retention areas (Tab. A. 4), Flood partnerships (Tab. A. 10), Behavioural preparedness (Tab. A. 12)
Reactivation of a near-natural floodplain is one element of flood protection on the Werse. Photo: Kreis Warendorf, Christiane Vogel	
Description and objectives	After the devastating flood of 2001 the district of Warendorf together with the towns of Ahlen and Beckum implemented flood-protection measures in the region in connection with the ecological development of the Werse River waterbody. Between Ahlen and Beckum a natural aquatic landscape with floodplains was created over a 10 km stretch. The channel straightening of the 1960s and 70s was corrected and numerous natural restoration measures were carried out (e.g. bringing in dead wood, removal of bed drops, new plantings). Even during heavy rainfall events there is now sufficient retention area in the natural flooding areas. Additional water can be held in a 240,000 m^3 large flood-water retention basin before being fed back into the Werse in a controlled manner. Within the towns, measures such as the installation of sand traps, planting of greenery, the conversion of drop structures to rocky slopes or ramps, and widening of the channels were carried out. During the multi-year project, many different aspects such as flood control, biotope development and local recreation were considered. Implementation of the measures also serves adaptation to climate change by counteracting a possible increase of high water run-off in the future.
Timeframe of implementation	2002–2015 The project was divided into four planning and six construction phases.
Costs/financing	10 million euros, 80 % funded by the state of North Rhine-Westphalia
Participants	State authorities of North Rhine-Westphalia, Warendorf District, Town of Beckum, Town of Ahlen, Flick Engineering Association, ARGE Water Agency, farmers, land owners, tenants, water and soil management association, nature conservation organisations, private individuals

Challenges, solutions and successes	⨯ Acceptance, the legal status, financing, and data availability were constraints in implementing the measures. ✓ To overcome potential obstacles, early-stage open discussions were held with the affected parties (owners, residents and tenants) and support agencies, and the implementation of measures was linked to a municipal pool of mitigation sites and anticipatory compensation measures (Ökokonto). The purchase and exchange of property was largely carried out voluntarily. Information on progress was continuously available and public relations work was carried out regularly. ✓ The effectiveness of the measures was demonstrated during the high water event of 2010: The water level in Ahlen was significantly lower than previously measured values. ✓ The measure conforms with the standards of the EU WFD and has resulted in a permanent reduction of maintenance expenses for the water and soil management association.
Contact	Environmental Protection Office Warendorf
Further information	• Umweltbundesamt: Entwicklungsplanung Werse – Hochwasserschutz und ökologische Entwicklung. Tatenbank. Link: *www.umweltbundesamt.de/themen/klima-energie/klimafolgen-anpassung/werkzeuge-der-anpassung/tatenbank/entwicklungsplanung-werse-hochwasserschutz* • Umweltbundesamt (2013): Handbuch zur guten Praxis der Anpassung an den Klimawandel • Heuckmann: Lebendige Werse. Hochwasserschutz und Gewässerentwicklung an der Werse in Beckum - Gewinn für Mensch und Natur. Link: *www.beckum.de/fileadmin/daten-stadt/pdf/UMWELT/Gewaesser/Werse/vortrag_lebendige_werse_4112014.pdf* • Stadt Beckum: Die Werse - von der Wasserautobahn zum Auenland. Link: *www.beckum.de/de/umwelt/gewaesser/werse.html* • Kreisverwaltung Warendorf: Kooperation Werse. Link: *www.kreis-warendorf.de/unsere-themen/umwelt/eg-wasserrahmenrichtlinie/kooperation-werse/*

Example 2: Field of action - Inland flood protection and protection against high groundwater levels: Facilitation of flood partnerships

Field of action	Inland flood protection
Practical example	**Facilitation of flood partnerships by state authorities**
Climate adaptation measures	Flood partnerships (Tab. A. 10), Behavioural preparedness (Tab. A. 12)
Overview of the existing flood partnerships in Baden-Württemberg.	
Description and objectives	Flood partnerships are a significant component of the flood-protection strategy in Baden-Württemberg. They are initiated, organised and coordinated by the WBW Society of Advanced Training for Water Development mbH. They are networks involving the communities, expert administrations and institutions within a catchment area. Together, these can implement measures for flood precautionary measures, exchange experiences and raise awareness of flood hazards. Partnership members have regular opportunities to attend events such as workshops and continuing education programmes on the subject of floods. They create a broad foundation for discussion among all stakeholders, which is why the communities are represented by political decision-makers as well as by individuals from various professional levels. Additional members include regional associations, authorities, industry and commerce etc. (see below). The flood partnerships also support adaptation to climate change, as flood run-offs may increase in the future.
Timeframe of implementation	since 2003
Costs/financing	-
Participants	WBW Society of Advanced Training for Water Development mbH, municipal political decision-makers, municipal expert levels, local water authorities, local authorities for hazard control and disaster control, regional commissions, regional associations, industry and commerce, historical preservation authorities
Challenges, solutions and successes	× Large number of diverse participants ✓ For every flood partnership one or two moderators are selected who are available as a contact person for all members. There is a meeting once each year for exchange among all the moderators in Baden-Württemberg. ✓ Appropriate materials for public information are provided to the communities by the WBW Society of Advanced Training for Water Development mbH.
Contact	WBW Society of Advanced Training for Water Development mbH
Further information	• WBW Fortbildungsgesellschaft für Gewässerentwicklung mbH (2012): Hochwasserpartnerschaften in Baden-Württemberg • WBW Fortbildungsgesellschaft für Gewässerentwicklung mbH: Hochwasserpartnerschaften. Link: *https://wbw-fortbildung.net/pb/Home/Taetigkeiten/Partnerschaften.html*

Example 3: Field of action - Inland flood protection and protection against high groundwater levels: Flood protection in Dresden

Field of action	Inland flood protection and protection against high groundwater levels
Practical example	**Flood protection in Dresden-Gorbitz**
Climate adaptation measures	Activation of additional retention areas (Tab. A. 4), Technology of flood protection (Tab. A. 2), Behavioural preparedness (Tab. A. 12), Alteration of hydromorphological structures (Tab. A. 48), Identification and presentation of areas at risk of waterlogging (Tab. A. 8)
Object area 5 of the Dresden flood prevention plan: Gorbitz. Photo: © State capital Dresden	
Description and objectives	**Dresden plan for flood prevention:** Immediately after the extreme flooding events on the Elbe and Weißeritz in August 2002, with extensive flooding in large parts of the Dresden urban area, the efforts to improve preventative flood protection measures began. In order to identify the areas in need of action, beginning in 2004, a plan for flood prevention in Dresden was developed. Investment measures that could ensure protection against a 100-year flood were worked out for 23 object areas. It became clear that, as a rule, entire packages of measures were necessary because the hazards always had to be considered in the context of the interactions of different water systems. The measures also address adaptation to climate change, as flood run-offs may increase in the future. **Example of implementation in the district of Gorbitz:** In the Dresden district of Gorbitz various protection measures were implemented in the Weidigtbach and its tributary the Gorbitzbach. For example, 18 consecutive retention troughs and one retention basin were built. In addition, the stream bed was widened and given a more natural form. The area near the stream was converted to a local recreation area with footpaths and a natural playground with a flowing stream. **High groundwater tables:** Following flooding events on the Elbe, large-scale elevations of the groundwater table usually also develop in the Dresden urban area. In the public interest, the city of Dresden provides materials on the internet for citizens to evaluate their own individual areas of concern. Furthermore, an automated high water observation system for groundwater publishes the current water table level at 63 gauging stations at www.dresden.de/grundwasser. For the protection of culturally significant buildings on the historical-district side of the Elbe there are eight relief installations for high groundwater levels with private and public owners and a total of 23 wells.
Timeframe of implementation	2010-2014 (Dresden-Gorbitz)
Costs/financing	3 million euros (Dresden-Gorbitz)
Participants	City administration Dresden, Dresden public transportation, the Free State of Saxony, BMBF REGKLAM project, affected property owners (railroad cooperative, agricultural cooperatives), general public
Challenges, solutions and successes	× Negotiation processes with landowners ✓ The effectiveness of the measures was demonstrated with the spring high waters of 2013. ✓ Residents and involved parties were directly involved through public relations work and realisation of the measures (e.g. natural playground).

	✓ Because a single strategy was developed for the entire catchment area, a variety of funds was accessed, including street and urban development funds as well as resources for neighbourhood improvement.
Contact	Environmental Office Dresden, Dept. of Community Environmental Protection, Specialty Field Soil and Water/Flood Protection 2nd order water bodies (Dresden-Gorbitz)
Further information	• Landeshauptstadt Dresden: Plan Hochwasservorsorge Dresden. Link: *www.dresden.de/de/stadtraum/umwelt/umwelt/hochwasser/oeffentlich/Plan_Hochwasservorsorge_Dresden.php* • Umweltbundesamt (2013): Handbuch zur guten Praxis der Anpassung an den Klimawandel • Landestalsperrenverwaltung des Freistaates Sachsen (2010): Hochwasserschutz für Dresden. Bürgerinformation • Umweltamt Dresden (2010): Umweltbericht Grundwasser

5.2 Coastal protection

5.2.1 Concerns

The Coastal Protection field of action is sub-divided into the areas of coastal flood protection (protection from flood waters from the sea) and coastal protection (preservation of the coasts against shore retreat and erosion).

Due to the accelerating rise in sea level, an increase in hydrological pressures can be expected, accompanied by increased maintenance and repair costs for coastal defence systems. Wherever sand replenishment is carried out, the required quantities of sand and frequency of repetition will increase (MELUND SH 2015, NLWKN 2010). However, the reduction of direct ice cover and less frequent occurrence of ice in shore areas can be beneficial for coastal protection structures, particularly on the Baltic Sea coast. The impact could be mitigated and result in a lengthened effective lifetime and longer maintenance intervals (MWAT MV 2010).

<u>Hotspots</u>

Around 2.5 million people live in the ca. 12,000 km^2 area of the German coastal plains. They are protected from storm surges by almost 1,500 km of sea dikes and other coastal defence systems (Hofstede et al. 2009). Material assets worth almost 130 billion euros (NLWKN 2020) are contained in the dike protected areas of Lower Saxony. Without dikes in Bremen, circa 86% of the greater city area would be constantly under threat from flooding (HB 2019). In Mecklenburg-Western Pomerania, the occurrence of a design-based flood and a lack of storm surge protection structures would mean 85% of the total area of the Fischland-Darß-Zingst peninsula alone would be affected by flooding. About 1 million m^3 of sand is already being pumped onto Sylt annually to protect the coast (MELUND 2013). In addition to these densely populated areas, regions with a high potential for physical damage, such as the Port of Hamburg, are also at the centre of discussions on adapting coastal regions.

5.2.2 Climate adaptation measures (Annex Tab. A. 13 - Tab. A. 20)

Higher storm surge water levels and increasing impacts from the state of the sea and currents are expected as a result of rising sea levels. There is consequently an increasing need to adapt the existing coastal defences. Because of the increasing effects of erosion, coastal protection measures will very likely have to be intensified. Coastal stability can be maintained by sand replacement measures and bank protection structures. The higher risk of flooding from storm surges on the sea side can be mitigated with dikes, protective dunes and customised solutions, such as protective walls and dwelling mounds. When designing such structures, a climate markup and a construction provision facilitating future heightening are advisable.

Coastal states have already introduced a number of climate adaptation activities and measures:

- To ensure that changes in hydrological impacts related to climate change can be taken into account in a timely manner, safety reviews of key coastal flood-protection facilities in the coastal states should be carried out at regular intervals (see NLWKN 2007; MELUND 2013; MELUV 2012).
- In the design of coastal flood-protection facilities in future, coastal states will use a precautionary measurement, based on climate change, of 1.0 m. This measurement covers a period of 100 years in relation to the year 2000 or the current assessment date. Depending on the local conditions and the specific structure, the precautionary measurement can be implemented by different measures. The precautionary measurement is to be reviewed regularly or as required on the basis of new scientific findings and adjusted if necessary.
- In Lower Saxony and Bremen, for solid coastal protection structures built for storm surge defence, an adaptive capacity of up to one additional metre beyond the precautionary measurement should be envisaged in the foundations and load-bearing structure, taking account of functionality and lifespan.

- Furthermore, in Bremen, Lower Saxony and Schleswig-Holstein construction provisions are being planned for reinforcement measures to be implemented within the dike profile at a later date (NLWKN 2007, 2010; MELUND 2013). In Mecklenburg-Western Pomerania, land required for the future reinforcement of dunes and dikes, beyond the aforementioned precautionary measure, is to be legally secured with regard to construction works.
- In order to accommodate any later expansion measures that may be needed for coastal protection dikes to protect against storm surges, building-restriction zones in a strip on the landward side of the dikes have been included in the state legislation of Bremen, Hamburg, Lower Saxony and Schleswig-Holstein (Article 76 of the Bremen water act (Bremisches Wassergesetz), Article 6 of the Hamburg dike ordinance (Hamburgische Deichordnung), Article 16 of the Lower Saxony dike law (Niedersächsisches Deichgesetz) and Article 82 of the Schleswig-Holstein state water act (Landeswassergesetz Schleswig-Holstein)). In Hamburg, a legal pre-emptive right is envisaged for land required for flood protection needs (Article 55(b) state water act). In Mecklenburg-Western Pomerania, construction works can only be built 200 metres from the average water line if they are compatible with coastal protection needs (Article 89 state water act).

In addition to technological measures to reduce the risk of flooding, measures to minimise the potential damage caused by increasing hydrodynamic and hydrological pressures due to climate change are becoming more relevant. These include, in particular, area-based measures for usage management in vulnerable areas. According to Article 82 of the Schleswig-Holstein state water act, for example, buildings may not be erected or significantly altered in a coastal strip behind steep banks, dunes and beach ridges, or in coastal risk zones not (adequately) protected by state-protection dikes. Coastal protected areas have been designated in Mecklenburg-Western Pomerania to minimise the risks to vulnerable stretches of coast and, where necessary, to make areas available for coastal protection measures (Article 136 state water act).

In Lower Saxony, the use of designated protective dune areas is not permitted under the dike law. Stringent restrictions on use are in place for dike foreland areas. Other areas of responsibility that are becoming increasingly important as a result of climate change include emergency response and disaster prevention. In this context, the proper behaviour and adoption of urgent measures for extreme cases should be organised, communicated and tested.

Links with other fields of action	Flood control, drainage of low-lying areas, marine protection, conservation of aquatic ecosystems, navigability

5.2.3 Profiles of practical examples

Example 4: Field of action - Coastal protection: Hafencity Hamburg: Dwelling mounds instead of dikes

Field of action	Coastal protection
Practical example	**Hafencity Hamburg: Dwelling mounds instead of dikes**
Climate adaptation measures	Coastal flood protection through other flood defence systems (Tab. A. 17)
For the residential buildings at Dalmannkai, a minimum protection height of 7.5m above mean sea level is applied. Graph: © panthermedia.net /Jens Ickler	
Description and objectives	The Hamburg Hafencity district, completely surrounded by rivers and canals, lies to the south of Hamburg's main dike line, which is why the dikes cannot provide protection for the area. A dwelling mound, or elevated-foundation, solution was favoured over dike construction to protect the newly created urban district. A dike would have obstructed the view of the water and would have to have been completed before construction began. The buildings are now being constructed in stages on artificial dwelling mounds with a height of 8-9 m above mean sea level, which should be sufficient even during extreme floods. Many roads and bridges are also being built at flood-safe levels, so that the infrastructure can continue to be used during storm surges. The space within the dwelling mound base is used as an underground car park in many areas. In some cases, however, the car park entrances must be safeguarded by flood gates and thus remain closed in the event of flooding. Promenades and some squares have remained at the previous level of 4.5-5.5 m above sea level, thus maintaining the close connection to the water. There are sufficient flood-safe routes to the city centre. The potential increase in the risk of storm surges and floods due to climate change was a major factor in the creation of the dwelling mound concept.
Timeframe of implementation	Planning outline: Master Plan 2000, start of construction: 2001, completion of the first building: 2003, first occupancy: 2005, expected completion: 2025–2030; In November 2019, 77 projects were completed and further 63 either in the construction or planning stages.
Costs/financing	10 billion euros private investments, 3 billion euros public investments Approx. 7,500 apartments are to be built, around 1,500 - 2,000 of which will be subsidised.
Participants	HafenCity Hamburg GmbH, Free and Hanseatic City of Hamburg, developers, area planners
Challenges, solutions and successes	× Expensive living and office space, many office vacancies × The Zukunftsrat (council for the future), alleges that the project is unsustainable; social equity in particular is neglected ("elite quarter") ✓ The dwelling mound solution costs only about 10-20 % of what dam construction would have cost
Contact	HafenCity Hamburg GmbH
Further information	• HafenCity Hamburg GmbH: HafenCity Hamburg - Warften statt Deiche: Hochwasserschutz in der HafenCity. Link: *www.hafencity.com/de/konzepte/warften-statt-deiche-hochwasserschutz-in-der-hafencity.html* • HafenCity Hamburg GmbH: Daten & Fakten zur HafenCity Hamburg. Link: *www.hafencity.com/* • Bruns-Berentelg (2014): Die Hafencity Hamburg - Identität, Nachhaltigkeit und Urbanität

Example 5: Field of action - Coastal protection: "Climate Dike" concept

Field of action	Coastal protection
Practical example	**"Climate Dike" concept**
Climate adaptation measures	"Load case climate change" (Tab. A. 1), coastal flood protection through dikes (Tab. A. 15)
New climate profile for state-protection dikes in Schleswig-Holstein. The profile contains a construction provision: The outer slope is flatter, the dike crest wider and the revetment higher, so that improvements at a later stage are possible with minimal effort. Photo: J.L.A. Hofstede / MELUND-SH	
Description and objectives	The General Plan for Coastal Protection 2012 of the State of Schleswig-Holstein established a uniform safety concept for state-protection dikes. The dikes must be reinforced if, during a storm surge with a 200-year recurrence interval, more than 2 litres per second and running metre flow over the dike crest. In a review in 2011, a need for reinforcement was identified for 93km of the dike line. The "climate dike" concept is now being applied for planned dike reinforcements, for the first time, for damn reinforcement in Büsum and Nordstrand Alter Koog. Because of its wide top, flat outer slope overall and higher revetment, the dike can be raised again later if necessary without having to alter the size of the dike base. If reinforcement is necessary due to rapidly accelerating sea-level rise, a cap could be added to the dike relatively easily and cost-effectively in a second construction phase. Should this not be sufficient, the entire dike can be raised further without building over additional areas. The flatter outer slope provides additional protection already in the first construction phase, because the wave run-up is more effectively dissipated on a flatter slope. A total sea-level rise of up to 2 metres can be accommodated in several construction phases.
Timeframe of implementation	Conceptually since 2009; measures in Büsum/Nordstrand: 2013–2016
Costs/financing	Very different depending on location, between ca. 2 and 12 million euros per km of dike, financed with federal and state funds from the Joint Task for the Improvement of Agricultural Structure and Coastal Protection, and from the Programme for the Future: Rural Areas of the European Agricultural Fund for Rural Development
Participants	Ministry for Agriculture, the Environment, Nature and Digitalisation of the State of Schleswig-Holstein
Challenges, solutions and successes	× Increased construction costs and greater intervention in the existing landscape ✓ Lower construction costs in the future, no new land requirements, inter-generational equity ✓ Flat outer slope offers space for leisure activities; increased attractiveness as a seaside resort
Contact	Ministry for Energy, Agriculture, the Environment, Nature and Digitalisation of the State of Schleswig-Holstein
Further information	• Hofstede (2017): Küstenschutz in Schleswig-Holstein. Deichverstärkungen Büsum und Nordstrand Alter Koog • Landesbetrieb für Küstenschutz, Nationalpark und Meeresschutz Schleswig-Holstein (2015): Alter Koog Nordstrand. Küstenschutzmaßnahme Deichverstärkung

5.3 Urban drainage and wastewater treatment

5.3.1 Concerns

Changes in various climate parameters can affect urban drainage and the wastewater treatment system. These primarily include the potential increase in heavy rainfall, changes in the seasonal precipitation regimes and expected increases in wastewater temperatures.

Designing drainage systems

Precipitation design-case events for the safe discharge of rainwater have recurrence intervals of 2 to 5 years, in some cases up to 20 years (MKULNV NRW & MBWSV NRW 2016). With a probable increase in the intensity and frequency of heavy rainfall events, the design is likely to be exceeded more often, resulting in more frequent sewer overflow (MUEK NI 2012). In areas with separate sewerage systems, increased hydraulic stress in receiving waters is also to be expected as a result of heavy rainfall (DWA 2010). In combined rainwater and sewage systems, overflow events will lead to adverse effects on the quality of the receiving waters (DWA 2010). With the increase in heavy rainfall events, other weak points in the sewer system, such as throttle displacement, or changes in discharge volumes as a result of areas added to the system later, may also occurr more often.

Therefore, for new construction or major modifications to existing wastewater systems, it is recommended that their vulnerability to major design events be assessed. For this purpose, for example, it may be advisable to make calculations using design values plus 10%. If land drainage is planned, it must be determined whether backflow prevention according to the standards DIN 1986-100 (DIN EN 752 2017) or DWA A118 ((2006)) is necessary (e.g. StMUV BY 2016)

Practice has shown that stormwater drains have a limited drainage capacity, while in the pipe systems the hydraulic capacity has not yet been exceeded. The limited capacity of the drains is exacerbated by leaves and debris carried by the rainwater, which disrupt intake and result in a further loss of hydraulic performance. Alternatively, hydraulically efficient and safe stormwater drains should be developed and installed.

Flash floods in small catchment areas near residential areas are often a source of high sewage run-offs, which can cause significant damage. In addition, changes in the incidence of flooding influence the flood security of all the components of urban drainage and wastewater treatment systems (DWA 2010). It can be assumed for the future that extremely heavy rainfall events that exceed the design case cannot be managed by drainage systems. This is why it is particularly important to ensure water-sensitive urban planning, public-space planning and individual preparedness.

Drainage and wastewater treatment under seasonal precipitation shift

In combined systems, a change in seasonal rainfall distribution affects the hydraulic load of wastewater treatment plants. Increased winter precipitation can increase the hydraulic load in winter (DWA 2010). With a shift in the distribution of precipitation, water either more diluted or with higher substance concentrations could flow into the wastewater treatment plants. In principle, this does not change the long-term volume of material to be treated. However, the preliminary breakdown of oxygen-consuming constituents within the sewerage system is influenced by the amount of time spent in the sewer. The particulate-matter load can also be altered by changes in the erosion dynamics in the catchment area (Pinnekamp et al. 2015).

A seasonal shift in rainfall distribution can cause higher or more frequent discharges from combined systems and result in hydraulic and material pressures on water bodies.

An increase in dry periods combined with rising temperatures can promote the accumulation of sewer deposits, odours and corrosion in the sewerage system (DWA 2010). Longer dry periods can also result in a greater accumulation of pollutants on the ground surface between precipitation events. Depending on the duration and intensity of the ensuing precipitation event, some of this contamination will be washed into the sewerage system. In a combined system, substances deposited in the sewerage system during dry periods can be remobilised by precipitation events. Under certain conditions, this debris load can arrive at the wastewater treatment plant as a surge (Pinnekamp et al. 2015). This can result in changes in the requirements for the separation of heavy materials in the grit chamber and the pre-settling basin. Increased operating effort (e.g. additional sewer flushing) can mitigate the effects described above.

Wastewater treatment under changing temperatures

Wastewater treatment will be influenced in various ways by the expected increase in wastewater temperatures due to climate change. A change in wastewater temperatures (and in material concentrations) can particularly influence breakdown efficiency of the biological treatment processes in sewage treatment plants. If additional cool wastewater flows in during the winter due to increased levels of winter precipitation, the capacity for decomposition could also decline in winter (DWA 2010). If necessary, the treatment plant design must be reviewed.

Higher temperatures in general could lead to a more rapid conversion of easily degradable substances within the sewerage system, which could alter the composition of wastewater entering the treatment plant (DWA 2010).

In the biological treatment process, nitrification could be especially affected by higher summer and winter temperatures. Higher temperatures, accompanied by sufficient ventilation, can lead to an increase in the conversion of substances and lower outflow concentrations for ammonium. Because the solubility of oxygen decreases at higher temperatures, higher electricity costs could be incurred for oxygen input (MUKE BW 2015). However, other underlying conditions could change at the same time, and the overall impact on energy consumption might be negligible (REGKLAM-Konsortium 2013).

As a rule, the availability of easily degradable carbon is a limiting factor for denitrification, so in this respect no consequences of higher temperatures should be expected. However, an increase in early degradation could have a negative effect here, and the input of external carbon sources should be increased as needed (REGKLAM-Konsortium 2013; MUKE BW 2015).

Water quality in waters heavily influenced by sewage treatment plants

In small-scale receiving waters with sewage treatment plant discharge, sewage-plant outflows can contribute a significant proportion of the effluent during dry periods. This can lead to water quality problems, because the wastewater is less diluted due to the lower proportion of natural effluent.

With increasing dry periods, situations in which the effluent from wastewater treatment plants could play a crucial role, both quantitatively and qualitatively, may develop more frequently and for more prolonged periods in the future. Accordingly, the need for high-quality treated wastewater would become even more important. As a result, higher immission standards may be required of wastewater treatment plants in the future. This would have to be addressed by improving wastewater quality through process-related and operational adjustments (DWA 2010).

5.3.2 Climate adaptation measures (Annex Tab. A. 21 - Tab. A. 27)

The concerns arising due to climate change may require an adaptation of drainage strategies. The nature of the adaptation will vary depending on whether the area is drained via a separate system or a combined system (rainwater and wastewater are carried away together to the sewage treatment plant).

To mitigate the impact of more intense precipitation events, the separate systems may require centralised rainwater purification facilities, whereas combined water systems usually require reservoirs to hold the mixed water in case of a treatment-plant overload. In the combined system, storage capacity should also be optimised and/or increased in the sewerage systems in order to reduce the discharge of mixed water from the system and thus reduce water pollution.

The procedures in sewage treatment plants with combined-system drainage can also be optimised, thus facilitating a more rapid and effective treatment of mixed water. In both wastewater systems, additional adjustments to treatment plant operation may be necessary due to changes in the temperature of the water.

Regardless of the drainage system, a stronger emphasis on sustainable rainwater management is necessary in order to decouple the rainwater from the sewerage system over as large an area as possible. This means that, to the extent permitted by the material load and water management situation, the seepage and evaporation of rainwater into the soil near its source should be of greater priority than the drainage of rainwater through the sewerage system (LAWA 2010). This, in turn, also has a positive effect on groundwater recharge. In 2010, the preference for separate drainage, with rainwater management achieved as locally as possible, was incorporated into the German Federal Water Act (Art. 55 (2) WHG). In addition, limiting rainwater discharges to “natural” area run-offs is an effective measure for the promotion of decentralised measures. The offering of incentives is helpful for implementing many decentralised rainwater management and treatment measures. In view of the challenges of dealing with rainwater in urban areas posed by climate change, a number of options for urban development such as green roofs and façades (as evaporation measures) and measures to limit impermeable surfaces should be examined. Additional measures such as multi-purpose land use are also feasible for dealing with heavy rainfall events.

In order to ensure a desirable drainage efficiency, i.e. maintaining a tolerable frequency of congestion or overflow, particularly in the face of more frequent and intensive rainfall in the future, the persisting trend of new paving should be counteracted and all options for decentralised and semi-centralised rainwater management should be explored, with strict consideration of groundwater protection. In addition, with regard to the prevention of risks to persons and property, greater attention should be paid to the planning of discharge flows when design values are exceeded.

Links with other fields of action	Flood protection, heavy rainfall and flash floods, drainage of low-lying areas, marine protection, conservation of aquatic ecosystems, groundwater protection, public water supply, navigability, low water management in watercourses

5.3.3 Profiles of practical examples

Example 6: Field of action - Urban drainage and wastewater treatment: "Nature in grey zones" campaign

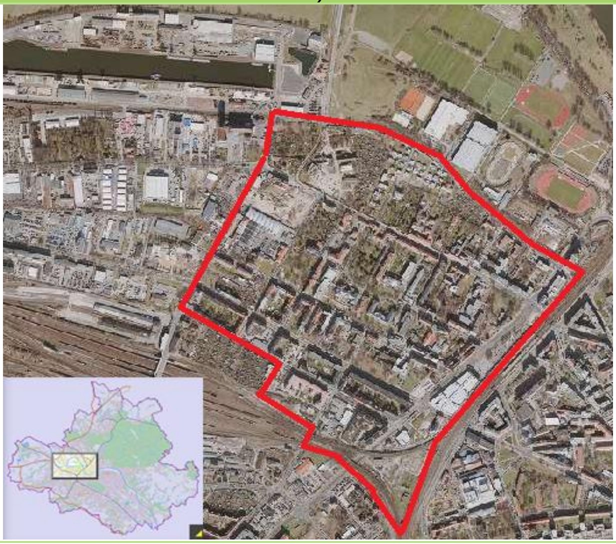
Field of action	Urban drainage and wastewater treatment
Practical example	**"Nature in grey zones" campaign and follow-up project "Green instead of grey"**
Climate adaptation measures	Centralised and decentralised retention measures in cities (Tab. A. 24), Utilising seepage potential (Tab. A. 25)
A planting campaign with numerous participants, including residents and employees. Photo: Wissenschaftsladen Bonn	
Description and objectives	The project "Nature in grey zones" was coordinated by Wissenschaftsladen Bonn e. V. and implemented in three pilot cities (Erfurt, Wiesloch and Duisburg). The aim of the campaign was to increase awareness among both citizens and business representatives of the potential for preserving biological diversity in the inner-city area, and to integrate nature into the urban environment. In cooperation with ten companies located close to each city centre, model areas were reclaimed and designed more naturally. For a greater symbolic impact, the areas were selected at very visible locations. In order to ensure effort was kept to a minimum, small areas of 50-100 m² were purposely selected (e.g. building entrance areas, parking lots, or leisure areas for customers and employees). Ideally, the removal of sealed surfaces and landscaping measures were undertaken by employees and local residents, and promoted by press coverage and events to encourage others to follow their example. The businesses were partially involved in the area planning through workshops, while employees, residents and citizens participated in the planting through online competitions, gardening campaigns and festivals. The project now has a follow-up project ("Green instead of grey - commercial areas in transition") and also offers advice to other cities on how to make existing commercial areas more climate resilient and nature-friendly. The reclaiming of sealed areas and horizontal and vertical greening can also contribute to a better adaptation of numerous fields of action to climate change.
Timeframe of implementation:	"Nature in grey zones" campaign: 2013–2016; Follow-up projects: 2016–2021
Costs/financing	637,000 euros, funded by the Federal Agency for Nature Conservation, the Environment and Development Foundation NRW and the "Lebendige Stadt" Foundation; Follow-up project ca. 2 million euros, funded by the Federal Ministry of Education and Research
Participants	Company management, staff, municipal administrations, cooperation partners Technische Universität (TU) Darmstadt, Osnabrück University and the Global Nature Fund
Challenges, solutions and successes	× Costs and time required of businesses × A lot of effort required from local project partners to support the project ✓ Every business is supported with project funds for planning and implementation of measures ✓ The municipalities were able to use funds from tree preservation bye-laws for planting on company premises. ✓Companies often decide to participate in the measures without financial support.
Contact	Wissenschaftsladen Bonn e.V.

Further information	• Wissenschaftsladen Bonn e. V. 2016: Natur in graue Zonen - Unternehmensflächen im Fokus. Mehrwert für Mensch, Natur und Unternehmen • Wissenschaftsladen Bonn e. V. 2019: Gewerbegebiete im Klimawandel. Leitfaden für Kommunen zur Klimavorsorge • Cooperation partner "Green instead of grey 2019: Mehr Natur im Gewerbegebiet. Leitfaden für Kommunen zur Beratung von Unternehmen • Wissenschaftsladen Bonn e. V. no year: Grün statt Grau - Gewerbegebiete im Wandel. Available at: www.gewerbegebiete-im-wandel.de/ • German Environment Agency: Nature in grey zones. Available at: *www.umweltbundesamt.de/themen/klima-energie/klimafolgen-anpassung/werkzeuge-der-anpassung/tatenbank/natur-in-graue-zonen*

Example 7: Field of action - Urban drainage and wastewater treatment: Wegenkamp Primary School - Schoolyards with sustainable rainwater management

Field of action	Urban drainage and wastewater treatment
Practical example	**Wegenkamp Primary School – Schoolyards with sustainable rainwater management**
Climate adaptation measures	Centralised and decentralised retention measures in cities (Tab. A. 24), Incentives for decentralised rainwater management (Tab. A. 26), Utilising seepage potential (Tab. A. 25)
The Wegenkamp schoolyard during the conversion with a trough in the background.	
Description and objectives	In 2009, the Hamburg Environment and Energy Authority and HAMBURG WASSER initiated the RegenInfraStrukturApptation (RISA) project. Its aim is an integrated rainwater management system with the motto "Living with water". One component of RISA is a holistic approach to dealing with rainwater in Hamburg schools. In this context, a handbook was published ("Rainwater Management at Hamburg Schools") and sustainable rainwater strategies were implemented at a number of model schools. The schoolyard of the Wegenkamp Primary School is the first to be converted according to these principles. Rainwater from the roofs is no longer drained away in pipes, but fed into grass-covered depressions through open channels. There, the water can seep into the ground, evaporate or be captured and fed into the public sewerage system. Paved areas have been redesigned or relocated so that rainwater can be directed into nearby green areas. To ensure the safety of the students, a maximum water depth of 30 cm is not exceeded in the troughs. Comparing the costs of conventional drainage systems to decentralised rainwater management plans, it was found that decentralised systems can be considerably more cost-effective. The measures also facilitate adaptation to climate change.
Timeframe of implementation:	2012/2013
Costs/financing	Annual savings in wastewater charges of around 2,000 euros compared to conventional drainage
Participants	Hamburg Environment and Energy Authority, HAMBURG WASSER, Schulbau (school construction) Hamburg
Challenges, solutions and successes	✓It was possible to simultaneously provide facilities for the children's leisure and play activities as well as educational programmes relating to water.
Contact	Schulbau (school construction) Hamburg
Further information	• Behörde für Stadtentwicklung und Umwelt Hamburg (2013): Regenwasser Handbuch. Regenwassermanagement an Hamburger Schulen. Regenwasserhandbuch SBH und RISA. Ganzheitlicher Umgang mit Niederschlag an Hamburger Schulen • Bundesinstitut für Bau-, Stadt- und Raumforschung (2015): Überflutungs- und Hitzevorsorge durch die Stadtentwicklung. Strategien und Maßnahmen zum Regenwassermanagement gegen urbane Sturzfluten und überhitzte Städte • Hamburg Wasser: RISA - RegenInfraStrukturAnpassung. Link: *www.risa-hamburg.de/*

Example 8: Field of action - Urban drainage and wastewater treatment: "Danger from sewerage system overflow" project

Field of action	Urban drainage and wastewater treatment
Practical example	**"Danger from sewerage system overflow" project**
Climate adaptation measures	Performing risk assessments (Tab. A. 38), Centralised and decentralised retention measures in cities (Tab. A. 24), structural improvement and optimised operation of existing sewer networks (Tab. A. 21), Construction and securing of emergency water routes (Tab. A. 33)
The area investigated in detail in the Dresden-Friedrichstadt district Photo: © State capital Dresden	
Description and objectives	In the research project "Development and Testing of a Regional Climate Change Adaptation Programme for the Model Region Dresden" (REGKLAM), among other tasks, an assessment was carried out of the hazard potential of water leaking from the sewerage system in a specific area. The hydrodynamic sewer network model HYSTEM-EXTRAN was used for the city of Dresden, and the change in overflow behaviour was determined and evaluated using a climate scenario for 2050. Flow-path and hazard maps were then created for the selected area. This was followed by the development of strategies for reducing the frequency of overflow and for controlled surface drainage after overflow events. This method of hazard assessment should be applicable to other areas and the strategies developed should provide ideas for possible options for action. For example, the effects of measures that disconnect areas from the sewerage system, an integrated control system for the sewer network, an increase in the sewer cross-section, the elimination of hydraulic bottlenecks, and the creation of emergency surface waterways were investigated and evaluated. Overall, it was concluded that the risk of flooding increases with climate change. Possible climate change through to 2050 was explicitly considered in the project.
Timeframe of implementation:	2008–2013
Costs/financing	-
Participants	Drainage companies, urban planning office, road construction and public works office
Challenges, solutions and successes	-
Contact	Institute for Technical and Scientific Hydrology (itwh GmbH)
Further information	• REGKLAM-Consortium (2013b): Integrated regional climate adaptation programme for the Dresden region. Foundations, goals, measures • REGKLAM-Consortiium (2011): Effects of climate change on the overflow performance of Dresden's sewer system. REGKLAM subproject 3.2.4 • REGKLAM-Consortium: REGKLAM. Link: *regklam.de/en/about-regklam*

5.4 Flood protection: heavy rainfall and flash floods

5.4.1 Concerns

Heavy rainfall events followed by local flooding (flash floods) with little advance warning have recently caused extensive damage in several regions in Germany. Heavy rainfall with a risk of torrential surface run-off or flash flooding will probably occur more frequently or with greater intensity in all regions in the future due to climate change. As a result, the need for protective and preventive measures against direct damages from heavy rain and the high water from flash floods will increase. An understanding of the regional and local relationships between the incidence of heavy rain, development of run-off, and the amount of potential damage is extremely important in being able to respond to the individual problems. Damage prevention is an interdisciplinary community task for which not only the public authorities, but also individual citizens can take mitigating or defensive measures.

Particularly severely affected areas

Intensive precipitation can have extensive or even catastrophic consequences, especially in developed areas. But damage can also occur in outlying areas, for example, on agricultural or forestry lands. Direct damage can result from heavy rainfall or damage can be caused by heavy surface-water run-off and the resulting flooding. Flooding can occur as slope run-off (torrential flow), overflow of small urban rivers or overload of the drainage system (Regionalverband Ruhr 2010). The topography (relief as well as surface irregularities, both of which influence run-off intensity) as well as the hydrology, land use/development, type of vegetation (land cultivation) and infiltration capacity of the soil are all important factors in the potential impact.

In principle, heavy rainfall events can occur anywhere. The potential for damage is higher in cities and municipalities than in the surrounding areas. This is partially due to the high density of critical infrastructures, but also because of the abundance of paved (sealed) surfaces that prevents efficient infiltration into the soil and thus contributes to flash flooding (LANUV NRW 2016). Heavily populated v-shaped valleys and the inhabited narrow valleys of small rivers are especially susceptible to a possible increase in flash floods caused by heavy rainfall (MUEV SL 2011).

Special features in the Alps

If, in the future, a smaller proportion of winter precipitation falls as snow due to higher temperatures, immediate run-off will occur more often. This could be a relevant factor in catchment areas that until now have been snow-influenced, particularly in the Alpine region. This means that increased intensive precipitation, which may fall exclusively as rain in the future, will produce a faster run-off reaction than previously, and have other consequences than just flooding (e.g. debris flows)(StMUV BY 2016). This could result in the flooding of larger and previously unaffected areas in the Alps in the future. This also applies to slope movement, so the need for protective forests may increase in the future. With high residential pressure, there is ample reason to be concerned about the proximity of settlements to dangerous areas. (StMUV BY 2015).

Urban drainage during heavy rainfall

Urban drainage generally falls under the remit of those responsible for wastewater disposal. As a rule, it should be ensured that precipitation events with annualities of 2 to 5 years, or in some cases up to 20 years, can be discharged without damage. Due to the high variability of heavy rainfall events in local and small areas, with no statistical significance for their presumed general increase over time, there is currently no general, quantitative basis for assigning a flat-rate climate-change adjustment factor in the design of drainage systems (SUBV HB 2012). On the other hand, implementing a blanket size increase for drainage systems should also be viewed with caution considering the possibility of “drought,” which is the other extreme. For these reasons, decentralised rainwater management should also be considered seriously in the context of urban adaptation to climate change. This can be a strategy for reacting flexibly to the uncertain extreme weather conditions of heavy rainfall and drought in the future.

In contrast to the responsibilities for urban drainage, damage prevention related to more frequent heavy rainfall events is a joint, interdisciplinary communal task that should be addressed by various stakeholders, and for which no action schemes have yet been established (MKULNV NRW & MBWSV NRW 2016; DWA 2013).

In the event of exceptionally heavy rainfall events, the discharge quantities are usually so high (LUBW 2016) that even a sewerage system designed according to established regulations cannot fully accommodate them. In the case of more frequent and intense heavy rainfall events, more frequent and intense input volume to overflow and retention basins would therefore have to be anticipated (SUBV HB 2012). As a result, more frequent adjustments or emergency relief of the basins could become necessary (MUEK NI 2012). Especially in small, predominantly residential and hilly catchment areas, rapid torrential flooding with significant potential for damage can be expected to accompany local heavy rainfall events (MUEK NI 2012).

Heavy rainfall risk management

In contrast to river floods, which are restricted to the surrounding valley and floodplain areas close to the river, and which originate from the water body itself, heavy rainfall events can basically affect any location when flooding is due to surface run-off. The particular dangers from heavy rainfall events and flash floods result from the short warning times, high flow velocities and debris transport as well as occasionally extreme and unpredictable changes in flow paths due to deposition and erosion (Bronstert 2016).

Flash floods can pose major hazards in congested-area (urban) watercourses and in areas that lie further away from watercourses, or in normally dry run-off channels in low-lying terrain that are suddenly filled with large volumes of water during heavy rainfall. A lack of awareness of the dangers posed by such waters and areas often leads to inadequate maintenance of these watercourses (LUBW 2016). In the event of flash floods in towns, water flowing in from outside areas, e.g. uncontrolled run-off from slopes, also plays a significant role (IBH & WBW 2013).

Increased occurrences of heavy rainfall events therefore present many municipalities with challenges that they have not had to deal with in the past. For flood protection outside of high flood-risk areas, systematic discharge routes for surface run-off outside the waterways have not yet been universally established. These overflow pathways will become increasingly important, however, with more frequent and intense heavy rainfall events (MUEK NI 2012).

When flooding occurs in residential areas, it is not only the height of flood waters that is instrumental in causing damage, but also the velocity of the surface flow. Possible damage also includes danger to life, e.g. the risk of drowning in flooded cellars or when attempting to cross the run-off area. Damage can also occur to infrastructure and other structures, by water flowing into buildings, for example, or building foundations being washed away (LUBW 2016).

The input and transport of sludge, debris, driftwood and other flotsam from landslides, bank erosion or bed erosion and the uprooting of trees are also highly significant. Debris also poses a danger to life. Furthermore, flotsam can cause obstructions on roadways or at bridges, which can divert watercourses and displace structures, thus opening up completely new flow routes. This should be taken into account in the context of planning for damage prevention (LUBW 2016).

Agricultural land and soil erosion

Outside of developed areas, the damage caused by heavy rainfall can be expected to result primarily from erosion processes. In addition to direct damage to the eroded areas, neighbouring areas and infrastructures can be adversely affected by the accumulation of eroded material (KLIWA 2012a).

On areas of land affected by erosion, in addition to the loss of soil and resulting reduction in soil fertility, crop losses (e.g. eroded seeds or washed-out roots) can also occur. Elongated structures produced by erosion (grooves, channels or even trenches) can also develop and can cause considerable operational problems. However, crop losses can also occur when eroded material from neighbouring areas is deposited on top of existing plants (MWKEL RP 2013; StMUV BY 2015).

Heavy rainfall events can cause considerable soil erosion, especially if the soils are not protected by a cover crop or no intermediate mulch is applied to late-seed crops (StMUV BY 2015). In addition, there is a significant risk of surface water washing away soil on slope areas that are cultivated by tilling (MLU ST 2013). More frequent occurrences of heavy rainfall therefore have a general impact on agricultural planning and yield performance (water erosion, soil erosion, nutrient and humus transfer, and rotting of specialised crops) (StMUV BY 2016). Compliance with good agricultural practice (GAP) is thus essential.

Non-agricultural land can also be indirectly affected by erosion. For example, contamination may accumulate in public areas (pathways and roads, ditches and sewers) and in private areas (residential areas, private property). The formation of surface run-off accompanying erosion, especially on slopes, can increase the risk of local flooding in nearby areas (StMUV BY 2015).

Areas particularly at risk from erosion include the Bavarian Tertiary Hills, Kraichgau (Baden-Württemberg) and the Saar-Nahe highland (Rhineland-Palatinate, Saarland) (LABO 2010; MWKEL RP 2013), but also the mountain and hill country of Lower Saxony and the loess plains of Lower Saxony.

Infiltration capacity

The infiltration capacity of soils is very important with regard to the formation of surface run-off when heavy rainfall occurs in non-paved areas (LUBW 2016). Depending on the kind of soil, infiltration capacity can also be influenced by prevailing environmental conditions, such as long dry periods. If wetlands and bogs dry out due to more frequent and longer dry spells in the summer, for example, their natural ability to buffer the impact of heavy rainfall events through their storage capacity will be reduced (MUEK NI 2012). Infiltration capacity can also be reduced by the impact of rain drops on unprotected soil during very heavy rainfall. This damages the soil structure and causes mud to form on the surface. The formation of mud diminishes the capacity of the soil to absorb water, increasing surface run-off volume and thus also the erosive potential. These factors can be relevant in the development of floods, especially in small catchment areas and during short, intensive precipitation events. Higher rainfall intensity also means that, depending on the infiltration capacity, a smaller proportion of the total water volume seeps into the soil to contribute to groundwater recharge (Regionalverband Ruhr 2010). Under certain conditions, however, very high-intensity precipitation can also result in a migration of pollutants carried by the percolating water (LABO 2010).

Soil compaction and structural stability

In addition to the direct influences of climate change on infiltration and evaporation described above, changes in soil properties due to climate change can also have a considerable indirect effect on the soil water content (MWKEL RP 2013; Engel & Müller 2009). Soil compaction, for example, adversely affects the soil moisture regime due to increased density and reduced porosity. It is often caused by driving farming equipment on soils that are too wet to be worked. The risk of this is especially high in the spring and fall. If, in the future, the number of day with rainfall occurring in the spring and autumn increases, the impacts of compaction will increase accordingly.

Extended growing seasons with greater utilisation potential, including the possibility of two harvests with multiple cultivation, also increase the risk of soil compaction (Rheinland-Pfalz Kompetenzzentrum für Klimawandelfolgen 2013). With a decrease in the number of frost days, groundwater regeneration in compacted soils can be inhibited (StMUV BY 2016). The consequences of soil compaction for agriculture and irrigation requirements include reduced water-storage capacity, rooting ability and infiltration capacity. Simultaneously, there is an increase in the propensity for mud formation. This may be accompanied by increased waterlogging and erosion of the soil (MUEK NI 2012). Consequently, even with irrigation, optimal growth conditions cannot be achieved in compacted soils (StMUV BY 2016).

Soils in coastal regions (marshes), young moraine formations, loess areas, and other clay-rich soils are especially susceptible to the risk of compaction. Furthermore, regions where two annual harvests might be feasible in the future are also at risk (LABO 2010; MUELV HE 2012).

Higher soil temperatures could lead to an accelerated breakdown of humus. This could have an adverse effect on the structure, and thus on the filtering and buffering capacity of the soil, as well as on the water transport and storage capacity (DWA 2010). On the other hand, humus breakdown is slowed in both very wet and very dry conditions (MLUR SH 2011). Increased mineralisation during mild, damp winters and reduced breakdown during dry summers could thus be conceivable (Rheinland-Pfalz Kompetenzzentrum für Klimawandelfolgen 2013). Presently, however, it is not possible to make definitive statements on changes in the content and supply of organic matter or on its impact on the soil moisture regime (UBA 2011).

A decrease in the number of frost days could have a negative effect on frost mould, not only for compacted soils but also for especially clay-rich and loam-rich soils, and thus also on the structural stability and soil moisture regime (MUEK NI 2012). In winter, on the other hand, more water may infiltrate when the ground is not frozen.

Soil erosion

If precipitation intensity increases in the future the risk of erosion will also increase, for example, during drought-related periods with poor vegetation cover, during extended periods of no cover between harvesting and sowing, or through severe dehydration of the soil surface (Rheinland-Pfalz Kompetenzzentrum für Klimawandelfolgen 2013). In addition to changes in the character of precipitation, factors related to temperature increase (soil moisture, evapotranspiration, infiltration, plant growth and ground cover) will also have an influence on soil erosion (Sauer et al. 2013). Erosion can cause a loss of humus-rich topsoil on agricultural lands. Impacts on the soil moisture regime can also be expected with this.

Water quality

The influx of soil-borne substances into water bodies as a result of heavy rainfall can diminish water quality. The occurrence of algal blooms (e.g. cyanobacteria) can be enhanced after dry or extremely warm periods. The use of aquatic areas for tourism, for example, can be severely restricted by the presence of algal blooms. The increased input of nutrients or sediments can have additional negative ecological consequences (StMUV BY 2016). The discharge of water from rain and mixed-water systems as a response to extreme precipitation events also adversely affects water quality.

Indirect effects on smaller water bodies

Heavy rainfall events can lead to hydraulic overloading in smaller water bodies. This can have an impact on their morphology, for example, in the form of increased bed erosion. This, in turn, can have more far-reaching consequences, e.g. the endangerment of structures (e.g. bridges), infrastructures along waterways, or the permanent reduction of water levels due to deepening of the bed (StMUV BY 2016). In addition to erosion, debris input can also cause the course of a waterway to be altered (LUBW 2016).

5.4.2 Climate adaptation measures (Annex Tab. A. 28 - Tab. A. 38)

Drainage measures in urban areas have already been discussed in the field of action "Urban drainage and wastewater treatment". Now, in the field of action "Flood protection: heavy rainfall and flash floods", focus will be placed on dealing with possible increases in the intensity and frequency of heavy rainfall events in urban and outlying areas.

To protect urban areas, it is important to prevent water from flowing in uncontrolled from the surrounding areas. This can be accomplished through water retention measures in the outlying areas, but sediment retention is also important due to the high flow velocities. Additionally, the flow from outer areas can be redirected around these localities using barrier structures such as dams or ditches. The adoption of these kinds of measures is particularly important on slopes because the risk of flash flooding increases as slopes become steeper. Because of the greater flow velocity on slopes, special drainage mechanisms and management methods should also be considered. This increases the need to observe good agricultural and forestry practices, and compliance in critical areas can be required by regulatory authorities if necessary. In this regard, the run-off- and erosion-reducing effects of forested areas should also be highlighted.

Because sewerage systems in urban areas are generally designed with only limited overflow or flooding safety in mind, it is important to develop emergency strategies for the event of flooding. Emergency watercourses to limit damage as much as possible by rerouting water over surfaces with otherwise different functions may be a viable solution. The objective is to provide adequate protection against flooding in endangered buildings and infrastructures. Possible building precautions range from simple thresholds, steps and cellar-window skirting to stop-logs and sealing systems. The appropriate behaviours and actions in response to extreme events should be organised, communicated and tested.

To ensure that water is captured and discharged in a timely manner in the event of an emergency, drainage systems must be designed optimally and need to be inspected, maintained and cleaned regularly. Identification of locations especially susceptible to erosion or to flooding from congested sewerage systems or flash floods is a key requirement for planning additional measures, and these should be made accessible to the public, possibly in the form of heavy rainfall hazard maps.

A comprehensive description of climate adaptation measures is being prepared by LAWA (2018).

Links with other fields of action	Flood control, urban drainage/wastewater treatment, drainage of low-lying areas, marine protection, conservation of aquatic ecosystems, groundwater protection, public water supply, hydropower, irrigation, dam and reservoir management, low water management in watercourses

5.4.3 Profiles of practical examples

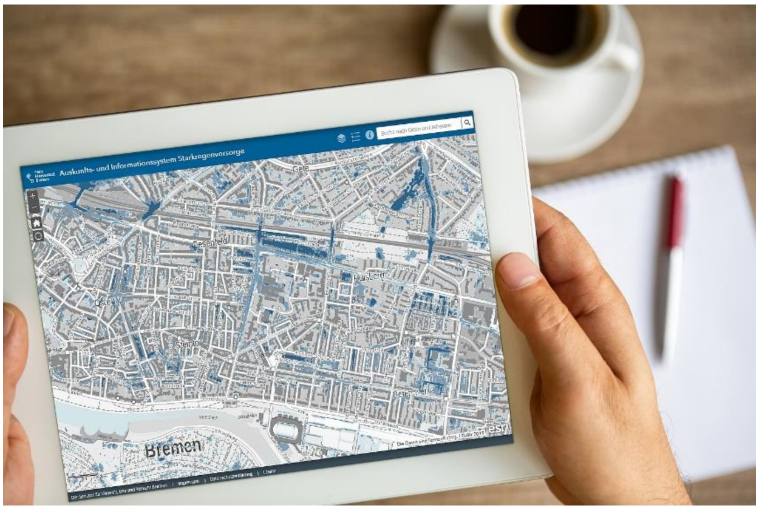
Example 9: Field of action - Flood protection: heavy rainfall and flash floods: Pilot project "Adaptation to climate change by improving water and soil retention in the Glems catchment area" (KliStaR)

Field of action	Flood protection: heavy rainfall and flash floods
Example	**Pilot project "Adaptation to climate change by improving water and soil retention in the Glems catchment area" (KliStaR)**
Climate adaptation measures	Water and sediment retention in outlying areas (Tab. A. 28).
A filled retention basin after heavy rainfall events in May 2016 in Leonberg-Warmbronn.	
Description and objectives	The KliStaR pilot project brought together the eight municipalities of Ditzingen, Gerlingen, Hemmingen, Korntal-Münchingen, Leonberg, Markgröningen and Stuttgart in a network of land users and experts. KliStaR's activities were focused on climate adaptation measures to help reduce soil erosion and surface run-off, as well as to improve the soil moisture regime in rural areas. The project was thus established in an effort to adapt to climate change. Initially, a number of priority areas were identified within the scope of two events. Using model calculations, maps of soil erosion hazards and surface run-off were produced, both for the present and for expected climate changes in the future. Finally, various local protection measures were discussed with land users and local representatives, and subsequently implemented. For example, measures such as the expansion of a retention basin and the agricultural technique of strip cultivation were implemented. As a planning guide for other communities, a catalogue with 23 sheets of measures was created.
Timeframe of implementation:	2014/2015
Costs/financing	Project shown: construction approx. 25,000 euros, planning costs approx. 8,000 euros
Participants	Municipality representatives, land users, specialists (geomer GmbH, bodengut und Forstliche Versuchs- und Forschungsanstalt BW)
Challenges, solutions and successes	× Usage conflicts, conflicts with existing agricultural support measures × Diverse motivations of the participants ✓ The implementation of measures involved complex processes such as stakeholder participation, decision-making, planning procedures, etc.
Contact	geomer GmbH Heidelberg
Further information	• Billen et al. (2017): Klimaanpassung durch Stärkung des Wasser- und Bodenrückhalts in Außenbereichen (KliStaR) • geomer GmbH et al. (2015): KliStaR. Agriculture and forestry help to adapt to climate change • Billen et al. (2016): Flood and soil protection through enhanced water and soil retention

Example 10: Field of action - Flood protection: heavy rainfall and flash floods: "Strong against strong rain" project

Field of action	Flood protection: heavy rainfall and flash floods
Example	**"Strong against strong rain" project**
Climate adaptation measures	Performing risk assessments (Tab. A. 38), Behavioural preparedness (Tab. A. 36)
The project was accompanied by a poster campaign and an information exhibition. Photo: © Lippeverband	
Description and objectives	Within the framework of the European cooperation "Future cities - urban networks to face climate change" the Lippeverband has initiated the project "Strong against strong rain." In cooperation with municipal representatives, heavy rainfall hazard maps were compiled for the pilot municipality of Unna which, for the first time, identify areas vulnerable to heavy rainfall in the town and surrounding areas. Based on these maps, various municipal departments can now obtain information about heavy rainfall risks, and can plan and implement damage-reduction measures. The project's approach is based on an "Adaptation Compass," a planning tool developed by "Future Cities" to systematically identify the need for action and procedures for adapting to climate change. The project is complemented by a communication and information campaign that uses posters, exhibitions and an internet platform to inform the public about the dangers, and to identify options for personal preparedness. The website www.stark-gegen-starkregen.de, which provides insights into what municipalities and homeowners can do to be prepared is the core of the campaign. Heavy rainfall hazard maps are publicly available on the website. The project was initiated with a view to adapting to the consequences of climate change.
Timeframe of implementation:	since 2014
Costs/financing	-
Participants	Lippeverband, Benning, Gluth & Partner Gesellschaft für Kommunikation mbH, Unna district town
Challenges, solutions and successes	× The publicity campaign with posters and exhibition was only carried out for one month. ✓ In spite of the short duration, many citizens of Unna were contacted, informed and made more aware.
Contact	Lippeverband
Further information	• Stemplewski et al. (2015): The "Strong against strong rain" project. Korrespondenz Wasserwirtschaft • Lippeverband: Strong against strong rain. Link : *www.starkgegenstarkregen.de /starkregenkarte/*

Example 11: Field of action - Flood protection: heavy rainfall and flash floods: Project "Climate adaptation strategy - Extreme rain events" (KLAS)

Field of action	Flood protection: heavy rainfall and flash floods
Example	**Project "Climate adaptation strategy– Extreme rain events" (KLAS)**
Climate adaptation measures	Centralised and decentralised retention measures in cities (Tab. A. 24), Utilising seepage potential (Tab. A. 25), Incentives for decentralised rainwater management (Tab. A. 26), Performing risk assessments (Tab. A. 37), Property protection against the risk of flooding (Tab. A. 34), Behavioural preparedness (Tab. A. 36)
The heavy rainfall information system (Das Auskunfts- und Informationssystem Stark-regenvorsorge, AIS) provides the public and administrations with information on where to expect water during the next heavy rainfall event and what adaptation and protective measures can be taken. Photo: The senator for climate action, environment, mobility, urban development and housing Bremen within the framework of the KLAS project; http://www.klas-bremen.de & http://www.starkregen.bremen.de	
Description and objectives	The specific motivation for initiating the KLAS project was extreme rainfall in the summer of 2011, which led to widespread flooding and considerable property damage in Bremen. The aim of the project is to develop strategies and measures that could help to reduce the negative impacts of heavy rainfall events, and to better manage the associated risks. These strategies should take into account the conditions and requirements of the city of Bremen and to be jointly pursued by all relevant parties. The project is also committed to implementing measures on the surface for flood protection and for the long-term incorporation of "water and climate-sensitive urban development" into city planning and development. The involvement of KLAS in several urban and public planning and construction measures ensures that heavy rainfall precautions are properly considered. Another aim of the project is to raise awareness among the citizens of Bremen concerning private precautions for individual property. To this end, the heavy rainfall portal was set up at http://www.starkregen.bremen.de. Here users will find a map of heavy rainfall events and area-specific information and advice as well as information material. The information on offer is to be extended to include internal administrative processes along with the heavy rainfall information system (Das Auskunfts- und Informationssystem Starkregenvorsorge, AIS) currently under development. In an online web application, AIS will provide all the necessary bases for planning and decision-making regarding heavy rainfall precautionary measures and a near-natural approach to dealing with rainwater. The project was initiated as a climate adaptation measure.
Timeframe of implementation:	2012-2014, 2015-2017, 2018-2020
Costs/financing	268,400 euros project funding from the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, 278,559 euros project funding from the German Federal Environmental Foundation, 121,386 euros project funding from the German Federal Environmental Foundation (DBU)
Participants	The senator for climate action, environment, mobility, urban development and housing Bremen, hanseWasser Bremen GmbH, the Bremen University of Applied Sciences. Dr Pecher AG

Challenges, solutions and successes	✓ Interdisciplinary cooperation ✓ Provision of relevant planning and decision-making bases and maps via a web-based information system ✓ Raise awareness among landowners about the heavy rainfall portal (starkregen.bremen.de
Contact	Free Hanseatic City of Bremen, the senator for climate action, environment, mobility, urban development and housing Bremen
Further information	• Koch et al. (2017): Schlussbericht des Projektes "Entwicklung einer neuen Methodik zur vereinfachten, stadtgebietsweiten Überflutungsprüfung nach Vorgaben des technischen Regelwerks und GIS-basierte Darstellung der Analyseergebnisse zur Berücksichtigung bei kommunalen Planungsprozessen im Rahmen eines zu entwickelnden Auskunftssystems" • Hochschule Bremen (2017): Praxisleitfaden. Ermittlung von Überflutungsgefahren mit vereinfachten und detaillierten hydrodynamischen Modellen • Koch et al. (2016): Weiterentwicklung der KLimaAnpassungsStrategie Extreme Regen in Bremen: KLASII – Projektergebnisse, Modellbetrachtungen und Entwicklung eines Auskunfts- und Informationssystems Überflutungsvorsorge. Korrespondenz Wasserwirtschaft • Koch et al. (2015): KLimaAnpassungsStrategie Extreme Regenereignisse (KLAS). Schlussbericht des Projektes „Umgang mit Starkregenereignissen in der Stadtgemeinde Bremen“ • hanseWasser Bremen GmbH (2019): Sicherheit für Ihr Haus! Schutz vor Kanalrückstau und Oberflächenwasser bei Starkregen, Schutz vor schadhaftern Grundleitungen und Feuchteschäden • Senator für Umwelt, Bau und Verkehr der Freien Hansestadt Bremen (2014): Dezentrale Regenwasserbewirtschaftung in Bremen. Merkblatt über technische und rechtliche Voraussetzungen • Senator für Umwelt, Bau und Verkehr der Freien Hansestadt Bremen (no year): Merkblatt für eine wassersensible Stadt- und Freiraumgestaltung. Empfehlungen und Hinweise für eine zukunftsfähige Regenwasserbewirtschaftung und eine Überflutungsvorsorge bei extremen Regenereignissen in Bremen • Senator für Umwelt, Bau und Verkehr der Freien Hansestadt Bremen (2014): Bremer Häuser im Klimawandel. Schutz vor Starkregen und Hitze

5.5 Drainage of low-lying coastal areas

5.5.1 Concerns

In addition to regions with high damage potential, such as urban coastal areas, discussions on adapting coastal regions must also address the endangerment of wetlands and lowland areas.

Lowlands are areas bound by banks and not self-contained that lie no higher than 2.50 m above sea level, and whose run-off into the sea is effected through ditches, canals and rivers (AG Niederungen 2012). These areas are often important for tourism, nature conservation and agriculture. Around one-fifth of the total land area in Schleswig-Holstein is made up of lowland areas. The typical landscape in this region is characterised by lowlands that are the result of an historical cultural achievement (AG Niederungen 2012).

In lowlands near the coast, the impacts of increasing flood run-off and severe rainfall events will be compounded by more limited drainage possibilities due to rising sea level. Drainage of these areas is thus strongly affected by climate change. Additional pumping stations will need to be built in order to continue to ensure drainage in low-lying areas. This will prevent fish passage. Here, the principle of no deterioration of waterbody status pursuant to the EU Water Framework Directive must be considered on a case-by-case basis (see section 5.7.1).

Basic concerns regarding lowland drainage

Drainage of lowlands is significantly influenced by topography and hydrology as well as by sea level. Correspondingly, various climate-change factors are also involved. Water run-off from generally increased winter precipitation as well as run-off from more frequent and intensive heavy rainfall events accompanied by the possibility of higher groundwater levels stand in direct conflict with the increasingly limited drainage possibilities associated with sea-level rise. This problem is further exacerbated by the changes in tide dynamics and storm surge water levels. Changes in the amounts of snow and ice can also contribute to changes in the run-off regime. Overall, drainage conditions will continue to worsen (AG Niederungen 2012; Marschenverband SH, MELUND SH & AG Niederungen 2014).

Demands on drainage engineering

The actual consequences of climate change may vary depending on the kind of drainage structure that is in place. There are four basic types of areal drainage: free-flow natural drainage, tidal-gate drainage, pumping-station drainage and combined tidal-gate/pumping-station drainage. There are also some areas with multi-stage drainage, e.g tidal-gate drainage with an upstream retention basin (Marschenverband SH, MELUND SH & AG Niederungen 2014).

Currently in Schleswig-Holstein around 53 % of the low-lying areas are already being drained by pumping stations. Around 27 % are drained by tidal gates and about 18 % by a combination of tidal gates and pumping stations. Only 3 % of the areas flow naturally into the sea or into open tidal waters.

Tidal dynamics (especially the rise in low-tide levels), in conjunction with mean sea level, can restrict the free-flow drainage options through tidal gates. In principle, a reduction in tidal gate outflow periods can be expected. The demands and requirements for the size of retention areas will therefore increase in the future, especially for tidal-gate drainage systems (Marschenverband SH, MELUND SH & AG Niederungen 2014).

The need for and amount of drainage by pumping stations is also expected to increase accordingly. The increased use of pumping stations will be accompanied by higher energy costs (Marschenverband SH, MELUND SH & AG Niederungen 2014). Extremely high water levels due to storm surges can, however, cause the geodetic head of pumping stations to be exceeded and also result in an interruption of drainage (Marschenverband SH, MELUND SH & AG Niederungen 2014).

Agricultural and forestry use of lowlands

In addition to the type of drainage structure, other important concerns include the size of the individual catchment areas and the land uses involved. In lowlands used for agriculture and forestry, the fact that longer and more frequent dry seasons in summer can result in limitations for irrigation-intensive uses must be considered (in addition to the poor drainage conditions and their associated consequences for agricultural and forestry use) (Marschenverband SH, MELUND SH & AG Niederungen 2014).

Additional influencing factors

Irrespective of climate change, it should be noted future changes in the elevation of soils comprised primarily of organic matter will also be a factor in the drainage of lowlands due to settling and subsidence, e.g. as a result of the mineralisation of peat soils (Marschenverband SH, MELUND SH & AG Niederungen 2014), because lowering of the terrain results in a shallower water table relative to the terrain surface.

5.5.2 Climate adaptation measures (Annex Tab. A. 39 - Tab. A. 42)

In sparsely or completely unpopulated lowland areas being used for agriculture or forestry, consideration could be given in some cases to abandoning this use or replacing it, for example, with paludiculture or peatland restoration.

An attempt can be made to reduce water flow to the lowlands by enhancing run-off retention in the upper parts of catchment areas. Otherwise, pumping stations will have to be built or extended if the utilisation pressure is high. Where tidal-gate drainage is currently still in use, it may be possible to continue this passive form of drainage with the addition of upstream reservoirs. Forecasting systems and a forward-looking management of receiving waters can support lowland drainage.

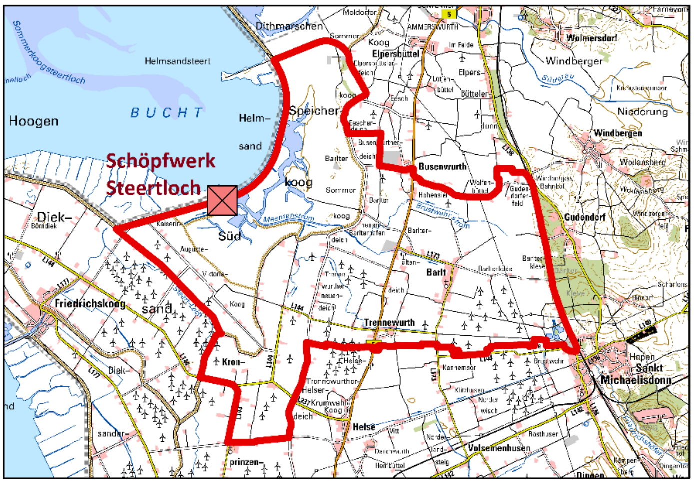
Links with other fields of action	Flood control, coastal protection, urban drainage/wastewater treatment, flood protection: heavy rainfall and flash floods

5.5.3 Profiles of practical examples

Example 12: Field of action - Drainage of low-lying coastal areas: ALNUS project

Field of action	Drainage of low-lying coastal areas
Practical example	**ALNUS project (Baltic Sea region)**
Climate adaptation measures	Adaptation of land use (Tab. A. 39)
Within the scope of the ALNUS project, an area of about 10 hectares was planted with alders. The cultivation took place in a number of locations on small boundary plots. The alders on the parcels show healthy growth after 7 years, as the area has been permanently soaked since the rewetting was carried out. Photo: P. Röhe	
Description and objectives	The aim of the project was the sustainable production and use of alder wood on rewetted peatlands as an economically and environmentally sound form of land use. Production processes for alder wood have been developed for this purpose that minimise environmentally damaging processes and resource consumption. Applying aspects of forestry, ecological, and (socio-) economic knowledge, criteria and indicators were developed for the selection and management of reforestation areas. A 10 ha, degraded fen area in the district of Demmin was rewetted and reforested with black alder. In the process, various plantation establishment processes were tested, and a new technique that was more oriented toward soil conservation was developed for preparation of the site. In addition, an implementation-orientated guideline was established. In this way, a sustainable method of land use for the North German coastal lowlands was developed that might also offer a solution with respect to the threat of growing waterlogging problems with climate change.
Timeframe of implementation:	2002-2005
Costs/financing	German Federal Environmental Foundation (DBU)
Participants	University of Greifswald, Institute of Botany and Landscape Ecology, Institute DUENE e.V., and State Forest Administration Mecklenburg-Western Pomerania
Challenges, solutions and successes	✓The studies show that alder forests - especially on semi-wet peatland sites - are effective carbon sinks and thus contribute to climate change mitigation.
Contact	University of Greifswald, Institute of Botany and Landscape Ecology and the Ministry of Agriculture and Environment Mecklenburg-Western Pomerania, Unit 240 Silviculture, Mecklenburg-Western Pomerania state foresty institute
Further information	• University of Greifswald: ALNUS Guidelines. Link : *https://www.moorwissen.de/de/paludikultur/paludikultur.php* • Röhe & Schröder (2010): Grundlagen und Empfehlungen für eine nachhaltige Bewirtschaftung der Roterle in Mecklenburg-Vorpommern • Greifswald Mire Centre: Paludikultur - ALNUS - Erstaufforstung auf Niedermooren. Available at: *www.moorwissen.de/de/paludikultur/ projekte/alnus/index.php*

Example 13: Field of action - Drainage of low-lying coastal areas: "Sommerloch-Steertloch tidal gate - conversion to a pumping station" project

Field of action	Drainage of low-lying coastal areas
Example	**"Sommerloch-Steertloch tidal gate - conversion to a pumping station" project (North Sea region)**
Climate adaptation measures	New construction of pumping stations (Tab. A. 41)
Map with overview of the Steertloch tidal gate plans Photo: © DHSV Dithmarschen und Geobasis-DE/L VewrmGeo-SH	
Description and objectives	To facilitate drainage of a 66.5 km² catchment area, the Dithmarschen dike and central tidal gate association is planning to build a pumping station at the site of the former Steertloch tidal gate. The tidal gate is part of the state protection dike located in front of the Dithmarschen polder. This measure is necessary because sedimentation and siltation are increasingly impacting foreland areas. In recent years attempts have been made to use additional impounded sea-water for sediment removal. The State of Schleswig-Holstein incurs substantial annual costs associated with dredging activity to maintain tidal-gate operations. The pumping station will generate an overall uniformity of water flow, but will eliminate the two-way passability of water and the organisms living in it. According to the "Steertlochsiel Water Management Study," it is not possible to drain the area through other measures. The continued operation of the tidal gate would probably result in widespread flooding, with significant adverse effects on agricultural use.
Timeframe of implementation:	In planning since 2012, Implementation 2017-2019
Costs/financing	-
Participants	Dithmarschen dike and central tidal gate association, "Sommerkoog-Steertloch Tidal Gate" engineering consultancy, spb planning and consultancy firm (spb Bremen mbH) and Lindemann + Ulrich engineering firm (Lindemann + Ulrich Ingenieure GmbH & Co. KG), Günther & Pollock landscape planning consultancy
Challenges, solutions and successes	× Poor compatibility with the principle of no deterioration of waterbody status under the EU WFD (fish migration): Generally conceivable technical solutions to maintain migratory passability would entail disproportionately high effort. ✓ Due to very low migratory activity, the loss of continuity will be acceptable and, as a compensation measure, passability at the Broklandsau pumping station will be established.
Contact	Dithmarschen dike and central tidal gate association (Deich- und Hauptsielverband Dithmarschen)

Further information	• Dithmarschen Dike and Central Tidal Gate Association: Pumping station Steertlochsiel. Available at: *www.dhsv-dithmarschen.de/* • Dithmarschen Dike and Central Tidal Gate Association (no date): Plan for the conversion of the Sommerkoog-Steertloch Tidal Gate into a pumping station. Explanatory report • Günther & Pollock Landschaftsplanung (2016): Sommerkoog-Steertloch Tidal Gate – Conversion to a pumping station. Technical contribution to the Water Framework Directive regarding the compatibility of the project with the management objectives according to Articles 27, 44 and 47 WHG (Federal Water Act)

5.6 Marine protection

5.6.1 Concerns

"The marine environment is a precious heritage that must be protected, preserved and, where practicable, restored with the ultimate aim of maintaining biodiversity and providing diverse and dynamic oceans and seas which are clean, healthy and productive." (Recital [3] of Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive - MSFD)).

With the entry into force of the MSFD on 15 July 2008, a framework was established within which Member States are to take the necessary measures to achieve or maintain good environmental status in the marine environment. The Directive requires an ecosystem-based approach to be applied to the management of human activities, ensuring that the collective pressure of such activities is kept within levels compatible with the achievement of good environmental status [...] while enabling the sustainable use of marine goods and services by present and future generations (Article 1(3) MSFD). The Directive also requires that the structures, function and processes of the constituent marine ecosystems together be taken into account.

Coastal waters, including their seabed and subsoil, are an integral part of the marine environment, and as such are also covered by this Directive. In Germany, the federal states are responsible for territorial waters (up to the 12 nautical mile limit), while marine protection in the exclusive economic zone (EEZ), which is adjacent to territorial waters, falls within the jurisdiction of the federal government. Overlaps with the programmes of measures to implement the Water Framework Directive (WFD), e.g. in the transitional and coastal waters, should be kept as low as possible.

In order to achieve or maintain good environmental status in the marine environment, Member States are required to develop marine strategies as a basis for programmes of measures which apply an ecosystem-based approach to the management of human activities. The good environmental status to be achieved must be determined at the level of the marine region or subregion on the basis of qualitative descriptors. As it is rolled out across the regions, the future integrated maritime policy should safeguard synergetic effects and policy coherence, add value and fully comply with the principle of subsidiarity. The EU Marine Strategy Framework Directive, with its ecosystem-based approach, thus forms the environmental pillar of integrated maritime policy.

In order to prepare the marine strategies, Member States were required to conduct an initial assessment, to be completed in 2012, of the current environmental status of their marine waters, determine the good environmental status of the waters concerned and establish a series of environmental targets and associated indicators[9]. This initial assessment and description of the status of marine waters was updated in 2018.

"In view of the dynamic nature of marine ecosystems and their natural variability, and given that the pressures and impacts on them may vary with the evolvement of different patterns of human activity and the impact of climate change, it is essential to recognise that the determination of good environmental status may have to be adapted over time." (Recital 34 of the Directive).

Monitoring programmes based on the indicative lists of characteristics, pressures and impacts set out in Annex III of the Directive were then to be established by a 2014 deadline. These monitoring programmes were updated in 2020. Climate change and its impacts are not mentioned specifically in the Annex III tables but are implicit in some of the characteristics and pressures.

The establishment of programmes of measures by a 2016 deadline was the third and final step in the Directive's implementation (2012– 2017) and builds on the previous preparatory stages. The programme of measures lists actions to improve the marine environment, many of which are carried out as part of the implementation of other EU directives, mainly the WFD, since the major rivers are the main route by which many loads and contaminants enter the sea. In addition, 31 new measures were developed

[9] Reports are available at http://www.meeresschutz.info .

specifically in order to meet the seven environmental targets for marine protection, which Germany notified to the European Commission in 2012. Data sheets set out a timeframe for the implementation/performance of the new measures identified in the programme.[10] The programme of measures is currently being revised and further measures will be added. Climate change and its consequences for the marine environment will also be taken into consideration in the conceptualisation of the measures.

Table 1: National environmental targets (ETs) for marine protection.

ET	Descriptor
ET 1	Seas unaffected by human-induced eutrophication
ET 2	Seas not polluted by contaminants
ET 3	Seas with marine species and habitats unaffected by impacts of human activities
ET 4	Seas with sustainable and environmentally sound use of resources
ET 5	Seas without marine litter pollution
ET 6	Seas not impacted by the introduction of anthropogenic energy
ET 7	Seas with natural hydromorphological character

The environmental impacts of the programme of measures on the assets to be protected pursuant to Germany's Environmental Impact Assessment Act are entirely positive, according to the strategic environmental assessment (SEA) conducted within the programme framework. At present, the significance of the positive effects on the climate cannot be determined. The extent of the positive impacts on the climate cannot currently be determined, but result from two measures to reduce climate-damaging emissions and two further measures which, depending on their design and the environmental balance of the available options, have the potential to reduce energy use.

Although not explicitly mentioned in the programme of measures, the achievement of the objective - good environmental status in the North Sea and the Baltic Sea - will also build the resilience of local ecosystems to the impacts of climate change.

[10] http://www.meeresschutz.info

5.6.2 Climate adaptation measures (Annex Tab. A. 43 - Tab. A. 46)

In general, stable natural ecosystems are more resilient, i.e. have better adaptive and defence capacities against climate change compared to ecosystems already weakened by other impacts. Accordingly, the measures to protect marine ecosystems under the MSFD automatically help to improve the seas' capacities to adapt to climate change and its impacts. Nutrient and pollutant loads which put pressure on (and impair) marine ecosystems should therefore be reduced. In parallel, the establishment of marine protected areas (MPAs) helps to create refuges for sensitive and endangered species and habitats. In order to limit the invasion of alien species and pathogenic organisms, the provisions of the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention), adopted by the International Maritime Organization (IMO) and in force since September 2017, must be implemented in a timely and consistent manner. The establishment of an early warning system for invasive alien species in accordance with the relevant EU regulation will support monitoring of these species. Germany is a party to various regional marine protection conventions, including the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR), the Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) and the Agreement for Cooperation in Dealing with Pollution of the North Sea by Oil and Other Harmful Substances (Bonn Agreement), and is engaged in cooperation on the protection of the Wadden Sea within the framework of the Trilateral Government Conference (UBA 2015c). Rigorous implementation of existing rules, particularly EU directives, is essential to maintain and improve marine resilience to the impacts of climate change.

Links with other fields of action	Coastal protection, urban drainage and wastewater treatment, flood protection: heavy rainfall and flash floods, conservation of aquatic ecosystems, groundwater protection, navigability, irrigation

5.6.3 Profiles of practical examples

Example 14: Field of action - Marine protection: Wadden Sea Strategy 2100

Field of action	Marine protection
Example	**Wadden Sea Strategy 2100**
Climate adaptation measures	
The Wadden Sea is characterised by dynamic natural processes. Photo: J.L.A. Hofstede / MELUND-SH	
Description and objectives	The State of Schleswig-Holstein's Wadden Sea Strategy 2100 was initiated as a response to the potentially far-reaching consequences of climate change for the Wadden Sea. The Strategy was developed as a two-year project involving a stakeholder group consisting of Schleswig-Holstein's coastal defence and national park administrations, the Island and Halligen Conference (Insel- und Halligkonferenz), the Wadden Sea Conservation Station (Schutzstation Wattenmeer), WWF and an advisory council of regional institutions and scientists. The main common visions and development goals defined in the strategy are the preservation of the protective functions of the Wadden Sea as a wave energy conversion zone, conservation of the islands and halligs, the maintenance of ecological functions and dynamics of the characteristic Wadden Sea structures, and sustainable development of the Wadden Sea region as a whole. Furthermore, two climate scenarios were presented and evaluated for the development of the Wadden Sea. The evaluations show that by the second half of the 21st century, at the latest, options for adaptation will be required for the protection of the Wadden Sea in line with these common visions. The Strategy makes the case for practical measures in sediment management to balance out the existing deficit in sediment accumulation rates, and for flood defence schemes, spatial planning, public relations, awareness-raising and heritage protection. Other actions identified include: • Regular publication online of updates regarding the implementation of the Wadden Sea Strategy 2100 • Hydromorphological and biological monitoring programmes • Development of a Wadden Sea model • Development of a sediment management strategy • Implementation of pilot projects on sediment management. The Strategy was adopted by the state government of Schleswig-Holstein on 30 June 2015.
Timeframe of implementation:	Development of the Strategy: 2012– 2015; Implementation: from 2015
Costs/financing	-
Participants	Schleswig-Holstein Ministry for Energy, Agriculture, the Environment, Nature and Digitalisation, Schleswig-Holstein Office for Coastal Protection, National Park and marine protection (Landesbetrieb für Küstenschutz, Nationalpark und Meeresschutz Schleswig-Holstein - LKN-SH), Island and Halligen Conference (Insel- und Halligkonferenz - IHKo), Wadden Sea Conservation Station (Schutzstation Wattenmeer), regional institutions and scientists
Challenges, solutions and successes	-
Contact	Schleswig-Holstein Ministry for Energy, Agriculture, the Environment, Nature and Digitalisation

Further information	• Ministerium für Energiewende, Landwirtschaft, Umwelt, Natur und Digitalisierung des Landes Schleswig-Holstein (2015): Strategie für das Wattenmeer 2100. Link: *www.schleswig-holstein.de/DE/Fachinhalte/K/kuestenschutz/strategieWattenmeer2100.html* • Ministerium für Energiewende, Landwirtschaft, Umwelt, Natur und Digitalisierung des Landes Schleswig-Holstein: Landesportal Schleswig Holstein - Strategie Wattenmeer 2100 beschlossen. Link: *www.schleswig-holstein.de/DE/Landesregierung/V/_startseite/Artikel/150630_wattenmeer2100.html*

5.7 Conservation of aquatic ecosystems

5.7.1 Concerns

Pursuant to Article 27 of the German Federal Water Act (Wasserhaushaltsgesetz - WHG) implementing Article 4(1)(a) of the WFD, surface waters are to be managed in such a way that a good surface water status and a good ecological potential is maintained or achieved. A management plan is to be produced for each river basin district.[11] These plans also address aspects of climate change.

The objective of measures aimed at implementing the WFD is to achieve or maintain a good status of waters and thus to increase the waters' resilience to the impacts of climate change. The measures therefore constitute an important contribution to climate change adaptation.

The impacts of climate change on the measures' effectiveness can be assessed at the local level on a case-by-case basis in the course of the detailed planning stage for the implementation of the programme of measures. Specific statements regarding changes caused by climate change impacts on the effectiveness and efficiency of the measures can only be made at the level of detailed planning. These statements will then be taken into consideration in further planning. Moreover, where it comes to energy intensive measures (e.g. wastewater treatment plants) attempts are also made to minimise greenhouse gas emissions with a view to mitigating climate change.

Examples of concerns

- The Alpine region particularly affected by the impacts of climate change, suffering adverse impacts on its biodiversity in particular. Especially endemic species of flora and fauna have hardly any opportunities to adapt if their habitats decrease in size or are lost (BMU, no year given).

  Lakes, the upper reaches of watercourses and cold Alpine waters have been particularly affected (StMUV BY 2016).
- Sea-level rise can effect changes in rivers flowing into the North and Baltic Seas. Additional pumping stations will need to be built to continue to ensure drainage in low-lying areas. This will prevent fish passage. Developments of this nature must be assessed against the principle of no deterioration under the WFD (see section 5.5.1). Moreover, there may be an increase in tidal dynamics and thus higher inputs of energy from currents as well as an upward shift of the turbidity zone. Altered tidal dynamics would result in increased up-river transport of suspended solids/sediments. Moreover, sediment transport is highly dependent on upstream flow.
- In slow-flowing watercourses subject to backwater effects and additional abstraction, drought periods have particularly critical effects on the water`s chemical and biological properties. It is likely that there will be higher concentrations of nutrients and pollutants that are harmful to aquatic biocoenoses.

We explicitly refer to the measures set out in Tab. A. 47 which contain further information on concerns with regard to the conservation of aquatic ecosystems.

[11] See for example: Rhine River Basin Community (FGG Rhein): http://www.fgg-rhein.de/servlet/is/4367/; Elbe River Basin Community (FGG Elbe): https://www.fgg-elbe.de/berichte.html; Weser River Basin Community (FGG Weser): http://www.fgg-weser.de/oeffentlichkeitsbeteiligung/veroeffentlichungen/eg-wrrl

5.7.2 Climate adaptation measures (Annex Tab. A. 47 - Tab. A. 56)

Similar to the "marine protection" field of action, climate adaptation measures in the "conservation of aquatic ecosystems" field are primarily aimed at strengthening natural ecosystems with a view to resilience towards climate change. One strand of actions concerns water-body structures: The establishment of aquatic structures that are as natural as possible and offer good longitudinal continuity, variable and widened hydromorphological structures, and developed riverbanks covered in vegetation aims at providing a range of different conditions with varied niches and refuges. In times of stress, these offer refuge and allow for recolonisation following extreme events such as the drying out of individual segments of a river. Watercourse maintenance should also be conducted in an environmentally-friendly manner. Moreover, existing near-natural habitats should be protected. Another strand of actions concerns water quality: The aim is to re-establish a level of water quality in watercourses that is as natural as possible and approximates levels of pollutants and nutrients which would be found in the absence of human influence. To this end, point-source substance and heat pollution may need to be amended or dynamised in terms of threshold values for abstraction and discharges. Good agricultural practice must be further developed and consistently applied to remove non-point nutrient pollution which primarily originates in the farming sector. These adaptation measures are therefore consistent with the measures and objectives of the WFD. The consistent implementation of the WFD also has a positive effect on the resilience of aquatic ecosystems, as described above. In low water situations, the abstraction and discharge of coolant water for example is restricted under alarm plans in Bavaria (e.g. alarm plan for the Bavarian regulated aquatic ecology of the River Main).

Upstream transport of sediments in estuaries can be counteracted by way of an optimised sediment management strategy. Upstream flow is also impacted by surface water abstraction and the different uses served by the water supply; it can be controlled by measures taken in the upper and median river segments.

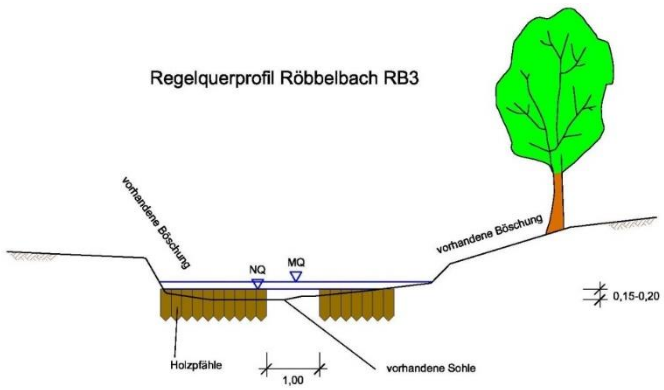
Links with other fields of action	Flood control, coastal protection, urban drainage and wastewater treatment, flood protection: heavy rainfall and flash floods, marine protection, groundwater protection, public water supply, cooling water, hydropower generation, navigability, irrigation, dam and reservoir management, low water management in watercourses

5.7.3 Profiles of practical examples

Example 15: Field of action - Conservation of aquatic ecosystems: Floodplain revitalisation at the Weser River

Field of action	Conservation of aquatic ecosystems
Example	**Floodplain revitalisation at the Weser River**
Climate adaptation measures	Restoration of floodplains (Tab. A. 3), Alteration of hydromorphological structures (Tab. A. 48), Promoting natural water retention (Tab. A. 109), Reducing nutrient and pollutant inputs (Tab. A. 43)
For the purposes of floodplain revitalisation at the Weser River in Bremen-Habenhausen, parts of the bank revetment were lowered and flood channels and inundation zones where created, including a sandy riverbank.	
Description and objectives	With a view to increased structural diversity, a floodplain was connected to the Weser River along a roughly 500 metre long, anthropogenic section of the river in the area of the higher water flood channels between the Werdersee Lake and the Weser River in Bremen-Habenhausen. In order to connect the 7.4 ha site to the river, the rock revetment was reduced down to 30 cm below the river's mean water level along much of the site's length, allowing river water to flow into the floodplain. A diverse site which includes flood channels, shallow water areas, reed beds and a near-natural sandy riverbank developed in front of the existing levee. In the southern section, a sandy bathing beach offers water-based recreational opportunities. The aim for the more shallow northern section is for it to develop into a mosaic of shallow water areas, sandy habitats, reed beds and ruderal vegetation, free from anthropogenic use. This will create spawning grounds for fish as well as habitats for insects, amphibians, juvenile fish and birds. The project also serves climate change adaptation. Specific construction measures include: • Establishment of a flood channel with permanent flow and a smaller floodway at the riverbank; • Establishment of a near-natural sandy riverbank along with deeper waters; • A levelled out topography between the the outer toe of the Habenhausen dike and the newly created sandy riverbank; • Removal of the bridge between the level sill spillway and the Weser riverbank; • The lowering of the bank revetment along the Weser riverbank; • Initial plantings of a variety of reed species.
Timeframe of implementation:	2013/2014
Costs/financing	Approx. 2 million euros (approx. 50% funded by the European Regional Development Fund, ERDF)
Participants	The senator for climate action, environment, mobility, urban development and housing of the Free Hanseatic City of Bremen, bremenports
Challenges, solutions and successes	✓The measures also meet WFD requirements and ERDF objectives.
Contact	Bremen's Senator for the environment, construction and transport (Der Senator für Umwelt, Bau und Verkehr Bremen)
Further information	• Freie Hansestadt Bremen: Eine naturnahe Bucht für Habenhausen. Link: *www.efre-bremen.de/sixcms/detail.php?gsid=bremen59.c.14830.de*

Example 16: Field of action - Conservation of aquatic ecosystems: Watercourse renaturalisation of the Röbbelsbach

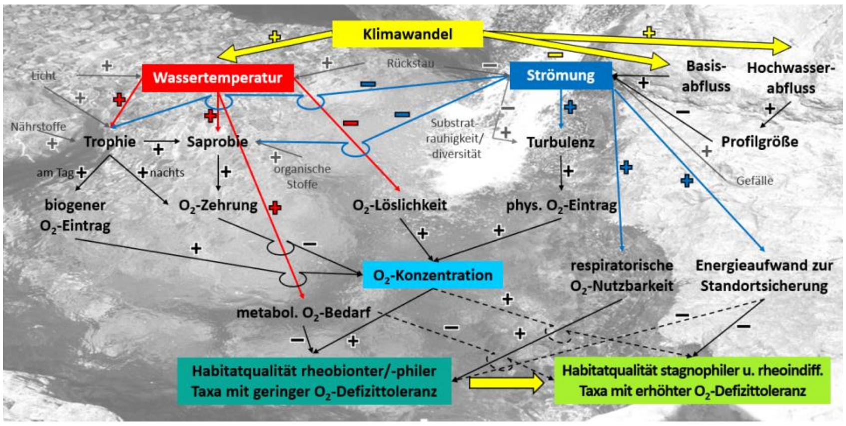
Field of action	Conservation of aquatic ecosystems
Example	**Watercourse renaturalisation of the Röbbelsbach**
Climate adaptation measures	Alteration of hydromorphological structures (Tab. A. 48), Protection and development of riparian zones (Tab. A. 49), Improving continuity of watercourses (Tab. A. 47)
The typical cross-section profile for the renaturalisation of a 300 m section of the Röbbelbach stream shows different flow profiles, depending on water levels. Photo: Heuer-Jungemann	
Description and objectives	The watercourse renaturalisation project at the Röbbelsbach was initiated in order to mitigate climate change impacts on watercourses by means of hydraulic engineering measures. Different flow profiles were created for future low water discharge caused by climate change, maximum flows to cater for heavy rainfall events, and shading to combat increases in water temperature. The aim was to develop a robust procedure allowing those responsible for managing smaller watercourses in physiographic regions sharing similar characteristics to determine the necessary scope of watercourse development measures. Double trapezoid profiles were created in a roughly 300 m section of the stream; additionally, low water flow was consolidated by placing site-appropriate materials in the streambed. This serves to generate semi-natural flow behaviour and create conditions conducive to the development of characteristic native habitats. The results were compiled in a guideline.
Timeframe of implementation:	2012/2013
Costs/financing	-
Participants	Watercourse and landscape management association for the middle and upper reaches of the Ilmenau River (Gewässer- und Landschaftspflegeverband Mittlere und Obere Ilmenau), Leuphana University of Lüneburg, Institute of Ecology, Bureau of applied limnology and landscape ecology (BAL Büro für angewandte Limnologie und Landschaftsökologie), Dipl.-Ing. Heuer-Jungemann
Challenges, solutions and successes	× Land availability ✓ All landowners agreed to the implementation of these measures. ✓ The measures increased shear stress in the low water current line and sand accumulation no longer occurs on the streambed as had been the case in the formerly straightened stream.
Contact	Watercourse and landscape management association for the middle and upper reaches of the Ilmenau River (Gewässer- und Landschaftspflegeverband Mittlere und Obere Ilmenau)
Further information	• KLIMZUG-NORD (2013): Arbeitspaket 3: Erprobung eines Verfahrens zur praxisnahen Bestimmung wasserbaulicher Maßnahmen zur Sicherung des ökologisch notwendigen Mindesabflusses kleiner Fließgewässer. Teil I Endbericht • German Environment Agency (UBA): Naturnahe Umgestaltung des Röbbelbachs. Link: *www.umweltbundesamt.de/themen/klima-energie/klimafolgen-anpassung/werkzeuge-der-anpassung/tatenbank/naturnahe-umgestaltung-des-roebbelbachs*

Example 17: Field of action - Conservation of aquatic ecosystems: Dynamisation of the Danube floodplains between Neuburg and Ingolstadt

Field of action	Conservation of aquatic ecosystems
Example	**Dynamisation of the Danube floodplains between Neuburg and Ingolstadt**
Climate adaptation measures	Restoration of floodplains (Tab. A. 3), Alteration of hydromorphological structures (Tab. A. 48), Improving continuity of watercourses (Tab. A. 47), Maintenance and expansion of protected areas (Tab. A. 52)
Minor flooding events regularly flood parts of the alluvial forest.	
Description and objectives	As a result of the damming and diking of the Danube, the former Danube floodplains have been largely cut off from the river's flood and groundwater dynamics. This has put species and habitats typical of floodplains at risk. This project was to reverse these developments in part with a view to preventing further losses of these alluvial forest biotopes and aquatic habitats and also in order to create more flood retention spaces as a climate adaptation measure. To this end, the Bergheim barrage dam was made biologically permeable and water was directed into a bypass watercourse which now flows through the adjacent alluvial forest before rejoining the Danube. The bypass watercourse has a total length of approximately 8 km and has several links with the Danube. Newly constructed bridges, culverts and fords allow for the continued use of existing tracks in the alluvial forest. A weir in the dam of the barrage allows for 100 ha of the alluvial forest to be regularly flooded even during minor floods. The project was accompanied by a scientific study ("MONDAU Monitoring Donauauen") which monitored and assessed the hydrological regime, flora and fauna. The findings provided recommendations and allowed for optimisations of construction measures in other comparable situations along major rivers.
Timeframe of implementation:	Planning: 2003–2005, Implementation: 2006-2011
Costs/financing	Approx. 15 million euros, funded by the European Union, the Bavarian Free State, the Bavarian Nature Conservation Fund (Bayerischer Naturschutzfonds), the city of Ingolstadt, and the district of Neuenburg-Schrobenhausen
Participants	Bavarian Free State, Arbeitsgemeinschaft Auenrenaturierung (expert working group on floodplain restoration), Catholic University of Eichstätt-Ingolstadt - Aueninstitut Neuburg, Weihenstephan-Triesdorf University of Applied Sciences, Osnabrück University of Applied Sciences, Technical University of Munich
Challenges, solutions and successes	✓The project complies with the requirements of the Habitats Directive and the WFD
Contact	Ingolstadt Water Authority (Wasserwirtschaftsamt Ingolstadt)

Further information	• Ingolstadt Water Authority (*Wasserwirtschaftsamt Ingolstadt*): Dynamisierung der Donauauen zwischen Neuburg und Ingolstadt. Link: *www.wwa-in.bayern.de /fluesse_seen/massnahmen/mass05/index.htm* (English language PDF flyer) • Ingolstadt Environment Authority & Neuburg-Schrobenhausen District Office (*Umweltamt Ingolstadt & Landratsamt Neuburg-Schrobenhausen*): Donauauenkonzept. Link: *www.ingolstadt.de/donauauen/* • Catholic University of Eichstätt-Ingolstadt: MONDAU - Monitoring auenökologischer Prozesse und Steuerung von Dynamisierungsmaßnahmen. Link: *www.umweltgeographie.ku.de/mgf/geographie/umweltgeo/forschung-und-praxis/forschungsprojekte/mondau/*

Example 18: Field of action - Conservation of aquatic ecosystems: KLIWA-Index$_{MZB}$: Monitoring methods designed to indicate biocoenotic impacts of climate change

Field of action	Conservation of aquatic ecosystems
Practical example	**KLIWA-Index$_{MZB}$: Monitoring methods designed to indicate biocoenotic impacts of climate change**
Climate adaptation measures	Climate-change-specific evaluations and adaptation of watercourse monitoring (Tab. A. 56)
Assessment of climate change impacts on watercourse quality and habitat conditions Photo: Martin Halle (umweltbüro essen)	
Description and objectives	In order to provide improved assessments of the impact of climate change on watercourse quality and habitat conditions, two studies as part of the KLIWA cooperation (Climate Change and Consequences for Water Management) developed evaluation options for the index-based assessment (KLIWA-Index$_{MZB}$) of the summer respiratory habitat conditions of macrozoobenthos (MZB) communities in watercourses. The index is given in degrees Celsius as the bioindicated equivalent temperature for the summer respiratory habitat conditions of the macrozoobenthos. These depend on the summer water temperature, the flow as well as oxygen-consuming and trophic acting substances. This index was formulated on the basis of existing data on water temperatures and macrozoobenthos establishment derived from WFD monitoring programmes conducted in the federal states. The KLIWA-Index$_{MZB}$ can be calculated based on standardised analyses of macrozoobenthos communities. This group of organisms was selected as many species are sensitive to changes in temperature and flow conditions. Changes in the composition of the biocoenoses should be reflected in a shift in the KLIWA-Index$_{MZB}$. In order to simplify the use of the index, a software application for the calculation of the KLIWA-Index$_{MZB}$ was developed as part of the project. The fact that the respiratory conditions indexed in the KLIWA-Index$_{MZB}$ have a very large impact on the ecological status assessment (using the PERLODES assessment) was demonstrated in a practical test.
Timeframe of implementation:	Start of climate monitoring in the KLIWA states and in Hesse: 2017
Costs/financing	-
Participants	KLIWA working group (Arbeitskreis KLIWA), environmental consultancy Umweltbüro essen Bolle & Partner GbR, Senckenberg Research Institute and Natural History Museum in Frankfurt - Biodiversity and Climate Research Centre
Challenges, solutions and successes	-
Contact	KLIWA working group (Arbeitskreis KLIWA)
Further information	• Arbeitskreis KLIWA (2016): Ableitung von Temperaturpräferenzen des Makrozoobenthos für die Entwicklung eines Verfahrens zur Indikation biozönotischer Wirkungen des Klimawandels in Fließgewässern. KLIWA-Berichte • Arbeitskreis KLIWA: Gewässerökologie. Link: *www.kliwa.de/ gewaesseroekologie.htm* (Germany only) • Arbeitskreis KLIWA (2018): Praxistest und Verifizierungen des KLIWA-IndexMZB. Abschlussbericht. Link: *www.kliwa.de/publikationen-projektberichte.htm*

Example 19: Field of action - Conservation of aquatic ecosystems: Thermal load plan for the tidal Elbe River

Field of action	Conservation of aquatic ecosystems
Practical example	**Thermal load plan for the tidal Elbe River**
Climate adaptation measures	Amendment of threshold values for abstraction and discharge (Tab. A. 54)
In 2008, Hamburg, Schleswig-Holstein and Lower Saxony established a new thermal load plan for the tidal Elbe River between Geesthacht and Cuxhaven. This plan must be taken into consideration with respect to any decisions taken by the authorities on thermal discharges into the tidal Elbe River. Photo: FGG Elbe	
Description and objectives	In a context of plans for the construction of numerous power plants and the associated discharges of cooling water, a thermal load plan was established for the Elbe River between Geesthacht and Cuxhaven; the plan came into force in 2009. The aim is to analyse the impacts of thermal discharges on the tidal Elbe River in their spatial and temporal distribution, with a view to be able to preserve the entire river ecosystem. The thermal load plan is based on a comprehensive hydraulic-ecological model, which can be used to assess current thermal emissions as well as thermal emissions under specific planning conditions, and to take these into consideration when selecting a location for power plants. Estimates of thermal emissions also help the licensing authorities to better assess the impacts of thermal discharges. Potentially harmful cumulative impacts of several thermal emitters can be mitigated by using the thermal load plan to better record and observe impacts and to coordinate the discharge quantities and their timing. The plan also includes guide values for the maximum allowable water temperature (28 C), the maximum allowable temperature rise in the river (3 K), the minimum oxygen concentration in the river (3 mg O_2/l) , and a target value for the oxygen concentration in the river (6 mg O_2/l). Major emitters must provide evidence of compliance with these values and must be prepared for possible restrictions to their operations for compliance purposes. The hydraulic-ecological model is available as an application and can thus be used by applicants in the preparation of approval documents.
Timeframe of implementation:	Preparation: by 2008; in force since 2009
Costs/financing	-
Participants	Special task force for the tidal Elbe River (Sonderaufgabenbereich Tideelbe) of the federal states of Hamburg, Schleswig-Holstein and Lower Saxony, Elbe River Basin Community (FGG Elbe - formerly Elbe River water quality authority (Wassergütestelle Elbe))
Challenges, solutions and successes	-
Contact	Elbe River Basin Community (Flussgebietsgemeinschaft Elbe)
Further information	• Behörde für Stadtentwicklung und Umwelt Hamburg et al. (2008): Wärmelastplan für die Tideelbe

5.8 Groundwater protection and groundwater use

5.8.1 Concerns

Potential impacts of climate change on groundwater recharge, available groundwater resources and groundwater levels are described in section 4.2. Notably, a great deal of uncertainty still surrounds projections of the future development of these parameters. Their actual trajectory not only depends on the development of climatic parameters (primarily precipitation and air temperature), but soil conditions and geology also impact on groundwater and can therefore result in differences in the way in which future changes manifest at local level. Moreover, direct human interventions in the groundwater regime (primarily groundwater abstraction) have a major influence, and these anthropogenic influences may conceivably change in future. Overall therefore the range of conceivable developments is so wide that both higher rates of groundwater recharge and rising groundwater levels as well as lower groundwater recharge rates and declining groundwater levels may be possible, with variations across the regions. This section outlines concerns for both scenarios.

Quantity: Higher groundwater recharge rates and rising groundwater levels

Higher groundwater recharge rates and rising groundwater levels would increase the risk of waterlogging for both agricultural and forestry land as well as for built structures. There would also be greater quantities of groundwater to be collected by drainage systems for removal towards surface waters or wells. However, there may also be greater exploitation of groundwater resources. If precipitation increased, there would also be an increase in the proportion of extraneous water in the sewage system; this could result in higher operating expenses for its removal through the sewage network (e.g. cost of pumping, hydraulic capacity) and may be detrimental to the purification capacity of wastewater treatment plants. Rising groundwater levels would also impair the functioning of small-scale treatment systems and other systems (systems falling under the definition of the Ordinance on Installations for the Handling of Substances Hazardous to Water - AwSV, landfill sites) insofar as they require minimum distances between groundwater and installations. In general, specifications for the construction design of percolation systems are harder to meet, the higher the groundwater level (e.g. minimum infiltration distance within the unsaturated zone when the mean highest groundwater level occurs (DWA-A 138 2005)).

Areas with already high groundwater tables or where the water table is directly connected to a surface water would probably be particularly strongly impacted by higher groundwater recharge rates and rising groundwater levels. In this scenario, consideration must be given to the fact that rising temperatures generally result in lower groundwater recharge rates due to increased evaporation, longer growing seasons and changes in groundwater utilisation. This effect would need to intersect with significantly higher precipitation during the hydrological winter season for groundwater recharge rates and groundwater levels to rise. Otherwise groundwater levels are more likely to fall with a corresponding drop in available groundwater resources.

Interactions with other influencing factors

Waterlogging resulting from changes in precipitation may be exacerbated by a decline in the utilisation of naturally available groundwater resources on the part of households, agriculture, industry and commerce, and in some regions by the abandonment of mining operations and cessation of the associated lowering of the groundwater level (MLU ST 2011). Many other factors impact on the level of waterlogging, especially in built-up areas. These include the sealing of soil surfaces, conversion of open spaces to other uses, urban drainage, construction measures along watercourses in urban areas, rural settlement and the corresponding open spaces, changes in groundwater management, and impacts on groundwater conditions resulting from subsoil disturbance due to engineering measures. Outside of built-up areas, potentially significant factors include land uses and installations employed to regulate the local hydrological regime. Therefore, potential climate change-induced shifts constitute only one of many factors influencing waterlogging (MLU ST 2011). Protection from high groundwater levels is thus driven not only by climate change, but by numerous other factors. This makes it expedient to assess the concerns in conjunction with these other influencing factors.

Areas with already high groundwater tables or where the water table is directly connected to a river would probably be particularly strongly impacted by higher groundwater recharge rates and rising groundwater levels.

<u>Quantity: Lower groundwater recharge rates and falling groundwater levels</u>

These situations may exacerbate conflicts of interest in terms of water resources management and result in groundwater scarcity and thus scarcity of drinking water resources and overuse, which in turn presents new challenges in terms of the security of public water supply. Additionally, increasing drought and the associated water deficits may result in increased irrigation needs for agricultural land, parks, gardens, sports grounds etc. Where these irrigation needs are met by means of groundwater abstraction, further declines in groundwater levels as well as changes to the groundwater quality (salination, nutrient inputs) may ensue. Low groundwater levels may impair shallow wells serving public and private water supplies.

Lowered groundwater recharge rates would particularly affect areas with not very productive aquifers used for drinking water abstraction (eastern Bavarian basement rock). It would also strongly affect areas already characterised by drought and low groundwater recharge rates (e.g. central regions of eastern Germany and the northern Upper Rhine Plain).

Groundwater-dependent terrestrial ecosystems such as wetlands and peatlands tend to be particularly impaired by declining groundwater levels. It is possible for peatlands to lose their carbon sink function and thus contribute to climate change. Where subsoil layers dry out that are sensitive to subsidence, the structural integrity of buildings may be impaired and under certain circumstances there may be impacts on underground utilities in affected areas.

<u>Increase in natural groundwater fluctuations</u>

Increases in the variability of groundwater recharge and groundwater levels, which also means more frequent highs and lows, present complex challenges for groundwater management.

<u>Groundwater quality and temperature</u>

Changes in groundwater recharge quantities can also impact indirectly on groundwater quality. Groundwater is normally subject to relatively stable physico-chemical conditions. Changed air and groundwater temperatures as well as changing groundwater levels may impact the groundwater's chemical and ecological condition.

In areas where increased winter precipitation results in increased groundwater recharge there may be an associated increase in the input of substances into aquifers during winter. For example, it is likely that the nitrates issue will worsen given that there is weak uptake by plants of nitrates during summer drought periods and a resultant greater level of leaching during winter. However there may also be compensatory dilution processes (StMUV BY 2016). Where extreme events result in failed harvests or the destruction of crop plants, fertilisers will no longer be taken up by the plants or remain on the land in the form of crop residues; these processes can similarly result in significant levels of nitrate deposition into groundwater Tab. A. 58 (DWA 2010).

Sandy soils under agricultural land use are particularly prone to nitrate leaching through seepage water. In Schleswig-Holstein this affects the Geest landscapes (LLUR SH 2014). There are also other regions in Germany that are characterised by sandy soils and thus affected by this problem.

Inshore aquifers may suffer adverse effects from saltwater intrusion as a result of sea-level rise (DWA 2010). Under specific hydrogeological conditions it is also possible for saltwater contained in deep aquifers to rise up to near-surface groundwater sources (Nillert et al. 2008).

5.8.2 Climate adaptation measures (Annex Tab. A. 57 - Tab. A. 63)

As there still is significant uncertainty as to the impacts of climate change on groundwater reserves, it is difficult to identify the kind of adaptation measures that must be taken. The potential climate-related changes do not pose fundamentally new problems for groundwater protection and management, but exacerbate existing problems at regional and local levels. Universal recommendations for action are therefore not suited to solving the issues; regional adaptation strategies including flexible options for readjustments are needed instead.

In all cases, comprehensive groundwater monitoring is an important prerequisite. A close eye must be kept not only on groundwater levels but also on changes in groundwater quality resulting from changes in conversion and decomposition processes, the speed of which can increase with higher temperatures, and on changes in releases and transports of substances in the soil as well as on dilution rates. Doing so will enable a swift response if action is needed. Series of data spanning several years are important (i.e. continuity of networks of sampling stations).

Other measures correspond to existing water management tools. In a context of climate change these must be applied with particular foresight.

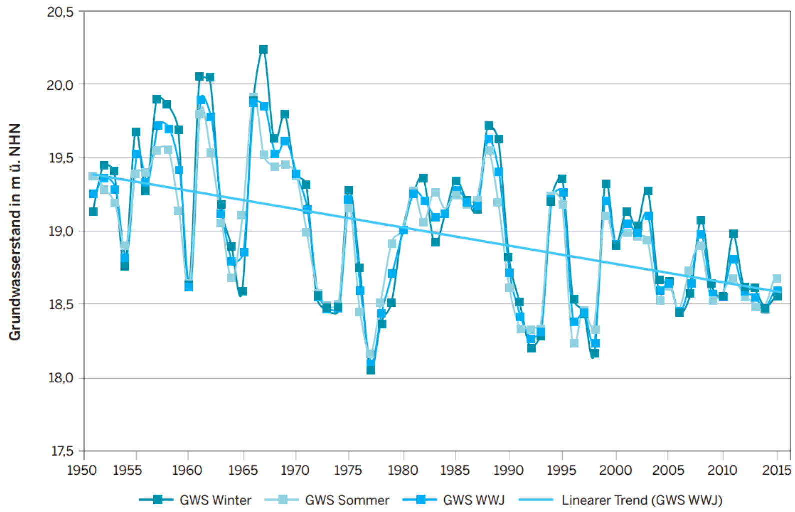
In order to prevent excessively low groundwater levels at times of high water demand and to protect groundwater-dependent terrestrial ecosystems, measures can be taken to increase the available groundwater supply and promote groundwater recharge. These primarily include the economic and prudent use of water and soil resources, especially for farming purposes. Groundwater resources must generally be managed sustainably; pursuant to the management objectives set out in the WFD, the Federal Water Act (Wasserhaushaltsgesetz, WHG), and the German Groundwater Ordinance (Grundwasserverordnung, GrwV) long-term groundwater abstraction rates must not exceed recharge rates. This requires knowledge of the long-term groundwater balance and of climate change impacts on the available groundwater resources as well as close monitoring of groundwater levels and spring discharges. Increased attention must be paid to potential conflicts over water use. Moreover, potential additional abstraction for the purposes of increased irrigation must be taken into account in groundwater management planning.

Measures to protect groundwater quality provide for the minimisation of substances entering groundwater from soils. To this end, it is necessary to apply groundwater-protecting agricultural land-use methods, i.e. to establish land-use types that involve lower levels of fertiliser applications and less irrigation. This in turn means that compliance with good agricultural practice will be all the more important; it may also require amendments to or advancements in what is considered good agricultural practice. In critical situations regulatory authorities may order compliance.

Links with other fields of action	Flood control, urban drainage and wastewater treatment, flood protection: heavy rainfall and flash floods, marine protection, conservation of aquatic ecosystems, public water supply, irrigation, low water management in watercourses

5.8.3 Profiles of practical examples

Example 20: Field of action - Groundwater protection and groundwater use: Groundwater monitoring in North Rhine-Westphalia

Field of action	Groundwater protection and groundwater use
Example	**Groundwater monitoring in North Rhine-Westphalia**
Climate adaptation measures	Climate-change-specific evaluations and adaptation of groundwater monitoring Tab. A. 57
Annual groundwater levels at the Hamminkeln sampling station in the hydrological summer season, the hydrological winter season, and the full water management year for the 1951-2015 period. The trendline for the annual mean indicates declining levels. Image: Dept. 37, LANUV NRW	
Description and objectives	Groundwater quantities are monitored by observing groundwater levels. In parts of North Rhine-Westphalia (NRW) observations go back to up to 50 years. Results obtained at approximately 30,000 sampling stations in NRW are stored in a central groundwater database for the state, allowing them to be analysed with respect to a range of different issues. The sampling stations are owned primarily by water utilities, companies and associations. In addition, the state has established its own network consisting of some 2,400 stations. Moreover, groundwater quality is monitored at a total of 6,330 stations. The latter also include the sampling stations used to monitor landfill sites. In 2011, NRW was the first German federal state to establish a state-wide indicator-based climate impact monitoring system which documents the impacts of climate change to enable timely and appropriate responses to changes and risks. In this context, groundwater condition is monitored through the two indicators "groundwater level" and "groundwater recharge". Out of 29 evaluated sampling stations, 21 showed a significant trend in declining groundwater levels. Similarly, the lysimeter station at St. Arnold has been showing a significant decline in groundwater recharge since 1966.
Timeframe of implementation:	Groundwater monitoring since the 1960s; climate impact monitoring since 2011
Costs/financing	-
Participants	The North Rhine- Westphalia State Agency for Nature, Environment and Consumer Protection (Landesamt für Natur, Umwelt und Verbraucherschutz NRW), water utilities, associations, companies, landfill operators
Challenges, solutions and successes	-
Contact	The North Rhine- Westphalia State Agency for Nature, Environment and Consumer Protection (LANUV)
Further information	• Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen: Groundwater levels. Link: *www.lanuv.nrw.de/umwelt/wasser/grundwasser/grundwasserstand/* • Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen: Groundwater quality. Link: *www.lanuv.nrw.de/umwelt/wasser/grundwasser/beschaffenheit/* • Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen (2016): Klimawandel und Klimafolgen in Nordrhein-Westfalen. Ergebnisse aus den Monitoringprogrammen 2016. LANUV-Fachbericht. Download at: *www.lanuv.nrw.de/uploads/tx_commercedownloads/fabe74_01.pdf* (Report on climate change and climate change impacts in NRW;)

Example 21: Field of action - Groundwater protection and groundwater use: KLIMOPASS: KLIMOPASS: Vulnerability research on water utilities in the southern Black Forest

Field of action	Groundwater protection and groundwater use
Example	**KLIMOPASS: Vulnerability research on water utilities in the southern Black Forest**
Climate adaptation measures	Integrating climate change into public water supply planning (Tab. A. 64), Standby water extraction systems (Tab. A. 65), Adaptation of public water supply infrastructure (Tab. A. 66)
Water extraction plant in the southern Black Forest	
Description and objectives	As part of the "Climate change and model-based adaptation in Baden-Württemberg" programme (Klimawandel und modellhafte Anpassung in Baden-Württemberg, KLIMOPASS), 21 municipalities in the southern Black Forest were assessed with respect to the vulnerability of their public water supplies. As a first step, the existing public water supply structures were recorded. Water demand was estimated taking into consideration a higher daily peak demand under conditions of climate-change-induced increasing drought as well as existing storage capacities. In addition, the hydrogeological preconditions for groundwater storage in the region were investigated. Following this, groundwater models were used to project potential seepage water and spring discharges, based on three different climate scenarios for the near (2021 to 2050) and distant future (2071 to 2100). Finally, using the examples of three supply areas, an overall analysis assessed the vulnerability of the public water supply to climate change. The analysis found that in most areas of the overall project area, there was no risk of water shortages under the projected changes in the climate. Only in four small supply areas water shortages could not be ruled out. While spring discharges will continue to decline in drought periods, individual municipalities had already joined forces and constructed deep wells prompted by experiences with drought periods in the past. The knowledge gained in the southern Black Forest and the methodology developed in this project could in principle be transferred to other areas. However, other climate-change-induced changes might need to be taken into account in other physiographic regions.
Timeframe of implementation:	2014/2015
Costs/financing	Financially supported by the Baden-Württemberg State Agency for the Environment, Measurements and Nature Conservation (Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg, LUBW) and the Ministry of the Environment, Climate Protection and the Energy Sector (Ministerium für Umwelt, Klima und Energiewirtschaft Baden-Württemberg)
Participants	Baden-Württemberg State Agency for the Environment, Measurements and Nature Conservation (Landesanstalt für Umwelt, Messungen und Naturschutz), Water Technology Center (DVGW-Technologiezentrum Wasser)
Challenges, solutions and successes	-
Contact	Water Technology Center (DVGW-Technologiezentrum Wasser)
Further information	• Stauder et al. (2015): Vulnerabilitätsanalyse von Wasserversorgungsunternehmen im südlichen Schwarzwald hinsichtlich des Klimawandels

Example 22: Field of action - Groundwater protection and groundwater use: Restoration of industrially harvested raised bogs in the Alpine foothills - The "Abgebrannte Filze", "Hochrunstfilze" and "Kollerfilze" sectors of the Rosenheimer Stammbeckenmoore peatlands

Field of action	Groundwater protection and groundwater use
Example	**Restoration of industrially harvested raised bogs in the Alpine foothills - The "Abgebrannte Filze", "Hochrunstfilze" and "Kollerfilze" sectors of the Rosenheimer Stammbeckenmoore peatlands**
Climate adaptation measures	Protection of groundwater-dependent terrestrial ecosystems (Tab. A. 60)
Cottongrass (Eriophorum) is an indicator of good peatland growth. Photo: © G.van Eyken	
Description and objectives	At a total size of approximately 43 km², the Rosenheimer Stammbeckenmoore constitute one of the largest peatland complexes in Bavaria and southern Germany. Between 2005 and 2010 it was the site of a LIFE project, the primary objective of which was to restore about 400 ha of raised bog. Other project aims included the conservation and management of adjacent straw meadow habitats (meadows mown for animal bedding), support for breeding meadow bird species through visitor activity management, the removal of woody species, and provision of information to the public on the significance of this peatland complex. Further restoration measures were taken from 2010 onwards in the "Südliche Hochrunstfilze" and "Kollerfilze" raised bogs which had been damaged by drainage and milled peat cutting. Further measures are planned for 2020. The project's set goal was to block the drains and sculpt the site into flat basins in order for these to develop into marshy peatlands or at most very shallow surface waters that are primarily rain-fed. In addition to catchment-based water retention, improved local climate and species and habitat protection, these measures are primarily aimed at climate mitigation (maintaining natural carbon sinks). Large-scale water retention in the peatland area and improved species protection are components of climate change adaptation.
Timeframe of implementation:	since 2005
Costs/financing	LIFE-Nature programme, 2005-2010, Costs: approx. 1.87 million euros, financed by: • European Union: 50% • Bavarian conservation fund (Bayerischer Naturschutzfonds): 10% • Bavarian Environment Ministry: 1% • Rosenheim District: 39% 39% As part of the Bavarian climate programme (Klimaprogramm Bayern, KLIP 2050), special funding of approximately 2 million euros per annum have been made available by the Bavarian Free State since 2008 for peatland conservation in Bavaria.

Participants	LIFE project coordination: District government of Upper Bavaria, Rosenheim District Office. Coordination and implementation of measures as part of KLIP 2050: Bavarian Environment Agency (Landesamt für Umwelt Bayern, LfU), nature conservation authorities of the district government of Upper Bavaria, Rosenheim District Office in association with the competent municipality Raubling and the Schliersee Forestry Authority (Forstbetrieb Schliersee). Accompanying scientific research: Weihenstephan-Triesdorf University of Applied Sciences, external consultancy firm, WWA Rosenheim water utility.
Challenges, solutions and successes	× Guarantees had to be given that the restoration measures would not cause adverse impacts on an adjacent housing development and a business as a result of rising groundwater levels and run-off in the event of the peatland becoming flooded. There was a possibility that the area might need to be excluded from the restoration area. The collection of evidence is to ensure the early detection of any impairment of third parties caused by restoration measures so as to allow for appropriate countermeasures to be taken. To this end, a groundwater monitoring programme was conducted in the target area, using piled sleeves which had to be installed. ✓ Restoration of a highly damaged, extensive peatland combined with climate mitigation objectives, flood protection and support for rare species of peatland-specific flora and fauna, intensive public outreach, establishment of a visitor centre with an environmental awareness agenda, and visitor activity
Contact	Untere Naturschutzbehörde (Sachgebiet III/3), Rosenheim (District-level nature conservation authority) District government of Upper Bavaria, 51 - Nature Conservation, Munich
Further information	• Landratsamt Rosenheim: LIFE-Nature Project "Rosenheimer Stammbeckenmoore" 2005-2010. Link: *www.life-rostam.de/* (German and English versions) • Landesamt für Umwelt Bayern: Moorschutz in Bayern. Link: *www.lfu.bayern.de/natur/moore/index.htm*

5.9 Public water supply

5.9.1 Concerns

In Germany, some 5 billion m³ raw water is withdrawn each year for public water supply. Around 60 % of this comes from groundwater, and approx. 8 % from spring water. Bank filtrate, enriched groundwater and water from lakes and reservoirs are also used, as is a small amount of river water (UBA 2015d).

The future (quantitative and qualitative) development of groundwater resources and surface waters thus crucially determines the future security of public drinking water supply. To what extent climate change leads to restrictions will depend primarily on future groundwater recharge rates and surface water availability. At a regional level, however, the sufficient availability, in quantitative and qualitative terms, of other raw water resources may also be decisive for potable water supply. For instance, in southern Germany the water of Lake Constance plays a vital role in water supply, while in the Ruhr region the water of the River Ruhr has that role.

Fundamental concerns

Public water supply is a service of general public interest (Article 50 (1) Federal Water Act - WHG); it has a high standing in society and priority over other water uses. It may thus be assumed that even if utilisation disputes intensify due to changed demand-side structures, public potable water supply will continue to have priority over other uses such as irrigation and cooling-water supply (StMUV BY 2016). Thus, as long as these principles are retained, it need not be expected that potable water supply will be impaired in Germany on a widespread basis or in a sustained manner.

There are, however, numerous local and regional exceptions from this fundamental statement. For instance, near-coastal groundwater resources could be impaired substantially by saltwater intrusion. Furthermore, problems could amplify in those areas where potable water supply is already under pressure today or where it competes with other uses such as agricultural irrigation. Such areas include eastern parts of the Lüneburg Heath (Lüneburger Heide) and central parts of eastern Germany. Heightened concerns may also ensue in regions in which water supply is based mainly on sources from low-yield joint aquifers; these include the southern German moraine landscapes, the southern part of the Black Forest, the Rhenish Slate Mountains (Rheinisches Schiefergebirge) and the eastern Bavarian basement complex (Neumann & Wendel 2013).

Raw water from groundwater and spring water

If groundwater recharge is reduced in future, at least temporary shortages of potable water are a definite possibility. This is particularly the case where water supply is based on rock aquifers or on spring water from small, near-surface catchments which, due to low storage capacities, depend directly on inputs from precipitation. In such situations, alternatives sources of supply need to be provided for in good time, possibly by means of integrating water supply systems (LAWA 2010). Low spring discharge rates can not be adjusted to demand during dry periods (LfU BY 2016). In contrast, where water is extracted from wells technical interventions can influence the amount of water withdrawn to a certain degree. However, in regions where groundwater levels are falling, low supply pressure can cause cavitation problems in well pumps. In areas where precipitation patterns across the year change, elevated nitrogen inputs to groundwater and rising nitrate levels in wells can result. Iron clogging in wells can also occur. In extreme cases, wells can fall dry (DWA 2010).

Raw water from bank filtrate and watercourses

If raw water is extracted from watercourses, for instance to produce bank filtrate or recharge groundwater, elevated concentrations of substances during low water situations can cause water quality problems (DWA 2010). If low water situations persist for long periods, restrictions on withdrawals may need to be applied. High water situations with extremely high water levels can also impair water supply from bank filtrate, as in extreme cases the extraction facilities can be overflooded, leading to inputs of polluted surface water (DWA 2010).

The greater threat is presented, however, by potential heavy rainfall events. These lead to an increased probability of waterborne or water-transmittable pathogens entering water bodies and being conveyed in them, and of other substances or pollutants becoming mobilised and posing risks to drinking water abstraction and quality.

Raw water from drinking-water dams and lakes

Various parameters determined by climate change must also be taken into account when extracting raw water from dams and reservoirs. If the management procedures of multifunctional dams are configured to take account of mounting flood hazards, this can cause the storage volume assigned to drinking-water supply to become constrained (DWA 2010). Heavy rainfall events can impair raw water quality by introducing substances (such as micro-organisms) with surface run-off and with increased overflow from sewerage systems (DWA 2010).

If raw water is extracted from dams, phases with major water demand often occur in conjunction with falling water levels. In such phases the volume suitable for abstraction can be reduced. The volume of the hypolimnion can account for a small proportion of the overall volume, and problems can arise at extraction points due to low inlet pressure. Moreover, the capacity to buffer polluted inflow drops (DWA 2010), while raw water temperatures or plankton content may increase, depending on the trophic state.

Shifts in precipitation and run-off regimes, in conjunction with a substantially more differentiated seasonal water demand as a secondary consequence of climate change, can cause the demands placed on the quantitative storage and buffering functions of drinking-water reservoirs to increase.

Elevated temperatures in ambient air cause an intensification of the vertical temperature gradient in lakes and reservoirs. This tends to make thermal layering more stable. The duration of full circulation is extended if in winter there is no ice cover and thus no stagnation. A lengthier stagnation period in summer in conjunction with raw water abstraction causes the size of the hypolimnion to dwindle. Longer stagnation periods mean longer periods in which no atmospheric oxygen enters the deep water. Shifts in circulation and stagnation periods cause changes to the ecosystem. Changes in phytoplankton structure are particularly relevant to drinking-water abstraction. As drinking water is generally extracted from the hypolimnion, this, too, can result in restrictions in terms of the quality and quantity of available raw water (DWA 2010).

Furthermore, elevated temperatures accelerate biological and chemical processes in surface waters. The consequences depend on further factors such as nutrient and oxygen availability, which can impact on raw water quality. Shifts in the growth phases of phyto- and zooplankton can also result (DWA 2010).

For instance, algal blooms can occur more frequently, which cause odour and taste impairment, and bacterial exo- and endotoxins can be released. Shifts in the growth phases of phyto- and zooplankton can also result from this, which in turn can disrupt trophic chains (DWA 2010).

Drinking water treatment

In Germany, drinking water meets the requirements of the Drinking Water Ordinance (Trinkwasserverordnung). If in future precautionary groundwater protection measures and surface water protection activities should no long suffice, with the result that the quality of raw water deteriorates, additional treatment measures may need to be taken into consideration.

Within distribution networks, too, changes in water quality can arise. Depending upon the state and operation of the network, elevated air and soil temperatures can amplify existing tendencies towards bacterial aftergrowth. In the event of insufficient network maintenance (depositions), high temperatures in drinking water networks can cause the oxygen concentration and thus the redox potential to drop. This can in turn lead to bacterial growth that can be detected as an indicator of hygienic impairment (Korth et al. 2008).

Conflicts with other water uses

Beyond drinking water supply, water withdrawals under what are defined as "rights of public use" (Gemeingebrauch) can become problematic when drought and low water situations increase. Such uses include, for instance, withdrawals from surface waters to water gardens and lawns or fill garden ponds, and withdrawals by local authorities to irrigate public green spaces and sports grounds.

Moreover, many state water acts allow the abstraction of groundwater in small amounts for irrigation. Where such established rights prevail, a prohibition of these water uses in critical phases may not be feasible. In both cases the only course of action is to appeal to users to reduce their withdrawal as far as possible. Where industrial facilities are concerned, withdrawal restrictions on cooling and process water can lead to production outages and thus substantial economic losses and competitive disadvantages (LAWA 2007b). Utilisation conflicts can also emerge in regions where demand for irrigation rises. Cooling water use is discussed in a dedicated section of this report.

Designing the water supply infrastructure

The parameters that determine the design of water supply infrastructure are modified continuously by anthropogenic changes in demand structure and demand-side behaviour (e.g. demographic developments, consumer behaviour, utilisation of water-saving technology and substitution of drinking water, e.g. by utilising rainwater). Climate change effects are thus only one among several factors influencing these parameters (MUKE BW 2013).

A climate-change-induced increase in phases of extreme drought and heat can cause peak demand for water to rise. At the same time, a dwindling population and an increasing use of water-saving technologies can be expected to bring about changes in baseload demand. This leads to a wider range between peak and baseload demand, which will need to be taken into account when planning, constructing and operating supply infrastructure (DWA 2010). An increase in maximum daily demand necessitates larger collection, treatment, transportation and storage capacities. An increase in maximum hourly demand can necessitate larger water distribution capacities (MUKE BW 2013).

5.9.2 Climate adaptation measures (Annex Tab. A. 64 - Tab. A. 71)

Because groundwater abstraction is the source of drinking water across large parts of Germany, the adaptation measures presented in the "Groundwater protection and use" field of action are linked directly to the "Public water supply" field.

To ensure the security of water supply in the future, the planning and adaptation of water supply systems needs to be climate-resilient; it must also give consideration to other uses that may experience mounting demand (such as irrigation) and ongoing developments in society. With extreme weather events becoming more frequent, the prioritisation of drinking water supply over other water uses is to be discussed. To ensure sufficient quantity and quality, in some waterworks standby water extraction systems and water infrastructure (e.g. integrated piping networks) may need to be expanded. To limit drinking water demand, it may be expedient to promote rainwater use in hygienically unproblematic applications. Here it must first be appraised whether significant amounts are actually available in periods when there is demand, and whether the advantages of such approaches outweigh the disadvantages. Measures to reduce water demand during dry periods help to reduce pressure on the then falling groundwater table.

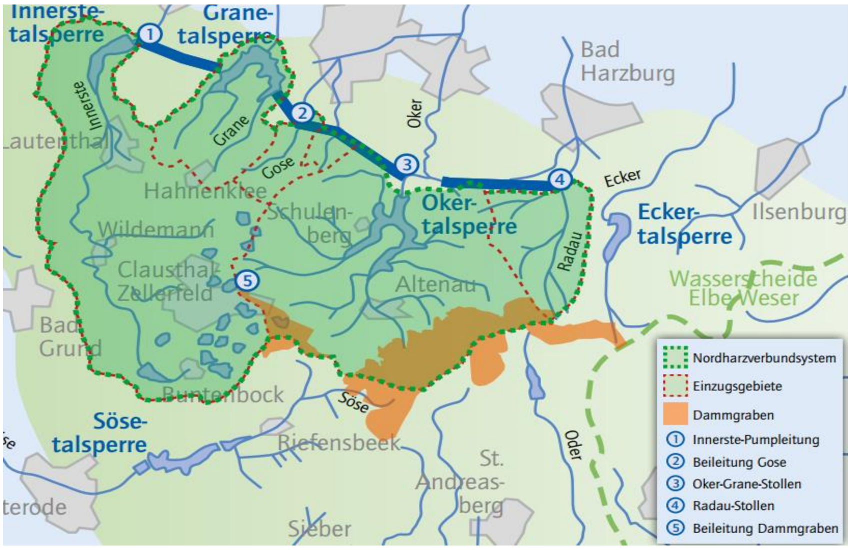
Furthermore, additional measures to ensure drinking water quality may become necessary in view of rising air, soil and water temperatures, beyond measures to monitor drinking water quality and intensify its treatment. Adjustment in the management of water utilities with regard to organising and agreeing emergency response strategies may become necessary.

For drinking water reservoirs, mainly the climate adaptation measures listed in Tab. A. 98 result from the "public water supply" field of action.

Links with other fields of action	Flood control, urban drainage and wastewater treatment, flood protection: heavy rainfall and flash floods, conservation of aquatic ecosystems, groundwater protection, hydropower generation, irrigation, dam and reservoir management, low water management in watercourses

5.9.3 Profiles of practical examples

Example 23: Field of action - Public water supply: New approval procedure for the North Harz integrated system

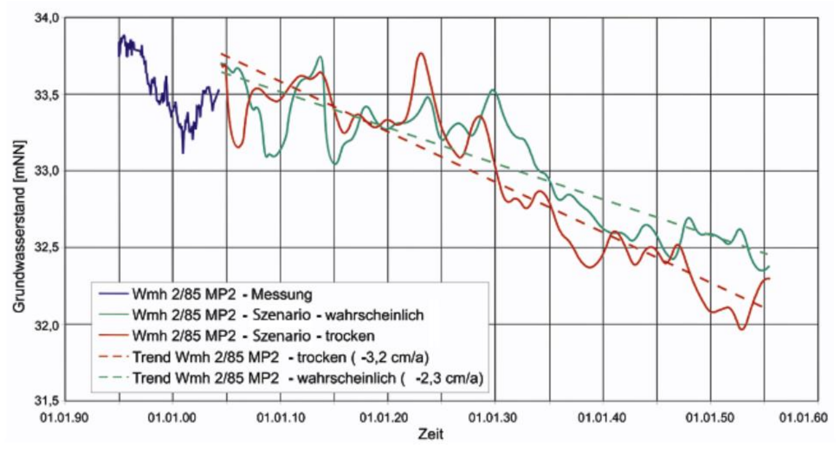
<table>
<tr><td>Field of action</td><td>Public water supply</td></tr>
<tr><td>Example</td><td>New approval procedure for the North Harz integrated system</td></tr>
<tr><td>Climate adaptation measures</td><td>Integrating climate change into public water supply planning (Tab. A. 64), Systematic combined management of several dams (Tab. A. 100), Review and structural optimisation of existing facilities (Tab. A. 96)</td></tr>
<tr><td>The Granetal dam is the key component of the water supply system in the western Harz region. Significant water quantities also come from neighbouring catchments to the dam via the Radau and Oker-Grane tunnels. Through a pumping line, water from the Innerste dam can be transferred to the Granetal dam at its higher elevation.
Image: Harzwasserwerke</td><td>
</td></tr>
<tr><td>Description and objectives</td><td>The North Harz combined system plays a major role for the drinking water supply of large parts of the state of Lower Saxony, and for regional flood control. It includes the Grane, Oker and Innerste dams and a range of collecting works. The time-limited water approvals for the system expired on 31 December 2017. The application for a revision of the authorisations under water legislation - new approval for the North Harz integrated system – for the 2018-2048 period was based on various studies on water resources management in the western Harz under climate change (Wasserwirtschaft im Westharz - Hydrologische Untersuchungen mit Blick auf ein sich veränderndes Klima) that takes account of anticipated climatic changes and current technical rules and statutory provisions. The scheme should ensure that the multifunctionality of the dams (flood control, public water supply, raising water levels in low water situations, environmentally compatible dam operation, renewable energy generation from hydropower, recreational uses) is retained in principle and optimised with regard to multi-criteria appraisals. Raw water abstraction for drinking water supply should be increased, flood retention volumes are to be increased, and the benefits of an integrated system better exploited. Moreover, the run-off situation downstream of the dams should be made more ecologically compatible, e.g. by introducing a "FlexiLamelle" system (flexible slats), the management of which shall ensure optimised delivery behaviour with consideration of ongoing hydrological and meteorological situations; this is accompanied by dynamic tailwater deliveries that are to be defined case-by-case within a defined dynamisation corridor.</td></tr>
<tr><td>Timeframe of implementation:</td><td>2013-2017</td></tr>
<tr><td>Costs/financing</td><td>-</td></tr>
<tr><td>Participants</td><td>Harzwasserwerke GmbH (HWW), Lower Saxony Water Management, Coastal Defence and Nature Conservation Agency (NLWKN - Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz)</td></tr>
<tr><td>Challenges, solutions and successes</td><td>✓ The above-mentioned measures were fully implemented and authorisation was granted by NLWKN on 1 January 2018 for 30 more years.</td></tr>
<tr><td>Contact</td><td>Harzwasserwerke GmbH</td></tr>
</table>

Further information	• Harzwasserwerke GmbH: Neubewilligungsverfahren Nordharzverbund-system 2013-2017. Link: *www.harzwasserwerke.de/fileadmin/user_upload/downloads/files/pdf/Flyer/infomaterial/neubewilligungsverfahren-nordharzverbundsystem-2013-2017.pdf* • Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz: Nordharzverbundsystem: Neue Bewilligungen beantragt. Link: *www.nlwkn.niedersachsen.de/aktuelles/pressemitteilungen/nordharzverbundsystem-neue-bewilligungen-beantragt-144452.html*

Example 24: Field of action - Public water supply: Dynaklim pilot project: Secure water supply under climate change

Field of action	Public water supply
Example	**Dynaklim pilot project: Secure water supply under climate change**
Climate adaptation measures	Integrating climate change into public water supply planning (Tab. A. 64)
Climate change check for water supply in the Ruhr region.	
Description and objectives	The goal of this interdisciplinary project was to elaborate options by which to adapt drinking water supply in the Ruhr region to climate change. For each process stage of water supply, a universally applicable methodology was developed that permits a systematic, facility-specific status and hazard analysis. Furthermore, potential options for adaptation to changing conditions were identified and the methodology was checked by applying it to a concrete example in practice. In addition, the costs of precautionary measures were determined. Several representative surveys of the public were carried out to ascertain the level of acceptance among drinking water customers for changes in price structures in response to changed demand-side behaviour and climatic influences. The outcomes have been compiled in a brochure (Sichere Wasser - versorgung im Klimawandel) and the climate change check has been presented in a manner accessible to other water suppliers. The approach developed is also transferable to other regions of Germany.
Timeframe of implementation:	by 2014
Costs/financing	-
Participants	IWW Zentrum Wasser, RWW Rheinisch-Westfälische Wasserwerks - gesell - schaft mbH, Dr. Papadakis GmbH, FiW e.V., ahu AG, RUFIS an der Ruhr-Universität Bochum, RISP an der Uni Duisburg-Essen, sfs an der TU Dortmund
Challenges, solutions and successes	× Accessing the vulnerability of a supply system necessitates extensive data collection. ✓ Involving experts is helpful. ✓ To address possible utilisation conflicts between water supply, agriculture and industry, a reconciliation procedure for regional stakeholders was tested.
Contact	IWW Zentrum Wasser
Further information	• IWW Rheinisch-Westfälisches Institut für Wasserforschung GmbH (2014): Sichere Wasserversorgung im Klimawandel. Wege zur Klimawandelanpassung der Trinkwasserversorgung im Ruhrgebiet • IWW Zentrum Wasser: dynaklim: Abschluss des Pilotprojektes „Sichere Wasserversorgung im Klimawandel". Link: *www.iww-online.de/abschluss-des-dynaklim-pilotprojektes-sichere-wasserversorgung-im-klimawandel/* • German Environment Agency (UBA): Sichere Wasserversorgung im Klimawandel: Klimawandel-Check. Link: *www.umweltbundesamt.de/themen/klima-energie/klimafolgen-anpassung/werkzeuge-der-anpassung/tatenbank/sichere-wasserversorgung-im-klimawandel-klimawandel* • Wuppertal Institut für Klima, Umwelt Energie GmbH & Kolleg für Management und Gestaltung nachhaltiger Entwicklung gGmbH (2014): dynaklim Transferhandbuch. Klimawandel braucht Kompetenzen: Weiterbildungsangebote in NRW

Example 25: Field of action - Public water supply: Study on the impacts of climate change upon the Potsdam Leipziger Straße waterworks

Field of action	Public water supply
Example	**Study on the impacts of climate change upon the Potsdam Leipziger Straße waterworks**
Climate adaptation measures	Integrating climate change into public water supply planning (Tab. A. 64)
The development of the groundwater level at the Whm 2/85 sampling station projected by model analyses reveals a distinct decline in the ground water level for both a probable and a very dry scenario over the period to 2055.	
Description and objectives	The Energie und Wasser Potsdam GmbH utility commissioned the generation of complex groundwater models in order to examine the impacts of climate change on public water supply. To simulate the hydrological regime for the period from 2004 to 2055 specific climate scenarios were used for the catchment of the Potsdam Leipziger Straße waterworks that had been produced by the Potsdam Institute for Climate Impact Research. The influence of climate change on groundwater recharge, groundwater levels, bank filtration and the rise of saline groundwater from deep aquifers were analysed in greater detail. It was found that water supply is secure over the long term with the existing extraction points, but climatic changes in this area will have an appreciable impact on the available resource and on flow regimes. Furthermore, an increasing influence of saline water will cause significant changes to groundwater quality. Recommendations for action were derived from the findings. An adjustment and rigorous continuation of monitoring programmes is recommended urgently. As a supplement to the usual collection of data on groundwater levels, abstraction quantities and hydrogeochemical developments, the collection of meteorological and climatological data is proposed, as is a detailed review of the development of the yield situation roughly every five years.
Timeframe of implementation:	by 2008
Costs/financing	-
Participants	Energie und Wasser Potsdam GmbH, GCI GmbH Grundwasser Consulting Ingenieurgesellschaft; climate & environment consulting Potsdam GmbH
Challenges, solutions and successes	-
Contact	Energie und Wasser Potsdam GmbH
Further information	• Nillert et al. (2008): Auswirkungen der regionalen Klimaentwicklung auf die Wasserversorgung am Beispiel Wasserwerk Potsdam Leipziger Straße. gwf Wasser/Abwasser • German Environment Agency (UBA): Auswirkungen der regionalen Klimaentwicklung auf die Wasser-versorgung am Beispiel Wasserwerk Potsdam Leipziger Straße. Link: *www.umweltbundesamt.de/themen/klima-energie/klimafolgen-anpassung/werkzeuge-der-anpassung/tatenbank/ auswirkungen-der-regionalen-klimaentwicklung-auf*

5.10 Cooling water availability

5.10.1 Concerns

Conventional thermal and nuclear power stations are capable of converting only a portion of the energy contained in their fuel into electric power. The residual unused energy remains in the form of heat. It is possible to recover and use a portion of this heat, for example as process energy in combined heat and power (cogeneration) systems. The remaining waste heat, however, must be released into the environment via re-cooling heat exchangers and cooling towers. These cooling systems frequently use river or canal water as the cooling medium. The availability of cooling water depends on watercourse discharge, water temperature and sometimes other properties (e.g. salt content) of the flowing body of water used. Hence, alteration of these variables wrought by climate change can impact cooling water supply.

Other industrial sectors such as the paper industry need cooling water for their production processes. In a broader context, the concerns described below are relevant for such industrial operations as well. In certain situations, effluent from sewage treatment plants and industrial direct dischargers can also raise the temperature of the receiving body of flowing water. As their attributable impact is minor compared to that of power plants, however (LfU BY 2016), these sectors are not specifically considered below.

Direct cooling water shortages due to low discharge

Cooling water supply shortages can occur during periods of drought due to low water availability in watercourses used as cooling water sources (MUEK NI 2012). Such conditions occur mainly in catchments with low run-off where extracted cooling water can amount to a relatively high portion of watercourse flow (e.g. Germany's Neckar River). Minimum discharge limits are mandated for bodies of water used heavily for cooling water purposes, triggering restrictions on cooling water abstraction when levels fall short. If low water phases occur in future with greater frequency and/or for longer periods of time, these regulated limits could be breached more often and/or for longer periods, putting even further constraints on cooling water usage.

Indirect cooling water shortages due to water temperature limits

Indirect cooling water shortage denotes the situation in which adequate quantity of river water is available for cooling, but reintroduction of (heated) post-process cooling water to the watercourse would be impermissible due to elevated water temperatures (UBA 2015e) Various temperature limits may apply for what is allowed in terms of river warming due to cooling water discharge (e.g. the maximum temperature rise of the cooling water, maximum cooling water temperature, maximum temperature rise of the river water due to cooling water discharge, and the maximum value of the calculated mixing temperature of the river water). Should water temperatures rise, regulations governing maximum temperature limits (of the cooling water as well as of the calculated mixing temperature) could lead to more frequent and longer periods when cooling water use is restricted.

Higher water temperatures can also reduce the efficiency of river water as a coolant (KLIWA 2012a), making it necessary to extract more cooling water from the river to achieve the same cooling capacity (SUBV HB 2012). Thus when water temperatures rise excessively at the same time as low water events, a proportionally higher fraction of the river water can be warmed up. This can likewise push water temperatures to the maximum temperature limits in force (SUBV HB 2012).

Impact of cooling technology on these concerns

The consequences of cooling water shortages depend heavily on what cooling technology is used. Power stations with once-through cooling systems transfer all their waste heat to the receiving watercourse, while those employing supplemental cooling are equipped with cooling towers so that part of the waste heat is discharged to the atmosphere by evaporation. The cooling water (partially) cooled in the cooling tower is returned to the river. Where closed-circuit cooling systems are used, almost all of the waste heat is discharged via cooling towers to the ambient air (Strauch 2011). When cooling water restrictions are imposed due solely to water temperature conditions, power plants using once-through cooling are generally impacted more seriously than those fitted for supplemental or closed-circuit cooling via cooling towers (UBA 2015e). Power stations equipped to variably switch between these different cooling systems can take account of fluctuations in the heat transfer capacity of their cooling water source and select the fitting operating mode.

In situations in which water shortages occur solely because of low discharge in low-flow watercourses, power plants with cooling towers that evaporate water and thus permanently remove the water from the cooling water source may be affected more heavily (depending on the regulations in force). If low discharge and high water temperatures occur simultaneously, water use may be restricted irrespective of the cooling technology used, as even plants equipped with variable cooling systems offer no significant benefit.

Other possible influencing factors

Like water temperature and available water quantity, changes in other influencing factors brought on by climate change can also have restricting effects on cooling water usage. Any future rise in salt content in watercourses (e.g. from salt intrusion) could combine with high water temperatures to create conditions conducive to corrosion, for example. Yet, while such conditions could become relevant for cooling water sources (SUBV HB 2012), they are projected to be more localised by nature and of secondary significance.

Economic consequences of restricted cooling water use

The consequences of cooling water shortages (both direct and indirect) can range from reduced plant production capacity to complete shutdown of power-generating operations - while at the same time power grid stability must be ensured. Reduced output from thermal power plants can in turn lead to price rises on the electricity market (UBA 2015e). The more often power plants are forced to make generating load changes, the higher the stress loads on the plant, and the greater the wear and tear on plant systems and equipment (SUBV HB 2012).

In terms of residual heat rejected from production sites, it is important to note that the complexity of production processes makes it virtually impossible to flexibly control thermal discharge. Required cooling capacity must be maintained so that the maximum waste heat produced can be discharged in a manner compliant with the statutory requirements even when river flow rates and water temperature conditions are unfavourable (LfU BY 2016).

How the changing energy mix impacts these concerns

In addition to cooling water availability, Germany's future energy mix and thus cooling water demand will likely also change. Nuclear power plants will be hit particularly hard by reduced generating capacity resulting from cooling water shortages (UBA 2015e). As a result of the planned phase-out and decommissioning of Germany’s nuclear power plants, cooling water abstraction and heat discharge at these sites will cease, or at least diminish if new fossil-fuel power plants are erected in their place. As the share of electric power generated by fossil-fired facilities is expected to shrink, however, cooling water demand will decline overall. Moreover, equipping more power plants with variably employable cooling towers could also help alleviate the problems associated with cooling water use (UBA 2015e).

5.10.2 Climate adaptation measures (Annex Tab. A. 72 - Tab. A. 76)

Industrial sectors that use cooling water may need to take adaptation measures. Taking plant cost-effectiveness into account, industries should consider whether alternative cooling processes can be used which for the most part operate independently of watercourse discharge rates (LAWA 2010). Instead of discharging process waste heat to watercourses, residual thermal energy can benefit other uses (e.g. district heating or power generation, etc.) or be released into the ambient air (for example by dry cooling processes) or alternative bodies of water. Post-process cooling water, once re-cooled, can also be recirculated. Plants with no alternative but to use cooling water drawn from rivers should integrate cooling towers that can be used variably depending on watercourse flow conditions.

Responses when power stations are forced to dial back production output should be organised in advance. Planning should likewise consider how power supply grid stability can be ensured despite such conditions. As most cooling water users are fossil-fuel power plants that generate electricity, it can be assumed that this sector will require fewer adaptation measures to be implemented as power generation continues its steady shift to renewable energy sources.

Links with other fields of action	Conservation of aquatic ecosystems, navigability, irrigation, dam and reservoir management, low water management in watercourses

5.10.3 Profiles of practical examples

Example 26: Field of action - Cooling water availability: Rhine thermal model

Field of action	Cooling water availability
Example	**Rhine thermal model**
Climate adaptation measures	Low water and temperature forecasting (Tab. A. 102), Usage restrictions (Tab. A. 104), Emergency response plans (Tab. A. 75)
The model considers point discharges from power plants and sewage treatment plants as well as heat exchange with the atmosphere. The fore-casts include computational analyses from existing thermal models covering Germany's Main River, the Neckar River catchment area and the southern part of the state of Hesse as well as run-off forecasts from the hydrological regime models of regions abutting the Rhine River likewise serve as input for this forecasting.	
Description and objectives	Three German states - Baden-Württemberg, Rhineland-Palatinate and Hesse - have collaborated to develop a water temperature model (Large Area Run-off Simulation Model, LARSIM) for the Rhine River between the cities of Basel and Cologne which, in automated operation, updates daily to deliver river drainage and water temperature forecasts for the coming days. The model enables timely warning of developing conditions critical to aquatic ecosystems with elevated water temperatures and, potentially, simultaneous low flow. The model is run using operationally available measurement and forecast data on meteorology, run-off, water temperature and industrial waste heat discharge to the river water. Inflow rates and in some cases the associated water temperature data from comparable operational LARSIM models are provided by the Baden-Württemberg State Institute for the Environment, Measurements and Nature Conservation (LUBW), Hessian State Office for Nature Conservation, the Environment and Geology (HLNUG) and Rhineland-Palatinate State Office for the Environment (LfU RLP). Current and projected waste heat discharges from the relevant power plants, industrial direct dischargers and sewage treatment plants are also considered. Computational analysis results are automatically optimised based on measured flows and water temperatures. The model plays an important role especially during hot-weather periods when temperatures and oxygen content in the Rhine River reach critical levels for many living organisms. Action such as restricting water abstraction for industrial and agricultural use, shifting power generation activities to regions less critically affected, importing electricity, or preparing monitoring programmes can be initiated before values reach critical limits. Such actions are triggered in accordance with EU framework directives when water temperatures rise to an orientation value of 25°C. It should be noted, however, that water temperatures of up to 28°C are allowed in the immediate vicinity of certain power plants. In addition to operational forecasting, the model enables estimates to be generated of potential future water temperatures.
Timeframe of implementation:	In operation since 2014
Costs/financing	The model is being operated and further developed as a cooperative undertaking of the German federal states Baden-Württemberg, Rhineland-Palatinate and Hesse.
Participants	Rhineland-Palatinate State Office for the Environment, Hessian State Office for Nature Conservation, the Environment and Geology, Baden-Württemberg State Institute for the Environment and HYDRON GmbH
Challenges, solutions and successes	✓ Has been in continuous operation for several years

Contact	Baden-Württemberg State Institute for the Environment
Further information	• Hessian State Office for Nature Conservation, the Environment and Geology, and the Rhineland-Palatinate State Office for the Environment Water: temperature forecasts for the Middle Rhine (Rhine Gorge) section of the Rhine River. Link: *www.waermemodell-mittelrhein.de/html/* • Rhineland-Palatinate State Office for the Environment et al.: Managing water temperatures in the Rhine River from Basel to Cologne: Being prepared for heat waves. Press release. Link : *www.lubw.baden-wuerttemberg.de/-/wassertemperaturmanagement-im-rhein-von-basel-bis-koln-auf-hitzezeiten-vorbereitet-sein-* • State Government of Rhineland-Palatinate: Protecting the Rhine ecosystem. Link: *www.rlp.de/de/aktuelles/einzelansicht/news/detail/News/das-oekosystem-rhein-schuetzen/*

Example 27: Field of action - Cooling water availability: Project "Recovering waste heat from the MiRO Oil Refinery's production processes to feed the district heating network in Karlsruhe"

Field of action	Cooling water availability
Example	**Project "Recovering waste heat from the MiRO Oil Refinery'sproduction processes to feed the district heating network in Karlsruhe"**
Climate adaptation measures	Use of residual heat (Tab. A. 74)
Waste heat from the refinery is distributed via district heat transport lines serving the city.	
Description and objectives	The Karlsruhe-based oil refinery Mineralölraffinerie Oberrhein (MiRO) and the municipal utility Stadtwerke Karlsruhe have in recent years implemented measures to use the refinery's low-temperature process waste heat for district heating. This residual thermal energy exiting the refinery's production processes, one in MiRO Plant 2 and, since 2015, the second in Plant 1, is recovered by 20 heat exchangers (some plate-type units and others of shell-and-tube design) and fed into the municipal utility's district heating network. The waste heat is transported through a 5-km-long district heating pipeline to Heizkraftwerk West plant, where it is fed into Karlsruhe's central district heat supply system. Another 7-km-long district heating transport line delivers heat to the new residential areas in the city's Knielingen and Neureut districts. This district heat is distributed to up to 43,000 households. The Karlsruhe district heating network will be systematically further expanded in several districts. It is the city's largest climate action project as every year over 100,00 tonnes of CO_2 are saved through the predominant use of low-temperature waste heat from the MiRO oil refinery which would otherwise have been released unused into the environment. The municipal utility has won several prizes in recognition of this model expansion project at national level.
Timeframe of implementation:	Agreement: 2007, Start of construction: 2008, First feed-in: 2010
Costs/financing	Some 100 million euros investment costs (including a grant of 5 million euros from the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety)
Participants	MiRO Mineralölraffinerie Oberrhein GmbH & Co. KG, Stadtwerke Karlsruhe GmbH, and the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)
Challenges, solutions and successes	× Constant, steady-state refinery operation while district heat demand is subject to wide, seasonal fluctuation × Limited space available for heat transfer equipment ✓ Innovative plate heat exchangers requiring less space were installed next to shell-and-tube heat exchangers that take up considerable space. ✓ Excess heat is recooled by air coolers at Heizkraftwerk West plant so that the district heating water returning to the refinery is maintained at a largely constant temperature. ✓ The refinery's energy efficiency is increased by 5 %.
Contact	MiRO Mineralölraffinerie Oberrhein GmbH & Co. KG, Stadtwerke Karlsruhe GmbH

Further information	• Schmidt & Spieth (2017): Refinery process waste heat for Karlsruhe's district heating supply network. Link : *www.stadtwerke-karlsruhe.de/swk-media/docs/regionales/umwelt-nachhaltigkeit/100-Betriebe-Ressourceneffizienz-SWK.pdf* • Stadtwerke Karlsruhe GmbH: District heating project with MiRO. Link : *www.stadtwerke-karlsruhe.de/swk/regionales/umwelt-nachhaltigkeit/prozessabwaerme.php*

5.11 Hydropower generation

5.11.1 Concerns

The power generation capacity of a hydroelectric plant depends on the flow rate, the head (i.e. the vertical change in elevation between the (reservoir) water level and the tailwater (downstream) level), and the type and efficiency of the technology used. Hydropower production is therefore most likely to be affected by flow fluctuations potentially resulting from climate change.

Although mean annual discharge volumes are unlikely to change significantly in future, greater seasonal variability with increased flow rates in winter and decreases in summer is one scenario often discussed. The resulting increase in electricity production in winter and decrease in summer may even help to achieve a closer alignment of future supply and demand (Godina 2013). However, climate change may also lead to shifts in seasonal energy demand for heating and cooling (Dengler 2012). Regional scenarios which diverge from these trends described also have to be expected.

<u>Flow dynamics: run-of-river hydroelectric plants</u>

For run-of-river hydroelectric plants, which are mainly relevant to Germany, a key determinant of hydropower production trends, besides mean discharge volumes over time, is a change in flow dynamics (Schädler & Volken 2013). A consistent flow of water provides optimum conditions for full utilisation of hydropower capacity at plants without water impoundment facilities or an upstream reservoir. Extreme flows (high/low) – which may also occur more frequently as a result of climate change – can have a highly detrimental effect on year-round production (Schädler & Volken 2013). As well as shifts in precipitation patterns, earlier snow melting in snow-affected areas can also cause greater flow irregularity and thus reduce the normal operating capacity of hydropower plants (StMUV BY 2015).

In low flow situations, much less water is available for run-of-river hydropower plants compared with the flow rate at which they were designed to operate. A turbine operating at partial load achieves a low level of efficiency, and combined with a low flow rate, this will reduce electricity output. In such circumstances, conflicts may also arise as a result of other users' claims on the water resources: for example, a residual water volume (minimum flow) must remain in the main river channel, so diversions for electricity generation may have to be suspended or reduced (MUKE BW 2013). An adequate supply for fish passage facilities also reduces the flow rate of water for electricity production.

Hydropower generation at diversion plants may be indirectly impacted if more stringent environmental regulations are adopted (such as the setting of residual water volumes based on environmental criteria) in response to more prolonged and more frequent low water periods in future. This could further reduce output (DWA 2010).

With high stream flows, much of the excess water beyond the plant's specified flow rate remains unused. Flood conditions may also elevate the tailwater surface, reducing the head and limiting output. Furthermore, floating debris in floodwater may cause a deterioration in hydraulic conditions at power plant intakes at all facility types, leading to production decreases (MUKE BW 2013). Removal of the debris also requires increased use of financial and human resources during periods of flooding (Hauenstein 2009).

The constraints described above mainly affect run-of-river hydropower plants without a surge capability, primarily small plants using more simplified technology (MUKE BW 2015). Power plants which have already optimised their efficiency curves or have installed efficient stepped operations with several power units are less affected by flow fluctuations (UBA 2012). Hydropeaking is generally viewed critically from an aquatic ecology perspective and is particularly problematic along fish migration routes. It is therefore rarely permitted for this type of operational setup.

<u>Plants with impoundment facilities</u>

Hydroelectric plants with storage facilities (known as impoundment facilities) can at least mitigate the impacts of extreme flows by utilising appropriate storage control systems. However, here too, the operation of the hydropower plant depends on water reserves and storage capacities. Hydropower production along regulated stretches of river or impoundments may be adversely affected by climate change in other ways, e.g. if the retained water also has to be used for other purposes, such as minimum flow management, flood control (e.g. the special operation of power plants on the Upper Rhine) (ICPR 2015) or navigation (raising low water levels).

Damage from floods and other natural hazards

In addition to shifts in electricity output resulting from changes in flow rates and distribution patterns, hydropower plants can sustain damage as a result of extreme events. Floods are a particular hazard due to the exposed location of many hydropower plants. The design of most hydropower plants normally ensures that even extreme floods only cause minimal damage; however, if more stringent safety standards are introduced and retrofitting is required, this may mean that some plants will no longer be commercially viable (UBA 2012).

It should be noted, particularly in relation to impoundment facilities in Alpine regions, that the main flood-related threat to reservoir safety and security may come from debris damming and debris flows etc., rather than from the volume of water itself (Hauenstein 2009).

Areas particularly affected

More than 80% of Germany's hydroelectricity is generated in Bavaria and Baden-Württemberg (UBA 2015e). These two states are therefore particularly vulnerable to these potential impacts.

5.11.2 Climate adaptation measures (Annex Tab. A. 77 - Tab. A. 82)

In relation to power generation, efforts should be made to improve plant efficiency in order to make better use of more frequent flow fluctuations i.e. more low and high flow conditions that are likely in future. Improved efficiency can be achieved by adjusting the configuration of the turbines. In order to make optimum use of larger run-off areas, stepped power units are recommended. Larger flow variations can also be counteracted with flow-balancing measures such as water storage, retention and groundwater recharge.

Germany is already utilising most of its hydropower potential (for NRW, for example, see LANUV NRW2017). Growth in hydropower production can therefore be achieved primarily by optimising, modernising or reactivating existing plants (UBA 2012). To optimise the performance of existing hydropower plants, regionalised mean and low water values which have already factored in the impacts of climate change as far as possible should therefore be the starting point. Case-by-case assessment is required to determine the extent to which upgrading of existing small plants is commercially viable.

To prevent any weakening of aquatic ecosystems and their resilience to climate change, compliance with environmental regulations pertaining to hydropower plants is essential (continuity, minimum ecological flow, fish protection, no hydropeaking). Reduced designed capacity at new plants or reconfiguration of turbine technology to accommodate lower designed capacity as part of forthcoming extensions of operating licences, in order to maintain high levels of efficiency under changed flow conditions, should also be mentioned as options here.

Links with other fields of action	Flood control, flood protection: heavy rainfall and flash floods, conservation of aquatic ecosystems, groundwater protection, public water supply, navigability, dam and reservoir management, low water management in watercourses

5.11.3 Profiles of practical examples

Example 28: Field of action - Hydropower generation: A pilot shaft power plant at Großweil on the River Loisach

Field of action	Hydropower generation
Example	**A pilot shaft power plant at Großweil on the River Loisach**
Climate adaptation measures	Ecological hydropower (Tab. A. 79), Increasing efficiency (Tab. A. 77)
The shaft power plant at Großweil will be installed at an existing semi-passable river bottom ramp and will be largely inconspicuous due to its placement in the river bed. Image Christian Bäck / TUM	
Description and objectives	Scientists at the Technical University of Munich (TUM) have developed a hydropower plant which according to research findings is nature-compatible, protects fish from injury and can be built relatively cost-effectively. The shaft power plant is designed to meet stringent environmental standards and as such permission was granted for a proposed pilot plant to be built in a Natura 2000 protected area on the River Loisach near Großweil. The project's objective is nature-friendly hydropower generation, even under difficult circumstances with high driftwood and bedload discharges. A further aim was to design a power plant which due to its compact structure would also be more economically competitive with low heads. The shaft power plant at Großweil will be built on an existing river bottom ramp. Passability for fish can be ensured in the entire run-off area by installing two fish ladders near the river banks. The turbine and generator are located underwater in a shaft built into the river bed. The shaft power plant at Großweil is based on a twin-shaft design. As the technology is located entirely under water, the power plant is inconspicuous and not at risk from flood run-offs which will become more frequent and extreme due to climate change. Extensive scientific studies, focusing on ecology and power plant technology, are planned to accompany the project. In addition to numerical studies, the power plant design was tested in detail and optimised at the Obernach Research Institute of the Technical University of Munich using a full-scale physical model and a 35 kW prototype facility. The shaft power plant design is also suitable for large hydropower systems: in addition to larger shafts and turbines, an in-line arrangement of several individual shafts can be made.
Timeframe of implementation:	Approved: 2014, legal challenge and court decision: 2015-2016, ground-breaking ceremony: 2017, start of construction: 2018, start of operation: 2020
Costs/financing	Approx. 5.5 million euros (estimate)
Participants	Wasserkraftwerk Großweil GmbH (implementation), HYDROSHAFT GmbH (licensor), Technical University of Munich

Challenges, solutions and successes	× Legal challenge by the State Fishery Association (Landesfischereiverband) and the environmental organisation Bund Naturschutz to the power plant's proposed location in an area designated under the Habitats Directive with protected fish stocks. ✓ Agreement on more stringent fish protection standards NB: The anticipated positive effects have yet to be validated.
Contact	Chair of Hydraulic and Water Resources Engineering, Technical University of Munich
Further information	• Technische Universität München: Wasserkraftkonzept Schachtkraftwerk. Link: *www.cee.ed.tum.de/wb/projekte/schachtkraftwerk/* • Technische Universität München: Ein Kraftwerk, das sich versteckt. Schachtkraftwerk: ein neues Konzept für umweltverträgliche Wasserkraft.. Link: *www.tum.de/die-tum/aktuelles/pressemitteilungen/details/32332* • HYDROSHAFT GmbH: Konzept Schachtkraftwerk. Link: *www.hydroshaft.com/*

5.12 Navigability

5.12.1 Concerns

Climate change will have tangible impacts on Germany's waterways and river systems and therefore also on inland waterway transport (IWT). The anticipated changes in flow regimes are of particular relevance here. Waterway development and maintenance measures must take these changing ambient conditions into account and respond appropriately.

For Germany as a hub of industry, the shipping and waterways system is an integral element of national and international logistics chains, which - for the purposes of forward planning - must adapt to these changes in ambient and climatic conditions in good time. Given the long lifespans of infrastructure - which in some cases (e.g. locks, weirs) remains in use for up to 100 years - and the investment decisions which need to be taken in the near future, the impacts of climate change must be factored into planning processes without delay. A working aid on this topic is currently in development (Federal Waterways and Shipping Administration WSV - in preparation). In addition to the impacts of climate change on the shipping industry - such as the increased financial risk resulting from draught restrictions and a decrease in the number of sailing days - various downstream effects are likely to be felt in sectors such as port operations, warehousing and industries that rely on low-cost bulk transportation of goods by ship.

In 2007, the German Federal Ministry of Transport and Digital Infrastructure (BMVI) launched a departmental research programme entitled Impacts of Climate Change on Waterways and Navigation in Germany - Searching for Options of Adaptation (KLIWAS). As part of this applied preliminary research, an initial toolkit was developed (model chains), with a particular focus on long-term waterway and climate projections, in order to provide planners and decision-makers with more robust information on the regional and local impacts of climate change. These projections are now being progressively operationalised, integrated and continuously expanded ((BMVI 2015).

BMVI is continuing the work that began in 2007 by pooling the expertise available within its departmental research facilities and subordinate authorities. The launch of the BMVI Network of Experts, whose guiding theme is Knowledge - Ability - Action, established a basis on which to pursue the objective of building a resilient and environmentally sound transport system in Germany. The aim is to cluster competences on a broader basis, to network more intensively and, by doing so, to promote the transfer of knowledge and technology.

Topic 1 addressed by the Network of Experts aims to determine the vulnerable areas of transport and infrastructure to climate change and extreme weather events and to develop appropriate adaptation options on this basis. Here, making national transport infrastructure resilient to extreme weather and climate change and thus facilitating sustainable usability is particularly important. The Deutscher Wetterdienst (German Meteorological Service - DWD), the Federal Maritime and Hydrographic Agency (BSH), the Federal Institute of Hydrology (BfG), the Federal Waterways Engineering and Research Institute (BAW), the Federal Railway Authority (EBA) and the Federal Highway Research Institute (BASt) are working together to combine their specialist knowledge on climate development with practical knowledge of the three modes of transport, namely waterways, road and rail (BMVI 2017).

Concerns resulting from low water levels

Extremely low water levels disrupt transportation on federal waterways and cause water quality problems.

The draught of a ship in (fully) laden condition is dependent on the water level. If water levels are low, the draught may have to be reduced by discharging some of the cargo; this process is called “lightering” or “lightening”. In such cases, cargo may have to be placed in temporary storage or transhipped, both of which increase costs and possibly also transport times (StMUV BY 2015). Transport delays can also cause supply bottlenecks. The narrowing of navigation channels in low water conditions increases the risk of accidents due to ships running aground or being involved in collisions along busy routes (LAWA 2007a). These disruptions can affect not only cargo shipping but also passenger services and ferry operations (LAWA 2007b).

Along regulated stretches of river and in canals, natural flow fluctuations can usually be balanced out by installations such as locks and barrages. This also applies to the additional fluctuations caused by climate change. Along regulated waterways, climate change impacts on shipping are therefore likely to be less severe than along free-flowing waters (StMUV BY 2016).

Lock and sluice operations, however, will be impacted by water shortages, for example, which may make it necessary to extend lock and sluice operating times or temporarily suspend operations (MUEV SL 2011; LAWA 2007b). The costs of supplying water to canals with no inflow of their own will increase due to the need to move water over long distances.

Concerns resulting from high water

High water and flood events lead to river closures and the suspension of shipping activity. They can also induce permanent morphological changes and remobilise sediment that may contain pollutants.

In high water conditions, maximum loads have to be restricted to accommodate the changed clearance height under bridges. Fast stream velocities may limit manoeuvrability, and floating debris can pose an additional hazard (StMUV BY 2015). Once the highest navigable water level (HNWL) is reached, shipping operations must be suspended.

Variations in flow can also affect sediment transport and deposition. Sedimentation can create bottlenecks along shipping routes, particularly in low water conditions (LfU BY 2016).

Concerns resulting from ice and ice formation

In addition to low and high water conditions, the formation of ice on federal waterways can disrupt shipping. In the past, this mainly - and regularly - affected the east German rivers, notably the Oder and Elbe, along with some sections of the regulated waterways and the entire German canal system. During extremely cold winters, ice has occasionally led to the suspension of shipping on regulated tributaries of the Rhine that would not normally be affected. The Rhine itself last froze over in 1963 (BMVI 2015).

Strategies to deal with ice formation on waterways are mainly intended to extend the navigation period and prevent ice-related flooding.

Ice-related disruptions to shipping are likely to become less frequent as a result of climate change. Given the extent to which it had been disrupted by ice-bound waterways so far, shipping may well benefit from climate change (BMVI 2015).

5.12.2 Climate adaptation measures (Annex Tab. A. 83 - Tab. A. 87)

In the transport sector, a broad range of measures exists to deal with potential hazards posed by changes in meteorological and hydrological conditions, e.g.:

- Adaptation of the waterway infrastructure (e.g. construction of water-saving locks, sediment management)
- Water level forecasting
- Improved water resources management
- Modifications to ships' design.

Within Topic 1 addressed by the BMVI Network of Experts, selected measures are described in terms of their implementation and/or impact, and inter-modal linkages are established. Selected results from the risk analysis are taken as a basis for investigating the economic viability of adaptation measures on a case-specific basis. The aim is to assist transport operators and decision-makers working on issues falling within BMVI's remit to determine whether, when and to what extent adaptation measures are required.

Links with other fields of action	Flood control, coastal protection, marine protection, conservation of aquatic ecosystems, cooling water availability, hydropower generation, low water management in watercourses

5.12.3 Profiles of practical examples

Example 29: Field of action - Navigability: BMVI projects 2009-2020

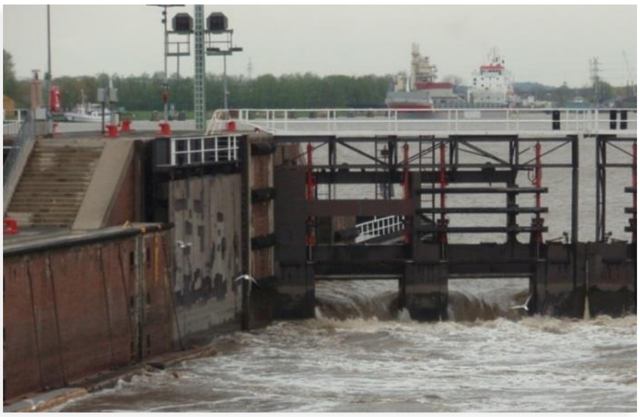
Field of action	Navigability
Example	**BMVI Network of Experts, Topic 1: Adapting Transport and Infrastructure to Climate Change and Extreme Weather Events (2016-2025)** **Pilot of a Forecasting Service for Waterways and Shipping (ProWaS) (2017-2021)** **and** **The DAS Core Service “climate and water” (since 2020)**
Climate adaptation measures	Adaptation of operation measures (Tab. A. 83), Adaptation in water resources management (Tab. A. 85), Water level forecasting (Tab. A. 84), Adaptation of waterway infrastructure (Tab. A. 86)
KLIWAS Programme logo, BMVI and PRoWaS Network of Experts	KLIWAS Klima · Wasser · Schifffahrt BMVI Expertennetzwerk Wissen Können Handeln
Description and objectives	Among other things, the aforementioned programmes develop methods and data for assessing the impacts of possible future developments on water levels and run-off and thus on the navigability of federal waterways. The navigability, quantities of goods transported and thus the safety and ease of shipping are particularly affected by water level fluctuations. Waterway management is also affected by solid matter flows (e.g. dredge volume) and water quality (e.g. time window for excavating). The BMVI Network of Experts (topic 1 and its predecessor, the KLIWAS research programme) aims to carry out necessary research, e.g. on methods of analysing future changes in low water discharges, fine sediment inputs and oxygen concentrations in federal waterways. The DAS Core Service “climate and water”, currently in development, is dedicated to the sustainable implementation, maintenance and long-term provision of data products based on consolidated methods. This will provide a permanent standardised basis for planning and decision-making at federal level, along with information to support interdepartmental assessment of adaptation needs.
Timeframe of implementation:	2009–2013 (KLIWAS) 2016–2025 (Network of Experts), 2017–2021 (ProWaS), since 2020 (establishment of DAS Core Service “climate and water”)
Costs/financing	KLIWAS; approx. 19 million euros; ProWaS: approx. 3 million euros, BMVI Network of Experts topic 1 approx. 7.5 million euros (2016 - 2019 phase).
Participants	Deutscher Wetterdienst (German Meteorological Service - DWD), Federal Maritime and Hydrographic Agency (BSH), Federal Institute of Hydrology (BfG), Federal Waterways Engineering and Research Institute (BAW), in addition, in the BMWI Network of Experts (Topic 1) the Federal Railway Authority (EBA) and the Federal Highway Research Institute (BASt)
Challenges, solutions and successes	✓Interdisciplinary and inter-institutional research work: Solution Based on climate research findings, an interdisciplinary analysis of the current and future situation in relation to navigable waters produces a coherent set of scenarios across different fields of action (KLIWAS, BMWI Network of Experts). ✓ Long-term services: Targeted development work in the area of automating technical work flows along model chains through to providing information can reduce or eliminate hurdles in dealing with climate change on the user side, reduce costs and create coherent foundations for adaptation decisions. This can in turn provide guidance for questions being addressed by the BMVI, the BMUB (e.g. in connection with the German Adaptation Strategy, international river basin commissions) and other government authorities. ×Various challenges remain: the provision and updating of long-term reference data for Central Europe as a whole; correction of systematic errors (bias) in climate projections; modelling of the hydrological regime; identification of the diverse causes (attribution) of observed changes in measured time series in managed systems; reduction of uncertainties/range of future projections; assessment of potential hazards and risks associated with climate change.

Contact	• The DAS Core Service “climate and water” (water management sector): Dr Enno Nilson, Federal Institute of Hydrology, Koblenz • BMVI Network of Experts, Topic 1: Dr Lara Kippel, German Meteorological Service (DWD), Offenbach
Further information	• Bundesministerium für Verkehr und digitale Infrastruktur: BMVI Expertennetzwerk. Link: *www.bmvi-expertennetzwerk.de/* • Bundesministerium für Verkehr und digitale Infrastruktur: KLIWAS. Link: *www.kliwas.de* • Bundesministerium für Verkehr und digitale Infrastruktur (2015): KLIWAS - Auswirkungen des Klimawandels auf Wasserstraßen und Schifffahrt in Deutschland. Abschlussbericht des BMVI. Fachliche Schlussfolgerungen aus den Ergebnissen des Forschungsprogramms KLIWAS • Nilson et al. (2019): ProWaS – Climate Projection service for Waterways and Navigation in Germany (Pilot study). Geophysical Research Abstracts. Link: *meetingorganizer.copernicus.org/EGU2019/EGU2019-13688-1.pdf* • Nilson, E., Astor, B., Bergmann, L., Fischer, H., Fleischer, C., Haunert, G., Helms, M., Hillebrand, G., Kikillus, A., Labadz, M., Mannfeld, M., Razafimaharo, C., Patzwahl, R., Rasquin, C., Riedel, A., Schröder, M., Schulz, D., Seiffert, R., Stachel, H., Wachler, B. und Winkel, N. (2020): Beiträge zu einer verkehrsträgerübergreifenden Klimawirkungsanalyse: Wasserstraßenspezifische Wirkungszusammenhänge. Schlussbericht des Schwerpunktthemas Schiffbarkeit und Wasserbeschaffenheit (SP-106) im Themenfeld 1 des BMVI-Expertennetzwerks.

Example 30: Field of action - Navigability: Construction of a new water-saving chamber for Wanne-Eickel lock

Field of action	Navigability
Example	**Construction of a new water-saving chamber for Wanne-Eickel lock**
Climate adaptation measures	Adaptation of waterway infrastructure (Tab. A. 86), Adaptation in water resources management (Tab. A. 85)
Wanne-Eickel lock with the old (north) chamber (left) and the new (south) chamber (right) Photo: WSA Duisburg-Meiderich	
Description and objectives	As a replacement for the north chamber, which was no longer in use due to structural damage, a new water-saving chamber is being constructed at Wanne-Eickel lock. When the chamber is emptied, some of the sluice water is held in saving basins and can then be used to (partially) refill the chamber for vessels going uphill. This reduction in water loss during emptying means that less energy is used to pump water back into the lock. According to climate projections, the River Lippe - the source of much of the water supply for the west German canal system - will be affected by an increase in summer low water situations over the course of the 21st century. Assuming that there is no change in the volume of shipping and intensity of use of the canals, this will require an increased management effort (pumping) in order to meet demand. Measures such as the construction of water-saving locks have the potential to mitigate the impacts of climate change here.
Timeframe of implementation:	Planning: 2009-2021 Implementation of measures: 2022-2026
Costs/financing	approx. 72 million euros Federal Waterways and Shipping Administration (WSV)
Participants	Waterways and Shipping Administration, Duisburg-Meiderich; Waterways Construction Office, Datteln; Federal Waterways Engineering and Research Institute (BAW); Federal Institute of Hydrology (BfG)
Challenges, solutions and successes	× Some disruption of shipping during construction, increase in volume of traffic due to deliveries of materials
Contact	Waterways and Shipping Administration, Duisburg-Meiderich; Section 3 / Water Supply Remote Operations Unit, Datteln; Federal Institute of Hydrology (BfG), Department M2
Further information	• Bundesanstalt für Gewässerkunde (2017): Untersuchungen zu den Auswirkungen des Neubaus der Schleusenkammer Nord am Standort Wanne-Eickel auf die Auslastung der Pumpwerksketten des westdeutschen Kanalsystems bis Münster • Bundesanstalt für Gewässerkunde (2019): Untersuchungen zu den Auswirkungen des Klimawandels auf die Wasserbewirtschaftung des westdeutschen Kanalsystems. Schlussbericht

Example 31: Field of action - Navigability: Studies on water resources management in the Kiel Canal in critical situations in the context of climate change

Field of action	Navigability
Example	**Studies on water resources management in the Kiel Canal in critical situations in the context of climate change**
Climate adaptation measures	Adaptation in water resources management (Tab. A. 85), possibly also Adaptation of waterway infrastructure (Tab. A. 86)
Drainage of water at Brunsbüttel Photo: WSA Brunsbüttel	
Description and objectives	The Kiel Canal (Nord-Ostsee-Kanal – NOK) connects the North Sea at Brunsbüttel at the mouth of the River Elbe to the Baltic Sea, terminating at the Kiel Fjord. In addition to its primary function as a federal waterway, the Kiel Canal forms part of the drainage basin for the surrounding area and is the largest artificial receiving body of water in Schleswig-Holstein. The water level in the Kiel Canal is kept as close to mean sea level (MSL) as possible in order to ensure the safety and efficiency of navigation and safeguard the structural integrity of buildings and embankments. Water inflow from the 1530 km² catchment can usually be discharged into the North Sea and the Baltic without major disruption to shipping. Free-flow drainage drainage is possible when the water level in the canal is above sea level. The main problem affecting the management of the canal is the prevalence of westerly winds, which over a longer period can cause high sea levels combined with heavy rainfall in the catchment area. In these conditions, discharge of water from the canal is restricted or becomes impossible. Shipping comes to a standstill, and rainwater accumulates in the surrounding lowlands. Critical situations, such as those which have arisen occasionally in the past, may become more frequent in future due to climate change, which will also causes sea-level rise. Recognising the need for forward planning in water resources management and in the maintenance of this federal waterway, the Federal Waterways and Shipping Agency (GDWS in Kiel) therefore commissioned the Federal Institute of Hydrology (BfG) to model various scenarios and thus derive limit states for the future management of the canal (21st century) and to identify changes in the frequency of their occurrence, taking into account climate projections and altered operational requirements. The studies commissioned provide information on changes in the occurrence of critical situations in the management of the Kiel Canal in the context of climate change. Based on the findings, it will then be possible to determine whether and to what extent a different management strategy or additional drainage capacities will be required in order to guarantee the continued safety and efficiency of navigation in future.
Timeframe of implementation:	Start 2014, final report of BfG submitted for approval to GWDS in Kiel (2019)
Costs/financing	Staffing costs: BfG 50,000 euros/year (excluding external funding)
Participants	Federal Waterways and Shipping Agency (GDWS) in Kiel, Offices for Waterways and Shipping, Brunsbüttel and Kiel-Holtenau

Challenges, solutions and successes	×In order to develop the hydrological regime model for the simulation of inflow from the catchment and for the modelling of canal management, the dataset for the parametrisation and validation of the toolkit had to be improved. × Consistent and continuous climate change projections, focusing on sea-level rise along the North Sea and Baltic Sea coasts but also on inland regions were not available for the project. Work is therefore underway to remedy this deficit within the framework of current research projects. In the interim, a pragmatic approach was adopted, which involves the aggregation of the available data on future meteorological changes in inland areas and on sea-level rise; this is then combined with empirical observations so that appropriate scenarios can be developed for further study.
Contact	Volker Neemann, GDWS in Kiel
Further information	• DHI-WASY (2013): Wasserbewirtschaftungsmodell für den NOK – Konzeptstudie (Teil 1) • Bundesanstalt für Gewässerkunde (2015): Aufbau eines Wasserhaushaltsmodells auf der Basis des Modellsystems LARSIM für den NOK im Tageszeitschritt • Ebner von Eschenbach (2016): Simulation der Wasserbewirtschaftung des Nord-Ostsee-Kanals – Herausforderungen und Lösungsansätze

5.13 Water abstraction for irrigation in agriculture

5.13.1 Concerns

Concerns with regard to irrigation primarily relate to changes in the soil moisture regime to be expected in the future.

Fundamental concerns

Warmer and drier summers may result in increased evaporation and a decrease of water available for infiltration. Especially on soils with low groundwater levels and soils with low water retention capacity, this may result in low levels of plant-available soil water levels and frequent decreases in moisture below the wilting point. According to climate predictions (e.g. KLIWA 2012a), reductions in soil moisture are expected to occur predominantly in the hydrological summer season while the hydrological winter season is likely to be warmer with resultant higher evaporation but likely also wetter resulting in higher soil water levels. Therefore, water availability in soils would potentially be limited during the growing season in particular, thus increasing the risk of drought stress and decreases in agricultural output (LABO 2010; MWKEL RP 2013; KLIWA 2012a).

More frequent and longer periods of drought combined with increases in heavy rainfall events may increase surface run-off. Precipitation that ends up as surface run-off is not available for on-site infiltration, thus further exacerbating local soil water shortages and irrigation requirements (MWKEL RP 2013).

However, where steps are taken to ensure a sufficient water supply (using irrigation if necessary), higher temperatures (provided they do not exceed certain optima) and higher atmospheric CO_2 concentrations may increase plant growth (dependent on photosynthesis type). Under these conditions, higher CO_2 concentrations may also result in improved plant water use efficiency (indirect CO_2 fertilisation) (StMUV BY 2015).

Irrigation requirements

Irrigation of agricultural land in Germany is significant in terms of water management as it impacts on local hydrological regimes. More than half of all irrigated land in Germany is situated in the mostly sandy regions of Lower Saxony. Germany's largest contiguous irrigated area is located in the north-east of this state (Blattermann & Theuvsen 2010).

In principle, the farming sector can compensate for more extreme and more frequent droughts by expanding and adapting irrigation regimes. However, in many cases there are financial or legal constraints, and in extreme conditions, limits on water abstraction for irrigation can reasonably be expected. While water-saving production and irrigation techniques as well as the construction of water reservoirs may offer solutions, they also entail significant costs which under certain conditions may render the production of field crops with greater water requirements uneconomic (StMUV BY 2015, 2016). Restrictions resulting from limited water rights issued by licensing authorities and sectoral administrations are also important and may necessitate changes in the spectrum of crops and crop varieties produced as an alternative to crop irrigation.

The German Association for Water, Wastewater and Waste (DWA) is currently preparing a guidance document which will assess the abstraction of water for irrigation from the water management perspective and deduce the quantities of water required for irrigation (Merkblatt DWA-M590 "Wasserwirtschaftliche Bewertung zur Entnahme von Wasser zur Bewässerung").

Climate-change-induced increases in air temperature are likely to result in quantitative changes in irrigation needs as well as in an even earlier onset of growing seasons. The currently valid irrigation schedules may change as a result (Regionalkonferenz 2014). However, such changes are greatly dependent on the crops under cultivation.

In order to adapt to changed soil water conditions, the knowledge of changes in median balances alone will likely not be sufficient. Information on extremes and potential temporal progressions (e.g. extreme periods of drought) are also needed. In the agricultural sector, it is generally possible to compensate relatively well for gradual climatic changes by employing a variety of production measures (e.g. choice of cultivars, soil cultivation). More frequent extreme weather events however are a problem (StMUV BY 2016).

Water conflicts may arise where regional irrigation needs increase while simultaneously summer groundwater levels potentially decrease. In particular, potential conflicts with drinking water provision and shipping must be addressed at an early stage (LAWA 2010). Similarly, in the case of abstraction of irrigation water from surface waters, the periods of highest abstraction demand coincide with reduced discharges, thus necessitating measures to ensure that abstraction does not result in negative impacts on the source watercourses and especially on their aquatic ecology (LfU BY 2016). Particularly in watercourses that fall dry due to anthropogenic impacts, water abstraction must be limited and illegal water abstraction must consistently and persistently be halted.

Areas particularly affected

Across the whole of Germany, numerous regionally distributed areas with already unfavourable climatic hydrological regimes or with shallow sandy or clay soils are likely to be affected by drought stress and increased irrigation needs. These include the following areas, among others:

- In Bavaria, for example, the “Franconian Sand Axis” (Nürnberger Sandachse) and the foothills of the Steigerwald region (Steigerwaldvorland) (StMUV BY 2016).
- The already dry regions along the Upper Rhine Plain (Oberrheingraben) in Baden-Württemberg, Rhineland-Palatinate and Hesse (BMU, no year given).
- Other areas in Baden-Württemberg such as, for example, the Gäu Plateaus, parts of the Swabian Jura (Schwäbische Alb) and the Bauland landscape (MUKE BW 2015).
- The already dry central regions of eastern Germany, especially in Brandenburg (north-eastern German lowlands, south-eastern German basins and hills) (BMU no year).
- The drier eastern part of Mecklenburg-Western Pomerania (MWAT MV 2010).
- In Schleswig-Holstein, primarily the sandy geest areas (MLUR SH 2011).

Primary soil characteristics

With their storage and regulatory functions, soils play a significant role in the hydrological cycle. Pore volume, pore size distribution and pore continuity influence the soils' air, heat, nutrient and hydrological regimes. Soil water reacts immediately to changes within the system. With increasing drought during the growing period, the soils' water retention capacity becomes increasingly important. Soils with a high utilisable field capacity are able to store greater amounts of precipitation and in turn are able to make available a greater amount of water for plant growth during periods of drought. The differences in yields and irrigation needs of soils with high and low water retention capacity respectively may therefore become more pronounced (MWKEL RP 2013). In addition to the direct impact of climate change on infiltration and evaporation as already described above, climate-change-induced changes in soil characteristics and resultant impacts, such as reduced stability of soil structural aggregates, soil compaction and soil erosion, may further indirectly impact on the soil water levels and thus potentially on irrigation needs (MWKEL RP 2013) (see also section 5.4).

Salination and translocation of substances

On highly irrigated sites, future increased water consumption by plants as well as higher evaporation as a result of higher temperatures may lead to salination. There are concerns that this is a development which is likely to affect regions in eastern Germany with a subcontinental climate and already pronounced summer droughts. Additionally, soils in coastal regions may be affected by salination as the expected sea-level rise might bring these soils into contact with saltwater for the first time (UBA 2011).

Soil water and changes in soil water conditions as a result of climate change may also affect other materials cycles (translocation and turnover). For example, under unfavourable soil water conditions during drought periods, plants have difficulties taking up nitrate. During (extreme) precipitation events, this nitrate may then leach out which means it is no longer plant-available. Long periods of drought may also exacerbate cracking in clayey soils and impact on the translocation of substances as it allows substances to be translocated from near the soil surface to deep into the soil profile (StMUV BY 2016).

5.13.2 Climate adaptation measures (Annex Tab. A. 88 - Tab. A. 95)

Given that due to climate change many regions in Germany are likely to experience increases in the frequency and duration of drought periods as well as an increase in air temperatures, it is reasonable to assume that irrigation needs in agriculture and horticulture will rise. First of all, however, it will be important to maintain or even improve the soils' water retention capacity by taking measures such as raising the organic matter content, protecting soil from erosion, general soil conservation, or conservation tillage (e.g. non-inversion soil cultivation), as greater soil water retention means that plants can survive longer drought periods by merely drawing on soil water. This should result in a less pronounced increase in irrigation needs. Adaptations in crop production can lead to plants requiring less water and using water more efficiently while also lowering evaporation and protecting soils from erosion. Similar effects can be achieved through cultivar selection and the cultivation of drought- resistant crops. From the point of view of water management, compliance with good farming practice in combination with site-appropriate crop selection are urgently required.

With regard to irrigation, it is advisable that highly efficient methods be developed and given preference. If possible, irrigation water should not be drawn from already heavily used groundwater resources; stored rainwater or surface water should be given preference. In certain locations, e.g. in wine-producing regions, it may be prudent to construct rainwater storage systems for irrigation purposes. Many farmers have yet to invest in newer, more efficient irrigation technology; the increases in irrigation needs must be taken into account in water resources management plans and exploitation rights must be apportioned. In this respect, organisational adjustments are called for. For example, the introduction of a low water management system (cf. section 5.15.) with the involvement of all affected stakeholders might raise awareness of the issues and lead to sustainable solutions.

Farmers should be given comprehensive and timely information as to the expected regional climatic developments. Good and timely agri-meteorological forecasts may also contribute to appropriate management. Depending on local or regional conditions, the establishment of water management boards charged with the organised and equitable distribution of the available surface water may be an important climate adaptation measure.

Links with other fields of action	Urban drainage and wastewater treatment, flood protection: heavy rainfall and flash floods, conservation of aquatic ecosystems, groundwater protection, public water supply, cooling water availability, dam and reservoir management, low water management in watercourses

5.13.3 Profiles of practical examples

Example 32: Field of action - Water abstraction for irrigation in agriculture: Crop cultivar strategies for adaptation to climate change

Field of action	Water abstraction for irrigation in agriculture
Example	**Crop cultivar strategies for adaptation to climate change**
Climate adaptation measures	Adaptations in crop production (Tab. A. 91)
Winter wheat in an on-farm trial in Brandenburg	
Description and objectives	The objective of sub-project #8 of the Innovation Network of Climate Change Adaptation Brandenburg Berlin (INKA BB) was to make available specialised information and advice to support agricultural holdings in Brandenburg in their selection of crop cultivars for production. To this end, the knowledge and experience held by official cultivar testing, the seed industry, and agricultural practitioners were brought together and supplemented with further cultivar trials. For the four most economically significant crop types in Brandenburg, different cultivars were tested in multiannual field trials on four farms under a variety of site conditions with a view to their ability to adapt to climate change (e.g. in terms of their ability to tolerate heat or drought). Mobile weather stations were set up at the relevant locations in order to establish correlations between weather conditions and plant development. Additional scientific precision trials were conducted by the regional states' (Länder) official cultivar testing, at the Humboldt University Berlin and at the Brandenburg State Agency for Rural Development, Agriculture and Land Consolidation (LELF Brandenburg). Information on this topic will continue to be accessible on the project homepage beyond the project term. The project was explicitly initiated in response to climate change.
Timeframe of implementation:	2009-2014
Costs/financing	Support from German Federal Ministry of Education and Research (BMBF)
Participants	INKA-BB, Humboldt University of Berlin (Division of Agronomy and Crop Production), Brandenburg State Agency for Rural Development, Agriculture and Land Consolidation (LELF Brandenburg), the regional seed producers' association Märkischer Saatgutverband, and the state farmers' association Landesbauernverband Brandenburg e. V.
Challenges, solutions and successes	× Lack of funding for trial seed resulted in dependence on seed merchants. It was not possible in all cases to ensure seed consistency for multiannual cultivar trials, which to some extent reduced the volume of data obtained and hampered the evaluation of results. ✓ Well-functioning network of stakeholders, i.e. practitioners, scientists and agricultural associations as well as involvement of additional institutions. ✓ Active knowledge transfer and exchange between the scientific community and practitioners.
Contact	Humboldt University of Berlin - Division of Agronomy and Crop Production
Further information	• Innovationsnetzwerk Klimaanpassung Brandenburg Berlin (2014): INKA BB - Innovationsnetzwerk Klimaanpassung Brandenburg Berlin. Schlussbericht • Innovationsnetzwerk Klimaanpassung Brandenburg Berlin: INKA BB. Available for download at: *www.inka-bb.de/* • German Environment Agency: Sortenstrategien für verschiedene Nutzpflanzen zur Anpassung an den Klimawandel (INKA-BB, Teilprojekt 8). Available for download at: *www.umweltbundesamt.de/themen/klima-energie/klimafolgen-anpassung/werkzeuge-der-anpassung/tatenbank/sortenstrategien-fuer-verschiedene-nutzpflanzen-zur*

Example 33: Field of action - Water abstraction for irrigation in agriculture: "Aquarius – Farmers as water managers in a changing climate"

Field of action	Water abstraction for irrigation in agriculture
Example	**"Aquarius – Farmers as water managers in a changing climate"**
Climate adaptation measures	Irrigation efficiency (Tab. A. 92)
As part of this project, practical field trials were conducted on optimised water use in agricultural irrigation. Key questions addressed included the determinants of future irrigation needs as well as the expected impacts of groundwater abstraction on the landscape hydrological regime and options for water retention Photo: Friedrich Dräger	
Description and objectives	The objective of the "Aquarius" project was to simultaneously safeguard both water quantity and quality in streams and groundwater in the eastern Lüneburg Heath (Lüneburger Heide) and meet the needs of irrigation farming. On behalf of the Lower Saxony Agricultural Chamber's Uelzen District Office, the project investigated the interconnections in the eastern Lüneburg Heath between groundwater recharge, low water discharge by streams during the summer, and groundwater abstraction. In addition, the project produced estimates of future water demand for farming and conducted practical field trials addressing research questions on efficient water use for irrigation. To this end, cultivar selection trials in cereal cropping as well as precision irrigation trials were conducted. Moreover, the project established a project-accompanying discussion platform in which representatives of the participating groups and institutions discussed procedures for offsetting implemented measures against water abstraction permits (ecosystem services) as well as scenarios for hydrogeological modelling, among other topics. Changes resulting from climate change were an important driver for the initiation of this project.
Timeframe of implementation:	2009-2012
Costs/financing	Financed by the European Regional Development Fund, the Lower Saxony Agricultural Chamber (Landwirtschaftskammer Niedersachsen), the Lower Saxony Ministry for Environment and Climate Protection (Niedersächsisches Ministerium für Umwelt- und Klimaschutz) and the Johann Heinrich von Thünen Institute in Braunschweig.
Participants	Lower Saxony Agricultural Chamber Uelzen District Office, Johann Heinrich von Thünen Institute, relevant sectoral state government authorities
Challenges, solutions and successes	✓ Evaluation of cultivar-specific water consumption and indications for cultivar selection and irrigation in cereal cropping; evaluation of precision irrigation and underlying sensor-based soil moisture measurements; determination of minimum water discharge in minor gravel-dominated watercourses; evidence of the existence or otherwise of stream-aquifer contact; model-based scenario analysis of impacts of different groundwater abstraction strategies; development of a follow-up-project for the assessment and remuneration of ecosystem services resulting from forest conversion on the groundwater regime (water-retention forests); investigation of local opportunities for water retention and implementation of a pilot project (rainwater harvesting). × Only two trial harvests could be obtained in the course of the short project term.
Contact	Lower Saxony Agricultural Chamber Uelzen District Office

Further information	• Landwirtschaftskammer Niedersachsen (2012): Aquarius – Dem Wasser kluge Wege ebnen! Projektbericht (project report in German) • Landwirtschaftskammer Niedersachsen: AQUARIUS – Dem Wasser kluge Wege ebnen! Accessible at: *www.lwk-niedersachsen.de/index.cfm/portal/6/nav/203/article/12396.html* (in German) • Johann Heinrich von Thünen Institute: Aquarius – Farmers as water managers. Accessible at: *http://www.thuenen.de/en/at/projects/environmental-technology-soilplant/farmers-as-water-managers-in-a-changing-climate/*

5.14 Dam and reservoir management

5.14.1 Concerns

Dams and reservoirs are affected by changes in various climate parameters (mainly precipitation, but also factors such as wind and insolation). Because their economic life is long and their technical life is often even longer, existing or currently planned facilities are likely to be affected by climatic changes forecast to occur in the distant future. In addition, existing facilities may have been designed and had their original purpose defined some time ago: the conditions that prevailed then may have since changed (DWA 2014b, 2014a). Be that as it may, however, the operation of dams can be adapted to changing circumstances.

The majority of dams in Germany are located within a band running west to east, mainly across North Rhine-Westphalia, Thuringia and Saxony. In south and north Germany (with the exception of the Harz) there are relatively few dams (UBA 2015e); as a result, the relevance of the dams and the extent to which they are affected by climate change varies from region to region.

Management and normal water levels

Possible changes in climate parameters influence the inflow regime and the physical, chemical and biological processes taking place in the water body. This has consequences for management e.g. definition of normal water levels and control. In the case of drinking water dams, management of the hypolimnion is particularly important, because it should ideally remain available to supply raw water up to the end of the summer stagnation period in the autumn. The technical components of water storage facilities can also be affected by changes.

While dams and reservoirs are affected by climate change, there is also potential for utilising their regulatory and storage functions to buffer the undesirable impacts of climate change on the hydrological regime (DWA 2014b). Demands on the use of water storage facilities may thus change in future. Regional flexibility resulting from reduced water consumption may be absorbed by reductions in water availability (DWA 2014b, 2014a).

Concerns resulting from changes in the inflow regime

The effects of altered precipitation and the resulting changes in discharges and usage requirements have wide-ranging impacts on the management of dams and reservoirs. In the summer months, more frequent or longer dry periods may reduce reservoir inflow while simultaneously increasing the demands on the provision of water (e.g. for water supply and to raise low water levels) (DWA 2010).

In addition, the increased incidence of heavy rain and flooding may mean that the facilities need to play a more important part in flood control (Sieber 2014). If less winter precipitation falls as snow, this reduces the land's retention and may therefore increase the importance of retention in dams and reservoirs (MLU ST 2013).

Overall this is likely to mean that water levels in the dams will vary more widely over the course of the year (MKULNV NRW 2011). It may temporarily not be possible to adhere to current normal and drawdown levels. In the case of multipurpose storage dams, the changes may result in increasing conflicts over use (Sieber 2014). Facilities that are currently monopurpose may in future be put under pressure to fulfil a number of functions. This means that both the design parameters and the operating plans may need to be amended in the light of this multipurpose use (raising low water levels, flood control, nature conservation and local recreation) (MLU ST 2013).

Dams with over-year storage capacity (storage volume greater than total annual inflow) are usually able to compensate for seasonal fluctuations or shifts in inflow. If volumes are relatively low, changes in inflow quantities can cause more major problems (UBA 2015e).

As a result of changes in precipitation intensity and extreme discharge, it is possible that in areas prone to erosion there will be increased deposition of sediment in reservoirs. This requires appropriate and if necessary large-scale management of solid matter (DWA 2010; MLU ST 2013). The increasing deposition of humic matter in dams via inflows is currently being monitored and analysed at selected locations (MLU ST 2013).

Summer floods may impact adversely on raw water quality because they mean that in drinking water dams intended to protect against floods, high-quality hypolimnion water must be released downstream and is therefore no longer available to the raw water treatment process. Some dams therefore incorporate mechanisms for epilimnetic water release (e.g. roller gates in the Saidenbach dam, fish-belly flap gate in the Klingenberg dam). In addition, heavy rain events in summer lead to the introduction of particles and nutrients that increase phytoplankton production and can impair raw water quality.

Concerns as a result of higher air temperatures and increased solar radiation

Increased solar radiation and extension of the summer stagnation period may amplify eutrophication processes.

The expected rise in air temperature will inevitably result in raised water temperatures in inflows and in the reservoir. This may alter limnological conditions in the water body. Consequently, the duration of the temperature-related stagnation and circulation periods may be affected; lengthening of the summer stagnation phase may be particularly critical for the development of water quality and may, for example, increase the work involved in treating raw water (MLU ST 2013) to produce drinking water.

Concerns as a result of changes in wind conditions

Changes in wind direction and higher wind intensity may amplify wave formation on the reservoir surface and likewise affect limnological conditions in the entire water body.

The formation of waves by wind is an important factor in determining the size of the safety-related freeboard of a dam or retaining wall and may thus affect the height of the crest of the barrier. However, very little information on the future development of these parameters is available (DWA 2014b).

Changes in wind conditions can also affect surface evaporation and the temperature stratification that develops in the water body of reservoirs (see above); this can in turn impact on water quality.

Combinatorial effects

Consideration must be given not only to the direct effects of individual climate elements, most of which can be understood intuitively, but also to the combinatorial effect of several climate elements and possible secondary changes. As with individual effects, it is changes in the mean, fluctuation range and timing that are of significance in the case of combinatorial effects (DWA 2014b).

Effects of design and dimensioning

Climatic changes can also impact directly on the design and dimensioning of storage zones, dam structures and structural components and dam operating equipment. The following key concerns should be considered.

Changes in the inflow and temperature regime may necessitate adjustment of the size of the storage area and of the normal and drawdown water levels in the reservoir of the dam. It may be necessary to review and recalculate release rates; any altered requirements in relation to the management of water quantities or quality and any changes in usage conditions will need to be taken into account in this process.

The increase in extreme weather conditions with more intense precipitation and more frequent flooding, may affect the dimensioning of both the dam's planned (normal) flood retention area and its flood spillway. Design flood inflows that take account of altered conditions (e.g. multi-crest flood waves, peaks, filling surges) – possibly also influenced by changed management of the reservoir – may result in adjustment of the spillway's discharge capacity. In connection with higher discharge quantities it is necessary to consider not only hydraulic and static loads but also the effects downstream.

With regard to the extremely rare flood design events (HQ1,000 and HQ10,000) that are used in the verification of reservoir safety, current knowledge of climate change provides no reason to adjust these design parameters. In this respect, under the present state of knowledge, there are also no general indications of adverse impacts on the (flood) safety of reservoirs covered by the design requirements of DIN 19700 (2004) (DWA 2014b).

Changes in the way the dam is managed or controlled can also impact on the dimensioning of the bottom outlets and operating outlets, such as the withdrawal mechanisms for non-potable water, and result in a need for adjustment. This may affect both the outflow capacity and the arrangement of the corresponding mechanisms. Solutions that maximise flexible and adaptive management of the facility are becoming increasingly important.

Altered loads on structures and structural components such as larger and more frequent load changes as a result of fluctuating water levels, higher thermal loads and solar radiation, can affect fitness for purpose or in extreme cases load-bearing capacity; this should be checked on a case-by-case basis. Finally, consideration should also be given to potential consequences for the features and arrangement of measurement devices for monitoring the dam.

Overall it should be assumed that the importance of dams and reservoirs will increase further as a result of the expected increase in the variability of the water supply, growing usage requirements and greater interlinking of facilities (e.g. water transfer systems) (DWA 2014b).

5.14.2 Climate adaptation measures (Annex Tab. A. 96 - Tab. A. 101)

Because dams can buffer possible adverse impacts of climate change on the hydrological regime, it is to be expected that greater demands will be placed on them and/or that demands on their use will change. At the same time, steps must be taken to ensure that the facilities can be operated safely and efficiently even under conditions of climate change.

Compliance with the technical requirements of DIN 19700 (2004), including under changed climatic conditions, is an important aspect of dam supervision and of adaptation or optimisation of the facilities. When new dams are built, attention should always be paid to ensuring that subsequent retrofitting can be performed with minimum time and effort. More work may be involved in maintaining the structures because sediment transport and the risk of obstruction by floating debris are likely to increase.

In addition, to adapt to changes in usage demands and requirements, normal reservoir water levels must be reviewed and if necessary adjusted and/or dynamised; in the case of multipurpose dam use, for example, normal levels that vary from season to season could become increasingly important.

Hand-in-hand with changes in quantity management, and coordinated with them, goes adaptation of quality management. Water quality in dams depends to a significant extent on precisely where on the one hand the cleanest water is withdrawn for drinking water use, and on the other hand the less clean water is extracted for flood relief and delivery downstream.

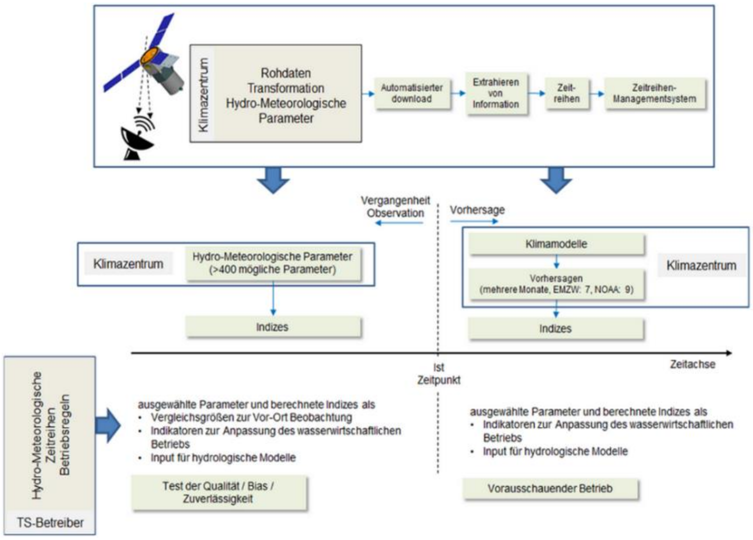
Potential conflicts of use e.g. between flood control, supply of drinking water for and water for industrial purposes, low water management, hydropower, provision of irrigation water, tourism and shipping, should be tackled at an early stage.

During prolonged dry periods, combined management of several dams may be needed in order to safeguard the supply of water. This further increases the balancing effect of dams. To better compensate for the increasingly fluctuating hydrological regime, it may also be necessary to secure new sites for dams.

Links with other fields of action	Flood control, flood protection: heavy rainfall and flash floods, conservation of aquatic ecosystems, public water supply, hydropower generation, irrigation, low water management in watercourses

5.14.3 Profiles of practical examples

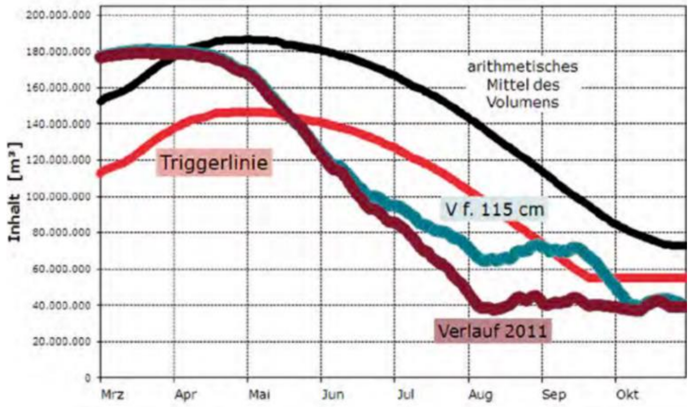
Example 34: Field of action - Dam and reservoir management: TASK - Climate Adaptation Strategy for Dams and Reservoirs

Field of action	Dam and reservoir management
Example	**TASK – Climate Adaptation Strategy for Dams and Reservoirs**
Climate adaptation measures	Adaptive dam management (Tab. A. 98), Review and structural optimisation of existing facilities (Tab. A. 96 A.97)
The TASK project aims to analyse the data and experience of various dam operators and use this information to create an overarching framework for action with a dynamic concept for regulating operation. Diagram: SYDRO Consult GmbH	
Description and objectives	The aim of the project is to investigate the effects of climate change, including shifting precipitation regimes, on dam operation and create an overarching framework for action on adaptation. This will involve analysing shifts in precipitation patterns, the resulting discharge and their impacts on dam operation and water quality. Finally, an overall strategy for adapting water management plans will be drawn up that is based on dynamic operating rules and seasonal forecasts and includes competing uses. The adaptation of dam management generally will be investigated and on the basis of the data and experience of all participating associations and in cooperation with the supervisory authority, universally applicable and transferable interrelationships will be identified, so that the validity of the concept does not need to be re-established on a case-by-case basis. Suitable indicators, mainly in the form of indices, will be identified and refined to enable the need for action to be determined promptly. Finally, for particular dams individual-case solutions can be worked out in the overarching framework.
Timeframe of implementation:	2017-2019
Costs/financing	Sponsored by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
Participants	SYDRO Consult GmbH, various water associations and supervisory authorities (Wasserverband Eifel-Rur, Wupperverband, Landestalsperrenverwaltung, Wahnbachtalsperrenverband, Aggerverband, Wasserverband Aabach-Talsperre) in North Rhine-Westphalia and Saxony, the municipality of Simmerath, Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen (Regional Office for Nature, Environment and Consumer Protection North Rhine-Westphalia) and the Cologne district authority.
Challenges, solutions and successes	✓ The network of participants created by the project will make it possible to develop new procedures, indicators and broad climate adaptation measures for which a single water association would not have sufficient capacity.
Contact	SYDRO Consult GmbH
Further information	• SYDRO Consult GmbH (2016): Talsperren Anpassungsstrategie Klima-wandel (TASK). Project description • SYDRO Consult GmbH: TASK – Talsperren Anpassungsstrategie Klimawandel. Link: *task.sydro.de/*

Example 35: Field of action - Dam and reservoir management: Carlsfeld Dam - Diversion for water contaminated with humic matter and for variable raw water withdrawal

Field of action	Dam and reservoir management
Example	**Carlsfeld Dam - Diversion for water contaminated with humic matter and for variable raw water withdrawal**
Climate adaptation measures	Measures to ensure water quality (Tab. A. 99)
The continuously height-adjustable mechanism for raw water withdrawal at the Carlsfeld Dam.	
Description and objectives	The catchment area of the Carlsfeld Dam includes many organic wetland areas, as a result there has been a significant increase in the amount of humic matter in the water entering the dam in recent years, particularly during heavy rainfall events. In 2010, in order to stabilise the quality of the raw water, a retention basin was built at the head of the Carlsfeld reservoir. The high humic-content water that is retained in this basin is then channelled via a pipeline on the reservoir bottom to the airside of the dam wall and into the river below the dam, the Wilzsch. To protect the Eibenstock drinking water dam which lies further downstream, the above-mentioned pipeline is being extended and carried outside the catchment area of the Eibenstock Dam. In addition, since the most recent renovation works (1997-2000) the Carlsfeld Dam now has a continuously height-adjustable raw water withdrawal system (Provar). This means that raw water for the drinking water supply can always be withdrawn at the point where the water quality is best. These structural improvements also promote adaptation to climate change, since there may in future be changes in water quality as a result of more frequent heavy rain events and the associated altered inflow of sediment and nutrients.
Timeframe of implementation:	Construction of the retention basin: 2009/2010, installation of the continuously height-adjustable water withdrawal system and other structural improvements: 1997 - 2000
Costs/financing	-
Participants	Landestalsperrenverwaltung des Freistaats Sachsen (State Reservoir Administration of Saxony)
Challenges, solutions and successes	-
Contact	Landestalsperrenverwaltung des Freistaats Sachsen (State Reservoir Administration of Saxony)
Further information	• Landestalsperrenverwaltung Sachsen (2010): Rückhaltebecken an der Tal-sperre Carlsfeld in Betrieb genommen. Meldeinformation. Link: *www.smul.sachsen.de/ltv/download/2010_12_09_Umleitung_Wlizsch_TS_Carlsfeld.pdf* • Landestalsperrenverwaltung Sachsen (2013): Die Talsperre Carlsfeld. Link: *www.wasserwirtschaft.sachsen.de/TS_Carlsfeld.html*

Example 36: Field of action - Dam and reservoir management: Edertal Dam water-saving model

Field of action	Dam and reservoir management
Example	**Optimised storage management of the Edertal Dam**
Climate adaptation measures	Adaptive dam management (Tab. A. 98)
Simulation of the saving model with constant 5-cm reduction to 115 cm at the Hannoversch Münden gauge: if this model had been used, the Edertal Dam would have been significantly fuller in the summer and autumn of 2011. Graph: © Wasserstraßen- und Schifffahrtsamt Hann. Münden	
Description and objectives	In dry years an alternative method of control is deployed at the Edertal Dam in order to use the overall system more effectively. If water is saved promptly, the end of the season during which water is managed (e.g. for shipping) can be extended. For this purpose the Hannoversch Münden Waterways and Shipping Agency established a trigger line. If the water level falls below this line, a water-saving model is triggered. Following consultation with all users it was agreed that the maximum water level at the Hannoversch Münden gauge below the dam will be reduced by 5 cm so that the saved water is retained longer in the system. The functions of the Edertal Dam include raising low water levels for shipping in the Upper Weser, reinforcing the Mittelland Canal, flood protection and energy generation. In addition, there are other use interests e.g. for nature conservation and recreation. It was therefore necessary to find a compromise between the various, at time competing, uses. In order to maintain scope for the various management scenarios, it was important that the trigger line did not trigger the saving mode too soon, but at the same time it needs to be triggered sufficiently early for enough water to be saved in the subsequent period. The trigger line varies depending on the time of year. The trigger line originally selected was approx. 40 million cubic metres below the multiannual arithmetic mean volume. Various saving models were calculated using real data from past years. The results were presented to the various users and political decision-makers and a water-saving model, which was then piloted until 2019, was selected jointly by everyone concerned. Based on the experience gained up to 2019, the trigger line was redefined based on how often levels fell short. In coordination with parties involved, the pilot operation was extended by 5 years.
Timeframe of implementation:	Investigations/plans: 2011/2012, pilot operation: since 2012
Costs/financing	-
Participants	Münden Waterways and Shipping Agency, shipping on the Upper Weser, company representatives, Kassel regional council, people living near the Edertel Dam, representatives of water tourism on the Weser and Edertal Dam
Challenges, solutions and successes	× Mediating in difficulties between different users and getting them to accept early restrictions. ✓ Generally accepted rules for restricting release ✓ Involving commercial users in the choice of water-saving model ✓ The saving measures meant that in 2015 sport and leisure boating was possible on the Edertal Dam until the end of the summer holidays and shipping was able to use the Upper Weser for roughly two to three weeks longer.
Contact	Münden Waterways and Shipping Agency
Further information	• Cemus & Lippel (2016): Entwicklung einer alternativen Steuerungsstrategie in trockenen Jahren und ihre Einführung in die öffentliche Akzeptanz. Wasserwirtschaft

5.15 Low water management

5.15.1 Concerns

The present state of knowledge regarding future changes in low water levels has been described in section 4.1.1.2. There are signs that in some regions low water phases may be more pronounced in future.

The findings with regard to future development of low water levels are based mainly on analysis of parameters (MNQ, MoMNQ, NM_7Q) that describe low water discharge rates with a return period of one year. In some situations, however – for example, in connection with the design of adaptation measures (DWA 2014b) – it is the trend of more extreme events with a lower probability of occurrence that is important. But, as with the analysis of flood discharges, less information is available on rarer events and greater uncertainty attached to the findings. Information on the development of mean average low water periods cannot be transferred directly to the development of more extreme events.

It should also be borne in mind that warmer and drier summers are not necessarily accompanied by lower water levels in water bodies, because groundwater conditions also significantly influence the low water discharge situation (MUELV HE 2012).

Water availability

When low water situations arise, water availability in flowing waters is limited. An extremely important aspect of water volume is then the quantity of inflows and transfers (e.g. raising of low water levels). Low water situations often occur at the same time as a rising demand for water. When water levels are low, conflicts over the use of the quantity of water therefore become more acute. (Temporary) withdrawal restrictions could then be extended or imposed more frequently. In water bodies that run dry, it is possible that this running dry will occur more frequently or last longer and there will thus be impacts on the aquatic fauna.

Water quality

When water levels are low it is often not only the quantity of water that poses problems. Water quality, too, may well be impaired. This is due, firstly, to the fact that if water levels fall while the material load remains the same, material concentrations will inevitably increase. Secondly, in low water situations with low discharge volumes, high water temperatures set in rapidly under certain meteorological conditions (in particular high air temperatures and long insolation). High water temperatures in turn bring about extensive changes in the material balance and hence in water quality. For example, dissolved oxygen concentrations will be lower.

Because of the poor dilution conditions when water levels are low, the quality of the water in inflows and transfers is also very important. For example, this is of relevance in connection with small rivers with large or numerous inflows from sewage treatment plants, where treatment plant discharge in dry periods can make up a significant proportion of the discharge. This may lead to water quality problems, because the waste water cannot be optimally diluted by the natural discharge. On the other hand, provided that the incoming water is of appropriate quality, the treatment plant outflows may continuously boost the discharge and hence prevent water levels falling below critical levels (StMUV BY 2015).

If low water situations and associated water quality problems become more frequent in future, it is likely that more stringent water quality requirements will need to be imposed on dischargers.

Low water as a cross-cutting issue

Because low water levels produce changes in both water quantity and quality, the (future) occurrence of low water affects many other fields of action - including most of the fields of action described in this report - in complex ways. The ways in which the fields of action covered in the report are affected by more frequent and more pronounced low water levels are detailed in the relevant preceding chapters. Among the fields of action that have been described, those most noticeably affected by low water include aquatic ecology, the availability of cooling water, shipping and irrigation. In addition to the fields of action covered in this report, there may be others that are affected by low water levels. Thus leisure use (tourism, local recreation) may suffer as a result of low water, for example if restrictions are imposed on swimming and water sports because the water is too shallow or water levels are too low. Swimming may also be banned because of poor water quality, and restrictions may be placed on private boats, passenger ships and ferries (LAWA 2007a).

There are connections and dependencies between the fields of action affected by low water, which means that conflicts of use may arise (LAWA 2007a). The conflict potential is frequently exacerbated by the fact that when low water is accompanied by drought, demand for water (e.g. for irrigation) rises at the same time as the discharge volume falls.

<u>LAWA guidelines on sustainable low water management</u>

To prevent such conflict situations long-term and regulate them when they arise, a sustainable low water management plan is required. The LAWA guidelines on sustainable low water management provide planning and water management authorities with strategies and principles for a low water management plan of this sort. The guidelines also recommend that climate change is taken into account (LAWA 2007a, 2007b).

5.15.2 Climate adaptation measures (Annex Tab. A. 102 - Tab. A. 109)

As a result of climate change, low water management is becoming increasingly important in many regions in Germany, because it is predicted that climate change will result in the more pronounced occurrence of low water flows in summer and autumn. So that measures can be put in place promptly when water levels are low, early forecasts of flows and temperatures are becoming increasingly important. The warning and forecasting services of the federation and the federal states now provide up-to-date information on water levels, discharge and flood forecasts, and in some cases low water forecasts and forecasts of temperature developments in the event of low water for the major rivers. The forecasting services are available to the authorities responsible for supervising water rights and can sometimes also be accessed directly by water users.

To protect aquatic ecosystems, action plans for the management of low water should specify measures that come into force when water volumes fall below certain threshold levels. Such measures include, among other things, (further) usage restrictions. Specific incentives to save water in the event of low water levels may help protect the water bodies. Safeguarding the water quality may require drastic measures, such as aeration, to conserve the aquatic ecosystems. Raising low water levels can also help protect water quality, and it prevents the water bodies drying out completely. In low water phases the basic groundwater discharge is extremely important for the flow of water bodies. Measures that promote the natural retention and seepage of water that contributes to groundwater recharge are therefore ultimately also helpful in increasing low water discharge.

Links with other fields of action	Flood control, urban drainage and wastewater treatment, flood protection: heavy rainfall and flash floods, conservation of aquatic ecosystems, groundwater protection, public water supply, cooling water availability, hydropower generation, navigability, irrigation, dam and reservoir management

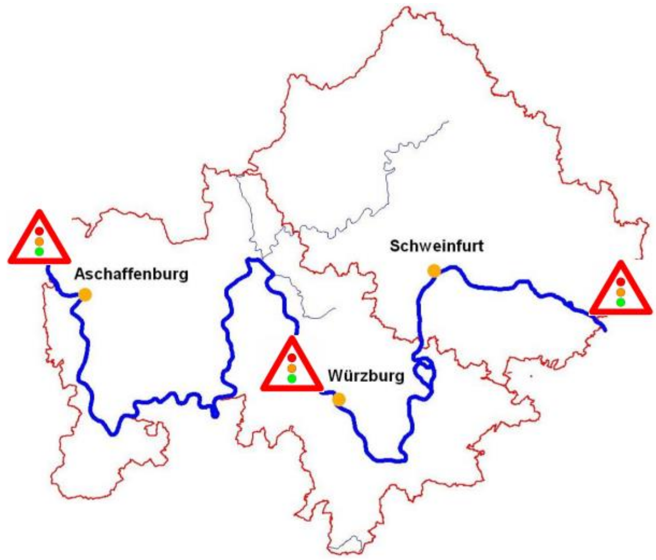
5.15.3 Profiles of practical examples

Example 37: Field of action - Low water management in watercourses: Pilot project "Management of low water in the Bergtheimer Mulde"

Field of action	Low water management
Example	**Pilot project "Management of low water to control abstraction of groundwater using the example of agricultural irrigation"**
Climate adaptation measures	Sustainable groundwater management (Tab. A. 63), Integrating climate change into public water supply planning (Tab. A. 64), Groundwater substitution (Tab. A. 93), Organisational adaptations in agriculture (Tab. A. 94)
In some parts of northern Bavaria most of the groundwater that is withdrawn is used to irrigate specialised crops.	
Description and objectives	Under the project, a recommendation for action for sustainable groundwater management is being developed. It contains supporting checklists for licensing and specialist authorities, a sample structure for preparing low water management plans and an accompanying information booklet with specialised information. The primary aim is to ensure that applications for abstraction of groundwater for agricultural irrigation are handled as uniformly as possible, taking into account low water situations, in order to avoid potential conflicts of use and overuse of available groundwater supply at an early stage. The recommendations are based on the determination of risk of conflicts of use in larger balance areas, which is then used to manage, for example, the amount of water approvals, the duration of permits and the monitoring requirements. Proactive, precautionary low water management with assessment of alternatives and predictive management of water abstraction in terms of location, quantity and time contributes both to adequate protection of water resources and to the measured provision of required irrigation water. One of the areas studied in the project in which conflicts arise over the use of groundwater is the Bergtheimer Mulde. It is an area in which intensive vegetable-growing takes place and around 50% of the land is irrigated mainly with groundwater. Around two-thirds of the groundwater that is extracted is used for irrigation purposes and only one-third for the supply of drinking water to the public. A comprehensive situation and needs analysis was performed in this area. The abstraction of groundwater taking place in the area is classed as relatively risky, because up to 30% of the mean groundwater recharge is being withdrawn and pressure for use continues to rise. The project is accompanied by hydrogeological modelling to enable better estimates of available supply and, based on this, to determine what share of this is usable. Alternative concepts for water abstraction, for instance from the Main River or the accompanying groundwater current of the Main with high run-offs and temporary storage, will be reviewed for feasibility, economic viability and environmental compatibility.
Timeframe of implementation:	2015-2019
Costs/financing	Bavarian State Ministry of the Environment and Consumer Protection (StMUV)
Participants	Government of Lower Franconia, external consultancy, farmers, associations, municipalities, district authorities, water authorities.
Challenges, solutions and successes	✓ Transparent participatory communication process: site visits, workshops, expert discussions, excursions ✓ Practical recommendations for sustainable groundwater management
Contact	Government of Lower Franconia

Further information	• Guschker (2017): Niedrigwassermanagement in Bayern. Lecture to the LAWA group of climate change experts on 27 April 2017 in Würzburg. Link: *docplayer.org/116679862-Niedrigwassermanagement-in-bayern.html*

Example 38: Field of action - Low water management in watercourses: Alarm plan for the regulated Bavarian Main - Aquatic ecology

Field of action	Low water management in watercourses
Example	**Alarm plan for the regulated Bavarian Main - Aquatic ecology**
Climate adaptation measures	Measures to be taken if flow rates fall below certain levels (Tab. A. 103), Water quality warning services (Tab. A. 55), Measures to ensure water quality (Tab. A. 105), Usage restrictions (Tab. A. 104), Raising low water levels (Tab. A. 107), Aeration (Tab. A. 106)
The section of the River Main that runs through Lower Franconia contains many barrages (28 barrages in 317.6 km). Since 2012, there has been a warning and notification plan in place for this part of the Main which is applied when water quality parameters reach critical levels. It covers the notification areas of both the Aschaffenburg and the Bad Kissingen water authorities.	
Description and objectives	The alarm plan is a warning and notification strategy that comes into play when water quality parameters in the Lower Franconian Main between Bamberg in Upper Franconia and Kahl am Main reach critical levels. It makes the public aware if weather conditions will give rise to sensitive ecological conditions in the Main. Through different warning levels, the plan recommends adapting uses, such as the operation of municipal and industrial sewage treatment plants or the abstraction and reintroduction of cooling water. These stages also limit the impact of construction activities and regulate the behaviour of the competent administrative authorities. The alarm plan is necessary because the barrages significantly reduce the speed of flow in the area and cause considerable warming of the water, which can result in significant adverse impacts on water quality and aquatic ecology. There are three warning levels that are triggered when the water temperature, oxygen content and discharge reach certain thresholds: • Advance warning (critical conditions expected shortly) • Warning (critical conditions in the water body) • Alarm (significant impairment of the entire aquatic biology system) Once the "advance warning" stage is triggered, the water authorities take additional measurements of the physical parameters and of the water quality in the Main. In the event of a "warning" or "alarm", all the affected local government authorities and the media are alerted in accordance with a defined notification plan. Using a list of contacts, the district authorities in turn inform all the municipalities as operators of the sewage treatment plants and all the industrial facilities in their area that discharge directly into the Main. Restrictions may be placed on operations in accordance with water legislation decisions. In addition, orders can be issued for oxygen aeration at the power plant turbine in Kleinostheim. It is also desirable to transfer as as much water as is permissible under the operating plan, from the Danube. Sludge removal and dredging in the Main and its tributaries are banned in this situation. As critical aquatic ecology conditions will become more frequent with the increasing impacts of climate change, the alarm plan will also support adaptation to climate change.
Timeframe of implementation:	-
Costs/financing	-

Participants	Government of Lower Franconia, Aschaffenburg and Bad Kissingen water authorities, other affected authorities such as the Bavarian State Ministry of the Environment and Consumer Protection, Waterway and Shipping Directorate South, Lower Franconia Police Headquarters, the District of Lower Franconia, affected district authorities and administratively independent towns of Lower Franconia, the governments and districts of Lower Franconia and Middle Franconia and the regional councils in Hessen and Baden-Württemberg
Challenges, solutions and successes	✓ In the hot and dry years 2015, 2018 and 2019 the threshold values for water temperature, oxygen content and discharge were reached. On the Main the advance warning and warning levels were reached on several occasions and sometimes lasted for several weeks. In 2018, the “alarm” level under warning level 1 was reached for several days. Damage to the aquatic ecology was avoided as a result of the strategy to transfer water from the Danube, the use of turbine aeration at the Kleinostheim power plant and the cautious behaviour of local residents, businesses and water users - who were made aware through the Alarmplan Main Gewässerökologie (Main aquatic ecology alarm plan).
Contact	Government of Lower Franconia
Further information	• Regierung von Unterfranken (2019): Alarmplan für den bayerischen, staugeregelten Main - Gewässerökologie. Link: *www.regierung.unterfranken.bayern.de/mam/aufgaben/bereich5/sg52/2019_06_alarmplan_main.pdf* • Regierung von Unterfranken: Alarmplan für den bayerischen, staugeregelten Main - Gewässerökologie. Link: *www.regierung.unterfranken.bayern.de/aufgaben/177673/177696/eigene_leistung/el_00288/index.html*

6 Strategic fields of action

6.1 Introduction

Water management resource concerns with respect to climate change have been presented in the preceding chapters and climate adaptation measures have been laid out for the individual issues. A long-term structured approach is recommended for maintaining a high level of coherence between the principles, measures and further development of water management actions within a climate adaptation strategy. In addition to the strategies of the federal states, the German Strategy for Adaptation to Climate Change (DAS - Deutsche Anpassungsstrategie), for example, proposes a cyclical approach (Fig. 16), which has been incorporated here as an outline for the following discussion.

Fig. 16: Cyclical approach to climate-change adaptation (Source: BBSR 2016).

In order to implement the individual steps, various questions, which are described in the following sections, must be addressed. Through the DAS, the German federal government offers support to the states and municipalities. These can take advantage of that support to build on, supplement and expand their own work. The research-based methods and tools developed by the federal government for identifying the effects of climate change, and for developing climate adaptation measures in a uniform and robust manner include:

- The monitoring system[12](UBA 2019), which uses indicators for the 15 DAS fields of action to track climate impacts as well as the effects resulting from adaptation measures will be updated every four years. The Water Balance, Water Management, Coastal and Marine Protection field of action is currently represented by 13 indicators.
- The nationwide vulnerability analysis[13], developed according to a standardised methodology, identifies future climate impacts on 8 water management issues and proposes courses of action. The vulnerability system is currently being updated, the update is due to be published in 2021.

[12] https://www.umweltbundesamt.de/publikationen/monitoringbericht-2019
[13] https://www.umweltbundesamt.de/publikationen/vulnerabilitaet-deutschlands-gegenueber-dem

- Methodological indications and recommendations for analyses of vulnerability and climate impact can be implemented in the various fields of action and in water resources management[14]. The German federal government set up the German Climate Action Portal (KliVoPortal) in 2018 for climate services and services to support actors at regional, municipal and state level as well as companies and civil society in the planning and implementation of preventive measures to combat climate change. The necessary climate data and projections, guidelines, tools, etc. are permanently available on the portal http://www.klivoportal.de/ for decision-makers and other users and are regularly updated. The offer consists of two complementary components. The German Climate Service (DKD)[15] of DWD provides monitoring, forecasting and projection services as a basis for planning and decision-making processes for climate-change adaptation. KlimAdapt, based at UBA, provides additional services to support climate adaptation[16], e.g. tools supporting decision-making. 49 services are available in the field of action water balance/water management.

The elements of DAS listed above assist national and state-level authorities, as well as other stakeholders, in the development of options for adaptation by providing information on conceptual and methodological implementation.

6.2 Concerns – understanding and describing climate change

The first reasonable step is to identify the **concerns** related to climate change with the goal of understanding its consequences and describing them within a regional scope. This objective can only be achieved through a well-developed monitoring programme that regularly provides observational climate data, water management data, and data on the condition of water bodies over periods of many years. In this context, the recommendations of the LAWA AO Small Group on Climate Indicators (LAWA 2017) should be noted, in particular the proposal for development and operation of climate-impact monitoring in water management, using synergies with existing water management monitoring networks.

Sustaining and expanding monitoring

The essential basis for successful climate adaptation strategies and sound decisions on adaptation measures in water management is the regular and continuous collection of high-quality measurement data. It is necessary to obtain multiannual climate-observation datasets as well as basic water management data, such as those compiled by the hydrological services of water management agencies. Additional status variables for the natural systems and water management systems must be incorporated as well.

Further development of monitoring based on existing systems

The monitoring of relevant parameters (e.g. meteorological and hydrological parameters, quality parameters, aquatic flora and fauna, health and hygiene-relevant microbiological parameters) at selected existing sampling stations with long time series, in combination with regular evaluation in the form of a water management review (e.g. every three years) is strongly recommended. An upgrade of existing time series should be considered in the further development of monitoring programmes. Furthermore, design specifications for the monitoring should be based on the spatial scope of the targeted information, i.e. it is necessary to distinguish whether statements reflect a regional focus or whether the respective sampling stations are more indicative of the state or federal level (problem of scale).

[14] https://www.umweltbundesamt.de/publikationen/leitfaden-fur-klimawirkungs

[15] The German Climate Service (DKD – Deutscher Klimadienst) is a network of authorities and public offices that provide regular, reliable and long-term climate information as well as climate services on an operational basis.

[16] KlimAdapt defines climate adaptation services as regularly updated and publicly accessible data, information, advisory services and tools that support decisions (such as planning, investments) and actions to deal with the consequences of climate change.

Making existing monitoring programmes comparable and utilising synergies

It is also useful, in view of the use of observational data in projections and technical models for assessing future climate impacts, to adopt uniform methodologies as early as the observation phase. In doing this, synergies should be pursued among different measurement programmes, possibly facilitating the use of data from other sectors in the assessment of climate impacts (e.g. from agriculture).

Identifying water management indicators

Not only climate change itself, but also its impacts on the hydrological regime can be described and monitored with the help of indicators. As a first step, and with the participation of the responsible federal and state authorities, ten indicators were developed within the framework of the monitoring report on DAS for the Water Balance, Water Management, Coastal and Marine Protection field of action, which reflect climate impacts for groundwater status as well as hydrological, limnological and marine systems based on existing data series. For the second monitoring report (UBA 2019), the indicators were further developed in close cooperation with experts from the federal government and the states in the German Working Group on water issues of the federal states and the federal government and extended to a total of 13 indicators. Some of the indicators were underpinned with extensive data provided by the authorities and the federal states. The goal was to establish a coordinated system of indicators for the water resources management sector, which could be used by the states for their own reporting systems in addition to the climate impact reports of the federal government.

Indicator concepts, where possible, should be developed using the methodological approaches of the DAS. The correlations underlying the indicators should be explained, application constraints and evaluation guidelines should be defined, and selection criteria for measurement networks or gauging stations should be formulated. The objective is to ensure optimised and cooperative procedures between the federal government and the states, and among the states themselves. Within a framework of nationwide coordination, it would be expedient to prioritise the indicators, taking into account their overarching political significance, technical validity, feasibility and costs of implementation.

Interpreting existing measurement series

The compilation and interpretation of long-time measurement series of meteorological, physical, chemical, biological, microbiological and hydrological parameters (precipitation, temperature, run-off, groundwater levels, sea level, changes in aquatic biocoenoses, etc.) and identification of the scientific connections are crucial for assessing the impacts of climate change. Possible future developments can be better evaluated through knowledge and understanding of the natural variability and past changes.

Further development of water- and heat-balance models

Water- and soil moisture regime models for river basins, and heat-balance models for rivers, are appropriate tools for completing the model chain to determine the future influences of climate change on hydrological regime parameters. With regional climate projections as input variables, the effects on all important hydrological regime parameters (e.g. run-off, groundwater recharge, water-body temperature) can be quantified, and possible future conditions can be envisioned. Furthermore, models offer the only possibility for differentiating the various causes of change. Depending on the problem, the spatial resolutions of the models must be adapted and refined.

Ensure availability of data and its suitability for evaluation

All general and observational data and the calculations from regional climate projections should be updated continuously and made freely accessible. Ultimately, this is the only way that decisions for adaptation measures can be made on a broader and more consistent basis. To ensure the availability of data, sufficient human and financial resources must be provided to support an adequately equipped IT infrastructure for data storage, data interpretation and modelling.

Expand public relations work

Data and findings on concerns related to climate impacts should be made available not only to the professional community but also to the general public, through means such as the Open Data Initiative and the implementation of e-government technology. In this context, it is important that analysis and presentation options (e.g. maps) are also offered. In addition, interpretation guidelines and good, target-group oriented public relations work are beneficial.

6.3 Hazards – Identifying and assessing hazards

When information about the concerns is available, both as the interpretations of observational data and summaries, e.g. in the form of indicators, as well as the modelling results for future climate impacts, then analyses of the actual **hazards** associated with climate impacts and assessments of vulnerability in the future can be carried out while taking adaptive capacity into account.

Assessing vulnerability

Assessments of vulnerability combine the concerns regarding climate change with adaptive capacity (UBA 2017; GERICS no year given), i.e. the ability to respond appropriately to the impending changes. The structure of the relationship between the level of concern and sectoral adaptive capacity can, for example, be illustrated via cross-tabulation (Tab. 2).

Example A (Tab. 2) is a recommendation of the Vulnerability Guide and, in principle, it is applicable to all fields of action. Before applying the table in Tab. 2, the concerns must be aggregated and assessed according to the significance of climate impacts.

Example B (Tab. 3) is taken from the climate adaptation strategy of the State of Baden-Württemberg. Here, exposure and sensitivity are taken into account when determining the vulnerability.

In spite of the differing approaches, the comparability of research results is an important objective for sectoral and cross-sectoral climate-impact and vulnerability analyses at both the federal and state levels.

Table 2: Cross-tabulation for determining the vulnerability of a field of action (source: UBA 2017).

Sektorale Anpassungskapazität	Betroffenheit: gering	gering bis mittel	mittel	mittel bis hoch	hoch
gering	gering	mittel	mittel	mittel bis hoch	hoch
gering bis mittel	gering	gering bis mittel	mittel	mittel bis hoch	mittel bis hoch
mittel	gering	gering bis mittel	gering bis mittel	mittel	mittel bis hoch
mittel bis hoch	gering	gering	gering bis mittel	mittel	mittel
hoch	gering	gering	gering	gering bis mittel	mittel

Table 3: Representation of the vulnerability of the hydrological regime taking into account the combination of exposure, sensitivity and adaptive capacity (source: UBA 2017 from: adelphi, PRC, EURAC 2015).

Schwerpunktthema	**Expositi-on**	**Sensitivität + poten-zielle Aus-wirkungen**	**Anpas-sungs-kapazität**	**Vulnerabilität**
Hochwasser	hoch	hoch	mittel	hoch
Niedrigwasser	hoch	hoch	gering	hoch
Gewässerökologie	hoch	hoch	mittel	hoch
Siedlungsentwässerung				
➢ Überflutung	hoch	hoch	mittel	hoch
➢ Regen-/Mischwasser-einleitungen	hoch	hoch	mittel	hoch
➢ Abwasserreinigung	hoch	mittel	hoch	gering
Grundwasser	hoch	mittel	mittel	mittel
Trinkwasser				
➢ Wasserdargebot	hoch	mittel	mittel	gering bis hoch
➢ Infrastruktur	hoch	mittel	mittel	gering bis hoch
➢ Wasserabgabe	hoch	mittel	gering	hoch
Bodensee				
➢ Zirkulationsverhalten	hoch	mittel	mittel	mittel
➢ Niedrigwasser	hoch	mittel	hoch	gering

Estimating ranges – using ensemble techniques

It is common practice to use several emission scenarios or concentration pathways, as well as the combination of a variety of climate models, to assess future climate impacts. These produce a range of different future climate projections within which the change that could occur as a result of climate variation is reflected. In evaluating the plausibility of the climate projections, the accuracy with which the actual conditions of precipitation, temperature and wind are depicted quantitatively and in their spatial distribution is an important assessment criterion. Another important criterion is how well the measured discharges can be simulated by the hydrological models with these as input variables.

Examining realistic time periods

In view of existing and future uncertainties, it is advisable to consider periods of time that are relevant to climate projections when identifying adaptation measures within the individual water management fields of action (e.g. the service life of structures). Water management adaptation measures should be regularly reviewed and upgraded in the light of new results in climate research. The establishment of a 6-year review cycle is recommended as it corresponds well with the implementation stages of the EU water directives.

Prioritising adaptation measures according to concerns

Generally, the effects of climate change should always be kept in mind during planning, measurement, design and similar processes. It may also be necessary to prioritise adaptation measures. This should be based on the impacts on protected assets under consideration. Studies to determine which water management tasks are impacted, and to what extent, can indicate where the most urgent needs for action lie, and help to mitigate potential undesirable consequences, even when their actual magnitudes are not yet known.

Applying uniform approaches

To ensure the comparability of regional and supra-regional vulnerability assessments, agreement on standardised methodologies in the emission scenarios, projections, reference periods, etc., used in regional climate modelling is of critical importance. The application of uniform principles, such as scenario calculations based on the current RCP scenarios, is recommended. DKD and KlimAdapt offer support in this area. LAWA and its technical committees provide a platform for cross-border co-ordination of the principles pertinent to water management.

6.4 Measures – developing and comparing measures

The development and selection of appropriate water management actions, taking into account climate impacts and adaptation options, is very challenging. The following principles can provide guidance in this regard.

Preference for flexible solutions

Flexible win-win and no-regret measures are the preferred option for adaptation measures (e.g. precautionary land use, making provision for structural expansion). These can minimise the risks of prevailing uncertainties because they make it possible to react cost-effectively to new information. For administrative practice, plausible and practicable solutions are preferred. Measures that are important from the perspective of climate change mitigation, but have only limited advantages in future adaptation to the impacts of climate change, can be suitable compromise solutions (low-regret measures).

Testing climate robustness, performing climate checks

Projects and plans that have consequences for the hydrological regime and water quality (e.g. flood and coastal protection, building measures, water abstraction, water use for cooling, discharges to receiving waters) should be evaluated with respect to their robustness vis-à-vis climate change. Some initial instruments are available for this, such as the water management screening tool[17]. Based on a structured survey, measures planned can be assessed with regard to their robustness and flexibility in view of climate change impacts. This is an important decision-making criterion in the planning of measures.

Utilising synergies with other strategies

In addition to the flexibility and robustness of measures, the synergy effects with other strategies should be assessed and, when possible, measures should be preferred that also contribute positively to other objectives. For example, links to nature conservation issues could be worthwhile.

River-basin considerations and the use of management plans

An integrated river-basin-related approach across national and state borders is advisable. The programmes of measures and management plans for implementing the WFD and the flood-risk management plans for implementing the EU Floods Directive must take account of climate change exigencies. These are the appropriate instruments because through them cross-sectoral aspects can also be considered. The adaptation strategies of the International Commissions for the Protection of the Rhine (ICPR 2015)[18] and of the Danube River (ICPDR 2013)[19] also apply here. The potential synergies should be used to ensure the greatest possible efficiency in all areas. Decisions should always be made with attention to cost-benefit aspects.

6.5 Implementation - planning and implementing measures

For the planning and **implementing** water management measures, taking account of climate impacts, consideration of the following points is recommended.

Awareness of conflicting objectives

Conflicting objectives can arise through different uses (for example, the use of river dams for energy production as well as flood retention, increased agricultural irrigation in competition with other forms of water abstraction). Priorities may need to be considered carefully. Here, forward-looking decision-making processes have to be established by water management administrations. Timely and comprehensive communication is necessary in order to prepare the public for possible consequences for temporary periods, e.g. limited tourism activity, restrictions on watering gardens in dry summers, or closed roads during heavy rains (see also section 6.7).

Considering extreme scenarios

If adaptation to extreme events (e.g. flooding or low water) is expressly called for under the precautionary principle and cost-benefit perspective, it may be expedient to take account of the range of variation in the climate projections.

Continued development of warning and alarm services

In view of the expected increase in extreme water management situations, it is reasonable to implement additional precautionary and management measures to minimise damage. These include the further development of appropriate predictive models as well as the continued adaptation and upgrading of warning and alarm services. The focus is increasingly shifting to low water warning and water-temperature forecasting, especially for small water bodies. Further research is needed especially in the prediction of heavy rainfall events.

[17] Preliminary information on the water management screening tool of the German Environment Agency (UBA) : https://www.umweltbundesamt.de/dokument/screeningtool-wasserwirtschaft-methodenentwicklung

[18] ICPR (2015) Strategy for the IRBD Rhine for adapting to climate change. Report No 219, Koblenz: , https://climate-adapt.eea.europa.eu/metadata/publications/strategy-for-the-irbd-rhine-for-adapting-to-climate-change/11279655

[19] ICPDR Strategy on Adaptation to Climate Change https://www.icpdr.org/main/activities-projects/climate-change-adaptation

Strengthening communication and raising awareness

A broad discussion of general societal goals and of the needs of nature conservation, environmental protection and climate change mitigation is vital. Under changing climatic conditions, it is possible that certain levels of protection or other objectives cannot be universally guaranteed over the course of the next 50 or 100 years. There must also be a wider social debate questioning uses that it may not be practicable to continue at previous levels. Furthermore, citizens need to be able to understand why adaptation measures related to climate change are necessary and why the costs of certain services could increase. It is also important to know about the possibilities for personal protection and the options for personal adaptation. Prevention, in contrast to follow-up measures, can also have financial advantages.

6.6 Monitoring & evaluation of adaptation

A quality-assured and comprehensive monitoring programme (see section 6.1) makes it possible to record and evaluate the further development of climate impacts, as well as the effectiveness of measures with regard to those impacts. This is thus an essential prerequisite for follow-up action and further adjustments.[20]

Establishment of review cycles

The EU Water Framework and Floods Directives specify 6-year cycles for the review and updating of the planning of measures. This enables a regular review of the implementation of measures, as well as a consideration of new findings from climate research or monitoring in a timely and structured way. The regular review of measures should thus be standard procedure in all water management planning processes.

Improvement of methods, further development of design procedures

In recent decades there has been a discernible trend of changes in various parameters. However, standard design procedures require the use of consistent parameters. There is a need for practical procedures for adapted extreme-value analysis. Recommendations developed to date on vulnerability analysis and decision-support systems should be applied and, if necessary, further developed on the basis of practical examples (see description of research needs in chapter 7).

Further development of climate models

The improvement of global and regional climate models is continuing steadily. DKD and KlimAdapt will make up-to-date information available on a continuous basis. The needs for addressing specific water management issues (precipitation, temperature and wind, in particular) should be identified, and developments in climate modelling should be followed and tested for their usability. Comparability of sectoral and cross-sectoral climate-impact and vulnerability analyses should be assured.

Sharing experience

The water management administrations of the states, the German federal government, and neighbouring countries should compare their experiences with regard to the evaluation and use of regional climate projections, in order to generate synergies and achieve the most coordinated approaches where technically feasible. This should provide a compatible basis for estimating changes in the hydrological regimes of river basins and for the assessment criteria in determining the urgency of recommendations for action.

[20] An example is Saxony's approach with *impact indicators for hydrological regime and water management* at http://www.klima.sachsen.de/wasserwirtschaft-24147.html.

6.7 Considering conflicting objectives in climate adaptation measures

In general, conflicts arise among the objectives of climate change mitigation, climate adaptation and various fields of action when positively effective measures in one field are disadvantageous or limiting for one or more other fields. Timely recognition of potentially conflicting objectives during the planning of measures is thus essential for a comprehensive and sustainable solution.

However, conflicting objectives often are only revealed as a result of the intensity with which a measure is implemented. For example, a massive increase in biomass cultivation (replenishable raw materials/renewable energy sources) in agriculture can have negative effects on intersectorally networked fields of action (substance input→ surface water/groundwater), nature conservation (monocultures→ species diversity/landscape quality) or agricultural itself (monocultures→ pests). In urban areas, for example, the competition for land is already a limiting factor in rainwater management. Involvement of the potentially affected (conflict-) partners in the planning of (sectoral) programmes of measures is essential. Regional coordination of biomass cultivation, for example, could alleviate further competition, e.g. for agricultural land in food production (Franck 2013). The objectives of water conservation can also be reconciled with agricultural interests if cooperation between water suppliers and farmers fosters the implementation and further development of water-conserving cultivation methods (UFZ 2017).

Water is a basic, universal medium is vital not only for the natural balance, but for almost all spheres of society. Thus, in the following subsections only a few examples of conflicting objectives that develop within the context of water management will be discussed. The list is by no means exhaustive. The sequence of the list does not follow any particular criteria nor does it reflect the intensity of the conflicts.

6.7.1 Agriculture and forestry, fisheries

Flood polder and floodplain connections ↔ Agriculture and forestry

Supplementary flood protection measures include connections to flood polders and floodplains. This improves the flood protection of areas and infrastructures downstream when the design-based flood is exceeded (see LfU BY 2017). The primary problem with this measure is that most of the suitable areas are privately owned or are already being used for agricultural or forestry purposes. Furthermore, retention areas required upstream are most often for the protection of communities along the lower course of a waterway, so a sense of responsibility must be instilled in those not directly affected. Through the construction of flood polders and dikes, the area of usable agricultural land often decreases, which poses a threat to the existence of farms in some cases. Therefore, the authorities cannot convert these areas without compensation and incentives for the owners. In order to reinforce the financial situations of the owners of flood-polder lands, in addition to compensation payments, agricultural uses may be promoted that are compatible with flood protection, such as the year-round use of agricultural land as grassland or intercropping using conservation tillage. This would diversify the range of agricultural products and improve soil properties for water storage and fertility. Despite the conflicting objectives related to agricultural issues, continuation of the national flood protection programme with its existing focus on retention measures with supra-local effectiveness is recommended.

Water erosion and soil compaction ↔ Agriculture and forestry

The compaction of soil and its erosion by water, each of which can be caused or exacerbated by agricultural use, particularly through cultivation, can be further amplified by climatic changes, especially by increases in the amounts and intensity of precipitation and the resulting changes in the soil moisture regime.

The risk of soil loss varies greatly due to small-scale variations in the influencing factors (precipitation, topography, soil structure and cultivation). Relevant information on the erosion risks of soils by water is available in a variety of formats (see State Geological Services). Increases in winter precipitation and of heavy rainfall events in general could lead to accelerated erosion in all of the typically erosion-threatened areas of Germany (e.g. Bavarian Tertiary hills, Kraichgau, Saar-Nahe highland, hill country of Lower Saxony and the loess plains of Lower Saxony).

But there is also a risk of soil erosion even in areas with lower, sometimes barely noticeable relief (as low as 2% slope) (MWKEL RP 2013). These are less conspicuous in the terrain and often do not result in severe damage. However, soil profiles and erosion monitoring reveal that this gradual soil erosion can lead to an eventual loss of the topsoil in many places and over wide areas. This can be accompanied by diminished soil fertility, can damage emerged seedlings, and lead to (nutrient) influx to adjacent ecosystems. However, smaller but relatively frequent precipitation events are also very significant for siltation in water bodies. Changes in land use, which can also be induced in part by climate change, may further contribute to the risk of erosion. But positive effects are also possible. For example, higher annual average temperatures and longer growing seasons can lead to an increase in the intervals of time with ground cover by main, second and catch crops.

Other important factors relating to the risk of water erosion are changes in the parameters that determine soil structure, and thus the aggregate stability and infiltration capacity of the soil.

A high sensitivity to compaction is already evident today in the soils of coastal regions (marshes) as well as the soils of the young moraine landscapes, loess plains and Tertiary hills. Due to the predicted changes in the precipitation regime, with increased precipitation levels in autumn, winter and spring, a regional increase in the risk of soil compaction and soil erosion can be expected, particularly in these areas. Furthermore, a reduction in the number of frost days could impair the physical loosening or breakup of the soil.

In regions where longer growing seasons are projected, increased utilisation potential can be expected, possibly even with two annual harvests. Multiple cultivations within the course of a year, shorter time periods for working the soil and harvesting that involves driving on the land with heavy machines, and unfavourable soil conditions can further increase the compaction risk.

As a result, removed soil material can technically and qualitatively alter adjacent waters into which it is released, and can adversely affect water quality through the input of nutrients and pollutants.

Aside from ground cover, the most important elements for avoiding water erosion include high infiltration and water-retention capacities. Even a ground-cover minimum of over 30 % will significantly help reduce the risk of soil erosion. It is thus crucial to minimise the periods of low ground cover. A key starting point for measures to prevent soil erosion is therefore in the area of cultivation (aid 2015, 2016):

- Establish diverse crop rotations, choice of crop type depending on potential erosion risk
- Conservation tillage: long-term plough-free, non-turning cultivation and mulch sowing, direct sowing where possible
- No winter furrow, leave the gleaning until spring
- Intercropping essentially in summer, possibly also in winter (e.g. after rape and before wheat)
- Leave straw and crop residues on the field
- Plant shorter crops between wide-spaced rows (e.g. corn and sugar beet)
- Use transverse cultivation (avoid downhill tilling, especially wheel tracks)
- Avoid soil compaction (maintain an open pore system down to the subsoil, high infiltration capacity)
- Apply organic matter and lime (preservation of soil structure, high microstructure stability, high water-storage capacity, favourable effects for soil organisms)

Where applicable:

- Long-term greening or refraining from the cultivation of arable land, establishment of permanent grassland and, where appropriate, development of forest areas
- Forego the conversion of permanent grasslands to arable land

Limited water resources ↔ Irrigation

The effects of drought on an area's natural hydrological regime and water-dependent ecosystems can be further exacerbated by water abstraction for irrigation purposes. Low water situations can be particularly severe because the times of greatest water demand usually coincide with the periods of lowest run-off (LfU BY 2016). Officially prescribed abstraction restrictions or bans can adversely affect the economic situations of farmers, so timely coordination in the adoption of measures is recommended (LfU BY 2016). In order to deal effectively with such conflicts, preventive measures are required that must be coordinated at regional or local level, and with the participation of all parties concerned. These include measures to reduce the need for irrigation, for example, a suitable selection of crop varieties, water-conserving soil-treatment measures (e.g. mulch-sowing methods), earlier sowing of summer crops, changes in crop rotation patterns, and the use of water-saving irrigation systems (drip irrigation, reduced irrigation intensity, nozzles instead of sprinklers, irrigation during periods of low evaporation/at night, mobile-controlled irrigation systems) (LfU BY 2016; DWA 2010) In some cases, e.g. in vineyards, the installation of rainwater storage tanks for irrigation can be beneficial and can also promote biological diversity.

Wastewater use for irrigation ↔ Groundwater quality

In Germany, supplemental agricultural irrigation is not yet necessary in most regions. However, a projected increase in the number of dry years due to climate change is expected to lead to increased irrigation requirements and water-use conflicts (Bundesregierung 2008). The DAS (Bundesregierung 2008) mentions the use of treated and microbiologically acceptable wastewater for the irrigation of agricultural land as a possible measure to improve the efficiency of water use. However, the use of treated wastewater poses a potential risk for some crucial protected assets, in particular for human health, soil and groundwater (UBA 2016). These are primarily hygienic risks from pathogens and pollutants that cannot be completely broken down or removed during conventional wastewater treatment (UBA 2016). For its possible use, more advanced wastewater purification/treatment processes will be necessary.

Fisheries ↔ Water supply

Fisheries and fish cultivation in ponds are more or less dependent on the run-off in flowing waters and on precipi-tation, so they could be adversely affected by the trend of decreasing summer rainfall and run-off with a simultaneous increase in evaporation (LfU BY 2016). For example, an assessment based on various climate scenarios with regard to their effects on fish farming in the Naab catchment area revealed that less water would be available in future to compensate for quantitative deficits or to ensure good water quality in the carp ponds studied. If flowing waters are dammed for water withdrawal, low flow volumes and high temperatures may result in oxygen deficiencies and reduced stream continuity.

An increase of the storage volume in ponds, e.g. by deepening, allows fish to be held even when the freshwater supply is interrupted for an extended period, e.g. during low water periods. This can compensate for utilisation conflicts in surface waters, and allows for water retention during the winter months. In principle, draining the ponds during low water levels in autumn can have a positive effect on the discharge into the receiving water as long as siltation is avoided, sludge settling systems are used, and heavily polluted treatment water is removed (LfU BY 2016).

In hydropower plants, a minimum volume of water must be maintained in the discharging pipelines. To raise water levels during low-level situations, public water reservoirs were built to compensate for utilisation conflicts in surface waters, among other purposes. In order to improve water quality during low water levels, measures are also recommended that reduce heat input, provide shade and refrain from damming (LfU BY 2016).

6.7.2 Energy generation

Surface water and groundwater protection ↔ Renewable energy (biomass, hydropower) & natural gas production through fracking and geothermal energy

Conflicting objectives between conventional energy sources and the use of renewable energies arise in relation to water management and the requirements of the WFD for achieving "good status" for all surface waters. The fracking process for natural gas production, for example, is fraught with high risks such as water contamination, regional lowering of the groundwater table, and changes in the physical and chemical properties of surface water and groundwater (UBA 2014). This has resulted in prohibitions or restrictions, particularly in certain rock formations, in the vicinity of drinking water protection zones, medicinal mineral springs, areas with mineral water deposits and in areas prone to flooding (UBA 2014).

The abstraction of water by power plants for cooling and its reintroduction into surface waters can lead to thermal and chemical pollution situations during low water periods (LfU BY 2016). As a precautionary measure, heat-load plans are advisable, which estimate the temperature conditions in low water situations and identify the effects of heat input and possible management measures (LfU BY 2016; StMUV BY 2016).

Increased geothermal use of groundwater can permanently alter the groundwater temperature and thus impact the groundwater ecosystem.

In addition, biomass cultivation contributes significantly to nutrient pollution in surface waters and in groundwater through nitrate leaching and increased soil erosion (UBA 2015b; Taube 2016). The combination of extended growing seasons with an overall decrease in precipitation is accompanied by increased requirements for irrigation, fertilisation and pesticides. In addition, increased leaching and erosion rates can be expected, especially for crops with a high erosion potential (e.g. corn), because of the expected higher frequency of heavy rainfall in the future. To reduce the N balance, innovations in crop rotation schemes (use of oats or grain legumes) or temporary land alternation between feed and market crops are recommended, each with synergies in reducing resistance problems in relation to the use of herbicides (Taube & Verreet 2007).

In order to mitigate the conflicting objectives that exist between agriculture (loss of production areas, loss of income), the need for biomass as an energy source, and water protection, new types of farming and products can offer solutions. Especially in the sensitive areas of water management such as river banks and wetlands (peatland areas, etc.), the cultivation of agricultural timber from native trees for energy production or the cultivation of bulrushes for producing insulating material can provide alternatives to more intensive agricultural uses. Agricultural woods – native softwood floodplain trees - and bulrushes are marketable products. They also retain nutrients, protect against erosion on the banks and slopes (in heavy rainfall and flash floods), and promote increased habitat biodiversity.

In the case of hydropower utilisation, the biological and morphodynamic continuity of the watercourse is interrupted. As a result, the habitat downstream can be disturbed by insufficient water volumes and flow dynamics in residual water stretches, as well as by changes in water depth and flow velocity. The limitations or obstacles for migrating organisms and the water status, however, can be improved by measures such as fish ladders, ensuring a minimum water flow, or by innovative concepts for hydropower use (StMUV BY 2012). The same applies to the avoidance of surge or "hydropeaking".

6.7.3 Tourism

Limited water resources ↔ Artificial snow

In regions where future snowfall levels are uncertain, efforts to preserve ski tourism through intensive use of artificial snow will require enormous water and energy expenditures as well as nature and landscape interventions (Abegg 2011; LfU BY 2008; Hamberger et al. 2015). This can exacerbate water usage conflicts as well as run-off and erosion on ski slopes due to the levelling and widespread disturbance of the topsoil that often accompanies such activities. Furthermore, the landscape and natural hydrological cycle are affected by the additional construction of reservoirs and pipes (Abegg

2011; Dietmann & Kohler 2005). Measures to mitigate these negative effects, such as restricting the further development of artificial snowmaking systems, proper re-greening of slopes, or the expansion of tourism services that do not rely on snow, can be found in Dietmann & Kohler (2005), for example.

<u>Biological pressures ↔ Swimming and recreational boating</u>

Conflicting objectives between water protection and tourism can also arise in summer under certain conditions. When increased levels of microbial activity are present in water bodies during periods of low run-off and high temperatures, health hazards for bathers may be a problem (LfU BY 2016). In addition, the sense of comfort and well-being of bathers and recreational boaters may be upset by the proliferation of macrophytes and filamentous algae. Recommendations for water-friendly management of these challenges include selective mechanical removal (“mowing”), which does not advance the undesirable spread of certain macrophyte species, and general measures to improve water quality and reduce nutrient inputs (LfU BY 2016). Compliance with good agricultural practice is essential.

6.7.4 Globalisation

Globalisation has not only created a worldwide network for the production and consumption of products, but also a global import and export network of water that is part of the production process (→ virtual water). The importation of water-intensive products externalises a proportion of a region's effective water consumption, which can lead to social conflicts and negative ecological impacts in dry production regions (see water footprint network 2017). In addition, a close connection between the uncertainty of water supply and socio-economic conflicts (water wars, migration waves) has been established, which can be expected to worsen in future due to climate change (World Bank Group 2016). In this connection, the World Bank (World Bank Group 2016) emphasises the opportunity to steer the global management of water resources towards climate sustainability through political goals, targeted dialogue with stakeholders, and the elimination of counterproductive incentives. These should primarily focus on better planning of the allocation of water resources, incentives for the use of water-efficient technologies, and investments in reliable water-supply infrastructures.

7 Research and development needs

7.1 General and overarching research and development needs

With increasing understanding of the interrelationships among the fields of meteorology, hydrometeorology, and hydrology, as well as the issues discussed in the 15 fields of action for water management, the existence of numerous causal relationships is becoming clear. These are not always obvious, and sometimes they only become apparent or relevant when they are openly exposed, for example, by self-reinforcing processes, conflicting objectives, or as a consequence of other measures.

Reliable fundamental data with sufficient spatial and temporal resolution are an indispensable element in the understanding of processes in and among the fields of water management. In addition to the resulting requirements for current water management activities, there is also a need for research and development (R&D) in this context. This includes, for example:

- Professional data-collection and archiving systems, standardisation of databases, data storage and data quality
- Development and standardisation of indicator concepts (see LAWA 2017)
- Development of scaling conventions for the transfer of data, methods and models in different spatial systems, e.g. from the federal to state level or from the river basin to the sub-basin
- Improvement in the assessment of events or the design rules, e.g. through extreme value analysis for transient measurement series
- Further development of models and tools for the better projection of extreme events
- Based on existing knowledge (measurement data and models), other issues related to water management are also identified as areas requiring further R&D in climatology and meteorology.
- Models: minimising systematic model errors, improving bias correction methods; improving consistency in coupling meteorological and hydrological models; development of robust methods for regionalising model data for river catchment areas
- Heavy rainfall: combining spatial data (radar) and long measurement series; tracking precipitation cells, identifying geographical hotspots; high-resolution climate projections
- Impact of methane on climate change: There are pertinent findings regarding the greenhouse gas methane, which has an even stronger greenhouse effect than CO_2, that suggest a more far-reaching trend that may strongly exacerbate climate change It is therefore essential to investigate the development of methane emissions as a feedback process from already prevailing climatic changes (increased emissions from permafrost and methane hydrates) and integrate them into the General Circulation Model (GCM).
- Since 2001 the strength of the thermohaline circulation (THC) has been measured by the RAPID project at 30ºN in the North Atlantic. The THC transports warm equatorial surface waters via the Gulf Stream to the high latitudes where it then descends to greater depths in the northwest Atlantic and is subsequently transported southwards as deep water. During the early years of the RAPID measurements, the strength of the THC and Gulf Stream diminished (Rahmstorf et al. 2015). Concurrently, measurements of sea-ice cover in the Arctic show a sharp decline in recent years. Observations have indicated a connection between the melting of sea ice and the occurrence of severe winters in the northern hemisphere. However, climate models so far indicate only minor correlations here, and these vary from model to model, so the climate projections cannot adequately portray this connection (Screen 2017). In this context, we refer to the IPCC Special Report Ocean and Cryosphere (section 4.3.1) published in 2019.

The R&D needs described here are very diverse and include basic data as well as process understanding and regional and transregional considerations. Because all of the federal states are affected by climate change, many of these issues are currently being intensively addressed at the state level as well. Therefore, an important initial step for continued work would be to consolidate this work in order to pool the knowledge and make it generally available.

Starting in 2018, the federal government will make all federal services for climate adaptation available through the German Climate Action Portal (KliVoPortal - Deutsches Klimavorsorgeportal). The portal is the hub for a large number of climate and climate adaptation services that are quality-assured and can be accessed by a wide range of users. In the future, the federal states will also be able to incorporate their services and tools and make them available to a large user group.

7.2 Influence of climate change on water-quality parameters

Measures for improving water quality could change in the future due to climate change, both in terms of their effectiveness and costs.

It has already been recognised in management plans, e.g. at FGG Weser[21], that climate change will also have an impact on the material balance of rivers and lakes, as well as on the biocoenoses, due to changes in seasonal run-off and temperature patterns. To the extent that changes in biocoenoses occur due to climate change, R&D needs are identified on the basis of when adaptations are required, both in terms of water-quality measures and ecological objectives, in response to the changing conditions.

There is also a need for research into the secondary effects of a modified precipitation regime on water quality. For example, the relationships between changes in heavy rainfall patterns, altered effluent discharges from special sewage structures, and the effects on water quality should be noted here, with regard to changes in both morphological and material impacts.

7.3 R&D needs in modelling, tools and applications

The diverse and complex interrelationships of climate research require advanced development of efficient computer models. The individual influencing factors on global warming can only be validated and delimited through the use of more powerful models. In addition to the greenhouse gases CO_2 and methane, there is a complex interaction among the effects of ocean currents, solar insolation, atmospheric processes, polar ice caps and volcanic eruptions.

The continued development of impact models is necessary in order to better estimate the consequences of climate change. Above all, conventions for file formats and the use of appropriate interfaces in the impact models are required to avoid time-consuming and labour-intensive conversions of file formats, and to be able to utilise climate projection data quickly and with minimal loss.

Statistically valid measurement series provide dependable evidence of climate change, but successful strategies for adapting to climate change demand more reliable medium-term projection data for pre-defined planning periods. Adaptation measures in the infrastructure field generally take several decades to implement and require high levels of investment. Validated planning data are of great importance.

With regard to modelling, it is necessary, for example, to bundle computing capacities and to provide centralised computing services for optimising expertise and resources, or for federal states that cannot accomplish this on their own. This would enable all interested parties and states to carry out regionally specific climate analyses and modelling. Professional data-collection and storage systems are also essential for well-structured and efficient handling of extremely expansive climate-projection data and results.

7.4 Spatial distribution and temporal changes of heavy precipitation events

There is still comparably little knowledge on the short-duration heavy rainfall that primarily occurs during the summer months in central Europe. There are some indications of an increase in the intensity of

[21] http://www.fgg-weser.de/gewaesserbewirtschaftung/handlungsfelder/klimawandel

convective events with increasing temperature. But for events of short duration there is still a need for research.

The climatological assessment of spatial and temporal changes in short-duration heavy rainfall requires precipitation data over long time series and covering extensive geographic areas. Long time series of high-resolution measurements of precipitation up to now only exist for relatively few stations. Over the past 15 years there have been additional automated, high-resolution in-situ measurements of precipitation from the DWD measurement network and the states from more than 1,000 stations nationwide. Radar measurements record heavy precipitation over a wide area, with a time period covered by the data currently on the order of 16 years. Combining the two types of measurements, ground and radar, can thus expand our knowledge of the spatial distribution and temporal changes of heavy rainfall events in Germany. This, however, requires continued research.

For predictions on the future development of short-term heavy precipitation, it is essential to use simulations based on convection-allowing models. Although a number of such projections already exist for spatially limited areas, the data foundation for large-scale ensemble evaluations is only now being systematically created. There is still a need for further research in this area.

7.5 Examples of adaptation research

7.5.1 Further development of rainwater management elements

In addition to other important water management procedures, rainwater management methods are particularly significant because they support the natural processes of the hydrological regime, reduce material and hydraulic pollution in groundwater and surface waters, and address the impacts of climate change indirectly (use of rainwater) and directly (reduction of flood risk). Development and R&D requirements are therefore identified for the following areas, among others (DWA & DVGW 2016):

- Application of measurement technology in the drainage system in order to gain a better knowledge and understanding of the hydrological processes in the sewerage system and in the specialised structures; this particularly concerns the characteristics of the special structures for discharge into the receiving waters.
- Further development of seepage methods with regard to quantity and treatment (area seepage, troughs, trenches, infiltration shafts), especially in combination with evaporation (including for cooling).
- Development and investigation of other methods (decentralised/centralised) for targeted cleaning of rainwater, in particular road run-off or rainwater from industrial yards or metal roofs.
- Investigation and implementation of land-use-efficient ("combination") solutions for decentralised rainwater management, especially in the case of heavy rainfall, taking into account the competition for land in urban areas.
- Development and study of multi-purpose areas for climate-robust and water-sensitive urban redevelopment, as a decision-making aid for city planning.

7.5.2 Further development of water-management-compatible agricultural and forestry practice

- A research project will be carried out to specifically investigate the anticipated changes in land use as a result of climate change, and the resulting consequences for water management concerns, particularly relating to groundwater and surface waters. The project will develop suggestions for solutions to the conflicting objectives between agriculture and forestry, water resources management, climate change mitigation and nature conservation, as well as appropriate suggestions for adaptation measures. This includes identifying suggestions for improvements to good agricultural practice, with a particular focus on water management issues and erosion protection.

- Of particular interest is the in-depth study of alternative cultivation systems (e.g. paludiculture) and products (industrial timber and bulrushes), and their impacts on water management, such as pollutant and nutrient retention and erosion control. The water management benefits should be put into perspective with regard to macro-economic benefits and effects on farming/businesses. The project should also develop and examine practical farming methods, including harvesting times, machine use, planting technology, etc. In various farms representative of the geographical conditions in Germany (climate, soil condition, relief, etc.), model operations that provide examples of best practice should be supported.

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List of abbreviations

APA	The Adaptation Action Plan
ASG	Abflussanteile aus Schnee- und Gletscherschmelze im Rhein und seinen Zuflüssen vor dem Hintergrund des Klimawandels“, a project on the snow- and glacier-melt components of streamflow of the river Rhine
AWG	Abfallwirtschaftsgesellschaft Kreis Warendorf, a municipal waste management company
BAG	Bundesamt für Güterverkehr – Federal Office for Goods Transport
BASt	Bundesamt für Straßenwesen – Federal Highway Research Institute
BauGB	Baugesetzbuch – Federal Building Code
BAW	Bundesanstalt für Wasserbau – Federal Waterways Engineering and Research Institute
BfG	Bundesanstalt für Gewässerkunde – Federal Institute of Hydrology
BSH	Bundesamt für Seeschifffahrt und Hydrographie – Federal Maritime and Hydrographic Agency
CMIP5	Coupled Model Intercomparison Project Phase 5
DAS	Deutsche Anpassungsstrategie an den Klimawandel – German Strategy for Adaptation to Climate Change
DJF	Meteorological winter quarter of the year: December, January, February
DKD	Deutscher Klimadienst – German Climate Service
DWA	Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall – German Association for Water, Wastewater and Waste
DWD	Deutscher Wetterdienst - German Meteorological Service
EBA	Eisenbahn-Bundesamt - Federal Railway Authority
ELWIS	Elektronischer Wasserstraßen-Informationsservice - Electronic Waterway Information Service
EU-VO	EU regulation
need for R&D	Research and development needs
FeWIS	Feuerwehren-WetterInformations-System – Fire Brigade Weather Information System
FFH-Schutzgebiete	Fauna-Flora-Habitat-Schutzgebiete - sites protected under the Habitats Directive.
GCM	Global Climate Model
GDWS	Generaldirektion Wasserstraßen und Schifffahrt – Federal Waterways and Shipping Agency
gfP	gute fachliche Praxis - good agricultural practice
HELCOM	Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea Area
HQ_{100}	Flood run-off with a recurrence interval of 100 years
HWRM-RL	EU Floods Directive
IKSD	International Commission for the Protection of the Danube River (ICPDR)
IKSR	International Commission for the Protection of the Rhine (ICPR)
IMO	International Maritime Organization
INKA BB	Innovationsnetzwerk Klimaanpassung Brandenburg Berlin, a climate adaptation innovation network
IPCC	Intergovernmental Panel on Climate Change
JJA	Meteorological summer quarter of the year: June, July, August
KAREL	"KlimaAnpassung des Regenwassernetztes von Elmshorn und UmLand", a climate adaptation project
KHR	Kommission für die Hydrologie des Rheingebietes, commission for the hydrology of the Rhine region

KLAS	"Klimaanpassungsstrategie - Extreme Regenereignisse", a climate adaptation project
KlimAdapt	Dienste zur Unterstützung der Klimaanpassung, climate adaptation support services
klimAix	"Klimagerechte Gewerbeflächenentwicklung in der Städteregion Aachen", a climate-resilience project
KLIMBO	"Klimawandel am Bodensee", a climate-change project at Lake Constance
KLIMOPASS	"Klimawandel und modellhafte Anpassung in Baden-Württemberg", an adaptation programme
KliStaR	"Anpassung an den Klimawandel durch Stärkung des Wasser- und Bodenrückhalts im Einzugsgebiet der Glems", an adaptation pilot project
KliVoPortal	Deutsches Klimavorsorgeportal - German Climate Action Portal
KLIWA	"Klimaveränderung und Konsequenzen für die Wasserwirtschaft", a cooperative project for water resources management under climate change
KoSaH	"Kooperation Sanierung Hausentwässerung" programme
KUK	"Klimawandel und Kanalnetzberechnung" project
KUP	Kurzumtriebsplantagen - short rotation plantation
LAWA	Working group on water issues of the Federal States and the Federal Government
MAM	Meteorological spring quarter of the year: March, April, May
MHQ	Mean high water run-off
MiRO	Mineralölraffinerie Oberrhein oil refinery
MQ	Mean run-off
MSL	Mean sea level
MSFD	EC Marine Strategy Framework Directive
NOK	Nord-Ostsee-Kanal, North-Baltic Sea canal
OSPAR	Oslo-Paris Convention for the Protection of the Marine Environment of the North-East Atlantic
ProWaS	"Klima und Wasser - Projektionsdienst für Wasserstraßen und Schifffahrt" pilot project
RCP scenarios	Representative Concentration Pathway - IPCC 2014 emission scenarios
REGKLAM	"Entwicklung und Erprobung eines regionalen Klimaanpassungs - programms für die Modellregion Dresden" research project
RISA	"RegenInfraStrukturAnpassung" project
SON	Meteorological winter quarter of the year: September, October, November
SRES scenarios	Special Report on Emission Scenarios - IPCC 2000 emission scenarios
TBT	Tributyl tin
ÜSG	flooded area
WETRAX	"Weather Patterns, CycloneTracks and related precipitation Extremes – Auswirkungen des Klimawandels auf großflächige Starkniederschläge in Süddeutschland und Österreich: Analyse der Veränderungen von Zugbahnen und Großwetterlagen" research project
WHG	Gesetz zur Ordnung des Wasserhaushalts (Wasserhaushaltsgesetz) – German Federal Water Act
WFD	EC Water Framework Directive
WSV	Federal Office for Wasserstraßen- und Schifffahrtsverwaltung des Bundes – the Federal Waterways and Shipping Administration
ZU	Environmental targets (ETs) for marine protection

Annexes

Annex I: List of references and links to web content published by the federal and the federal government

Federal state, federal government, working group	Literature	Links
LAWA	LAWA (2010): Strategiepapier „Auswirkungen des Klimawandels auf die Wasserwirtschaft“ - Bestandsaufnahme und Handlungsempfehlungen. LAWA (2007): Leitlinien für ein nachhaltiges Niedrigwassermanagement. LAWA (2013): Musterkapitel „Klimawandel“ für die zweiten Bewirtschaftungspläne der WRRL. LAWA (2013): Musterkapitel „Klimawandel“ für die Hochwasserrisikomanagementpläne.	http://www.de-ipcc.de/ http://www.mpimet.mpg.de/wissenschaft/modelle/ https://www.dwd.de/DE/leistungen/klimastatusbericht/publikationen/ksb2008_pdf/a2_2008.pdf?__blob=publicationFile&v=1 http://www.deltawerken.com/Der-Deltaplan/582.html http://www.kliwas.de/KLIWAS/DE/Home/homepage_node.html http://www.climate-service-center.de/ http://www.hzg.de/institutes_platforms/coastal_research/system_analysis/index.php.de https://www.nlwkn.niedersachsen.de/fsk/fsk_forschungsprojekte/harbasins-harmonised-river-basins-strategies-north-sea-183485.html www.nid.bayern.de http://www.ospar.org/ http://www.helcom.fi/ http://www.waddensea-secretariat.org/ http://www.bafg.de/Baggergut/DE/04_Richtlinien/IMO_Convention.html
Brandenburg	Hochwasserrisikomanagementpläne für den deutschen Teil der FGG Elbe und der FGE Oder. Ministerium für Ländliche Entwicklung, Umwelt und Verbraucherschutz des Landes Brandenburg (2008): Maßnahmenkatalog zum Klimaschutz und zur Anpassung an die Folgen des Klimawandels. Ministerium für Umwelt, Gesundheit und Verbraucherschutz (2014): Verbesserung des Landschaftswasserhaushaltes in Brandenburg - Bericht zum Förderprogramm 2002 bis 2012. Landesamt für Umwelt Brandenburg (2016): Klimareport Brandenburg 2016 - Das Klima von gestern, heute und in Zukunft. Landesamt für Umwelt Brandenburg (2016): Posterreihe Klimawandel in Brandenburg DWD (2019): Klimareport Brandenburg Fakten bis zur Gegenwart – Erwartungen für die Zukunft. 1. Auflage, Deutscher Wetterdienst, Offenbach am Main, Deutschland, 44 Seiten	https://mluk.brandenburg.de/mlul/de/umwelt/wasser/hochwasserschutz/hochwasserrisikomanagementrichtlinie/risikomanagementplaene/ https://lfu.brandenburg.de/cms/media.php/lbm1.a.3310.de/mk_klima.pdf http://www.lfu.brandenburg.de/cms/media.php/lbm1.a.3310.de/fb_150.pdf https://www.dwd.de/DE/leistungen/klimareport_bb/klimareport_bb.html http://www.lfu.brandenburg.de/cms/media.php/lbm1.a.3310.de/Plakate-Klimawandel.pdf

Berlin	Senatsverwaltung für Stadtentwicklung und Umwelt (2014): Klimaanpassung für Berlin Maßnahmen und Beispiele. Senatsverwaltung für Stadtentwicklung (2011): Stadtentwicklungsplan Klima Urbane Lebensqualität im Klimawandel sichern. Senatsverwaltung für Stadtentwicklung und Umwelt (2016): Stadtentwicklungsplan Klima Konkret. Klimaanpassung in der wachsenden Stadt. Reusswig, F.; Becker, C.; Lass, W.; Haag, L.; Hirschfeld, J.; Knorr, A.; Lüdeke, M.K.B.; Neuhaus, A.; Pankoke, C.; Rupp, J., Walther, C.; Walz, S.; Weyer, G.; Wiesemann, E. (2016): Anpassung an die Folgen des Klimawandels in Berlin (AFOK). Zusammen-fassung. Potsdam, Berlin. Senatsverwaltung für Umwelt, Verkehr und Klimaschutz (2019): Berliner Energie- und Klimaschutzprogramm 2030. Berlin.	http://www.inka-bb.de/ http://www.kuras-projekt.de/ https://www.stadtentwicklung.berlin.de/planen/stadtentwicklungsplanung/download/klima/step_klima_broschuere.pdf https://www.stadtentwicklung.berlin.de/planen/stadtentwicklungsplanung/download/klima/klimaanpassung_broschuere.pdf https://www.stadtentwicklung.berlin.de/planen/stadtentwicklungsplanung/download/klima/step_klima_konkret.pdf https://www.berlin.de/senuvk/klimaschutz/klimawandel/download/afok_zusammenfassung.pdf https://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/ib411.htm https://www.berlin.de/senuvk/klimaschutz/publikationen/download/BEK2030_Broschuere.pdf
Baden-Württem-berg	Ministerium für Umwelt, Klima und Energiewirtschaft (2015): Strategie zur Anpassung an den Klimawandel in Baden-Württemberg. Ministerium für Umwelt, Klima und Energiewirtschaft & LUBW (2017): Monitoring-Bericht zum Klimaschutzgesetz Baden-Württemberg. Teil I Klimafolgen und Anpassung. Baden-Württemberg (2014): Integriertes Energie- und Klimaschutzkonzept Baden-Württemberg (IEKK). KLIWA (2012): Klimawandel im Süden Deutschlands: Ausmaß – Auswirkungen – Anpassung. KLIWA (2016): Klimawandel im Süden Deutschlands: Herausforderungen – Anpassungen	https://um.baden-wuerttemberg.de/de/klima/anpassung-an-den-klimawandel/anpassungsstrategie-baden-wuerttemberg/ http://www.kliwa.de/ http://www.herausforderung-klimawandel-bw.de/ http://www.samuwa.de/ https://www.starkregengefahr.de/baden-wuerttemberg/ https://www.hochwasser.baden-wuerttemberg.de/hochwassergefahrenkarten https://www.lubw.baden-wuerttemberg.de/wasser/starkregen https://seewandel.org/ https://www.lubw.baden-wuerttemberg.de/klimawandel-und-anpassung https://www.igkb.org/aktuelles/klimbo-klimawandel-am-bodensee/

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Bremen	Der Senator für Umwelt, Bau und Verkehr (2015): Umwelt in Bremen und Bremerhaven - Umweltzustandsbericht 2015. Der Senator für Umwelt, Bau und Verkehr (2012): SUBV-Fachkonzept - Klimawandel in Bremen – Folgen und Anpassung. Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz (2007): Generalplan Küstenschutz Niedersachsen/Bremen -Festland-. Der Senator für Umwelt, Bau und Verkehr (2015): KLimaAnpassungsStrategie Extreme Regenereignisse (KLAS).	http://www.ikzm-strategie.de/ http://www.klas-bremen.de/sixcms/detail.php?gsid=bremen02.c.738.de https://bresilient.de/ https://www.bauumwelt.bremen.de/umwelt/klima_und_energie/klimaanpassung/anpassungsstrategie_an_die_folgen_des_klimawandels_fuer_das_land_und_die_staedte_bremen_und_bremerhaven-60162
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Mecklen-burg-Vor-pommern	Ministerium für Wirtschaft, Arbeit und Tourismus M-V (2010): Aktionsplan Klimaschutz Mecklenburg-Vorpommern - Teil A Grundlagen und Ziele Ministerium für Wirtschaft, Arbeit und Tourismus M-V (2016): Aktionsplan Klima-schutz Mecklenburg-Vorpommern - Teil B Klimaschutzaktionen Ministerium für Wirtschaft, Arbeit und Tourismus M-V (2010): Studie: „Folgen des Klimawandels in Mecklenburg-Vorpommern 2010". Regionaler Planungsverband Vorpommern (2011): Raumentwicklungsstrategie Anpassung an den Klimawandel und Klima-schutz in der Planungsregion Vorpommern. Regionaler Planungsverband Westmecklen-burg (2010): Analyse der Risken und Chancen des Klimawandels für die Region West-mecklenburg Regionaler Planungsverband Vorpommern (2012): Raumentwicklungsstrategie Anpas-sung an den Klimawandel und Klimaschutz in der Planungsregion Vorpommern – Phase II Anstieg des Meeresspiegels und Entwicklung im Küstenraum Regionaler Planungsverband Vorpommern (2013): Raumentwicklungsstrategie Anpas-sung an den Klimawandel und Klimaschutz in der Planungsregion Vorpommern – Phase II "Planungsgrundlagen zur Bewältigung des Meeresspiegelanstiegs" Regionaler Planungsverband Vorpommern (2018): Raumentwicklungsstrategie Anpas-sung an den Klimawandel und Klimaschutz in der Planungsregion Vorpommern – Grundwassernutzung im Klimawandel Regionaler Planungsverband Westmecklenburg (2010): Analyse der Risken und Chancen des Klimawandels für die Region Westmecklenburg Regionaler Planungsverband Westmecklen-burg (2012): Klimawandel – Regional-planerische Anpassungsstrategien Ministerium für Energie, Infrastruktur und Digitalisierung M-V (2018): Klimareport Mecklenburg-Vorpommern 5. Regionalkonferenz des Bundes und der Norddeutschen Länder (2018): Herausforde-rung Infrastruktur – Strategien und Maß-nahmen zur Anpassung an die Folgen des Klimawandels Ministerium für Landwirtschaft und Umwelt M-V (2010): Maßnahmenkonzept zur Anpassung der Wälder Mecklenburg-Vorpommerns an den Klimawandel Ministerium für Landwirtschaft, Umwelt und Verbraucherschutz M-V (2015): Broschüre "Überflutungsvorsorge – aktiv und planvoll", Eine Handlungsempfehlung für Gemeinden	https://www.regierung-mv.de/serviceassistent/download?id=54482 https://www.regierung-mv.de/serviceassistent/download?id=54486 https://www.rpv-vorpommern.de/fileadmin/Ablage/Projekte/Energie-und-Klimaschutz/Dokumente/Raumentwicklungsstrategie_Klimawandel_weboptimiert.pdf https://www.rpv-vorpommern.de/fileadmin/Ablage/Projekte/Energie-und-Klimaschutz/Dokumente/Broschuere_KlimaMoRo_Planungsgrundlagen_web.pdf https://www.ioew.de/publikation/grundwassernutzung_im_klimawandel/ https://www.regierung-mv.de/serviceassistent/download?id=1603976 https://www.regierung-mv.de/serviceassistent/download?id=1609787 https://www.regierung-mv.de/serviceassistent/download?id=21922 https://www.regierung-mv.de/serviceassistent/download?id=1560290

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Nordrhein-Westfalen	Ministerium für Klimaschutz, Umwelt, Landwirtschaft, Natur- und Verbraucherschutz des Landes Nordrhein-Westfalen (2011): Klimawandel und Wasserwirtschaft – Maß-nahmen und Handlungskonzepte in der Wasserwirtschaft zur Anpassung an den Klimawandel. Ministerium für Klimaschutz, Umwelt, Landwirtschaft, Natur- und Verbraucherschutz des Landes Nordrhein-Westfalen (2015): Klimaschutzplan Nordrhein-Westfalen - Klimaschutz und Klimafolgenanpassung. Potsdam-Institut für Klimafolgenforschung (2009): Klimawandel in Nordrhein-Westfalen - Regionale Abschätzung der Anfälligkeit ausgewählter Sektoren. Ministerium für Klimaschutz, Umwelt, Landwirtschaft, Natur- und Verbraucherschutz des Landes Nordrhein-Westfalen (2010): Handbuch Stadtklima - Maßnahmen und Handlungskonzepte für Städte und Ballungs-räume zur Anpassung an den Klimawandel - Langfassung. Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen (2016): Klimawandel und Klimafolgen in Nordrhein-Westfalen. Ergebnisse aus den Monitoringprogrammen 2016. LANUV-Fachbericht 74.	https://www.klima.nrw.de/ http://www.nauwa.de/ https://server.wver.de/index.php/gewaesser/eu-projekte/amice http://www.urbanesturzfluten.de/ http://www.wassersensible-stadtentwicklung.de/ http://www.encoreweb.eu/ http://www.dynaklim.de https://indikatoren-lanuv.nrw.de/kfm-indikatoren// http://starkgegenstarkregen.de/ https://www.lanuv.nrw.de/fileadmin/lanuv/wasser/abwasser/KISS_Bericht.pdf https://www.lanuv.nrw.de/fileadmin/lanuvpubl/3_fachberichte/Fachbericht_86-Klimaanalyse_web-gesichert.pdf

Rheinland-Pfalz	Ministerium für Wirtschaft, Klimaschutz, Energie und Landesplanung Rheinland-Pfalz (2013): Klimawandelbericht - Grundlagen und Empfehlungen für Naturschutz und Biodiversität, Boden, Wasser, Landwirtschaft, Weinbau und Wald. Rheinland-Pfalz Kompetenzzentrum für Klimawandelfolgen (2013): Klima- und Landschaftswandel in Rheinland-Pfalz. Themenblatt Wasser. Rheinland-Pfalz Kompetenzzentrum für Klimawandelfolgen (2013): Auswirkungen des Klimawandels auf die Ressource Wasser in Rheinland-Pfalz. Schlussberichte des Landesprojekts Klima- und Landschaftswandel in Rheinland-Pfalz (KlimLandRP), Teil 2, Modul Wasser. WBW Fortbildungsgesellschaft für Gewässerentwicklung mbH und Informations- und Beratungszentrum Hochwasservorsorge Rheinland-Pfalz (2013): Starkregen - Was können Kommunen tun? KLIWA (2016): Ableitung von Temperaturpräferenzen des Makrozoobenthos für die Entwicklung eines Verfahrens zur Indikation biozönotischer Wirkungen des Klimawandels in Fließgewässern. KLIWA-Heft 20. Ministerium für Umwelt, Energie, Ernährung und Forsten Rheinland-Pfalz (2017): Wasser und Klimawandel in Rheinland-Pfalz. Erkennen - Handeln – Anpassen. KLIWA (2017): Klimawandel im Süden Deutschlands. Herausforderungen –Anpassungen. Folgen für die Wasserwirtschaft. KLIWA (2017): Entwicklung von Bodenwasserhaushalt und Grundwasserneubildung in Baden-Württemberg, Bayern, Rheinland-Pfalz und Hessen (1951-2015), KLIWA-Heft 21 (PDF) KLIWA (2017): Klimawandel in Süddeutschland. Veränderungen von meteorologischen und hydrologischen Kenngrößen. Klimamonitoring im Rahmen der Kooperation KLIWA. Monitoringbericht 2016. Rheinland-Pfalz Kompetenzzentrum für Klimawandelfolgen (2018): Themenheft Klimawandel – Entwicklungen bis heute. Ministerium für Umwelt, Energie, Ernährung und Forsten Rheinland-Pfalz (2018): Auswirkungen des Klimawandels auf die Trinkwasserversorgung. Anpassungsstrategien zur Daseinsvorsorge. KLIWA (2018): Niedrigwasser in Süddeutschland. Analysen, Szenarien und Handlungsempfehlungen. KLIWA-Heft 23.	http://www.klimawandel-rlp.de/ http://www.klimlandrp.de/ http://www.kliwa.de/ https://naturgefahren.rlp-umwelt.de https://wasser.rlp-umwelt.de/servlet/is/1204/ http://www.kwis-rlp.de/de/klimawandelfolgen/wasserhaushalt/

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Saarland	Ministerium für Umwelt, Energie und Verkehr des Saarlandes (2011): INTERREG IV B PROJEKT C-Change - Changing Climate, Changing Lives, Konzeptionelle Vorschläge für die Landesplanung des Saarlandes zur Klimaanpassung und zum Klimaschutz.	http://www.iksms-cipms.org/
Sachsen	Staatsministerium für Umwelt und Landwirtschaft (2015): Klimawandel in Sachsen - wir passen uns an!	https://www.wasser.sachsen.de/index.html https://www.klima.sachsen.de/klimafolgenmonitoring-12477.html http://www.label-eu.eu/uploads/media/DE_LABEL_Climate_change_study_4.1.3_01.pdf http://www.umwelt.sachsen.de/umwelt/wasser/neymo/ https://www.klima.sachsen.de/index.html https://www.smul.sachsen.de/ltv/

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Thüringen	Thüringer Ministerium für Landwirtschaft, Forsten, Umwelt und Naturschutz (2013): IMPAKT - Integriertes Maßnahmenprogramm zur Anpassung an die Folgen des Klimawandels im Freistaat Thüringen.	https://umwelt.thueringen.de/fileadmin/001_TMUEN/Unsere_Themen/Klima/Klimaanpassung/IMPAKT_II_Broschuere.pdf
Internationale Kommissionen zum Schutze der Mosel und der Saar (IKSMS)	Broschüre des INTERREG-Projekts FLOW MS - Aktion 4: "Ermittlung der möglichen Auswirkungen des Klimawandels im Mosel- und Saareinzugsgebiet" (2013)	www.iksms.de/servlet/is/20107/Broschuere-Klimawandel(1).pdf?command=downloadContent&filename=Broschuere-Klimawandel(1).pdf
Internationale Kommission zum Schutz des Rheins (IKSR)	IKSR (2015): Klimawandelanpassungsstrategie für die IFGE Rhein (IKSR-Bericht Nr. 219, 2015). Weitere einschlägige Berichte der IKSR: Abschätzungen der Folgen des Klimawandels auf die Entwicklung zukünftiger Rheinwassertemperaturen auf Basis von Klimaszenarien (IKSR-Bericht Nr. 213, 2014) Darstellung der Entwicklung der Rheinwassertemperaturen auf der Basis validierter Temperaturmessungen von 1978 bis 2011 (IKSR-Bericht Nr. 209, 2013) Aktueller Kenntnisstand über mögliche Auswirkungen von Änderungen des Abflussgeschehens und der Wassertemperatur auf das Ökosystem Rhein (IKSR-Bericht Nr. 204, 2013) Szenarienstudie für das Abflussregime des Rheins (IKSR-Bericht Nr. 188, 2011)	http://www.iksr.org/de/themen/klimaaenderung/
Internationale Kommission zum Schutz der Donau (IKSD)	ICPDR Climate Change Adaptation Strategy (ICPDR 2012) Danube Climate Adaptation Study (2012)	http://www.icpdr.org/main/activities-projects/climate-change-adaptation

Internationale Kommission zum Schutz der Elbe (IKSE)	IKSE (2012): Hydrologische Niedrigwasserkenngrößen der Elbe und bedeutender Nebenflüsse.	http://www.ikse-mkol.org/fileadmin/media/user_upload/D/06_Publikationen/07_Verschiedenes/2012_IKSE-Niedrigwasserkenngroessen.pdf
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Field of action - Inland flood protection and protection against high groundwater levels

Tab. A. 1: Load case climate change

Field of action	Inland flood protection and protection against high groundwater levels
Climate adaptation measure	**Load case climate change**
Objective	The "design load case climate change" should be applied to every new flood-protection structure. It is possible to plan new structures with an added factor to adjust the currently recognised rated value (HQ_{100}), or to build them in such a way as to allow retrofitting in the future with relatively low additional effort. If an adaptation is not technologically possible, communication measures are necessary in order to communicate the changed protection objective.
In response to	Increased high water run-off
Actions	• Assessing the augmentation of design parameters by a climate-change factor • Reserves for later site development (keep area free, shallower slopes,...) • Assessing the sensitivity of the structure to changes in basic data/design parameters
Basis for decision-making	• Information services of the German federal states on flood-prone areas and flood-protection structures • Run-off projections, climate projections • Flood-hazard and risk maps
Responsible stakeholders	Federal states, districts, municipalities, plant operators
Synergies	Also relevant for the Coastal Protection field of action
Factors to be considered	Currently applicable additional costs; uncertainty of the actual future development of extreme run-off; legal certainty in the determination of flood zones
Examples	• Baden-Württemberg has already introduced regional climate-change factors for different annualities. • In Bavaria a climate markup of 15 % has been factored in since 2004. • North Rhine-Westphalia recommends assessing the sensitivity of the structure to changes in basic data or design parameters.

Tab. A. 2: Technology of flood protection

Field of action	Inland flood protection and protection against high groundwater levels
Climate adaptation measure	**Technology of flood protection**
Objective	Flood damages shall be reduced or avoided by the use of flood-protection structures, particularly in residential and cultivated areas that are threatened by floods and in economically developed areas. Maintenance of the systems shall also be guaranteed.
In response to	Increased high water run-off
Actions	• Designation of flood zones • Raising/strengthening of dikes, dams, dwelling mounds, flood-protection walls • Assessment of development reserves and climate markups on protective structures (*see Tab. A. 1*). • Mobile flood-control facilities (sand bags, bulkhead gates, protection walls) • Adaptation/construction of retaining structures (large dams, high water retention basins,…) (*see Tab. A. 96*) • Property protection (*see Tab. A. 34*) • Intensified maintenance • Overflow-proof structural components • Water-body design/maintenance: control and cleaning of rakes, grilles, debris traps to contain debris and flotsam, removal of bottlenecks
Basis for decision-making	• Information services of the German federal states on flood-prone areas and flood-protection structures • Run-off projections • Flood-hazard and risk maps • Operation, warning, and emergency plans
Responsible stakeholders	Municipalities, federal states, plant operators, private individuals
Synergies	-
Factors to be considered	Nature conservation; agriculture; forestry; infrastructure; keeping areas essentially free for natural water retention
Examples	• Planig Polder at Bad Kreuznach on the Nahe river

Tab. A. 3: Reclamation of flood zones and restoration of floodplains

Field of action	Inland flood protection and protection against high groundwater levels
Climate adaptation measure	**Reclamation of flood zones and restoration of floodplains**
Objective	There is great potential in many riverine areas for the reclamation of retention areas to accommodate or delay floodwaters, because around a quarter of the former floodplain areas in Germany are still preserved in their original diverse forms as cut-off meanders and flood channels.
In response to	Increased high water run-off
Actions	• Reconnection of terrain structures with potential for retention (e.g. oxbow cutoffs) • Dismantling of dikes and dams • Removal of bank stabilisation structures • Raising river-bed levels
Basis for decision-making	• Run-off projections • Flood-hazard and risk maps • Information on former wetland areas, oxbows (e.g. historical maps, flood-plain status reports)
Responsible stakeholders	Municipalities, districts, federal states
Synergies	Additional groundwater recharge; raising of low water levels; relevance of wetland areas for conservation and climate change mitigation; restoration of the natural soil moisture regime, nutrient and sediment retention; promotion of a natural run-off regime thus supporting the objectives of the EU WFD (also often the protected areas designated under the EU Habitats Directive→ thereby promoting the Natura 2000 network), the EU MSFD and the EU biodiversity strategy, local recreation and tourism
Factors to be considered	Land-use conflicts (e.g. agriculture); rising water table in neighbouring areas
Examples	• Dike relocation in the Elbe valley floodplain at Lenzen • The Blue Belt (Blaues Band) federal programme

Tab. A. 4: Activation of additional and optimisation of existing retention areas

Field of action	Inland flood protection and protection against high groundwater levels
Climate adaptation measure	**Activation of additional and optimisation of existing retention areas**
Objective	To enhance retention during high water events, new retention areas can be linked to the streams or constructed, and existing retention areas may be optimised. Controlled flood polders, with equal retention volumes, have a more notable effect on the flood peak than uncontrolled polders.
In response to	Increased high water run-off
Actions	• Construction of flood-retention basins, polders • Restoration and reconnection of floodplains (*see Tab. A. 3*) • Integration of control systems in existing flood polders • Emptying existing reservoirs prior to the onset of a flood event
Basis for decision-making	• Information services of the German federal states on flood-prone areas and flood-protection structures • Run-off projections • Flood hazard maps • Floodplain status reports
Responsible stakeholders	Federal states, municipalities
Synergies	The National Flood Protection Programme (NHWSP) supports nationwide effective retention areas and dike relocation.
Factors to be considered	Land-use conflicts with agriculture, forestry and infrastructure
Examples	• Through the flood-protection and ecology project in Hockenheim, flood protection has been improved to the 100-year flood level. As an added benefit, the continuous passage for fish and microorganisms is ensured. • A flood-protection and ecology project was likewise implemented in Rastatt. • Activation of a controlled flood polder in 2013 in Deggendorf for prevention of overflow and failure of the flood-protection facilities • The Blue Belt (Blaues Band) federal programme

Tab. A. 5: Utilisation planning in flood zones and flood-prone areas

Field of action	Inland flood protection and protection against high groundwater levels
Climate adaptation measure	**Utilisation planning in flood zones and flood-prone areas**
Objective	Prudent urban planning should serve to prevent flood damage early on when designating new building areas. Construction designs that are adapted to flooding can be stipulated in building planning law and building permits, or new development in crucial areas can be prohibited.
In response to	Increased high water run-off
Actions	• Flood-adapted planning, construction, renovation • No designation of areas for development • Modification/update of urban land-use plans • Removal/dismantling of flood-sensitive usages • Adapted agricultural use (e.g. grassland) • Switch from oil to gas heating or to renewable energies
Basis for decision-making	• Flood-hazard and risk maps
Responsible stakeholders	Municipalities
Synergies	Areas are suitable as green areas, parks, retention areas, biotopes etc.; improved microclimate; When utilisation plans involve agricultural areas: reduction of nutrient and plant-protection products, thus supporting the objectives of the EU WFD (also often the protected areas designated under the EU Habitats Directive→ thereby promoting the Natura 2000 network), the EU MSFD and the EU biodiversity strategy
Factors to be considered	Strained housing market; land-use pressure; rights of existing landowners
Examples	-

Tab. A. 6: Designation of priority and reserved areas

Field of action	Inland flood protection and protection against high groundwater levels
Climate adaptation measure	**Designation of priority and reserved areas**
Objective	In federal state and regional planning, areas to which particular uses are to be allocated can be designated as priority or reserved areas, and thus also be designated, for example, for preventive flood protection. It is advisable to keep areas free for any future flood relief and flood retention that may become necessary.
In response to	Increased high water run-off
Actions	Establishment of: • Areas intended for dike relocation • Areas for existing or planned flood-retention basins
Basis for decision-making	-
Responsible stakeholders	Federal states, municipalities
Synergies	Nature conservation
Factors to be considered	Land-use conflicts
Examples	• In the Würzburg regional plan, six priority areas for flood run-off and retention were identified for the Main-Spessart district. • Consideration of flood-protection areas (generally flood zones to be established in the future) in the current draft of the state development plan of the Berlin-Brandenburg capital region (LEP HR)

Tab. A. 7: Preparation of flood hazard and flood risk maps

Field of action	Inland flood protection and protection against high groundwater levels
Climate adaptation measure	**Preparation of flood hazard and flood risk maps**
Objective	Flood hazard maps have been prepared for all relevant waters in accordance with the EU Floods Directive, providing information on the possible extent and height of flooding. On the basis of the hazard maps, municipalities can generate weighted risk maps for the objects of protection – environmental quality, human health, economic activities and cultural assets – to plan and optimise preventive measures. The flood hazard maps are regularly updated on the basis of recent flood events. To raise public awareness, it is advisable to regularly inform the public and publish the maps.
In response to	Increased high water run-off
Actions	• Representation of the spatial extent of flood events with various annualities • Representation of the heights of floodwater • Representation of extreme historical events • Representation of floodwater protection facilities • Sufficient level of detail for local assessment and planning • Attention to utility installations and objects with high damage potential (e.g. transformer stations)
Basis for decision-making	-
Responsible stakeholders	Federal states, municipalities
Synergies	Insurance industry
Factors to be considered	-
Examples	• For the municipality of Nordwalde, a flood-protection concept was drawn up together with general drainage planning. • Flood hazard maps and flood risk maps are available for all currently defined flood-risk areas.

Tab. A. 8: Identification and representation of areas at risk of waterlogging (groundwater)

Field of action	Inland flood protection and protection against high groundwater levels
Climate adaptation measure	**Identification and representation of areas at risk of waterlogging (groundwater)**
Objective	Identification of areas with a shallow water table that are a potential risk during high groundwater conditions, and presentation of these areas on publicly accessible maps, may discourage their designation as building sites and help to inform landowners so that they can take protective measures.
In response to	Increasing fluctuation of groundwater levels, rising water table in winter, increase in high water run-off
Actions	• Providing basic data and maps • Information platform on current groundwater conditions and high groundwater levels • Information and advice on waterlogging problems and solutions
Basis for decision-making	• Multiannual measurement series of water-table levels
Responsible stakeholders	Federal states, municipalities
Synergies	Joint mapping of flood hazards and flood risks
Factors to be considered	-
Examples	• Information on current groundwater levels and maps of areas in Saxony-Anhalt at risk of waterlogging

Tab. A. 9: Property protection in the event of dangerously high groundwater levels

Field of action	Inland flood protection and protection against high groundwater levels
Climate adaptation measure	**Property protection in the event of dangerously high groundwater levels**
Objective	Appropriate measures can be taken to protect cellars and building stability from high groundwater levels.
In response to	Increasing fluctuation of groundwater levels, rising water table in winter, increase in high water run-off
Actions	• Sealing house walls through: • "white tank" or "concrete tank" cellar (floor and house wall of water-impermeable concrete), • "black" or "bitumen tanking" (outside sealing with bitumen strips or emulsions) • inside walls and floors (concrete and bitumen strips) • Pressurised water-tight pipe feed-through (drill core and screwable sealing inserts) • No oil tanks in cellars • New buildings without cellars • Deliberate flooding of cellars as an additional weight against destruction of the building by flotation
Basis for decision-making	• Maps with water-table depths/areas at risk of waterlogging • Maximum groundwater level design • Recommendations in municipal guidelines
Responsible stakeholders	Private individuals, municipalities
Synergies	Relatively simple implementation in new buildings
Factors to be considered	Complex technical challenge in retrofitting existing buildings; information and raising awareness are crucial
Examples	• The sports hall of the St. Benno secondary school (Gymnasium) Dresden was seriously at risk of high groundwater levels in 2002. "Quick dams" were set up in the hall to increase the building load and thus prevent a total loss.

Tab. A. 10: Flood partnerships

Field of action	Inland flood protection and protection against high groundwater levels
Climate adaptation measure	**Flood partnerships**
Objective	The aim of the measure is to bring together municipalities, administrative authorities and institutions within a catchment area to increase awareness of flood hazards, to pass on experience in prevention, and to build networks of responsible institutions. The objective is to achieve systematic cooperation among concerned parties.
In response to	Increase in high water run-off
Actions	• Participation of interested parties in the planning of measures • Joint plausibility assessment of flood hazard maps
Basis for decision-making	• Flood risks in catchment areas • Flood hazard and flood risk maps
Responsible stakeholders	Federal states, municipalities, companies, citizens' initiatives, local associations, educational providers
Synergies	Initiation of private prevention measures among the public through increased awareness; better disaster-response coordination in the case of an extreme event
Factors to be considered	Conflicts of interest between communities
Examples	• Flood partnerships in Rhineland-Palatinate • Flood partnerships in Baden-Württemberg, e.g. in the Upper Rhine catchment area

Tab. A. 11: Organised response measures in the case of an extreme event

Field of action	Inland flood protection and protection against high groundwater levels
Climate adaptation measure	**Organised response measures in the case of an extreme event**
Objective	If response measures have already been thought through in advance, it is easier to make the necessary decisions when an incident occurs. Alert and action plans are important for crisis management in municipalities. They are usually structured on multiple levels and designed to respond to as many different incidents as possible. If warnings are given early enough there may be time to prepare some measures in advance.
In response to	Increase in high water run-off
Actions	• Emergency strategies for transportation and supply infrastructure • Flood alerts and action plans • Agreements and cooperation with nearby fire brigades • Improved early warning in affected areas • Mobile warning systems that can inform the public effectively and quickly via media and WarnApps about storms and response measures
Basis for decision-making	-
Responsible stakeholders	Federal states, municipalities
Synergies	-
Factors to be considered	Consideration of alternative scenarios: ruling out of "false alarms"
Examples	• For the rapid and reliable communication of storm warnings to all fire brigades in Germany, the National Meteorological Service has developed a Fire Brigade Weather Information System (FeWIS). • Official disaster warning systems such as KatWarn Nina or the LAWA "Meine Pegel" (my gauge) app

Tab. A. 12: Behavioural preparedness and advanced training

Field of action	Inland flood protection and protection against high groundwater levels
Climate adaptation measure	**Behavioural preparedness and advanced training**
Objective	It is important for the general public, and especially for certain professions, to be informed about expected climate changes, the associated dangers, and the possible measures which can be taken. For example, advanced training for architects and urban planners on the topic of "flood-adapted construction" would be very helpful.
In response to	Increase in high water run-off
Actions	• Inclusion of topics specific to climate change in school and vocational training curricula • Advanced training • Information events • Leaflets, guidelines etc. • Flood-level marks reminiscent of past flooding events • Advice from municipal authorities (e.g. flood assessments) • Support programmes for personal preparedness
Basis for decision-making	-
Responsible stakeholders	Municipalities, federal states
Synergies	Groundwork for the acceptance of multiple additional measures
Factors to be considered	-
Examples	• Flood-level marks in the town of Meißen

Field of action - Coastal protection

Tab. A. 13: Coastal protection by fixed structures

Field of action	Coastal protection
Climate adaptation measure	**Coastal protection by fixed structures**
Objective	Protection of the coast from coastal retreat and erosion can be provided by solid coastal protection structures. Structures perpendicular to the coast protect against erosive currents and affect sediment movement. Structures parallel to the coast (longitudinal structures) reduce the wave surge and protect the shore against erosion.
In response to	Sea-level rise, increase in storm surges and erosion
Actions	Structures perpendicular to coast: • Groynes • Sea embankments Structures parallel to coast: • Breakwaters • Revetments • Seawalls
Basis for decision-making	• Regional climate projections • Current state of the existing structures, the coasts
Responsible stakeholders	Federal states, water and soil associations, municipalities
Synergies	-
Factors to be considered	Often no alternatives in areas with high levels of hydrodynamic impact and erosion; combination of sand replenishment measures to mitigate hydrodynamic impact and protect against colks is necessary; intervention in nature and landscape; interests of tourism have to be considered; follow-up measures may be necessary due to erosion in neighbouring areas; maintenance/repair possibly also necessary
Examples	• Revetment on the west coast of Norderney

Tab. A. 14: Coastal protection through sand replenishment

Field of action	Coastal protection
Climate adaptation measure	**Coastal protection through sand replenishment**
Objective	To combat loss of land on the coasts and to stabilise island foundations, the artificial input of sand can serve as a countermeasure to the erosive effect of the sea. Sand can be pumped either directly onto the beach or into the foreshore area.
In response to	Sea-level rise, increase in storm surges and erosion
Actions	• Beach replenishment (e.g. pumping directly onto the beach through a pipeline) • Foreshore replenishment (e.g. rainbow technique or dumping from a ship in the foreshore area)
Basis for decision-making	• Coastal surveys • Establishment of a base coastline: if the sand falls below this line, there is a need for sand replacement • Current-flow modelling
Responsible stakeholders	Coastal protection authorities, federal government, federal states
Synergies	Protection of dunes and remaining defence structures against undercutting; use of natural materials
Factors to be considered	Ecosystem intervention due to sand extraction and replenishment; Measures must be maintained permanently: continuing costs; possible restrictions of tourist use during replenishment
Examples	• Sand replacement measures on Sylt, Föhr, Langeoog, Norderney, Borkum, Wangerooge, Fischland-Darß-Zingst, Usedom

Tab. A. 15: Coastal flood protection through dikes

Field of action	Coastal protection
Climate adaptation measure	**Coastal flood protection through dikes**
Objective	Dikes and their elements such as forelands, berms and dike protection roads are the most important element of coastal flood protection. This also includes the barrages that make up the dike line. The dikes and the physical structures contained within them should be inspected and adapted to climate change with a climate markup and a construction provision.
In response to	Sea-level rise, increase in storm surges
Actions	• Sea dikes (state-protection dikes, regional dikes, primary dikes) • Secondary dike line • Climate markup and construction provision (*see Tab. A. 1*)
Basis for decision-making	• Safety inspections of the dikes
Responsible stakeholders	Federal states, water and soil associations, municipalities
Synergies	Relatively manageable raising of the dike at a later stage and a rapid response are possible
Factors to be considered	Land usage; intervention in nature and landscape; reusable resources clay and sand
Examples	• Reinforcement of the state-protection dike on a length of 2.7 km off Büsum according to the "climate dike" concept

Tab. A. 16: Coastal flood protection through protective dunes

Field of action	Coastal protection
Climate adaptation measure	**Coastal flood protection through protective dunes**
Objective	Protective dunes provide protection against storm surges and must therefore be safeguarded. Concepts to protect the dunes depend primarily on the sediment balance of the upstream beaches and the hydrodynamic loading. Material losses are to be compensated to safeguard their function in the event of storm surges. A rising sea level increases the amount of sand needed to compensate for material deficits on foreshores, beaches and dunes.
In response to	Sea-level rise, increase in storm surges and erosion
Actions	• Beach replenishment (*see Tab. A. 14*) • Sand filling (if there is enough space on the back side of the dunes) • Stabilisation with vegetation (e.g. beach grass) • Sand trapping with bush fences at the foot of the dunes and planting marram grass
Basis for decision-making	• Current condition and assessments of the protective dunes
Responsible stakeholders	Federal states, municipalities
Synergies	Natural and tourism-attractive solution
Factors to be considered	Ecosystem intervention through sand extraction and replenishment; possible building over areas which are very valuable from a nature conservation point of view; areas must be kept available in advance
Examples	• Dune reinforcements on Juist, Langeoog, Spiekeroog, Wangerooge, Fischland-Darß-Zingst, Hiddensee, Usedom

Tab. A. 17: Coastal flood protection through other flood defence systems

Field of action	Coastal protection
Climate adaptation measure	**Coastal flood protection through other flood defence systems**
Objective	Beside dikes, flood protection for coastal settlements, facilities, infrastructures, etc., can be provided by other structures.
In response to	Sea-level rise, increase in storm surges
Actions	• Dams • Walls • Bulkheads • Flood gates • Dwelling mounds
Basis for decision-making	• Regional climate projections
Responsible stakeholders	Federal states, municipalities, water and soil associations
Synergies	Possible multi-functional solutions such as causeway dams or esplanades
Factors to be considered	May require considerable technical effort and extensive maintenance
Examples	• Railway embankment between Morsum and Keitum on Sylt

Tab. A. 18: Coastal risk management through the designation of building restriction zones or priority and restricted areas

Field of action	Coastal protection
Climate adaptation measure	**Coastal risk management through the designation of building restriction zones or priority and restricted areas**
Objective	Buildings and other vulnerable land uses should be avoided in unprotected or insufficiently protected lowland areas. In regional development and landscape framework plans, areas that may be required for coastal protection structures due to future climate change should be secured and specified as priority or restricted areas. It is very important to preserve available space in these areas for possible necessary future extensions/raising of the existing coastal-protection facilities.
In response to	Sea-level rise, increase in storm surges

Actions	• Prohibition of construction in the dike and foreland and in the dike protection strip
	• Designation of priority and restricted areas for the purposes of:
	  • Raising and widening dikes
	  • Ensuring suitable sand-extraction areas in the coastal foreland areas by designating them as priority or restricted areas
	  • Securing protective dune areas as precautionary land use for coastal protection by designating them as priority or restricted areas

Basis for decision-making	-
Responsible stakeholders	Federal states, municipalities
Synergies	
Factors to be considered	Land-use conflicts
Examples	• The Bremen state water act (Landeswassergesetz Bremen), the Schleswig-Holstein state water act (Landeswassergesetz Schleswig-Holstein) and the Lower-Saxony dike law (Niedersächsisches Deichgesetz) provide the statutory basis for designating building restriction zones in coastal risk areas.

Tab. A. 19: Organised response measures in the case of an extreme event

Field of action	Coastal protection
Climate adaptation measure	**Organised response measures in the case of an extreme event**
Objective	Despite the high level of protection provided by coastal defences, they cannot guarantee absolute security against flooding. If the consequences of measures have been thought through prior to an event, it is easier to make the necessary decisions should such an event occur. Alert and action plans are important for disaster control and hazard aversion. They are usually structured on multiple levels and designed to respond to as many different incidents as possible.
In response to	Increase in storm surges
Actions	• Emergency strategies for transportation and supply infrastructure • Flood alerts and action plans • Improved early warning • Mobile warning systems that can inform the public effectively and quickly via media and WarnApps about storms and response measures
Basis for decision-making	-
Responsible stakeholders	Federal states, districts, municipalities
Synergies	-
Factors to be considered	Publicising of information systems
Examples	• Water-level forecast Mecklenburg-Western Pomerania: https://fis-wasser-mv.de/pegel-mv/pegel_mv.html • Water-level forecast Lower Saxony: https://www.pegelonline.nlwkn.niedersachsen.de/Start

Tab. A. 20: Behavioural preparedness and advanced training

Field of action	Coastal protection
Climate adaptation measure	**Behavioural preparedness and advanced training**
Objective	For their own protection, the public must be informed about possible hazards and the appropriate behaviour. Behavioural preparedness is strongly linked to risk awareness. People who are aware of the risks are usually more willing to take personal precautions. They are also more likely to accept the relatively high costs of coastal protection and other possible constraints.
In response to	Increase in storm surges, sea-level rise
Actions	• Inclusion of topics specifically related to climate change in training curricula • Cross-sector training courses • Information events • Leaflets, guidelines etc. • Support programmes for personal preparedness
Basis for decision-making	-
Responsible stakeholders	Federal states, municipalities, water and soil associations
Synergies	-
Factors to be considered	-
Examples	• The Oder estuary coastal information system offers a wide range of information, such as background material, learning modules and case studies on coastal protection on the Oder estuary.

Field of action - Urban drainage and wastewater treatment

Tab. A. 21: Structural improvement and optimised operation of existing sewage networks

Field of action	Urban drainage and wastewater treatment
Climate adaptation measure	**Structural improvement and optimised operation of existing sewage networks**
Objective	With low flow rates in a combined water system, a high concentration of solids can lead to an accumulation of these substances in the sewage networks. Channels can become blocked, give off unpleasant odours and develop corrosion problems. Simultaneously, the sewer networks are burdened by heavy rainfall. The objective is to evaluate the effects of extended droughts or more frequent heavy rainfall events in excess of the design-basis precipitation, in order to alleviate or minimise the consequences by means of existing measures. It can be assumed that the past design values of the sewage network, statistically speaking, could be classified differently in the future. Discharging untreated mixed water into water bodies should be minimised because the increased pollution burdens aquatic ecosystems.
In response to	Increase in the frequency and duration of dry periods, increased water temperatures, increased frequency and intensity of heavy rainfall events
Actions	Lower flow rate: • Flushing as required (possibly high-pressure flushing and the use of chemicals or machinery) • Hydraulically more effective pipe profiles • Decentralised pressure drainage in individual network sections Minimisation of mixed-water discharge: • Integrated management system • Sewerage system management • Measures for centralised and decentralised rainwater management (*see Tab. A. 24, Tab. A. 26*) • Supervision of the construction of wastewater infrastructures to ensure safe rainwater disposal based on municipal wastewater disposal concepts.
Basis for decision-making	• Analysis of the capacity of existing infrastructures under possible future climate conditions • Identification of system areas with a higher risk of low mixed-water discharge (regular cleaning intervals here) • Regular measurement of deposit levels
Responsible stakeholders	Sewage disposal services, municipalities
Synergies	Reduction of the impact on sewage treatment plants due to adjustments in the sewage system, no further adjustment measures in sewage treatment plants may be necessary
Factors to be considered	High costs; possible higher water usage
Examples	• With the help of a control system for the sewage network in Leipzig, it is possible to actively intervene in the drainage processes and make effective use of reservoir capacity. In addition to this, the city is planning an integrated control system. • As a pilot project, the DWA has developed and implemented the "KliWäss" training module for students, foremen and engineers with the theme "climate-adapted urban drainage". • The Climate Change and Sewage Network Calculation (KUK) project analysed and discussed historical flood events and existing design approaches for sewer networks, and profiled new adaptation strategies.

Tab. A. 22: Adjustments in sewage plant operation

Field of action	Urban drainage and wastewater treatment
Climate adaptation measure	**Adjustments in sewage plant operation**
Objective	Heavy rainfall events can lead to hydraulic congestion in sewage treatment plants. In the event of heavy rainfall, therefore, overflow structures upstream discharge directly into water bodies. The possible increase in future input of pollutant loads places a heavy burden on aquatic ecosystems, which should be limited as far as possible. By improving and stabilising the settling efficiency in treatment tanks, by optimising the feed to secondary settling tanks, or by dynamically increasing the inflow to the plant, a larger quantity of mixed water can be treated more quickly. Higher air temperatures can improve breakdown capacity which, in turn, can save on the required volumes of purification tanks and active biomass.
In response to	Increased frequency and intensity of heavy rainfall events and erosion, increased frequency and duration of dry periods, increased water temperature due to rising air temperatures
Actions	• Aeration tank settling • Optimising the final treatment • Addition of flocculants • Increase and dynamic adjustment of inflow to the wastewater treatment plant • Bypass flow of mixed water into the secondary tank • Reduction of specific tank volumes or active biomass and associated aeration through enhanced breakdown efficiency.
Basis for decision-making	• Analyses of the efficiency of sewage networks and treatment plants with regard to possible future climatic conditions
Responsible stakeholders	Municipalities, urban development planners, sewage treatment plant operators
Synergies	-
Factors to be considered	-
Examples	• In the Dresden-Kaditz sewage treatment plant, large-scale technical tests were carried out with aeration tank settling in conjunction with a rainy weather control system. • A flocculation filter was extended and retrofitted at the Arnstadt wastewater treatment plant. • In the Smart Cities context, the Water Management 4.0 model system offers possibilities for intelligent networking of urban infrastructure, like those implemented in Aarhus and Zurich.

Tab. A. 23: Systems for rainwater treatment

Field of action	Urban drainage and wastewater treatment
Climate adaptation measure	**Systems for rainwater treatment**
Objective	To protect groundwater and surface waters, it is important to remove contaminants from rainwater (polluted through contact with dirty roof or road surfaces) before it seeps into the soil or is discharged into water bodies. Centralised rainwater treatment in separate systems usually takes place shortly before discharge into the water body. Decentralised rainwater treatment is carried out near the source of the polluted rainwater run-off. Semi-centralised systems combine rainwater from several streets, for example, before the discharge facility is reached through a central rainwater collector. Numerous kinds of systems can contribute to improving the water: by retention of water to reduce the hydraulic load and through the effective removal of pollutants, in particular particles smaller than 63 micrometres that can be filtered out.
In response to	Increased frequency and intensity of heavy rainfall events and erosion, pressure on aquatic ecosystems due to the increased frequency and duration of droughts and low water run-offs
Actions	Centralised: • Rainwater sedimentation basin • Reed-lamellar sedimentation • Retention soil-filter basin Decentralised: • Sedimentation shaft, pipe, flume, basin • Vortex, lamellar separator • Filter shaft, flume, cartridge, sack • Seeping (possibly with special filter material) • Wetland green roof
Basis for decision-making	• Maps of areas or catchment areas that could be overloaded by rainwater
Responsible stakeholders	Municipalities, water authorities, businesses
Synergies	Nature conservation
Factors to be considered	-
Examples	• In the form of pilot projects, a modified retention soil filter (Plettenbergstraße) and a reed-lamellar sedimentation system for rainwater purification are being tested in Hamburg.

Tab. A. 24: Centralised and decentralised retention measures in cities

Field of action	Urban drainage and wastewater treatment
Climate adaptation measure	**Centralised and decentralised retention measures in cities**
Objective	Retention measures in cities help to prevent or reduce flooding or mixed-water overflows of the sewage system into the waterways. Contaminated mixed water is temporarily stored centrally and when capacity becomes available again it can be sent to the sewage plant for treatment, and rainwater retained centrally or decentrally can be used by plants or allowed to evaporate.
In response to	Increase in the frequency and intensity of heavy rainfall events
Actions	Centralised: • Rain overflow basin for storage of mixed water • Storage or transport outlet • Retention basins • Rain retention basins and cisterns for storage and use of rainwater Decentralised: • Multifunctional areas that can be used for water containment (roads, car parks, playgrounds, sunken gardens, water areas, etc.) • Green roofs, roof gardens • Green areas (e.g. unpaved tramway lines as lawn strips, lawns, trees, parks, etc.along the side of streets) • Expansion of urban wooded areas • Water areas • Water containment in buildings (water roofs, water cellars) • Cisterns for the storage and use of rainwater • Green-blue roofs (roofs with water retention beneath the green roof)
Basis for decision-making	• Regional rainfall statistics • Analyses of the efficiency of sewer networks and treatment plants with regard to possible future climatic conditions
Responsible stakeholders	Municipalities, city planners, architects, home and property owners
Synergies	Possible use of rainwater for watering plants; low wastewater charges (in case of separate wastewater charges)
Factors to be considered	Land-use conflicts
Examples	• Construction of more transport and storage outlets as part of the Hamburg Elbe relief programme • The KAREL project is developing an integrated and spatially extensive climate adaptation concept for rainwater drainage in the city of Elmshorn and the surrounding communities. A multi-area approach appears to be more promising than small-scale approaches. • The Fischbek rainwater playground in Hamburg is a park with a seepage basin and rainwater basin.

Tab. A. 25: Utilisation of infiltration potential

Field of action	Urban drainage and wastewater treatment
Climate adaptation measure	**Utilisation of infiltration potential**
Objective	To prevent rainwater from overloading the sewerage system, as much surface area as possible should be disconnected from the sewage system and the rainwater allowed to seep into the ground.
In response to	Increase in the frequency and intensity of heavy rainfall events
Actions	• Construction of infiltration systems and ponds, trough-trench systems • Reclaiming of sealed surfaces • Use of water-permeable surfaces (e.g. gravel, lawn paving stones, porous pavements, drainage asphalt pavements) • Improvement of seepage potential (e.g. use of ground-covering plants) • Avoiding soil compaction in green areas
Basis for decision-making	• Maps of infiltration potential • Property-related percolation testing
Responsible stakeholders	Municipalities, urban-development planning, businesses, homeowners
Synergies	More attractive area design; improved microclimate; increased groundwater recharge; possible certification of businesses for environmental measures
Factors to be considered	Seepage prohibition where the rainwater or the surfaces are contaminated, e.g. in known contaminated areas or where there are elevated pollutant levels in the soil; limited infiltration capacity due to soil compaction and low permeability; rising groundwater levels increase the risk of waterlogging at short distances from the surface.
Examples	• The guideline and recommended measures of the klimAix research project were tested at three existing industrial sites in Aachen, Eschweiler and Stolberg. • Rainwater from the schoolyard and roof areas of the Neuling school in Bochum is collected in open gutters, pipes and a waterfall, and then seeps away in a depression. • In the "Im Colm" new development area in the community of Illerich, excess rainwater can seep away in roadside troughs.

Tab. A. 26: Incentives for decentralised rainwater management

Field of action	Urban drainage and wastewater treatment
Climate adaptation measure	**Incentives for decentralised rainwater management**
Objective	Decentralised rainwater management decouples areas from the sewage system, thus preventing sewage system overloads during heavy precipitation. This requires the implementation of various measures on many different small areas. The implementation of decentralised rainwater management by private individuals is facilitated by measures such as legal provisions, subsidy programmes, and public information. Financial incentives for the implementation of decentralised rainwater management are also possible.
In response to	Increase in the frequency and intensity of heavy rainfall events
Actions	• Implementation of decentralised rainwater management priority in accordance with Article 55 (2) WHG (Federal Water Act) • Specifications in the drainage statutes of municipalities • Splitting of wastewater charges (separate charges for the disposal of wastewater and rainwater) • Promoting green roofs • Construction planning specification for rain retention on building sites
Basis for decision-making	-
Responsible stakeholders	Municipalities, federal states
Synergies	More attractive area design; improved microclimate; improved groundwater recharge
Factors to be considered	There is a risk of waterlogging when the groundwater depth is shallow and subsoil conditions are unfavourable.
Examples	• In Bremen, the Urban Drainage Law specifies that connection to a combined sewer is only allowed if decentralised rainwater disposal is not possible or not feasible. In addition, subsidies are available for green roofs, reclaiming sealed surfaces, and systems for rainwater utilisation or seepage. The public is informed through the pamphlet "Decentralised Rainwater Management in Bremen". • In Berlin landscape plans, specific target values for biotope-area factors (ratio of the area with an ecological impact to the total area of the site) have been established and thus provide incentives for de-sealing. • Cities in the Emscher region, the Environment Ministry of North Rhine-Westphalia, and the Emschergenossenschaft have jointly formulated an agreement for the future of rainwater to reduce rainwater run-off through the sewage system by 15 % in 15 years. • The city of Hamburg's green-roof strategy specifies that at least 70 % of flat roofs shall be planted and that the greening will be financially supported.

Tab. A. 27: Protection of wastewater systems against flooding

Field of action	Urban drainage and wastewater treatment
Climate adaptation measure	**Protection of wastewater systems against flooding**
Objective	Protection against flooding is very important for sewage treatment plants and rainwater relief systems, which are often located near waterways, because in the event of flooding, purified and polluted water could mix and be discharged without control.
In response to	Increase in flood run-off, increased frequency and intensity of heavy rainfall events
Actions	• Damming of the plants • Checking if structures can be elevated • Flood-proof construction of the mechanical and electro-technical components of the plant
Basis for decision-making	• Flood hazard and flood risk maps
Responsible stakeholders	Municipalities, urban drainage
Synergies	-
Factors to be considered	-
Examples	• Damming of the Straubing sewage treatment plant with mobile dike-beam locks on the access roads

Field of action - Flood protection: heavy rainfall and flash floods

Tab. A. 28: Water and sediment retention in outlying areas

Field of action	Flood protection: heavy rainfall and flash floods
Climate adaptation measure	**Water and sediment retention in outlying areas**
Objective	Water in outlying areas flows uncontrolled onto lands downstream, or is channelled off through ditches, channels, or other routing systems. Terrestrial ditches, decentralised retention basins and other structures that can retain water contribute to the protection of downstream communities. Along with the water, sediments are also retained in troughs. Transverse channels divert water away from the roads into adjacent areas.
In response to	Increase in the frequency and intensity of heavy rainfall events and erosion
Actions	• Restore waterways to a more natural form • Reconnect floodplains • Retention basins • Minor retention in area depressions • Small-scale rock filling in forest water bodies (but not extensive, the bed should remain exposed) • Transverse channels on forest and field roads • Kerbs with openings for draining road water into adjacent areas • Adapted slope management (*see Tab. A. 32*) • Creation of field-boundary strips • Conversion of arable land to grassland or forests (*see Tab. A. 59*) • Avoidance and regular removal of deposits and grass protruding onto the roadways
Basis for decision-making	-
Responsible stakeholders	Farmers, foresters, road construction authorities, municipalities
Synergies	More groundwater recharge; nature preservation; soil conservation
Factors to be considered	Soil conservation considerations are critical in the natural restoration of water bodies and the reconnection of floodplains.
Examples	• The community of Bad Hönningen istributed rock fill in the Hammersteiner Bach, in the forest upstream from the town, in order to reduce the flow velocity of the water during flooding events and create retention in the forest area. It is important that no disproportionately large dams are created and that the natural course of the stream bed is not obstructed. • The aim of the BebeR project ("Reduction of soil erosion in mountainous regions with the example of the Mansfeld-Südharz district") is to show how a planning and assessment process to reduce soil erosion can be carried out taking climate change into account with the involvement of various stakeholder groups. • "Land-use sharing and emergency watercourse Ohlendorffs Park" pilot project in Hamburg (RISA) (https://www.risa-hamburg.de/english/) https://www.risa-hamburg.de/projekte/freiraeume/ • Brochure "How do I protect my house from heavy rain?" which was reissued as part of the RISA project. Download: http://www.risa-hamburg.de/download/alle-downloads/

Tab. A. 29: Retention through changes in forestry

Field of action	Flood protection: heavy rainfall and flash floods
Climate adaptation measure	**Retention through changes in forestry**
Objective	More water retention and reduced erosion can be achieved through improved infiltration conditions in the soil and more water utilisation, capture and evaporation through and from trees.
In response to	Increased high water run-offs and increased frequency and intensity of heavy rainfall events and erosion
Actions	• Reforestation • Conversion of forests to more deciduous trees (better infiltration conditions than conifers)
Basis for decision-making	-
Responsible stakeholders	Forestry authorities, forest industry, forest owners
Synergies	Erosion protection; soil conservation; climate change mitigation; improved microclimate through increased evaporation
Factors to be considered	Facilitating water capture by converting to more conifers
Examples	• Planting of a mixed forest on a former open

Tab. A. 30: Barriers between urban and outlying areas

Field of action	Flood protection: heavy rainfall and flash floods
Climate adaptation measure	**Barriers between urban and outlying areas**
Objective	In order to curtail the flow of water from outlying areas into urban areas, in addition to retention measures, the run-off can be routed around urban localities by means of barriers such as dams or ditches or through retention installations.
In response to	Increase in the frequency and intensity of heavy rainfall events
Actions	• Frontline damms, embankments • Containment trenches • Special design of rural roads
Basis for decision-making	• Heavy rainfall and flood maps
Responsible stakeholders	Municipalities, water authorities
Synergies	-
Factors to be considered	Land and material requirements
Examples	• The Grindel/Eibweg residential area in Bad Waldsee is protected from uncontrolled slope flow by a barrier and routing of slope water to an infiltration basin.

Tab. A. 31: Design of inlet fixtures on slopes

Field of action	Flood protection: heavy rainfall and flash floods
Climate adaptation measure	**Design of inlet fixtures on slopes**
Objective	The higher the flow velocity of rainwater, the more difficult it is to safely steer the water into the gullies. High flow velocities occur mainly on sloping surfaces. Specially designed and positioned inlets in combination with transverse channels and trenches can facilitate water flow into the sewage system and prevent or inhibit flash flooding on slopes.
In response to	Increase in the frequency and intensity of heavy rainfall events
Actions	• Use of efficient slope inlets (with slightly bevelled struts) • Series of inlets positioned one after another in the direction of flow • Transverse gullies in the street • Construction of a parallel ditch with inlet structure, debris trap and/or floodway • Facilitating water uptake with steeper transverse gradients of the roads • Facilitating water uptake due through slight upturning or counter-slope of the road surface in the direction of flow
Basis for decision-making	• Flood maps
Responsible stakeholders	Municipalities, road construction offices
Synergies	Nutrient, pollutant and sediment retention, and contributions to achieving the WFD, MSFD and EU biodiversity strategy objectives
Factors to be considered	Full effectiveness only with regular cleaning
Examples	• Recovery inlets in Alfter

Tab. A. 32: Adapted slope management

Field of action	Flood protection: heavy rainfall and flash floods
Climate adaptation measure	**Adapted slope management**
Objective	Particularly when existing buildings are located at the foot of a slope, run-off- and erosion-control measures must be taken to reduce the risk of flash floods on the slopes. In this context, alignment of all excavation or depressions parallel to the slope is of great importance to ensure water and soil retention. Furthermore, slopes should be covered year round by vegetation. When farming on slopes, at a minimum, good agricultural practice must be observed.
In response to	Increase in the frequency and intensity of heavy rainfall events and erosion
Actions	• Ground-working and row-planting parallel to the slope • Lanes and paths parallel to slope • Grassland strips in the field parallel to slope • Establishing stream-bank strips on borders to farmland • New hedge-planting parallel to slopes • Intermittent greening of the lanes if slope-parallel use is not possible • Groundcover planting • Permanent vegetation • No-till soil cultivation, use of mulching methods, conservation tillage • Planting of woodlands • Cultivation and care of protective forests • Controlled water drainage via the pathway system
Basis for decision-making	• Erosion-hazard maps
Responsible stakeholders	Municipalities, farmers, agricultural associations, forestry offices
Synergies	Soil conservation, more water storage and infiltration into the ground, nutrient and sediment retention, promotion of a natural run-off regime thus supporting the objectives of the WFD (if sites designated under the Habitats Directive => support Natura 2000 network), MSFD and EU biodiversity strategy
Factors to be considered	Greater land requirements; implementation may be impossible on too-steep slopes.
Examples	• Experimental areas at the University of Hanover to minimise erosion through intermittent planting in tramlines on slopes near Adenstedt

Tab. A. 33: Construction and securing of emergency water routes

Field of action	Flood protection: heavy rainfall and flash floods
Climate adaptation measure	**Construction and securing of emergency water routes**
Objective	To avoid damage to buildings and infrastructures, surface run-off water should be diverted into receiving water bodies or retention areas. To ensure safe drainage of the water, it is recommended that emergency waterways in public areas and on private land are designated, kept available and stipulated in urban development plans.
In response to	Increase in the frequency and intensity of heavy rainfall events
Actions	• Equip roads that do not have a main throughway function with raised kerbstones or ground-level gutters • Overflow ditches • Guttering in garden areas • Replace pipe culverts with jam-free fords • No construction of new structures in the run-off water paths
Basis for decision-making	• Flood maps • Modelling of flow paths • Establishment of emergency water routes is possible under Article 9(1) No. 14 of the Federal Building Code (BauGB).
Responsible stakeholders	Municipalities, road construction departments, wastewater management corporations
Synergies	Simultaneous use as temporary water reservoirs
Factors to be considered	Restricted accessibility on roads with vertical kerbing; diversion from a property should not be detrimental to the neighbouring property; maintenance costs, because emergency flood routes must be kept clear of growth; In the case of private property, compensation payment may be necessary.
Examples	• Establishment of emergency waterways in the Lübeck University district

Tab. A. 34: Property protection against the risk of flooding

Field of action	Flood protection: heavy rainfall and flash floods
Climate adaptation measure	**Property protection against the risk of flooding**
Objective	Precautionary building measures can reduce the damage potential of floods in both the short and long term. Often, a single protective measure is not enough, rather an appropriate combination of measures would be advisable. Basement apartments, cellars and garages are particularly at risk. In addition to sealing measures and backup protection in the drainage systems, hazards can also be significantly reduced by a sensible arrangement of rooms and fixtures.
In response to	Increase in the frequency and intensity of heavy rainfall events
Actions	• Water barriers outside buildings (sills, walls) • Sealing of the building (edging on light shafts, stoplogs at building openings) • Protective gates at property entrances • Cellar with floor drains • Backflow protection for building and property drainage (backflow valve, sewage pumping system) • Water-resistant anti-corrosive paint on permanently installed systems • Practical arrangement of basement rooms: place appliances on blocks, raise cables, move heating-, power-supply units, telephone/internet to the upper floors. • No storage of water-polluting substances in areas at risk of flooding (e.g. oil tanks)
Basis for decision-making	• Heavy rainfall risk and flood maps
Responsible stakeholders	Home and property owners, companies, real-estate owners
Synergies	Also protection against flooding caused by high river-water levels; protection against high groundwater levels
Factors to be considered	Possibly high costs; raising public awareness is necessary for this
Examples	• At the Konrad Kocher School in Ditzingen a combination of individual property-protection measures was applied to prevent future flooding caused by heavy rainfall. By changing the transverse gradient of pathways, the flow routes of the water were corrected. In addition, changes made to the floor surfaces and control systems ensure that the buildings are protected.

Tab. A. 35: Organised response measures in the case of an extreme event

Field of action	Flood protection: heavy rainfall and flash floods
Climate adaptation measure	**Organised response measures in the case of an extreme event**
Objective	If the consequences of measures have been thought through prior to an event, it is easier to make the necessary decisions should such an event occur. Alert and action plans are important for crisis management in municipalities. They are usually structured on multiple levels and designed to respond to as many different incidents as possible. If warnings are given early enough there may be time to prepare some measures in advance.
In response to	Increased heavy rainfall events and erosion
Actions	• Emergency strategies for transportation infrastructures • Flood alerts and action plans • Agreements and cooperation with nearby fire brigades • Mobile warning systems that can inform the public effectively and quickly via media and WarnApps about storms and response measures • Targeted communication/activation of recommended action ("avoid basements") directly before or during the event
Basis for decision-making	• Improvement of (qualitative) early warning in affected areas, if applicable.
Responsible stakeholders	Federal states, municipalities, fire brigades
Synergies	-
Factors to be considered	Large uncertainties in the timely prediction of heavy rainfall events
Examples	• For the rapid and reliable communication of storm warnings to all fire brigades in Germany, the National Meteorological Service has developed a Fire Brigade Weather Information System (FeWIS). • The heavy rainfall event that led to the "July Flood of 2008" (26 July 2008) in Dortmund was thoroughly followed up to improve future operations and reduce damage. • During the heavy rainfall event in Münster in July 2014, private assistance was organised and coordinated through social media.

Tab. A. 36: Behavioural preparedness and advanced training

Field of action	Flood protection: heavy rainfall and flash floods
Climate adaptation measure	**Behavioural preparedness and advanced training**
Objective	For the general public, and especially for certain professions, it is important to be informed about expected climatic changes, the dangers of heavy rainfall, and the measures that can be taken. For example, advanced training for architects and urban planners on the topic of "flood-adapted construction" would be very helpful.
In response to	Increase in the frequency and intensity of heavy rainfall events and erosion
Actions	• Inclusion of topics specifically related to climate change in training curricula • Cross-sector training courses • Information events • Leaflets, guidelines, etc. • Raise awareness, especially in areas with water bodies that have not previously experienced flash floods • Support programmes for personal preparedness • Behavioural preparedness, e.g. through drills in schools and kindergartens or drills for evacuation in particularly dangerous situations
Basis for decision-making	-
Responsible stakeholders	Municipalities, federal states, sewage system utilities
Synergies	-
Factors to be considered	-
Examples	• hanseWasser Bremen GmbH has been conducting the "Cooperation for the Refurbishment of House Drainage" (KoSaH) programme for several years, during which a large number of information sessions as well as individual on-site consultations with homeowners have taken place in order to inform them about the causes of basement flooding and general property-protection measures.

Tab. A. 37: Regular maintenance and inspection of drainage systems

Field of action	Flood protection: heavy rainfall and flash floods
Climate adaptation measure	**Regular maintenance and inspection of drainage systems**
Objective	To ensure that water can flow unobstructed from built-up areas and to avoid congestion and flooding, it is necessary to regularly inspect bottlenecks in water bodies (e.g. ditches, agricultural drainage systems) and inlets to the sewage system. The term drainage system encompasses the entire above-ground catchment area and not just the sewers. Material that is trapped in the grates at inlets must be removed to prevent clogging. Water bodies can also be examined when carrying out stream inspections. In this way, problem areas can easily be identified, such as residents who have restricted the flow of the stream by building steps, for example, or installing fences or storing materials on the banks. Nor should the maintenance of streams and side channels in outlying areas be neglected. The public should be encouraged to report clogging and obstructions to the responsible maintenance offices.
In response to	Increase in the frequency and intensity of heavy rainfall events and erosion
Actions	• Use of three-dimensional grates (sediment-trap baskets) • Conduct water inspections • Encourage the public to report blockages. • Removal of sediment accumulation and plant growth
Basis for decision-making	-
Responsible stakeholders	Municipalities, road construction departments, communities living near rivers
Synergies	Public relations work
Factors to be considered	-
Examples	• The maintenance department of Ilse/Holtemme must conduct a public waters inspection once a year in every municipality. It assesses whether the water body has been properly maintained.

Tab. A. 38: Performing hazard appraisals

Field of action	Flood protection: heavy rainfall and flash floods
Climate adaptation measure	**Performing hazard appraisals**
Objective	Risk analyses should be carried out that take account of topography, residential and rural structures, and other types of development. Using modelling, local heavy rainfall hazard maps can be created and used to identify areas and critical objects at particularly high risk of flooding. The flood risk can also be monitored and highlighted during fire-safety inspections in buildings. Precautionary measures should be established based on the hazard analyses.
In response to	Increase in the frequency and intensity of heavy rainfall events and erosion
Actions	• Creation of local heavy rainfall hazard and risk maps • Analyses of heavy rainfall hazard and risk maps • More detailed analyses with site visits, local surveys and interviews in threatened areas • Review of the flood risk during the fire-prevention inspection of a building
Basis for decision-making	-
Responsible stakeholders	Municipalities, private individuals
Synergies	Creation of the heavy rainfall hazard and risk maps as independent data set in addition to the flood hazard and flood risk maps
Factors to be considered	-
Examples	• Eight municipalities in the Glems catchment area have looked more closely at the heavy-rainfall hazards in the area and have, among other things, produced heavy-rainfall hazard maps. • In the "RainAhead" project, a GIS-based, multi-level modelling system was developed for Lübeck that is aimed at identifying ways of relieving the drainage situation through planning, and being able to better cope with future extreme events.

Field of action - Drainage of low-lying coastal areas

Tab. A. 39: Adaptation of land use

Field of action	Drainage of low-lying coastal areas
Climate adaptation measure	**Adaptation of land use**
Objective	In the case of limited or a complete standstill of lowland drainage, conventional agriculture can no longer be practised, but more appropriate forms of land use may possibly be found.
In response to	Sea-level rise, increase in storm surges, increase in high water run-off and increase in the frequency and intensity of heavy rainfall events
Actions	• Paludiculture (reeds, rushes, alders) • Extensive grassland use • Restoration of peatlands (*see Tab. A. 60*) • Site-adapted grazing by water buffalo
Basis for decision-making	-
Responsible stakeholders	Federal states, dike and central tidal gate associations, agricultural associations
Synergies	Nature conservation; climate change mitigation; soil protection; nutrient retention and thus support in achieving the objectives of the WFD and MSFD.
Factors to be considered	Lower productivity; possible loss of income
Examples	• In the Pudagla lowland on Usedom there is a beachside lake, Lake Wocknin, surrounded by a fringe of reeds and high-sedge marsh. A large part of the area is covered with various types of marsh and wetland forests. • The 2050 lowlands working group comprises water and soil associations, representatives of agriculture and nature conservation, water authorities and the Ministry of Agriculture, Environment and Rural Areas of the State of Schleswig-Holstein and develops climate adaptation strategies for the lowlands.

Tab. A. 40: Run-off retention in upper catchment areas

Field of action	Drainage of low-lying coastal areas
Climate adaptation measure	**Run-off retention in upper catchment areas**
Objective	Measures to retain water in the upstream catchment areas of coastal lowlands are designed to alleviate flood run-offs that contribute to waterlogging in the lowlands.
In response to	Increasing flood run-off and increasing frequency and intensity of heavy rainfall events, sea-level rise
Actions	• Establishment of retention areas (*see Tab. A. 109*) • Rainwater management (*see Tab. A. 23, Tab. A. 26*) • Restoration of water bodies to natural state (*see Tab. A. 3, Tab. A. 47*) • Increase water-storage capacity of the soil through adaptation of usage and management • Technological water retention (dams, reservoirs, etc.) (*see Tab. A. 108*)
Basis for decision-making	• Run-off projections
Responsible stakeholders	Federal states, municipalities, private individuals, etc.
Synergies	More groundwater recharge; objectives of the WFD; nature conservation; soil protection
Factors to be considered	Land-use conflicts
Examples	-

Tab. A. 41: New construction and upgrading of pumping stations

Field of action	Drainage of low-lying coastal areas
Climate adaptation measure	**New construction and upgrading of pumping stations**
Objective	To adequately drain coastal lowland areas under changing climatic conditions, more powerful pumping stations and larger numbers of pumping stations may be required to supplement or replace existing tidal gates. The flood protection provided by these pumping stations must be considered. The operation of weirs and pumping stations should be coordinated between upstream and downstream sites in a catchment area.
In response to	Sea-level rise, increase in storm surges, increase in flood run-off and increase in the frequency and intensity of heavy rainfall events

Actions	• Construction of new pumping stations when tidal-gate drainage is no longer sufficient
	• Upgrading:
	  • More powerful pumps
	  • Construction of new pumping stations
	  • Flood protection: high entrances, mobile flood protection elements, doubly independent power supply
	  • Coordinated operation of weirs and pumping stations, e.g. through the formation of dam advisory boards, cooperation between water and soil associations or other operators, review and adaptation of water-regulation permits

Basis for decision-making	• Run-off projections • Climate projections of sea-level rise
Responsible stakeholders	Dike and central tidal gate associations, states
Synergies	-
Factors to be considered	High costs; near-natural management of receiving water in lowland areas and allowing fish passage (EU Water Framework Directive prohibits the deterioration of the status of waterbodies) at pumping stations is difficult; continued deep drainage of the soil resulting in subsidence and increased breakdown of organic matter in the soil
Examples	• Construction of a pumping station at Steertloch tidal gate at Dithmarsch Bay that will replace the existing gate.

Tab. A. 42: New construction and upgrading of retention basins

Field of action	Drainage of low-lying coastal areas
Climate adaptation measure	**New construction and upgrading of retention basins**
Objective	Retention basins are extensively used areas in which water can be collected for intermediate storage. With rising sea levels, there are fewer opportunities to open tidal gates for drainage, as the water level below the dikes is too high for longer periods of passive drainage. Therefore, in future more water will probably have to be temporarily stored behind the dikes before it can be drained into the sea.
In response to	Sea-level rise, increase in storm surges, increase in flood run-off and increase in the frequency and intensity of heavy rainfall events
Actions	• New construction of retention basins • Upgrading of retention basins
Basis for decision-making	• Run-off projections • Projections of sea-level rise/climate projections
Responsible stakeholders	Dike and central tidal gate associations
Synergies	Attractive breeding areas for meadow birds; climate change mitigation
Factors to be considered	Conflicting land uses; extensive soil excavation
Examples	• Holter Hammrich polder in the Leda-Jümme lowlands

Field of action - Marine protection

Tab. A. 43: Reducing pollutant and nutrient inputs

Field of action	Marine protection
Climate adaptation measure	**Reducing pollutant and nutrient inputs**
Objective	To minimise oxygen deficiency, eutrophication and shifts of marine species, concentrations of pollutants and nutrients in the environment should be kept as close to natural levels as possible. These inputs are transported into the marine environment via watercourses or are introduced directly e.g. as discharges from ships. Nitrogen and phosphorus emissions are of particular relevance here. Reducing discharges is not, in itself, a climate adaptation measure. However, it has the secondary effect of strengthening adaptive capacity and therefore makes a substantial contribution to adaptation.
In response to	Increased erosion and nutrient inputs via surface discharges due to more frequent and prolonged heavy rainfall and flood events. Need to strengthen the resilience of natural ecosystems to climate change.
Actions	• Setting of and compliance with pollutant and nutrient limits for watercourses • More stringent regulations on the use of fertilisers in agriculture • Reduction of discharges from ships • Regulations on use of nutrients in aquaculture, promotion of sustainable aquaculture • Prohibition of defined harmful substances • Nitrogen oxide reduction programmes in shipping (e.g. differentiated port infrastructure charges, based on emissions) • Criteria and incentive programmes for eco-friendly ships
Basis for decision-making	-
Responsible stakeholders	Legislators, agricultural associations, fishing associations
Synergies	Reduced pressure on ecosystems in surface waters and groundwater; soil conservation; thus contributes to the achievement of the EU Water Framework Directive (WFD) objectives
Factors to be considered	The many diverse, point and non-point sources of these inputs; complex monitoring; need for international cooperation
Examples	• As a result of the ban on tributyltin (TBT) in 2003, TBT inputs from anti-fouling paints used on ships are decreasing. TBT is an endocrine disruptor and can alter reproductive processes in certain groups of molluscs. • A measure which supports the implementation of the Marine Strategy Framework Directive is strengthening the natural self-purification capacities of estuaries. At the Ems Barrier, flexible tidal control is the first major step to reduce silt contamination (turbidity), the aim being to improve ecological status and strengthen the self-purification properties of the Ems estuary.

Tab. A. 44: Establishment of marine protected areas

Field of action	Marine protection
Climate adaptation measure	**Establishment of marine protected areas**
Objective	Marine protected areas in Germany's coastal areas are important refuges for species under pressure. Protected areas are most favourably maintained and developed as part of a coherent system which establishes corridors between them and allows for habitat networks. Compliance with regulations governing the use of these areas is essential and should be properly monitored.
In response to	Climate change in general, strengthening natural ecosystems to increase climate change resilience
Actions	• Inclusion of species and biotope types of particular ecosystem value • Coherent networks of protected areas (taking account of flyways, migration corridors, etc.)
Basis for decision-making	-
Responsible stakeholders	International institutions, federal government, federal states
Synergies	Nature conservation
Factors to be considered	Restrictions on use e.g. for fishing, resource extraction
Examples	• Mecklenburg-Western Pomerania has designated some sections of the Baltic coast as Sites of Community Importance (SCIs) under the EU Habitats Directive and/or as Special Protection Areas (SPAs) under the Birds Directive.

Tab. A. 45: Regulation/reduction of ballast water exchange

Field of action	Marine protection
Climate adaptation measure	**Regulation/reduction of ballast water exchange**
Objective	To control the avoidable introduction of potentially invasive species and microbes, ballast water exchange must be properly regulated. The International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention) was adopted by the International Maritime Organization (IMO) to introduce the relevant global regulations. The Convention entered into force in September 2017. Compliance with its provisions is essential and must be monitored.
In response to	Increased inward migration of invasive species
Actions	• Regulation of ballast water exchange in sensitive marine areas • Routine use of ballast water treatment systems • Compliance with the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention) adopted by the International Maritime Organization (IMO) and has been in force since 2017
Basis for decision-making	-
Responsible stakeholders	Federal government, federal states, maritime authorities
Synergies	-
Factors to be considered	-
Examples	• From 2008, Schleswig-Holstein's Ministry of Science, Economic Affairs and Transport supported an interdisciplinary research group which was working on the development of a UV/ultrasound ballast water treatment system. The system was piloted and tested at Flensburg Fjord by Flensburg University of Applied Sciences.

Tab. A. 46: Early warning systems for invasive species

Field of action	Marine protection
Climate adaptation measure	**Early warning systems for invasive species**
Objective	The impacts of invasive alien species on ecosystems require long-term research and monitoring. This is essential for improved assessment of the scale of the invasion of alien species, extinctions of native flora and fauna, and the effects of these processes.
In response to	Rising water temperatures, general climate change
Actions	• Collection of long-term biological data • Use of sports divers' observations to track the spread of known invasive species
Basis for decision-making	-
Responsible stakeholders	Federal government, federal states, research facilities
Synergies	Relevance for research
Factors to be considered	-
Examples	• In 2007, Schleswig-Holstein's State Agency for Agriculture, the Environment and Rural Areas, working with the Helmholtz Centre for Ocean Research Kiel (GEOMAR), tested an invasive species early warning system for hard substrate communities in the Baltic Sea.

Field of action - Conservation of aquatic ecosystems

Tab. A. 47: Improving continuity of watercourses

Field of action	Conservation of aquatic ecosystems
Climate adaptation measure	**Improving continuity of watercourses**
Objective	The interconnectedness of watercourses and the ability of aquatic organisms to traverse them are impeded by a great number of lateral barriers and vertical drops. The improvement of continuity is one of the requirements for achieving the WFD objectives. It contributes to restoring near-natural water-body structures and positively impacts on habitat conditions and the resilience of aquatic ecosystems. The reproduction of some species and thus their survival depends on the watercourses' continuity, among other factors. Continuity is also important for balanced drift and sediment transport.
In response to	Strengthening natural ecosystems with a view to resilience to climate change
Actions	• Construction of passage installations (e.g. bypass channel, bed glide, ramp, fish pass) • Removal/conversion of transverse structures (e.g. bridges, pipe culverts and box culverts, sag pipes, tidal gates and pumping stations) • Optimised control of culverts • Creation of passable groyne fields • Removal of obsolete artificial drainage systems
Basis for decision-making	• Map depicting structural qualities of water-bodies (Gewässerstrukturgüte -kartierung)
Responsible stakeholders	Water authorities, municipalities, federal states
Synergies	Achieving WFD objectives (if sites designated under the Habitats Directive→ support Natura 2000 network) and EU Biodiversity Strategy; improved sediment budget; reduced streambed erosion
Factors to be considered	-
Examples	• Removal of a bottom drop in the course of watercourse management at the Ferndorfbach in the Kreuztal urban area

Tab. A. 48: Alteration of hydromorphological structures

Field of action	Conservation of aquatic ecosystems
Climate adaptation measure	**Alteration of hydromorphological structures**
Objective	The more strongly a watercourse's structure and dynamics correspond to its natural state, the greater the likelihood that the aquatic ecosystem will be more stable in its response to the impacts of climate change. A rich morphological structure provides a diverse range of habitats and at all times a range of areas subject to different flow velocities under different flow conditions. Even at times of low water there tend to be areas of sufficient water depths to ensure at least the temporary survival of aquatic organisms. Moreover, the alteration of hydromorphological structures supports water retention.
In response to	Strengthening natural ecosystems with a view to resilience towards climate change, increased incidences of low water discharges, Increased incidences of flood discharges
Actions	• Removal of streambed and bank obstructions • Installation of flow control structures • Widening of the stream channel • Widened diverted reaches at outlets • Rerouting • Addition of rocks, deadwood,... • Increasing the channel length • Re-wetting of floodplains, wetlands • Establishment of gravel spawning grounds
Basis for decision-making	• Map depicting structural qualities of watercourses (Gewässerstrukturgüte - kartierung) • Drift transport measurements, sediment sampling, sampling for suspended solids • Hydraulic modelling
Responsible stakeholders	Water authorities, municipalities, federal states
Synergies	Nature conservation; flood control; fostering a natural discharge regime, thus supporting the achievement of WFD objectives (if sites designated under the Habitats Directive → support Natura 2000 network) and EU Biodiversity Strategy; restoration of a near-natural soil moisture regime
Factors to be considered	Balanced sediment balance and sufficiently large coherent networks of passable watercourse segments for aquatic organisms as a precondition; detailed planning of measures as large-scale and long-term sediment transfer processes may be triggered
Examples	• Isar River restoration in Munich • A discharge-controlled hydrological hydraulic method for calculating the natural discharge-adapted watercourse width was developed as part of the LAWA project entitled "Typspezifischer Flächenbedarf für die Gewässer-entwicklung" (type-specific area requirements for watercourse development). This concerns the width of watercourses that bed-forming high water discharge will shape in the long term. • The Blue Belt (Blaues Band) federal programme

Tab. A. 49: Protection and development of riparian zones

Field of action	Conservation of aquatic ecosystems
Climate adaptation measure	**Protection and development of riparian zones**
Objective	Riparian zones are legally prescribed 5 m wide strips (10 m in some federal states) of stream banks the use of which is restricted. Plants growing near a riverbank or lakeshore take up nutrients and perform filter functions contributing to the watercourses' natural purification. They also offer refuges for animals, and especially weakened animals, to escape pressure from predators. Shade provided by riparian woodlands also counteracts the warming of water bodies during hot spells. Moreover, plantings reduce erosion on riverbanks and lakeshores. The planting of riparian trees and shrubs is a measure that is relatively simple in its planning and implementation and which does not require the landowner's consent, since woody plants on riverbanks and lakeshores is considered part of water-body maintenance (Article 39 of the Federal Water Act - Wasserhaushaltsgesetz, WHG). Riparian zones can be expected to have a major impact especially on smaller watercourses outside of the forest areas.
In response to	Increase in the frequency and intensity of heavy rainfall events and erosion, increase in the frequency and duration of drought periods, increases in water temperatures
Actions	• Planting and development of riparian woodland • Structuring of woodland margins • Planting of reeds • Establishment of riparian zones on arable land
Basis for decision-making	-
Responsible stakeholders	Federal states, municipalities, those responsible for watercourse management
Synergies	Promotion of habitat networking; aesthetic landscape design; buffer strips to combat non-point inputs of nutrients, sediment and pesticides and thus support for the achievement of WFD objectives (if sites designated under the Habitats Directive→ support Natura 2000 network), MSFD and EU Biodiversity Strategy; soil protection, reducing water erosion of soils, restoration of a near-natural soil moisture regime
Factors to be considered	Land-use conflicts with agriculture, forestry, infrastructure; retention effects in the case of flood events on vulnerable sites; planting of species that are as site-appropriate as possible
Examples	• Planting of a riparian woodland strip under the riparian zone programme for the river Ill (Gewässerrandstreifenprogramm Ill) • Solid bank structures were removed along a 220 m segment of the Weser River at Rablinghausen and a near-natural sandy shore was established. • In Baden-Württemberg, the buffer effect of riparian zones on inputs from surrounding land was specifically highlighted in Article 29 of the state water act (Wassergesetz). • The Blue Belt (Blaues Band) federal programme

Tab. A. 50: Establishment of sedimentation barriers

Field of action	Conservation of aquatic ecosystems
Climate adaptation measure	**Establishment of sedimentation barriers**
Objective	To reduce siltation or the sanding up of the streambed as a result of increased occurrences of heavy rainfall events in conjunction with erosion, sedimentation in floodplains and riparian areas should be encouraged. Appropriate site vegetation can encourage the sedimentation in riparian areas of sediments as well as particle-bound substances (e.g. phosphorus) that tend to enter watercourses through surface run-off; this is a highly effective way of keeping such sediments out of watercourses.
In response to	Increase in the frequency and intensity of heavy rainfall events and erosion
Actions	• Green cover in riparian zones • Surges in floodplains
Basis for decision-making	• Identification of flow paths during heavy rainfall events
Responsible stakeholders	Municipalities, those responsible for watercourse management
Synergies	Potentially improved nutrient supply for plants in riparian areas; creation of valuable habitats for WFD conservation objectives; soil protection, reduction in erosion of soils from water
Factors to be considered	Requires sufficient acreage of available land along watercourses; may not be compatible with conservation objectives in floodplains; potential accumulation of pollutants in the riparian area
Examples	• Sediment traps at Leubnitzbach stream in Dresden

Tab. A. 51: Environmentally friendly water-body maintenance

Field of action	Conservation of aquatic ecosystems
Climate adaptation measure	**Environmentally friendly water-body maintenance**
Objective	Water-body maintenance measures pursuant to Article 39 of the Federal Water Act (Wasserhaushaltsgesetz - WHG) are necessary to ensure the safe discharge of precipitation water. The aim is to maintain the streambed, the banks, and the watercourses' functional capacity in environmental terms (especially as a habitat of fauna and flora). Additionally, water-body maintenance serves to maintain watercourses in a condition that is conducive to meeting water management requirements in terms of retaining water, sediment etc. To this end, sediment must be removed from water bodies by means of ditches, channels and watercourses, and plants and woody vegetation must be cut back. In many cases, landowners are required under state law to maintain ditches bordering their land. Given that most of ditches are also a habitat of plants and animals, it is important to carry out mowing and the clearing of ditches as carefully as possible. Attention must also be paid to the fact that the offspring of certain animals is at particular risk in certain seasons. With a view to improved adaptability to climate change, aquatic ecosystems should be protected where possible. Article 39(2)(3) of the Federal Water Act also provides for consideration to be given to ecosystems in the course of water-body maintenance.
In response to	Strengthening natural ecosystems with a view to resilience to climate change
Actions	• Removal of washed in, deposited material; streambed sediments and structure should be preserved to a certain extent • Mowing of vegetation and banks to a height of approximately 10 cm • Management to be performed in an upstream direction, against the direction of flow in order to ensure that displaced animals do not get caught twice • Restricting watercourse clearance to September and October, i.e. to a time outside the periods of spawning, bird breeding, and vegetation and insect development • Avoiding desilting at times when frost is expected, since many organisms overwinter in the sediment. • Retention of cut and dredged material for a period of 1 to 2 days on the banks, giving microfauna a chance to escape.
Basis for decision-making	-
Responsible stakeholders	Owners of water bodies, residents, water and soil associations, municipalities
Synergies	Nature conservation; supporting the achievement of WFD objectives
Factors to be considered	-
Examples	• To prevent ongoing erosion, bioengineering measures (faggots and live willow mattresses) were used to stabilise segments (approx. 1.2 km) of the Ilm River. • Research project on environmentally friendly management of the Fleete watercourses conducted by the association for levee maintenance on the western bank of the Weser River in Bremen (Bremischer Deichverband am rechten Weserufer) and the BUND (Bund für Umwelt und Naturschutz Deutschland/Friends of the Earth Germany)

Tab. A. 52: Maintenance and expansion of protected areas

Field of action	Conservation of aquatic ecosystems
Climate adaptation measure	**Maintenance and expansion of protected areas**
Objective	Protected areas are important refuges for species under severe pressure. Protected areas are most favourably maintained and developed as part of a coherent system which establishes corridors between them and allows for biotope networks. Conservation objectives can only be achieved in coordination with other land-use claims, such as agriculture, and in cooperation with different user groups.
In response to	Greater burdens on organisms caused by general changes in the climate, strengthening natural ecosystems with a view to resilience to climate change
Actions	• Sites designated under the Habitats Directive established with a view to maintaining water-dependent habitat types (including bans on watercraft, visitor management, regulation of recreational uses, ...) • Water protection areas
Basis for decision-making	• Mapping of protected species • Local landscape plan (Landschaftsplan)
Responsible stakeholders	Federal states, federal government, municipal landscape planning
Synergies	Landscape aesthetics; nature conservation; recreational function
Factors to be considered	Land-use conflicts
Examples	• The Hanseatic City of Bremen is surrounded by a ring of protected humid grassland sites.

Tab. A. 53: Reducing non-point inputs of pollutants and nutrients

Field of action	Conservation of aquatic ecosystems
Climate adaptation measure	**Reducing non-point inputs of pollutants and nutrients**
Objective	Inputs of pollutants and nutrients should, insofar as possible, be reduced to a natural level to prevent oxygen depletion and eutrophication in watercourses as well as toxic effects on organisms. While there has been a considerable reduction in point source pollution (e.g. cleaned discharge water from wastewater treatment plants) in recent years, the levels of non-point pollution from agricultural sources are still high. Nitrogen emissions are particularly signficant in this respect. More effective fertiliser use, measures to reduce erosion, and areas devoted to water and nutrient retention, for example, protect watercourses from excessively high substance inputs.
In response to	Increase in the frequency and intensity of heavy rainfall events and erosion; strengthening natural ecosystems with a view to resilience to climate change
Actions	• Support for organic farming • Conservation tillage, non-inversion soil cultivation, mulching methods • Reducing water erosion of soils (*see Tab. A. 88*); optimised use of fertiliser and pesticide (*see Tab. A. 58*) • Establishment and development of wide riparian zones (*see Tab. A. 49*) • Implementation of WFD measures/near-natural watercourse design, water retention areas • Increased forest cover • Peatland conservation
Basis for decision-making	• "Good agricultural practice" in the Fertiliser Application Ordinance
Responsible stakeholders	Farming associations, farmers, municipalities
Synergies	Nature conservation
Factors to be considered	-
Examples	• The federal state of Mecklenburg-Western Pomerania presented a strategy to reduce non-point inputs into watercourses of nutrients from agricultural sources, which includes a detailed catalogue of measures for the farming sector. • The Emscher River and its tributaries are to be developed into semi-natural watercourses as part of the Escher restructuring. Wastewater will in future be discharged in closed channels. • In its project on "data collection and determination of the available supply in focal areas of agricultural irrigation and development of provisions for assessing applications for irrigation permits" (Datenerhebung und Dargebotsermittlung in den Schwerpunktgebieten landwirtschaftlicher Bewässerung und Erarbeitung von Regelungen für die Begutachtungspraxis bei Bewässerungsanträgen) the Bavarian State Agency for the Environment (BayLfU) is developing irrigation management plans for selected areas while observing the interests of drinking water provision including at times of unfavourable hydrological conditions.

Tab. A. 54: Amendment of threshold values for abstraction and discharge (discharge quantity, discharge quality, incl. water temperature)

Field of action	Conservation of aquatic ecosystems
Climate adaptation measure	**Amendment of threshold values for abstraction and discharge (discharge quantity, discharge quality, incl. water temperature)**
Objective	Water abstraction from and water discharges into watercourses are subject to water permits, and for federal waterways also require waterway and maritime police permits. Threshold values for temperatures and certain substances must be complied with. Abstraction and discharge quantities are also regulated. Federal-level minimum requirements for wastewater discharge apply to numerous production branches. At times of low water flow, when discharges of water of reduced quality are insufficiently diluted by the watercourse's residual water, water quality increasingly deteriorates. With increasing water temperatures, the dischargeable cooling loads up to the threshold values for temperature will also decrease. Therefore, the existing threshold values should be reviewed and amended as appropriate taking into consideration possible impacts of climate change. Thermal load plans can help to better estimate thermal emissions for frequently used watercourses and take these emissions into consideration in the siting of powerplants.
In response to	Increase in water temperature, increase in the frequency and duration of drought periods, increased incidences of low water discharges, strengthening natural ecosystems with a view to resilience to climate change
Actions	• Article 57(1) of the Federal Water Act (Wasserhaushaltsgesetz - WHG) applies to the granting of water rights for the purposes of wastewater discharge. A legal assessment would need to be undertaken in order to determine the extent to which it is possible to take account of future climatic developments. With respect to water temperatures (thermal emissions), the ordinance on surface waters (Oberflächengewässerverordnung - OGewV) currently provides a legal basis. • Establishment of minimum water flows for power plant discharges taking into consideration future climatic developments • Development of thermal load plans taking into consideration future climatic developments
Basis for decision-making	• Monitoring of water temperatures and pollutants in watercourses • Monitoring of parameters of aquatic biology
Responsible stakeholders	Federal states, municipalities, water authorities
Synergies	Nature conservation
Factors to be considered	Restrictions on industry and wastewater treatment; ensuring security of supply; not all discharge regimes are flexible; costs incurred
Examples	-

Tab. A. 55: Water quality warning services

Field of action	Conservation of aquatic ecosystems
Climate adaptation measure	**Water quality warning services**
Objective	Water quality warning services are designed as public notification and warning strategies that come into play at times of very low flows and critical water qualities to prevent environmental damage to watercourses. Suitably defined warning levels can create awareness and warn stakeholders and allow for coordinated actions to be initiated and implemented. At such times, thermal discharges and wastewater discharges should be restricted to the absolute minimum necessary. It would be useful to combine increased measurements and observations of aquatic systems with these warning levels.
In response to	Increase in the frequency and duration of drought periods in summer, increased incidences of low water discharges, increases in water temperatures
Actions	• Introduction of a public system of graduated warning levels which are triggered based on certain threshold values for water temperatures and other parameters: • Pre-warning stage (critical temperatures expected shortly) • Warning stage (critical conditions in watercourse) • Emergency stage (significant impairment of aquatic biology up to and including fish) • Intensified water quality measurements on reaching the warning levels
Basis for decision-making	• Measurements and water temperature models as well as temperature profiles • Measurements of other water quality parameters, e.g. oxygen concentration • Biological watercourse monitoring
Responsible stakeholders	Federal states, municipalities, water authorities, local residents, discharging industries, operators of wastewater treatment plants
Synergies	Relevance of monitoring parameters for research
Factors to be considered	-
Examples	• Emergency plan for impounded sections of the Main River in Bavaria • To regulate oxygen in the Neckar, the oxygen content is recorded continuously at online stations and a warning is triggered if the content is less than 4 mg oxygen per litre. Aeration measures are then taken at the power plants and wastewater treatment plants in Stuttgart.

Tab. A. 56: Climate-change-specific evaluations and adaptation of watercourse monitoring

Field of action	Conservation of aquatic ecosystems
Climate adaptation measure	**Climate change-specific evaluations and adaptation of watercourse monitoring**
Objective	Using different indicators, the aim is to investigate the impacts of increased water temperatures and increased droughts on aquatic systems. Regular monitoring of spring discharges as a link between groundwater and surface water are also of significance for observations of climatic changes.
In response to	Increases in water temperatures, increase in the frequency and duration of drought periods, increased incidences of low water discharges, increased incidences of flood run-off, increase in the frequency and intensity of heavy rainfall events
Actions	• Monitoring at watercourses that are particularly strongly affected • Evaluation with respect to developments to date
Basis for decision-making	-
Responsible stakeholders	Federal states, municipalities
Synergies	Relevance for research
Factors to be considered	Ongoing costs
Examples	• The monitoring undertaken in the context of the German Strategy for Adaptation to Climate Change (Deutsche Anpassungsstrategie, DAS) includes a system of 55 impact indicators (monitoring the impact of climate change) and 42 response indicators (monitoring adaptation measures) as part of 13 different fields of action. For surface waters the following indicators are of relevance: median discharge, high water, low water, water temperature of stagnant waters, duration of stagnant period in stagnant waters, water-body structure and water use index. • The KLIMBO Projekt (Klimawandel am Bodensee - climate change at Lake Constance) investigated the impacts of climate change on Lake Constance. • As part of the KLIWA cooperation project, a method was developed for the use of macrozoobenthos populations for climate monitoring as well as the KLIWA-IndexMZB for data evaluation purposes. Climate monitoring by the federal states involved in KLIWA and including Hesse officially commenced in 2017 (also see Example 18 in section 5.7.2.).

Field of action - Groundwater use and protection

Tab. A. 57: Climate-change-specific evaluations and adaptation of groundwater monitoring

Field of action	Groundwater use and protection
Climate adaptation measure	**Climate-change-specific evaluations and adaptation of groundwater monitoring**
Objective	Regular monitoring of groundwater quantities, using the water level as parameter, and of groundwater quality, based on the analysis of its chemical constituents as well as on in-situ parameters (e.g. temperature), is important for both groundwater management and climate impact assessment.
In response to	Increase in the frequency and duration of drought periods, increase in the frequency and intensity of heavy rainfall events and erosion, increased nitrate leaching, increased fluctuations of groundwater levels, raised water temperature, sea-level rise
Actions	• Maintenance and expansion of networks of groundwater sampling stations • Maintenance and expansion of groundwater monitoring • Improved recording of groundwater temperatures and, where necessary, other parameters which have as yet not been a focus of groundwater monitoring (e.g. groundwater fauna) • Regular assessment of the informative value of groundwater monitoring with respect to climate-change-relevant issues • Observation of the impacts on groundwater of potential changes in vegetation and land use • Inspection of inshore groundwater collection
Basis for decision-making	-
Responsible stakeholders	Federal states and their water management authorities
Synergies	Relevance for research; information on the risks associated with high groundwater levels/waterlogging
Factors to be considered	Ongoing costs
Examples	-

Tab. A. 58: Push for groundwater-protecting agricultural land use (quality and quantity)

Field of action	Groundwater use and protection
Climate adaptation measure	**Push for groundwater-protecting agricultural land use (quality and quantity)**
Objective	Groundwater contaminated with nitrates is of limited use as a source of drinking water. There is therefore a need to adjust plant-available nitrogen fertiliser applications to plant needs. In addition to ensuring compliance with the provisions of the Fertiliser Application Ordinance (Düngeverordnung), the leaching of excess nitrogen in soils in the form of nitrates must be prevented where possible. Applications of plant-available nitrogen fertilisers that are adapted to plant needs ensure that the nitrogen is taken up by the plants to a maximum extent and prevent it from remaining in the soil and being converted into nitrates. An optimum supply of other nutrients, year-round vegetative cover, stabilised fertilisers and optimum timing of fertiliser applications improve the plants' nitrogen uptake. With a view to the prudent use of the available groundwater supply, groundwater should not be used for irrigation, or its use should only be permitted where there are no foreseeable adverse impacts for water management and nature conservation.
In response to	Inhibited nitrogen uptake by plants and accumulation of nitrogen in soils as a result of increased frequency and duration of drought periods; increased nitrate leaching after accumulation, due to increased frequency and intensity of heavy rainfall events and an increase in winter precipitation; increased irrigation needs on agricultural land
Actions	• Compliance with the provisions of the Fertiliser Application Ordinance • Strengthening of agricultural advisory services • Support for organic farming • Precision farming with special consideration of soil condition and soil quality • Use of low-emission fertiliser application techniques (trailing hose, trailing shoe, injection method) • Even distribution and immediate incorporation of slurry • Strip-tillage including subsoil application of fertilisers • Nitrogen foliar feeding • Use of stabilised nitrogen fertiliser at times of sufficient rainfall • Optimum supply of primary macronutrients (potassium, phosphate) • Use of fast-growing plants as catch crops/overwintering crops • Alterations of land uses (*see Tab. A. 59*) • Use of weather-based decision-making aids to adapt fertiliser use to weather-dependent crop needs • "Slurry exchanges" (cooperation between livestock farms and farms without livestock) • Excess nitrogen levy as a steering instrument • Groundwater management planning in agricultural areas
Basis for decision-making	• "Good agricultural practice" in the Fertiliser Application Ordinance • Precise forecasting of soil water conditions, weather conditions
Responsible stakeholders	Federal states, municipalities, farming associations, farmers, authorities
Synergies	Nature conservation; possibly also reduction in greenhouse gas emissions
Factors to be considered	Precise estimate of crop plants' nitrogen requirements; investment in new technologies
Examples	• Introduction of precision farming technologies on 12 Brandenburg farm holdings that are members of the Oderland and Fläming-Havel e.V. local action groups • As part of the Cliwat INTERREG project (sub-project "Der Untergrund von Föhr" - Föhr's underground structure) an assessment is being undertaken of the consequences of potential changes in the climate on salination of the island's groundwater.

Tab. A. 59: Land-use changes

Field of action	Groundwater use and protection
Climate adaptation measure	**Land-use changes**
Objective	Land-use changes affect groundwater in terms of both the quantity of groundwater recharge and quality. Much of the groundwater recharge originates in sites with high infiltration capacities and low evaporation. Land uses involving low fertiliser usage place a significantly smaller burden on groundwater in terms of nutrient loads and often also in terms of pesticides compared to land uses involving high fertiliser applications. Changing land uses to extensive uses in terms of fertiliser applications should be considered especially on low-yielding marginal sites, in hillside locations susceptible to erosion, in floodplains and in transition areas.
In response to	Increased nitrate leaching and leaching of other substances as a result of increases in the frequency and duration of drought periods and in the frequency and intensity of heavy rainfall events
Actions	• Organic farming • Conversion of arable land to grassland or forests • Conversion of grassland from intensive to extensive management • Afforestation
Basis for decision-making	-
Responsible stakeholders	Landscape planning, municipalities, farmers
Synergies	Significance of species-rich grassland as an important conservation asset; reduced risk of erosion; soil protection; climate change mitigation
Factors to be considered	Potential reduction in agricultural productivity
Examples	-

Tab. A. 60: Protection of groundwater-dependent terrestrial ecosystems

Field of action	Groundwater use and protection
Climate adaptation measure	**Protection of groundwater-dependent terrestrial ecosystems**
Objective	Long-term sustainable land-use strategies should be developed and put in place for peatland soils, as the environmental impacts arising from drained peatlands generally exceed any short-term gains. As a result of large-scale drainage, peat extraction and intensive agricultural and forestry land use, near-natural peatland sites have become exceedingly rare in Germany. Drainage and subsequent soil subsidence often inolve additional deeper drainage. Drained peatlands release nutrients and carbon. Similarly, there should be no further drainage of mineral groundwater soils, and their hydrology should be restored where appropriate, in order to reduce the decomposition of organic matter and avoid soil subsidence.
In response to	Strengthening of natural ecosystems with a view to increasing their resilience to climate change; increased fluctuations of groundwater levels
Actions	• Re-wetting of drained peatlands • Designation of peatlands as nature reserves • Alternative land uses on peatlands (e.g. paludiculture) • Site-appropriate land uses (grassland) on the mineral groundwater soils • Cessation of agricultural land use on peatlands
Basis for decision-making	-
Responsible stakeholders	Federal states, municipalities, water authorities
Synergies	Climate change mitigation; nature conservation; soil protection; watercourse protection; flood protection
Factors to be considered	Land-use conflicts
Examples	• Restoration of the Neustädter Moor peatland and protection by means of designation of nature reserves

Tab. A. 61: Measures to promote groundwater recharge

Field of action	Groundwater use and protection
Climate adaptation measure	**Measures to promote groundwater recharge**
Objective	Sites both inside and outside of built-up areas can contribute to groundwater recharge through the retention of precipitation water. Recently recharged groundwater increases the available groundwater supply.
In response to	Increase in the frequency and duration of drought periods and higher demand, increase in fluctuations of groundwater levels
Actions	• Provision of flooding areas • Re-wetting of wetlands • Restoration of near-natural water-body structures • Forest conversion to include higher proportions of deciduous trees • Reduction in the sealing of soil surfaces • Increase in the proportion of green spaces • Utilisation of infiltration potential • Improvement of soil structure by avoiding soil compaction, stabilisation of soil pore system by conservation tillage
Basis for decision-making	• Maps of infiltration potential • Estimate of potential future developments with regard to groundwater recharge and spring discharges • Soil maps
Responsible stakeholders	Federal states, municipalities, farming associations, farmers, forestry authorities, landowners
Synergies	Reduction of surface run-off; flood protection; soil protection
Factors to be considered	-
Examples	• As part of the KLIMZUG-NORD research coopeation project, almost 12 ha of conifer forest in the Lüchow-Dannenberg district were converted to a mixed forest comprising predominantly deciduous trees. • As part of the mixed forest programme for Berlin, approximately 100 ha per annum of pine forest are converted to mixed forests to increase groundwater recharge rates.

Tab. A. 62: Measures to increase the available groundwater resources

Field of action	Groundwater use and protection
Climate adaptation measure	**Measures to increase the available groundwater resources**
Objective	Artificial infiltration of surface water that has been purified to drinking water quality serves to both increase available groundwater resources and improve groundwater quality. Successful groundwater enrichment should help to alleviate conflicts (e.g. between the supply of drinking water and irrigation) over this resource.
In response to	Increase in the frequency and duration of drought periods and higher demand, increase in fluctuations of groundwater levels
Actions	• Infiltration of treated surface water in infiltration basins
Basis for decision-making	• Detailed groundwater monitoring • Estimate of potential future developments with regard to groundwater recharge and spring discharges • Overview of available, qualitatively suitable water
Responsible stakeholders	Municipalities, federal states, water management authorities
Synergies	-
Factors to be considered	Only possible on well-drained soils
Examples	• Artificial groundwater enrichment in the Ruhr district using untreated water from the Haltern and Hullern dams (Halterner Stausee / Talsperre Hullern) or in the Hessian Ried • As part of the KLIWA project (sub-project on groundwater), case study modelling was used to calculate dry weather groundwater recharge in southern Germany.

Tab. A. 63: Sustainable groundwater management

Field of action	Groundwater use and protection
Climate adaptation measure	**Sustainable groundwater management**
Objective	Sustainable groundwater management requires regular assessments of the available groundwater resources and the demand for groundwater as well as risk assessments for water supplies based on this information. The results must be taken into account in the allocation of water rights. In addition, greater attention should be paid to the question as to whether certain provisions as part of the approval processes under water legislation could already take account of future climate change impacts. An example of such a measure would be the establishment of minimum levels below which groundwater levels must not decline in the course of groundwater abstraction in order to protect not only the resource itself, but also groundwater-dependent ecosystems and built structures susceptible to subsidence.
In response to	Increase in fluctuations of groundwater levels, rising demand for water (e.g. for air conditioning and irrigation) due to increased air temperatures and increases in the frequency and duration of drought periods
Actions	• Management with regard to climate change impacts • Control of the quantities of abstracted groundwater based on groundwater levels • Establishment of local groundwater levels below which the levels must not decline • Making the allocation of water rights contingent on mandatory groundwater monitoring
Basis for decision-making	• Results of groundwater monitoring
Responsible stakeholders	Federal states, municipalities
Synergies	Nature conservation; protection of built structures susceptible to subsidence
Factors to be considered	Alternative supply required at times when groundwater levels are too low
Examples	• With a view to sustainable groundwater management, the AnKliG project (Adaptation Strategies for Climate Change and Extreme Weather Conditions and Measures for a Sustainable Groundwater Management) investigated the extent to which climate trends and extreme weather events impact on the groundwater regime and the degree to which adaptation strategies need to be developed for sustainable groundwater management. • The district government of Upper Franconia initiated the AKTION GRUNDWASSERSCHUTZ (groundwater protection initiative) with the aim of developing new ways of supplying water sustainably. It focuses in part on raising public awareness for the responsible use of this resource. • As part of the KLIWA project (subproject on groundwater), modelling was used to calculate available groundwater resources under dry weather conditions (dry decade) for groundwater recharge in 30 physiographic-hydrogeological units in southern Germany (KLIWA 2017)

Field of action - Public water supply

Tab. A. 64: Integrating climate change into public water supply planning

Field of action	Public water supply
Climate adaptation measure	**Integrating climate change into public water supply planning**
Objective	To be able to consider alternative supply options in a timely manner it is essential to review raw water quantities and qualities in the catchment areas of individual supply companies and to assess the security of drinking water supply in the context of anticipated climatic changes and the associated pressures on water supply systems. These appraisals should be updated regularly.
In response to	Increase in the frequency and duration of dry periods, increase in the frequency and intensity of heavy rainfall events, increased peak demand in dry periods, increased nitrate leaching
Actions	• Determination of available supply of water and demands, and of the supply balances of individual water supply facilities • Asessment of the raw water quality of individual supply facilities
Basis for decision-making	DVGW 2017
Responsible stakeholders	Federal states, municipalities, water suppliers
Synergies	Basis for further adaptation measures in the “public water supply” and “ground water use and protection” fields of action
Factors to be considered	-
Examples	• In Bavaria, a project on "Surveying and assessing public water supply in Bavaria" is examining on a broad scale the security of supply of water supply facilities, taking climate change into account. • The goal of the KLIWA subproject on groundwater ("Langzeitverhalten von Bodenwasserhaushalt und Grundwasserneubildung 1951 - 2015") is to assess the supply still available for agricultural irrigation in certain priority areas, taking account of drinking water supply interests even under unfavourable hydrological conditions. • In its Roadmap 2020, the dynaklim network sets out proposals and strategies for adaptation in the Emscher-Lippe region (e.g. modules for secure water supply and competing water uses).

Tab. A. 65: Standby water extraction systems

Field of action	Public water supply
Climate adaptation measure	**Standby water extraction systems**
Objective	When small municipal water suppliers join together in networks or connect to a long-distance supplier, and when they tap additional raw water resources of their own, this can greatly reduce the vulnerability of a water supplier to climate change as it can then take recourse to other sources if required.
In response to	Increase in the frequency and duration of dry periods, increase in groundwater table fluctuations, increase in peak water demand
Actions	• Tapping other, additional raw water sources • Development of regional and supra-regional network solutions (group suppliers, special-purpose associations, long-distance suppliers)
Basis for decision-making	• Appraisals of the yield of water resources under climate change conditions (*see Tab. A. 57*)
Responsible stakeholders	Water suppliers, municipalities, federal states
Synergies	Safeguard against suddenly occurring water quality problems
Factors to be considered	High costs; utilisation of diverse and large resources
Examples	• The own extraction areas of the Wasser- und Energieversorgung Kreis St. Wendel GmbH utility are located in St. Wendel (Wurzelbach), Nohfelden-Eiweiler, Nohfelden-Bosen, Freisen-Oberkirchen and Namborn-Rohrbacher Wiesen. Additional drinking water is procured from the Talsperren- und Grundwasser - aufbereitungs- und Vertriebsgesellschaft mbH company, the Wasserversorgungsverband Kreis St. Wendel special-purpose water supply association and the Wasserversorgung Ostsaar utility.

Tab. A. 66: Adaptation of public water supply infrastructure

Field of action	Public water supply
Climate adaptation measure	**Adaptation of public water supply infrastructure**
Objective	To the extent that water tables fall and drinking water quality declines, water supply facilities need to be optimised. An increase in maximum daily water demand necessitates greater collection, treatment, transportation and storage capacities, while an increase in maximum hourly demand can necessitate greater water distribution capacities. To be able to respond to both quantitative and qualitative emergency situations it is advisable to establish standby options for drinking water production or capabilities for drinking water treatment. Whole-area groundwater protection safeguards the option to install further extraction points.
In response to	Increase in the frequency and duration of dry periods, increase in groundwater table fluctuations
Actions	• Optimisation of existing water supply facilities (e.g. deeper wells and more powerful pumping facilities, extraction facilities at dams (*see Tab. A. 99*) • Establishment of standby extraction systems (*see Tab. A. 65*) • Creation of greater storage capacities in waterworks and water networks • Safeguarding further extraction options through widespread groundwater protection (see 5.8 “Groundwater use and protection” field of action) • Further drinking water treatment (*see Tab. A. 70*) • Safeguarding energy infrastructure in the event of extreme flooding or other natural hazards
Basis for decision-making	-
Responsible stakeholders	Water suppliers, municipalities, federal states
Synergies	-
Factors to be considered	High costs
Examples	-

Tab. A. 67: Rainwater use

Field of action	Public water supply
Climate adaptation measure	**Rainwater use**
Objective	Rainwater use in private households, companies, public institutions and industry can help to reduce water deliveries by public water suppliers. Rainwater can be used as non-potable water, e.g. for irrigation, to flush toilets, to cool buildings or as process water in industry.
In response to	Reduced groundwater recharge, increased peak water demand
Actions	• Collection and storage of rainwater in rain barrels, underground cisterns, ponds etc.
Basis for decision-making	-
Responsible stakeholders	Private individuals, public institutions, companies, industry
Synergies	Reduced demand for potable water, rainwater suitability for crops, reduced loading of sewerage, lower wastewater charges (where levied separately)
Factors to be considered	Second pipe network and pump required if rainwater is to be used to flush toilets; some roofing materials (e.g. those made of copper or zinc) are poorly suited to rainwater harvesting because of serious contamination issues. In legal terms installations are privately operated extraction facilities competing with public water suppliers (the high fixed-cost component in the pricing of most water suppliers can lead to rising cubic metre prices if potable water consumption falls due to rainwater harvesting).
Examples	-

Tab. A. 68: Reduction of water demand

Field of action	Public water supply
Climate adaptation measure	**Reduction of water demand**
Objective	Increased water demand during dry periods can be countered by taking action to reduce demand. Options include optimising the various water uses, mitigating transport losses or, in hygienically unproblematic applications, falling back on alternative sources of non-potable water or utilising non-potable water several times over. Such behaviour can be steered through drinking water pricing or making appeals to users during dry periods. Irrigation methods should be optimised, water-efficient production processes researched and refined and pipe system losses reduced.
In response to	Increase in the frequency and duration of dry periods.
Actions	• Research and development of water-efficient production processes • Restrictions on water uses (e.g. for irrigation, car washing) during dry periods • Rainwater harvesting (*seeTab. A. 24, Tab. A. 26*) • Multiple use of non-potable water • Incentives through drinking water pricing • Minimisation of pipe system losses (e.g. through increased system inspections) • Reducing own demands of water utility companies in relation to filter and pipe flushing by optimising processes • System inspections according to industry standards, maintenance and upgrading
Basis for decision-making	-
Responsible stakeholders	Federal states, municipalities, gardeners, private individuals
Synergies	(long-term) cost savings
Factors to be considered	A declining population can generally be assumed to lead to a reduction in water demand (exception: cities and conurbations), yet in dry periods an increase is more probable; where consumption-based water prices account for a large proportion of the overall price this can lead to insufficient cost recovery of water suppliers (high fixed cost component).
Examples	-

Tab. A. 69: Improving water quality in the pipe network

Field of action	Public water supply
Climate adaptation measure	**Improving water quality in the pipe network**
Objective	During extended hot periods, water temperatures in distribution networks can rise. In the temperature range between 15 and 25 °C, even a slight rise causes hygienically relevant bacteria to reproduce strongly. This particularly affects sections of the network with a low and stagnant flow, such as communication pipes.
In response to	Increase in water temperature, increase in the frequency and duration of dry periods

Actions	• Adjustment of system flushing
	• Regular emptying of water from communication pipes
	• Supplementary disinfection in storage and distribution
	• Reduction of warming through:
	  • Backfilling pipe trenches with material of low thermal conductivity and heat storage capacity
	  • De-sealing of surfaces above trenches
	  • Greater trench depths
	  • Thermal insulation of pipes
	  • Demand-led planning and adaptation of system structure

Basis for decision-making	• Regular measurements of water quality in various system sections and house service connections
Responsible stakeholders	Pipe network operators, municipalities
Synergies	Also relevant for the “urban drainage” and “flood protection: heavy rainfall and flash floods” fields of action
Factors to be considered	Potentially high costs; resource-intensive repairs
Examples	-

Tab. A. 70: Further drinking water treatment

Field of action	Public water supply
Climate adaptation measure	**Further drinking water treatment**
Objective	If dry periods and heavy rainfall events become more frequent, it is likely that contamination of drinking water with particles, nitrate and other nutrients will increase. High air and water temperatures favour the dispersal of waterborne pathogens. With rising temperatures, an elimination of pathogens, nutrients and algae or the dilution of polluted with less polluted water could become increasingly important.
In response to	Increased water temperature, increased nitrate leaching due to more frequent and lengthier dry periods and more frequent and intense heavy rainfall events
Actions	• Nutrient reduction • Disinfection • Dilution with less polluted water • Particle removal through: filtration, flocculation, membrane filtration etc.
Basis for decision-making	• Regular monitoring of the quality of raw and treated water
Responsible stakeholders	Water suppliers, health authorities
Synergies	-
Factors to be considered	Possibly switch to unimpaired water resources if the cost-benefit ratio for treatment is disproportionate.
Examples	• The Bronn and Niedernhall waterworks make use of an ion exchange unit, among other things, in drinking water treatment to reduce nitrate and sulphate levels.

Tab. A. 71: Adaptation measures in management

Field of action	Public water supply
Climate adaptation measure	**Whole-area water yield management**
Objective	Drinking water supply has priority over other water uses. Alongside public drinking water supply, water yield management must also take account of other relevant uses such as agricultural and horticultural irrigation or relevant industrial operations with own water supplies.
In response to	Increase in the frequency and duration of dry periods and increase in groundwater table fluctuations, rising water demand for irrigation
Actions	• Regional or state-wide water yield management, guided by the priority of public water supply • When electricity supply is insecure, priority for drinking water supply • Integrating climate change into public water supply planning (*see Tab. A. 64*) • Adapted dam management (*see Tab. A. 98*) • Detailed surveys of water extraction facilities at risk
Basis for decision-making	-
Responsible stakeholders	Federal states, municipalities, water suppliers
Synergies	-
Factors to be considered	-
Examples	• For the Hessisches Ried region, a regional water supply company coordinates all groundwater withdrawals and recharge measures.

Field of action - Cooling water availability

Tab. A. 72: Installation of alternative cooling processes extensively independent of river flow

Field of action	Cooling water availability
Climate adaptation measure	**Installation of alternative cooling processes extensively independent of river flow**
Objective	It is possible to cool power plant processes and equipment even during low water periods by switching to cooling processes that require no or only very little cooling water (e.g. dry and closed-circuit cooling) or use cooling water not from rivers, but from dedicated reservoirs specifically created for this purpose.
In response to	Increasing occurrence of low water conditions due to low catchment run-off, and increasing water temperatures
Actions	• Dry cooling • Hybrid cooling • Closed-circuit cooling (significantly more efficient use of cooling water than once-through cooling systems) • Cooling tanks/reservoirs • Compensating reservoirs • Rainwater use
Basis for decision-making	• Analyses and modelling of the specific river catchments affected
Responsible stakeholders	Power plant owners, federal states
Synergies	Prevention of vapour plume formation
Factors to be considered	Low thermodynamic efficiency; require extensive amount of space; complex measurement and regulation tasks; high operating and investment costs
Examples	-

Tab. A. 73: Construction of additional cooling towers

Field of action	Cooling water availability
Climate adaptation measure	**Construction of additional cooling towers**
Objective	Cooling towers serve to cool the water used as coolant in industrial and electricity-generating processes via the ambient air and to potentially re-use the water in a closed circuit cooling system. Efficient use of river water and the ambient air for cooling purposes acts to protect the ecosystems in rivers serving as the cooling water source against the impacts of thermal discharge.
In response to	Increased occurrence of low water discharge, raised water temperature
Actions	• Dry cooling • Recirculating wet cooling (requires very little water abstraction to offset evaporation losses) • Hybrid cooling tower offering both dry and wet cooling processes
Basis for decision-making	• Analyses and modelling of the specific river catchments affected
Responsible stakeholders	Power plant operators
Synergies	Possibility to adapt cooling towers to various ambient temperatures
Factors to be considered	Air cooling is less efficient than water cooling and becomes even less efficient as air temperature rises; lower efficiency in once-through cooling designs; complex measurement and regulation tasks; high operating and investment costs
Examples	• The new Unit 8 of Rheinhafen steam power plant in Karlsruhe is equipped with a once-through cooling system as well as a forced-draft wet cooling tower for supplemental cooling. However, the cooling tower is only used when river water levels drop to threshold values that prohibit abstraction of river water in sufficient volumes for once-through cooling.

Tab. A. 74: Expanded recovery and use of discharged residual heat

Field of action	Cooling water availability
Climate adaptation measure	**Expanded recovery and use of discharged residual heat**
Objective	In addition to generating electricity, power plants produce heat that is usually discharged as a waste product via water or air, and is harmful to aquatic ecosystems. Yet, this residual thermal energy can be harnessed and used for heating purposes or - via heat exchangers - for cooling purposes by distributing it from the power plant through district heating pipelines or transporting it via mobile thermal energy storage systems to locations with demand.
In response to	Increased occurrence of low water discharge, raised water temperature
Actions	• Use of process heat via district heating networks • Mobile thermal energy storage systems (based e.g. on water, salt hydrates, paraffins, zeolites or metal hydrides) • Development of local heating networks, expansion of integrated heating and cooling networks and groups
Basis for decision-making	• Analyses and modelling of the specific river catchments affected
Responsible stakeholders	Power plant operators, municipalities
Synergies	Climate change mitigation; nature conservation
Factors to be considered	High investment costs
Examples	• The municipal waste management company Abfallwirtschafts - gesellschaft Kreis Warendorf (AWG) and the firm Hammelmann Service have developed a mobile thermal energy storage system which, among its other uses, is now successfully deployed to heat a public swimming pool in the town of Ennigerloh.

Tab. A. 75: Emergency response plans

Field of action	Cooling water availability
Climate adaptation measure	**Emergency response plans**
Objective	Emergency response plans serve to define what safe and reliable actions can be rapidly implemented in a well-organised manner in the event that river water can no longer be used for cooling purposes.
In response to	Increasing occurrence of low water conditions due to low catchment run-off, and increasing water temperatures
Actions	• Regulation of prioritised water users and energy consumers • Agreements between water resources management authorities and energy producers on emergency response procedures • Formation of an emergency management team • Emergency water connections for power plants • Compensating reservoirs • Cooling towers
Basis for decision-making	• Analyses and modelling of the specific river catchments affected
Responsible stakeholders	Power plant operators, water authorities, federal states and municipalities
Synergies	Nature conservation, water resources conservation
Factors to be considered	Competing river water users
Examples	-

Tab. A. 76: Mitigating the impacts of power plant outages

Field of action	Cooling water availability
Climate adaptation measure	**Mitigating the impacts of power plant outages**
Objective	Production outages can occur at fossil-fuel power plants when low water conditions or hot-weather periods force implementation of restrictions on the use of river water as plant cooling water. Appropriate buffering measures are needed to cushion potential consequences of such outages to ensure grid power supply remains stable despite the loss of generating capacity. This dependence on cooling water supply is also a decisive factor in transregional power plant planning aimed at ensuring grid stability e.g. by what are termed "minimum power plant fleets", taking water management variables into account (water temperatures, oxygen content and watercourse flows). Ensuring minimum power supply cannot entirely rule out that mandated water temperature limits may be exceeded. Standby power generation systems are necessary. Fossil-fuel power plants can join together with renewable energy producers in integrated networks, for example. It is advisable in this regard to continue expanding renewable energies. Greater use of energy storage systems can also help bridge electrical production outages.
In response to	Increasing occurrence of low water conditions due to low catchment run-off, and increasing water temperatures
Actions	• Power plant networking system (e.g. linking fossil-fired plants with renewable energy providers) • Diverse decentralised power generation sources • Standby power generation systems • Development and promotion of energy storage systems
Basis for decision-making	• Analyses and modelling of the specific river catchments affected
Responsible stakeholders	Power plant operators, policy-makers, research institutions
Synergies	Climate change mitigation due to increased use of renewable resources
Factors to be considered	Potentially more complex power line systems
Examples	-

Field of action - Hydropower generation

Tab. A. 77: Increasing efficiency

Field of action	Hydropower generation
Climate adaptation measure	**Increasing efficiency**
Objective	Various turbine configurations facilitate hydropower generation under varying flow conditions (including low flow). Improved efficiency and adapted turbine control systems also help to improve efficiency in hydropower generation.
In response to	Increased frequency of flood run-off / low water conditions
Actions	• Power units with a stepped configuration • Improved efficiency through adjustment of turbines used (e.g. Kaplan turbine: high efficiency even with fluctuating flow-through volumes and low heads) • Use of existing transverse structures for hydropower generation • Automated turbine control • Automated weirs • Rake cleaning machines, intake and sluice gates • Better network integration of generated electricity with good forecasting
Basis for decision-making	• As far as possible, accurate forecasting of future flows
Responsible stakeholders	Hydropower operators
Synergies	Higher profits
Factors to be considered	Limited potential to increase capacity while level of use remains unchanged; high costs; threat to economic viability of small hydropower plants
Examples	• Installation of a Kaplan shaft turbine at Gündenhausen hydropower plant on the River Wiese.

Tab. A. 78: Flow-balancing measures

Field of action	Hydropower generation
Climate adaptation measure	**Flow-balancing measures**
Objective	Optimum energy yield from hydropower plants is achieved when flow rates are consistent. Storing water from flood discharges ensures that water is available for release during periods of low flow. Storage management and control measures are beneficial here. The capacity of hydropower plants which already have impoundment facilities can in some circumstances be increased or maintained by expanding storage capacity or adapting storage control systems. Run-of-river hydropower plants whose operation does not rely on storage facilities are more directly exposed to climate change impacts, but may benefit from natural retention measures.
In response to	Increased frequency of flood run-off and low water conditions
Actions	• Expansion of storage capacity (e.g. reservoirs, underground cisterns) • Adaptations to storage control systems • Other retention measures
Basis for decision-making	-
Responsible stakeholders	Municipalities,water authorities, dam operators
Synergies	Also useful in energy storage
Factors to be considered	Unplanned hydropeaking may be a critical issue in terms of aquatic ecology; Water Framework Directive prohibits the deterioration of the status of water bodies; competing land uses; possible conflict between the various storage requirements and uses
Examples	• Hydropower generation at multifunctional dams, e.g. hydropower scheme at Königshütte Dam

Tab. A. 79: Ecological hydropower

Field of action	Hydropower generation
Climate adaptation measure	**Ecological hydropower**
Objective	In order to ensure that the pressure on aquatic ecosystems from current hydropower generation is kept to the necessary minimum, it is important to establish and maintain the minimum ecologically compatible flow of water in the diversion channels. Upstream (and if necessary downstream) continuity in the river must also be safeguarded for aquatic organisms. Furthermore, technical and operational fish protection measures should be taken at the plant. With the development of the shaft power plant - a relatively new concept - an attempt has been made to eliminate the environmental impacts of a hydropower plant.
In response to	Adverse impacts of climate change on aquatic ecosystems, such as an increase in ambient temperature or more frequent summer droughts; strengthening natural ecosystems to boost resilience to climate change

Actions	• Identify and maintain minimum flows
	• Provide adequate leading flows for fish
	• Shaft power plants
	• Establish continuity, e.g. with:
	    • Upstream and downstream fish passage facilities
	    • Bypass channels
	    • River bottom slides
	• Fish protection, e.g. through:
	    • Improved rake systems
	    • Fish-friendly turbines (with slow rotation and narrow gaps)
	    • Fish migration-friendly operations

Basis for decision-making	-
Responsible stakeholders	Hydropower operators, scientists
Synergies	Improved compatibility with the EU Water Framework Directive (WFD)
Factors to be considered	High costs; very little newbuild capacity; long technical lifespans of old turbines; possible production losses; some environmental restrictions continue to exist; "old rights"
Examples	• A pilot shaft power plant is planned on the River Loisach in Upper Bavaria. • Modification of old Kuhlemühle hydropower plant, with the installation of a fish ladder and residual flow management, to bring it in line with the Water Framework Directive • Fish ecology monitoring at innovative hydropower plants in Bavaria

Tab. A. 80: Regionalisation of data on average and low water levels as a basis for appraisal of new sites

Field of action	Hydropower generation
Climate adaptation measure	**Regionalisation of data on average and low water levels as a basis for appraisal of new sites**
Objective	This measure is recommended as a basis for assessing proposed new hydropower sites. It enables the economic viability of new plants to be determined under current conditions, taking the possible impacts of climate change into account. The size of new plants can then be decided accordingly.
In response to	Increased frequency of flood run-off and low water conditions
Actions	• Regionalisation of data on average and low water levels for the respective regions, with climatic and geographical conditions as explanatory variables in regression
Basis for decision-making	-
Responsible stakeholders	Federal states, water authorities
Synergies	-
Factors to be considered	-
Examples	• On behalf of Bavaria's State Office for the Environment (Landesamt für Umwelt - LfU), data on average and low water levels, including duration curves, were regionalised for the whole of Bavaria.

Tab. A. 81: Adapted load management

Field of action	Hydropower generation
Climate adaptation measure	**Adapted load management**
Objective	For optimum alignment of energy supply and demand, grids need to become "smarter"; this means that as many energy generation facilities as possible should be connected and managed in a network based on digital communications technology (virtual power plants/smart grids). This enables a faster response to peak loads.
In response to	Increase in unpredictability of electricity supply from renewable energies, resulting, for example, from an increased frequency of flood and low flow conditions
Actions	• Virtual power plants/smart grids (open platform with many market participants) • Integration of renewable energies
Basis for decision-making	• Demand and supply forecasting
Responsible stakeholders	Federal government (Bundesnetzagentur - Federal Network Agency), the federal states, energy suppliers
Synergies	Generally more efficient energy use; potentially, lower electricity prices in the long term
Factors to be considered	-
Examples	• In the Bopfingen region, a virtual power plant maintains a balance between electricity demand and the supply from local power generation schemes.

Tab. A. 82: Investing in energy storage technologies

Field of action	Hydropower generation
Climate adaptation measure	**Investing in energy storage technologies**
Objective	At times when there is a high or surplus supply of electricity, energy can be stored to meet subsequent demand. As energy production from renewables tends to fluctuate, centralised and local energy storage technologies are extremely important. With greater variability of flow rates in rivers anticipated as a result of climate change, energy storage facilities will also become more important.
In response to	Increased frequency of flood run-off / low water conditions
Actions	• Pumped-storage plants • Batteries • "Power to gas" technology
Basis for decision-making	-
Responsible stakeholders	Federal government (Federal Network Agency), the federal states
Synergies	A key development for all renewable energies
Factors to be considered	Research requirement; critical in relation to (aquatic) ecology; impact on landscape appearance; limited number of suitable sites
Examples	• Hohenwarte I and II Pumped-storage power plants

Field of action - Navigability

Tab. A. 83: Adaptation in an operational context

Field of action	Navigability
Climate adaptation measure	**Adaptation in an operational context**
Objective	In an operational context, adaptation measures can help to ensure that shipping activity continues in low water conditions or close to highest navigable water level (HNWL). In low water conditions, several smaller, lightweight vessels may sail in coupled convoys or continuous operation in order to maintain transport capacity. It may be necessary to modify routes if some waterways are no longer passable. To cope with extreme cases when a large number of routes are no longer navigable, warehousing capacities should be expanded and the shipping industry should work together with other transport modes (e.g. rail).
In response to	An increase in the number of days on which the highest navigable water level (HNWL) is exceeded; longer-lasting low water conditions
Actions	• Small vessels in continuous operation • Small vessels in coupled convoys • Lighter loads • Modification of routes • Expansion of warehousing capacity • Rescheduling of transport operations • Cooperation with other transport modes • Further development of integrated logistics management
Basis for decision-making	• Waterway information services / ELWIS
Responsible stakeholders	Federal government, federal states, shipping industry, port operators
Synergies	-
Factors to be considered	Shift work for crews; reduced transport capacities; extension of routes; larger space requirement; high costs; less capacity
Examples	-

Tab. A. 84: Water level forecasting

Field of action	Navigability
Climate adaptation measure	**Water level forecasting**
Objective	For effective high water/flood and low water management, early assessment of the flow situation is essential to ensure that preventive measures, e.g. managed water retention or regulation of water levels, can be taken in a timely manner. Early adoption of these measures on the basis of water level forecasting is required to facilitate an appropriate operational response by shipping companies.
In response to	An increase in the number of days on which the highest navigable water level (HNWL) is exceeded; longer-lasting low water conditions
Actions	• Early water level forecasting • Access to forecasts from waterway information services (ELWIS) • Timely response to forecasting (water retention, water level regulation)
Basis for decision-making	• Flow modelling in catchments • If necessary, additional management models at barrages • Information systems
Responsible stakeholders	German government, federal states, research facilities
Synergies	Research relevance; flood control; low water management
Factors to be considered	-
Examples	• The Electronic Waterway Information Service (ELWIS) operated by the Federal Waterways and Shipping Administration (WSV) provides multi-day forecasts for some gauges along the main waterways. • The Climate Change Forecasting Service for Waterways and Shipping (ProWaS) builds on hydrological and water quality models for the Rhine and Elbe. It will provide structured and documented datasets for scientific use, mainly for the purpose of further modelling and analysis, and will also supply transregionally aggregated data for waterways management.

Tab. A. 85: Adaptation in water resources management

Field of action	Navigability
Climate adaptation measure	**Adaptation in water resources management**
Objective	In order to avoid excessively high or low water levels, which have the potential to disrupt shipping, flow equalisation measures may be beneficial. Structures such as barrages and reservoirs contribute to flood retention and help to raise low water levels. Water levels can be regulated more effectively with early forecasting of high or low water conditions.
In response to	An increase in the number of days on which the highest navigable water level (HNWL) is exceeded; longer-lasting low water conditions
Actions	• Water level regulation (e.g. with barrages, reservoirs) • Diversion of water into/out of adjacent catchments • Canal system management
Basis for decision-making	• Catchment modelling • Water level information services
Responsible stakeholders	The federal states, waterways and shipping authorities, competent authorities
Synergies	Flood protection; low water management
Factors to be considered	Nature conservation; user competition (mainly shipping, nature, tourism, energy), depending on water levels.
Examples	• In Hesse, the Edersee Dam and Diemel Reservoir are improving low flow conditions along the Weser.

Tab. A. 86: Adaptation of waterway infrastructure

Field of action	Navigability
Climate adaptation measure	**Adaptation of waterway infrastructure**
Objective	Maintenance and development measures can help to ensure that waterways remain open to shipping in low water conditions. This may include deepening of waterways and ports and designation of a low water channel to improve navigability. Water-saving locks can reduce water losses. In estuaries, narrowing measures and barrages can control peak water levels during storm surges. At barrage facilities, low weirs help to reduce sedimentation on the seaward side. Regular maintenance programmes prevent sedimentation at some sites and deepening of the river bed at others.
In response to	An increase in the number of days on which the highest navigable water level (HNWL) is exceeded; longer-lasting low water conditions Sea-level rise, increase in storm surges
Actions	• Deepening of the navigation channel, stepped navigation channels • Deepening of the navigation channel with groynes, construction of longitudinal dikes, backfilling of potholes, construction of sandbanks • Deepening of ports (as "parking areas") • Installation of modern lock systems (water-saving locks) • Designation of low water navigation channels • Barrages or narrowing measures for estuaries • Low weirs at barrage facilities • Continuous sediment management
Basis for decision-making	• Modelling
Responsible stakeholders	The federal states, waterways and shipping authorities, competent authorities
Synergies	-
Factors to be considered	Nature conservation; high level of effort; high costs
Examples	• In the Lower Weser (Tideweser), the Federal Waterways and Shipping Administration (WSV) is implementing various measures, such as dredging, to keep the riverbed in good condition. Based on an integrated sediment management strategy developed by Federal Institute of Hydrology (BfG), efforts are being made to reconcile transport sector and environmental interests.

Tab. A. 87: Construction and modification of ships

Field of action	Navigability
Climate adaptation measure	**Construction and modification of ships**
Objective	Low water means that only lower draught ships was pass use the waterway in question. Lower draught is generally achieved by constructing smaller, lighter vessels, but another option is to integrate additional design features into existing ships, such as a dynamic propeller pocket (also known as a tunnel). Improved manoeuvrability and navigability are beneficial in high water conditions as well.
In response to	Increased frequency of high water run-off and low water conditions
Actions	• Smaller vessels • Lighter vessels (e.g. lighter materials: high-strength steel, pared-down equipment) • Reduced maximum draught • Improved manoeuvrability and navigability • Dynamic propeller pocket • Diesel electric propulsion with multiple screws
Basis for decision-making	-
Responsible stakeholders	Industry, waterways and shipping authorities
Synergies	-
Factors to be considered	Lower transport capacities; higher investment and transport costs
Examples	• The CroisiEurope fleet now operates lightweight ships which are propelled by modern paddlewheel technology and are specially designed to cruise the shallow Elbe and Loire rivers. • Kiesschifffahrt Weser has developed a shallow-draught vessel which can also be used as a push barge in low water conditions.

Field of action - Water abstraction for irrigation in agriculture

Tab. A. 88: Soil protection/protection of soils from erosion

Field of action	Water abstraction for irrigation in agriculture
Climate adaptation measure	**Soil protection/protection of soils from erosion**
Objective	In order to ensure soil water retention and thus safeguard economic yield, it is important to protect agriculturally used soils from erosion and compaction. Good soil water retention characteristics are also favoured by high organic matter contents and they reduce irrigation needs. These are considered measures as part of "good agricultural practice".
In response to	Increase in the frequency and intensity of heavy rainfall events and erosion as well as in the frequency and duration of drought periods.
Actions	• Preventing soil compaction (fewer lanes, reduce ground pressure by using wide tyres) • Humus enrichment (*see Tab. A. 90*) • Leaving harvest residues on the land • Avoiding damage from trampling and overgrazing • Widening of crop rotations, foregoing crops that require hoeing • Cultivation of catch crops, overwintering crops • Conservation tillage (*see Tab. A. 89*) • Direct seeding/mulch seeding methods • Establishment of structural elements (e.g. hedgerows, trees/shrubs, arable margins) • Cultivation of temporary undersown crops • Establishment and management of transverse embankments on flat arable land • Establishment of green strips in areas susceptible to run-off • Dismantling of linear elements no longer required (e.g. tracks, extraction lanes) • Grass-based farming on slopes at high risk of erosion
Basis for decision-making	• Erosion monitoring • "Good agricultural practice" in the Fertiliser Application Ordinance • Plans showing existing lanes
Responsible stakeholders	Farmers, agricultural associations, forestry offices, municipalities
Synergies	Nutrient supply; protection of watercourses; achievement of WFD objectives; nature conservation; flood protection as a result of improved water retention; wind protection (reduced evaporation and wind erosion)
Factors to be considered	-
Examples	• The municipal administration of Altenstadt, farmers and agricultural advisers have worked together to optimise erosion protection in the Wetterau region. • The subproject on "Climate-resilient organic farming" undertaken by the Innovation Network of Climate Change Adaptation Brandenburg Berlin (INKA BB) was concerned with the development of novel tools allowing organic farms to better adapt to climate change impacts.

Tab. A. 89: Conservation tillage

Field of action	Water abstraction for irrigation in agriculture
Climate adaptation measure	**Conservation tillage**
Objective	Continuous conservation tillage (non-inverting, ploughless tillage) is recommended in combination with direct seeding/mulch seeding and strip-tillage. It improves soil water retention. The soil moisture regime is improved as a result of improved infiltration as it allows for the formation of more stable soil aggregates compared to conventional tillage. At the same time, water losses from surface run-off and evaporation are reduced due to the retention of crop residues on the soil surface.
In response to	Increase in the frequency and intensity of heavy rainfall events and erosion as well as in the frequency and duration of drought periods.
Actions	• Minimum tillage • Strip-tillage/soil loosening (only strips in which plants grow are tilled) • Mulch seeding/direct seeding
Basis for decision-making	-
Responsible stakeholders	Farmers, authorities, manufacturers of agricultural technology
Synergies	Protection from erosion; watercourse protection; achievement of WFD objectives; flood protection; nature conservation
Factors to be considered	Potentially reduced yields; potentially increased requirements for pesticide use (this can however be avoided by adapting the arable cropping system as a whole including the design of crop rotations, fertiliser use strategies, ...)
Examples	• The Dresdenhof Estate (Gut Dresdenhof) near Cologne uses conservation tillage practices to manage its arable land.

Tab. A. 90: Humus enrichment

Field of action	Water abstraction for irrigation in agriculture
Climate adaptation measure	**Humus enrichment**
Objective	Increased temperatures can result in higher rates of humus mineralisation. Targeted additions of organic matter should be used to counter decreasing humus contents which would also expose the upper, more humus-rich soil strata to increased erosion. A sustained supply of organic matter improves the soils' water retention and infiltration capacities.
In response to	Increase in air temperature, increased frequency and intensity of heavy rainfall events and erosion.
Actions	• Retention of harvest residues on the land • Application of organic fertiliser • Cultivation of catch crops and undersown crops (e.g. legumes) • Direct seeding/mulch seeding methods • Conservation tillage (*see Tab. A. 89*) • Retention of the natural soil moisture regime, foregoing drainage
Basis for decision-making	-
Responsible stakeholders	Farmers, agricultural associations
Synergies	Nutrient supply; protection from erosion
Factors to be considered	-
Examples	• Trials conducted by the Saxony State Office for Agriculture (Sächsisches Landesamt für Landwirtschaft) have shown that continuous conservation tillage results in humus enrichment and increased nutrient levels in the topsoil.

Tab. A. 91: Adaptations in crop production

Field of action	Water abstraction for irrigation in agriculture
Climate adaptation measure	**Adaptations in crop production**
Objective	Adaptations in crop production can serve as relatively simple, low-cost and short-term measures. There should be a focus on crops requiring little water especially at the time of year when droughts may occur. In as much as possible, precipitation water should be retained on the land and shading should the used to reduce evaporation. As a risk spreading measure, the cultivation of a variety of crop plants as well as of species mixes are recommended. Where drought stress is an issue, farmers should aim for less dense stocks containing stronger individual plants. The longer growth periods may provide opportunities for adaptations in terms of seeding rates and seeding times.
In response to	Increase in the frequency and duration of drought periods and the frequency and intensity of heavy rainfall events and erosion as well as increases in air temperature.
Actions	• Selection of drought-stress tolerant crops • Selection of crops which have their highest water needs outside of the summer months • Production of winter crops • Precision sowing • Avoiding large-scale cultivation of crops that are susceptible to run-off and erosion (e.g. maize, beets) • Alternating strip-cultivation of different crops • Shading (e.g. in agroforestry systems or by installing solar modules) • Adaptations in terms of seeding and harvest times
Basis for decision-making	-
Responsible stakeholders	Farmers, research
Synergies	Protection from erosion; efficient land use; possibly greater yields due to longer growth periods
Factors to be considered	-
Examples	• The Technology and Support Centre (TFZ) of the Bavarian Ministry of Food, Agriculture and Forestry conducted trials on sorghum, a millet species from the Sahel, in Germany and recommends this crop as a replacement for maize for biomass production due to its high biomass energy potential and its drought-stress tolerance.

Tab. A. 92: Irrigation efficiency

Field of action	Water abstraction for irrigation in agriculture
Climate adaptation measure	**Irrigation efficiency**
Objective	With a view to prudent water use, irrigation should only be used where water is urgently required. There are methods and techniques for determining the plants' water requirements. Some irrigation techniques are highly water-efficient. Drip irrigation, for example, very precisely delivers small amounts of water, thus minimising evaporation losses as much as possible.
In response to	Increase in the frequency and duration of drought periods, increase in air temperature.
Actions	• Drip irrigation • Demand-based irrigation • Precision irrigation
Basis for decision-making	-
Responsible stakeholders	Farmers, agricultural associations, manufacturers of agricultural technology, researchers
Synergies	Optimum irrigation provides optimum conditions for plant nutrient supply; less nitrate leaching compared to over-irrigation; less leaf wetting means that plants are less susceptible to fungal diseases.
Factors to be considered	Costly investments in new methods
Examples	• "Geisenheim Irrigation Scheduling" is a calculation method developed by the Geisenheim University for demand-based irrigation of outdoor vegetable crops at different growth stages. The calculation takes into account Penman evapotranspiration or FAO56 grass reference evapotranspiration, local precipitation and kc-values.

Tab. A. 93: Groundwater substitution

Field of action	Water abstraction for irrigation in agriculture
Climate adaptation measure	**Groundwater substitution**
Objective	In order to mitigate conflicts over the use of groundwater resources, alternative water resources, e.g. surface waters, should be used for irrigation in agriculture and horticulture where possible. Storage of winter precipitation water also offers great potential, but requires that storage systems are available or be constructed.
In response to	Increase in the frequency and duration of drought periods, decrease in summer precipitation, increase in winter precipitation.
Actions	• Utilisation of water from surface waters • Rainwater utilisation (storage of winter precipitation, e.g. in ponds) • Storage systems (e.g. Underneath grass cover along field boundaries, underneath segments of cropping areas or underneath farmyards).
Basis for decision-making	• Water resources management for the relevant groundwater body • Groundwater monitoring
Responsible stakeholders	Federal states, municipalities, agricultural associations, farmers, water utilities
Synergies	-
Factors to be considered	May be of concern from the point of view of aquatic ecology and low water management; land consumption.
Examples	• The horticultural enterprise Engels near Düsseldorf uses rainwater for irrigation. To this end, the company collects rainwater from the roofs of greenhouses and surrounding private houses which is then stored in six outdoor basins. Additionally, there are four large storage tanks underneath the greenhouses which can be used for rainwater storage. These also collect surplus irrigation water.

Tab. A. 94: Organisational adaptations in agriculture

Field of action	Water abstraction for irrigation in agriculture
Climate adaptation measure	**Organisational adaptations in agriculture**
Objective	More comprehensive water resources management plans, which also include agricultural water use, will facilitate the allocation of water quantities for usage and the timing of this usage. Irrigation equipment would most prudently be purchased by joint investment on the part of producers organised in irrigation associations. Water rights can also be more flexibly allocated within such associations. Moreover, potential safeguards in the event of crop failures should be taken into consideration.
In response to	Increase in the frequency and duration of drought periods and in the frequency and intensity of heavy rainfall events as well as other extreme meteorological events.
Actions	• Cross-departmental and complete recording of licenced abstractions in a single database ("electronic water rights record book") • Cross-departmental water resources management plans • Establishment of irrigation associations • Establishment of rules to mitigate the impact of crop failure • Establishment of rules for recording the actual quantities of water abstracted per annum.
Basis for decision-making	-
Responsible stakeholders	Farmers, agricultural associations, authorities, policy-makers, researchers
Synergies	-
Factors to be considered	-
Examples	• The main task of the Wasser- und Bodenverband zur Beregnung der Vorderpfalz (water users' association for irrigation in the Anterior Palatinate) is the provision of Old Rhine water for irrigation purposes for the large-scale production of vegetables and early potatoes.

Tab. A. 95: Forecasting/information

Field of action	Water abstraction for irrigation in agriculture
Climate adaptation measure	**Forecasting/information**
Objective	Precise knowledge of expected local weather conditions over the coming days and weeks contributes to efficient water use. Knowledge of the extent and speed of anticipated local impacts of climate change and the uncertainties attached to these predictions helps farmers and horticultural enterprises to take timely decisions on appropriate climate adaptation measures.
In response to	General climatic changes
Actions	• Improved agro-meteorological forecasting • Good access to GIS-based climate parameters for farmers, horticulturalists and the general public (both evaluations of historic data and potential regional climate scenarios)
Basis for decision-making	-
Responsible stakeholders	Federal states, research, farmers, horticulturalists
Synergies	Optimisation of fertiliser and pesticide use; optimisation of working hours; yield increases
Factors to be considered	-
Examples	• The Free State of Saxony initiated a regional climate information system (Regionales Klimainformationssystem, ReKIS) for Saxony, Saxony-Anhalt and Thuringia. This system provides necessary information and data for planning and decision-making processes – including simulated future projections – for a range of different stakeholders. It is continuously being advanced and adapted to new requirements.

Field of action - Dam and reservoir management

Tab. A. 96: Review and structural optimisation of existing facilities

Field of action	Dam and reservoir management
Climate adaptation measure	**Review and structural optimisation of existing facilities**
Objective	Dams and reservoirs should be reviewed to check whether they still meet the requirements of the dam standard DIN 19700 (2004) under changing climatic conditions. The extended checks that are prescribed and the application for and granting of water permits should therefore always be linked to a climate change check. Facilities may need to undergo structural and/or operational adaptation or optimisation. As part of this process, particular attention should be paid to flood relief.
In response to	Increase in heavy rain and flood discharge and low water situations and/or dry periods, increased demand for water (e.g. irrigation water)
Actions	• Redimensioning of storage zones with changes to the normal and drawdown water levels and possibly the freeboard • Increasing the flood relief capacity • Improving the controllability of the facility by configuring movable locks or additional withdrawal facilities • Introduction of climate markups for design parameters
Basis for decision-making	• Future-oriented projections of the key climate elements (e.g. precipitation, discharge, temperature, evaporation, wind) and (if appropriate) changes in requirements
Responsible stakeholders	Dam operators, federal states, competent authorities
Synergies	-
Factors to be considered	Sustainability of the measures, cost, relevance to safety, evaluation of the changes in the context of existing design uncertainties (e.g. flood design events with very low probability of occurrence) and safety reserves
Examples	• The state dam management authority for the state of Saxony is currently planning to enlarge the flood relief system at the Malter Dam. The Water and Environment Research Institute at the University of Siegen is conducting model tests to verify and optimise the hydraulic functionality of the system. • As part of a study carried out in 2007, the Ruhrverband sought to clarify whether the Ruhr dams will still be able to provide sufficient water for people in the Ruhr district and the Sauerland in the face of possible climatic changes.

Tab. A. 97: Sediment and flotsam management under changing climatic conditions

Field of action	Dam and reservoir management
Climate adaptation measure	**Sediment and flotsam management under changing climatic conditions**
Objective	The work involved in sediment and flotsam management in dams may increase as a result of increasing inflow quantities due to changed climatic conditions. As part of the management of water quantity and quality, regular sediment clearance, especially in the preimpoundment basins of dams, will be required. The risk of obstruction of withdrawal and relief systems by debris and driftwood can be minimised by regular clearance. Erosion prevention measures in the catchment area can reduce sediment input and thus reduce the need for maintenance at the dam.
In response to	Increase in the frequency and intensity of heavy rain events and erosion, increase in flood run-off
Actions	• Regular upgrading and clearing of preimpoundment basins • Adapted and large-scale management of solid matter • Measures to prevent erosion in the upstream catchment area (*see Tab. A. 88*)
Basis for decision-making	• Modelling of debris and suspended matter
Responsible stakeholders	Federal government, federal states, authorities, dam operators
Synergies	-
Factors to be considered	-
Examples	-

Tab. A. 98: Adaptive dam management

Field of action	Dam and reservoir management
Climate adaptation measure	**Adaptive dam management**
Objective	Dams are increasingly being used to perform multiple functions – flow regulation (flood protection, raising low water levels), hydropower use and provision of drinking water. However, in the context of climate change multi-purpose use requires adaptive dam management – i.e. dams must be managed on a temporally and spatially differentiated basis that takes account of differing requirements. Quantity management and quality management are related and must therefore be coordinated. Coordination should ideally be supported by model simulations. Quality management measures are set out in more detail in *Tab. A. 99*.
In response to	Increase in the frequency and intensity of heavy rain events, increase in flood run-off, increased occurrence of low water run-off
Actions	• Redivision of usage zones (barriers) • Dynamisation of normal and elevated water levels (e.g. establishment of variable storage targets according to the time of year) • Multi-criteria optimisation in the event of competing usage requirements • Ecological management: managing the water temperature in the downstream area to ensure that conditions are as natural as possible • Automation of operating procedures
Basis for decision-making	• Precipitation/run-off models • Forecasting of inflow and water level trends • Metrological monitoring
Responsible stakeholders	Dam operators, water authorities
Synergies	Flood protection; low water management; public water supply; hydropower generation
Factors to be considered	Possibility of incorrect management in the event of inaccurate forecasts
Examples	• An ecological management system was developed for the Leibis/Lichte Dam. Dynamic discharge regulation feeds the water of the Lichte into the Schwarza in such a way that its temperature is only minimally altered.

Tab. A. 99: Measures to safeguard water quality

Field of action	Dam and reservoir management
Climate adaptation measure	**Measures to safeguard water quality**
Objective	To ensure that the water that is released is of suitable quality for its intended purpose, there must be an integral system for managing the quantity and quality of water that takes adequate account of the interactions between the two. This is particularly important in multi-purpose dams. The water of the epilimnion should preferably be used for the abstraction of works water, minimum downstream water release, pre-release before flood events and the emptying of full floodwater retention areas after flood events. The clear, deep water of the hypolimnion should be saved for drinking water. To achieve this, the withdrawal mechanisms must be as adjustable and controllable as possible. Other measures that help safeguard the quality of drinking water include reduced sediment transport from upstream catchment areas, removal of pollutants via the bottom outlet, pre-cleaning in a preimpoundment basin, appropriate food chain management, aeration and appropriate treatment of the raw water.
In response to	Increase in the frequency and intensity of heavy rain events and erosion, raised water temperature, increase in flood run-off, increased occurrence of low water run-off
Actions	• Prevention of erosion in the upstream catchment area (*see Tab. A. 88*) • Installation of epilimnetic withdrawal facilities for flood relief, withdrawal of works water, etc. (e.g. descending sluice gate) • Installation of variable/multiple raw water withdrawal points • Aeration of the hypolimnetic water body during lengthy dry periods • Removal of pollutants via the bottom outlet after heavy rain events • Installation of preimpoundment basins for pre-cleaning • Appropriate food chain management • Appropriate water treatment facilities (outside the dams) (*see Tab. A. 70*)
Basis for decision-making	• Erosion models • Monitoring of water quality
Responsible stakeholders	Water authorities, dam operators
Synergies	-
Factors to be considered	Potential deterioration of water quality downstream; high costs; space requirements
Examples	• The Carlsfeld Dam has a continuously height-adjustable raw water withdrawal system and a pipeline for diverting water contaminated with humic matter.

Tab. A. 100: Systematic combined management of several dams

Field of action	Dam and reservoir management
Climate adaptation measure	**Systematic combined management of several dams**
Objective	The balancing effect of a dam can be increased by operating it in combination with several other dams. This requires the dams to be connected via water transfer systems, pipelines, tunnels, etc. and coordinated management of the combined dams is necessary.
In response to	Increase in the frequency and intensity of heavy rain events, increase in flood run-off, increased occurrence of low water run-off
Actions	• Coordinated management of several dams • Construction of collecting works • Construction of transfer systems (e.g. pipelines, ditches, tunnels)
Basis for decision-making	• Impact analyses based on models
Responsible stakeholders	Federal states, dam operators
Synergies	Increased security of the public water supply and low water management in watercourses
Factors to be considered	Consideration of the ecologically required minimum flow of the rivers that are used for transfer; more stringent management of dams; conflicts of objectives
Examples	• The Lehnmühle and Klingenberg dams are part of an integrated reservoir operation system that provides raw water for the drinking water supply of the city of Dresden and surrounding supply areas. The dam system can be augmented by piping in raw water from the Rauschenbach Dam (and if necessary also from the Lichtenberg Dam) in the central Erzgebirge.

Tab. A. 101: Securing further locations for dams/building new dams

Field of action	Dam and reservoir management
Climate adaptation measure	**Securing further locations for dams/building new dams**
Objective	If fluctuations in the hydrological regime continue to increase as a result of climate change, additional reservoirs and storage areas may be needed. In regions in which the need for reservoir space is likely to rise, other locations that might be suitable for dam construction should be investigated and, as part of forward-looking planning, be secured and kept free for the long-term public water supply, flood protection and the raising of low water levels. The land can, for example, be defined as a priority area or reserved area in regional or state development plans. As a precaution, new dams should be built in a way that enables subsequent retrofitting or expansion to be performed with minimum time and effort.
In response to	Increase in the frequency and intensity of heavy rain events, increase in flood run-off, increased occurrence of low water run-off
Actions	• Geographic and hydrological investigations • Modelling and impact analyses • Land acquisition, land designation
Basis for decision-making	-
Responsible stakeholders	Federal states, municipalities, water management authorities
Synergies	-
Factors to be considered	Preventing deterioration in the status of water bodies in accordance with the Water Framework Directive; acceptance among the public is difficult if concrete need for use does not yet exist; the land ownership situation
Examples	-

Field of action - Low water management in watercourses

Tab. A. 102: Low water and temperature forecasts

Field of action	Low water management in watercourses
Climate adaptation measure	**Low water and temperature forecasts**
Objective	Low water and temperature forecasts are an essential aspect of any scheme for managing low water. For example, such forecasts must be available if usage restrictions (see *Tab. A. 104*) are to be put in place promptly when critical levels are reached. On the basis of the forecasts, the public and affected users are to be informed of the expected development. The forecast should be extended and developed to include smaller water bodies. This requires better recording of low water discharges at the gauges.
In response to	Increasing occurrence of low water conditions due to low catchment run-off, and increasing water temperatures
Actions	• Adjusting the measurement grid and gauges to low water • Increased monitoring during low water phases • Creation and extension of forecasting models • Inclusion of water temperature and other water-body quality parameters in the models • More accurate forecasts for smaller at-risk catchment areas • Production of worst-case forecasts
Basis for decision-making	• Precise low water measurements • Adequate monitoring of water-body quality (incl. water temperature)
Responsible stakeholders	Federal states, water authorities
Synergies	Improved models also useful for assessing the impacts of climate change on low water and water temperatures
Factors to be considered	–
Examples	• In the event of low water, the low water information service publishes a status report for the whole of Bavaria detailing the current situation and likely developments. • Baden-Württemberg's high water forecasting centre publishes daily low water forecasts for around 100 state-operated gauges; temperature forecasts are produced daily and, where necessary, made available to the state authorities responsible for monitoring water law. • Baden-Württemberg's high water forecasting centre makes the flow readings at state-operated gauges available to all water users via the "Meine Pegel" app so that those affected can receive information in the form of push notifications on the current flow rate at a particular gauge. • Hesse and Rhineland-Palatinate publish forecasts of water temperature changes in the Rhine (http://www.waermemodell-mittelrhein.de/html/)

Tab. A. 103: Management plans with measures to be applied if discharge falls below certain levels

Field of action	Low water management in watercourses
Climate adaptation measure	**Planned measures to be applied if discharge falls below certain levels**
Objective	Management plans for water bodies should pay special attention to low water situations. Conflicts of use in connection with the management of water bodies should be identified in advance and priority users defined. Restrictions should be linked to defined threshold values and incorporated into decisions under water law. Existing decisions may need to be amended. Increased monitoring of water-body use in low water situations should also be organised in advance.
In response to	Increased occurrence of low water discharge
Actions	• Clarification of responsibilities • Definition of priority uses • Tightening rules governing discharges to water bodies when levels fall below threshold values • Emergency supply plan (for drinking water: e.g. use of tankers, public taps)
Basis for decision-making	-
Responsible stakeholders	Federal states, municipalities, water authorities
Synergies	-
Factors to be considered	Limited acceptance of economic losses
Examples	-

Tab. A. 104: Usage restrictions

Field of action	Low water management in watercourses
Climate adaptation measure	**Usage restrictions**
Objective	To avoid additional burdens on water bodies in the event of low water, restrictions on their use can be imposed in these situations. Existing rules on the use of water bodies should also be monitored more closely in low water situations and compliance with them enforced. To prevent conflicts over use, agreement on the usage restrictions should be reached in advance and priorities that apply when particular threshold values are reached should be defined. Decisions under water law may need to be adapted in the light of this and the restrictions should be appropriately communicated and monitored.
In response to	Increasing occurrence of low water conditions due to low catchment run-off, and increasing water temperatures
Actions	• Increased monitoring of uses permitted under water law • Restrictions on the public use of surface waters and use by owners and the local community • Restrictions on the withdrawal of non-potable water for the public (e.g. for watering gardens or washing cars) • Regulation of withdrawal for agricultural purposes • Restrictions on leisure use (e.g. kayaking) • Advance agreements on usage restrictions (e.g. definition of priorities) • Targeted communication of restrictions • Adaptation of decisions under water law
Basis for decision-making	• Monitoring of discharge, water temperature, oxygen content, etc. • Low water and temperature forecasts • Experience of past low water situations
Responsible stakeholders	Federal states, municipalities, water authorities
Synergies	-
Factors to be considered	Pressure of use on water bodies is expected to increase overall; increased human resource requirements; only practical if accompanied by information and awareness-raising; complexity of existing water use decisions and established rights
Examples	• During the prolonged drought in August 2015, a water supply company in the Forchheim area banned its customers from using potable water to water lawns or wash cars.

Tab. A. 105: Measures to safeguard water quality

Field of action	Low water management in watercourses
Climate adaptation measure	**Measures to safeguard water quality**
Objective	During periods of low water, water quality may deteriorate as a result of rising water temperatures, low flow rates and natural discharge only diluting to a limited extent industrial inputs and pollutants entering the water body. A particularly critical parameter is the oxygen content of the water, which is crucial to the survival of many aquatic organisms and heavily dependent on water temperature. It is therefore important to keep the water bodies as cool as possible, e.g. by providing shade or restricting the input of warmed cooling water. In addition, reduced retention times prevent strong warming of water bodies. Heat load plans help officials keep track of the heat loads to the entire river system and coordinate permits with each other. In extreme situations it may be necessary to boost the oxygen content through aeration or to boost discharge by raising low water levels.
In response to	Increasing occurrence of low water conditions due to low catchment run-off, and increasing water temperatures
Actions	• Reduction of inputs of nutrients and pollutants (*see Tab. A. 43*) • Reduction of the withdrawal and input of cooling water (*see Tab. A. 72*) • Providing shade by means of trees on the margins of water bodies (*see Tab. A. 49*) • Aeration • Heat load plans and models • Removal of water-retaining works • Raising low water levels (*see Tab. A. 107*)
Basis for decision-making	-
Responsible stakeholders	Federal states, municipalities, water authorities, farmers, industry
Synergies	Continuity of watercourses, dynamisation of discharge, conservation of aquatic ecosystems
Factors to be considered	-
Examples	• Water-retaining works were removed at a source near Klausdorf.

Tab. A. 106: Aeration

Field of action	Low water management in watercourses
Climate adaptation measure	**Oxygen management by aeration**
Objective	In the event of prolonged drought and high air temperatures, steps should be taken to aerate slow-flowing or stagnant water bodies to boost the oxygen content, in particular to prevent fish dying from asphyxiation.
In response to	Increasing occurrence of low water conditions due to low catchment run-off, and increasing water temperatures
Actions	• Turbine aeration • Aeration by means of weir overflow, surface irrigation over cascades • Paddle wheel aerators • Input of industrial oxygen • Wastewater aeration of sewage treatment plant discharge
Basis for decision-making	• Monitoring of discharge, water temperature, oxygen content, etc.
Responsible stakeholders	Federal states, water authorities, municipalities, hydropower plant operators
Synergies	-
Factors to be considered	High technical and energy costs; if there are water-retaining works the oxygen content falls as a result of low flow rates and warming
Examples	• To regulate oxygen in the Neckar, the oxygen content is recorded continuously via online stations and a warning is triggered if the content is less than 4 mg oxygen per litre. Aeration measures are then taken at the power plants and wastewater treatment plants in Stuttgart.

Tab. A. 107: Raising low water levels

Field of action	Low water management in watercourses
Climate adaptation measure	**Raising low water levels**
Objective	Raising low water levels serves to maintain a defined minimum flow and prevent aquatic ecosystems becoming completely dry. In smaller water bodies in particular, natural discharge may become so low that use of the water bodies - for example as receiving waters for cooling water and treated sewage - can seriously pollute them and risk damaging the aquatic ecosystem. Low water levels can be raised via regulated release of water from artificial storage systems or by transferring water from adjacent river catchments that are less severely affected by low water flows.
In response to	Increasing occurrence of low water conditions due to low catchment run-off, and increasing water temperatures
Actions	• Construction/expansion of water storage systems/dams (*see Tab. A. 108*) • Optimised management of existing multi-purpose dams (*see Tab. A. 98)* • Transfers from adjacent catchment areas
Basis for decision-making	• Modelling of the river catchment area • Consideration of hydrological conditions over the entire year and under possible future climate conditions
Responsible stakeholders	Federal states, municipalities, water authorities
Synergies	Navigability; hydropower generation; conservation of aquatic ecosystems
Factors to be considered	Competition with flood protection, public water supply; considerable effort and expense
Examples	• Bavaria's biggest and most important system for raising low water levels is the Danube-Main transfer system, which transfers water from the Danube area to the Regnitz and the Main at times of low discharge.

Tab. A. 108: Creating storage capacity

Field of action	Low water management in watercourses
Climate adaptation measure	**Creating storage capacity**
Objective	In low water situations, stored water from periods of high water levels can be used to raise low water levels and prevent aquatic ecosystems becoming completely dry. In smaller water bodies in particular, natural discharge may become so low that use of the water bodies - for example as receiving waters for cooling water and treated sewage - can seriously pollute them and risk damaging the aquatic ecosystem. Dilution with stored water may then be very important. Storage systems have a balancing function while at the same time providing flood protection and possibly also a source of drinking water.
In response to	Increased occurrence of low water discharge
Actions	• Retention basins with long-term storage • Dams
Basis for decision-making	• Geographic and hydrological investigations • Modelling and impact analyses
Responsible stakeholders	Federal states, municipalities, water authorities
Synergies	Flood protection; groundwater recharge, public water supply
Factors to be considered	Competing land use; prohibition of deterioration in the status of water bodies in accordance with the Water Framework Directive
Examples	• Raising low water levels in streams and rivers is a main or subsidiary purpose of 15 of the 25 dams and flood retention basins in Bavaria.

Tab. A. 109: Promoting natural water retention

Field of action	Low water management in watercourses
Climate adaptation measure	**Promoting natural water retention**
Objective	Natural retention and seepage of high discharges and precipitation promotes groundwater recharge. During low water phases the basic (groundwater-based) discharge accounts for a major proportion of water-body discharge. Increasing basic discharge through increased natural retention thus serves to increase low water discharge.
In response to	Increased occurrence of low water discharge
Actions	• Provision of floodplains • Re-wetting of wetlands (*see Tab. A. 60*) • Restoration of near-natural waters • Adapted land management • Increasing the amount of green space / reducing sealing • Improving the water storage capacity of the soil
Basis for decision-making	-
Responsible stakeholders	Municipalities, regional planners
Synergies	Flood protection, conservation of aquatic ecosystems, groundwater protection, soil protection
Factors to be considered	-
Examples	• Restoration of the Danube to a more natural state between Neuburg and Ingolstadt