ClimAware: impacts of climate change on water resources management. Regional strategies and european view. Final Report

S. Theobald, K. Träbing, K. Kehr, V. Aufenanger, M. Flörke, C. Schneider, Charles Perrin, Guillaume Thirel, Mathilde Chauveau, F. Dehay, et al.

ClimAware

IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES MANAGEMENT

- REGIONAL STRATEGIES AND EUROPEAN VIEW -

Final Report

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Contents

Policy Brief

WFD article targeted

The ClimAware project analysed the impacts of climate change on freshwater resources at the continental and regional scales to identify efficient adaption strategies, to improve water management for various socio-economic sectors and hence, to contribute to an effective implementation of the Water Framework Directive (WFD). The main focus is in this respect on the WFD instruments as provided in the river management plans and the programmes of measures. ClimAware particularly addressed the following WFD articles:

- Art. 4, which deals with the environmental objectives to achieve a good status for all surface waters until the year 2015 or at least to prevent any deterioration of the surface water status.
- Art. 11, which focuses on the programmes of measures to reach the environmental objectives.
- Art. 14, which treats information and consultation of the practice partners and stakeholders.

Key words

Water Framework Directive, climate change, socio-economic-developments, low and high water, flood and drought, water availability and water demand, water resources management, sustainability, hydromorphological conditions, dam management, agricultural water use, irrigation practices, stakeholders involvement, adaption strategies, hydrodynamic numerical modelling, hydrologic economic modelling.

Description of the project

The main objectives of the project have been addressed by combining a European modelling approach with case study analysis and regional (local) knowledge of water demand and water availability considering climate change as well as socio-economic developments. An integrated assessment for entire Europe was performed under the consideration of different scenarios and climate change projections. This large-scale perspective allows indicating regions which are potentially vulnerable to climate change and furthermore to identify regional adaptation measures which could be promoted at the EU level. Additionally three case studies were selected across Europe to investigate changes in hydrologic regimes, water availability and sectoral water use. These case studies are focusing on three different water management issues in three different regions.

In the first case study, the influence of climate change on the hydromorphological conditions according to the WFD were evaluated for a section of the Eder River (Germany). The objective of this case study was to examine whether the environmental WFD objectives can be achieved in a typical river section considering climate change impacts.

The second case study investigated water management, especially drinking water provision, and flood alleviation in the Seine river basin (France), which is partly based on the operation of artificial reservoirs. Scenarios were developed linking the impact of climate change on water resources and changes in water demand and its management.

The third case study assesses the quantitative effects of climate change on water balance components and water use in the agricultural sector of the Italian Apulia region, in order to support the adoption of adaptation measures. Actually, in the Apulia region agriculture still remains the primary user of water and the primary economical resource.

Policy focus

The objectives of the ClimAware project are twofold: first, to assess the impacts of climate and socio-economic changes and to develop adaption strategies to reduce them according to the most relevant questions in the context in each case study. This supports water managers and other stakeholders on river basin level. Second, these results are translated into region-specific recommendations for policy makers on the EU-level for strategic, tactical and operational management depending on the regional water issues.

Policy milestones, relevant projects key outputs and main recommendations

Within ClimAware different aspects of water resources management were investigated at the European and case study levels considering socio-economic scenarios as well as climate change projections with the following results:

From the European perspective, the majority of the EU needs to prepare for more water scarcity and droughts. Water scarcity is especially a problem in Southern and South-Eastern Europe. Therefore, regional adaptation strategies also need to address water demand management and more efficient use of freshwater resources. The uncertainty of climate projections and changes in human pressures (i.e. water demand) plays a major role as climate change impacts will be in addition to, or concurrent with, those associated with socio-economic developments. Therefore, all climate change adaptation policies should require actions that are chosen not only on the basis of their effectiveness to current climate variability and human pressures but also under future conditions. By comparing different scenarios it can be concluded that socio-economic scenarios dominate the dynamics of water scarcity although even a substantial decrease in water withdrawals does not prevent some regions from water scarcity particularly during the summer season. Therefore adaptation should not be discussed in isolation and the focus of any policy intervention should also be on the socio-economic drivers, such as land use and production patterns. For some regions technical measures that mainly aim to maintain the current state or try to reduce the impacts are probably not sufficient to save water and to diminish vulnerability to water scarcity in the future.

Regarding the improvement of the hydromorphological conditions of rivers according to the objectives of the WFD (Case Study 1), restoration measures, like they are implemented at the Lower Eder River, supporting morphodynamic fluvial processes, remain to be the best choice for stream restoration. Though the finally developing stream morphology may change due to climate change these morphodynamic self-adjustable measures are not expected to need adaption.

In terms of climate-change challenges as well as uncertainties on the non- or very-minor anthropogenic altered stream situation this kind of measure is the best choice for an effective WFD implementation strategy. Hydromorphological improvements support the improvement of the biological quality elements very well. Morphostatic measures like the installation and operation of fish passage facilities need to be adaptable for climate-change induced low-flow aggravation which is usually easy to achieve during design and construction as well as in most cases also in an already operating installation.

The objective of Case Study 2 (Seine River basin) was to provide an analysis framework to water managers for evaluating potential consequences of climate change on the river basin hydrology and assessing adaption strategies to cope with these changes. These adaption strategies were developed at tactical (adaption of target reservoir filling curves) and at operational (real-time reservoir management) levels.

The result is a centralized real-time controller called Tree-Based Model Predictive Control (TB-MPC) developed in collaboration with TU Delft (Netherlands) and Politecnico di Milano (Italy). For the reservoirs' management on the Seine River, this tool uses all the information available in real time, including ensemble weather forecasting, and hence, shows a distinct improvement for drought and flood management.

The Apulian Case Study (Case Study 3) identified a whole series of measures to adapt and/or mitigate adverse effects of climate change. At farm level, farmers adopt different strategies in their farm management: they reduce the irrigated surfaces and shift towards less water intensive techniques. In addition there is an effect of crop substitution and dangerously a serious phenomenon of land abandonment since a substantial area of the region will not be cultivated anymore. At system level, discussions with local experts in water management highlighted the need for enhancing some of the consortia management tasks, namely the survey of the irrigation demand, the optimization of the water allocation in view of the future reduced availability, the development of a drought early warning system and infrastructural interventions aiming to increase water availability. The reduction of the irrigation system vulnerability to drought could be achieved by enhancing the interconnection with other sources of water, both conventional and non-conventional. The former requires the development of new storage and delivering infrastructures. The latter needs reliable water treatment plants. Besides, the re-use of reclaimed water needs to deal with cultural barriers related to the willingness of farmers to use this water for irrigation. Results show that notwithstanding the complex farm strategies adopted farm income is seriously affected by future climate conditions. These results put in question the overall sustainability of the agricultural systems that is supposed to increase productivity to meet food security. Accordingly the socio-economic sustainability is also vulnerable with an income reduction for farmers of about 37 %.

Technical assistance and knowledge transfer processes together with the integration of the stakeholders' objectives and knowledge in a shared strategic vision resulted to be a crucial issue to facilitate the achievement of the adoption of effective adaptation measures.

Limitations identified by the project

The ClimAware project deals with the impact of climate change and socio-economic changes. Due to this the project results are developed based on climate and model uncertainties, which necessitates a continuous evaluation and adaption depending on the real development of water demand and water availability. Else, the chosen case studies are individual examples and the results always need to be validated and if necessary adjusted, when they are transferred to comparable problems.

Additional technical/scientific information: related deliverables

Brouwer, R., Hofkes, M. (2008). Integrated hydro-economic modelling: Approaches, key issues and future research directions. Ecol. Econ. 66:16-22. doi: 10.1016/j.ecolecon.2008.02.009.

Dehay, F. (2012). Etude de l'impact du changement climatique sur la gestion des lacs-réservoirs de la Seine. Master thesis ENGEES, Strasbourg. http://cemadoc.irstea.fr/cemoa/PUB00035975

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Schneider C., Flörke M. (2013). Floodplain wetlands at risk: The impact of dams on ecologically important flood flows. GWSP Conference "Water in the Anthropocene: Challenges for Science and Governance", 21.-24.5.2013, Bonn, Germany.

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Thirel G., D'Agostino D., Dorchies D., Flörke M., Kehr K., Perrin C., Scardigno A., Schneider C., Theobald S., Träbing K. (2014). The Climaware project: Impacts of climate change on water resources management – regional strategies and European view. EGU General Assembly 2014, Wien, Austria.

Further information on project:

Starting date: September 2010 (officially January 2011 for the French and Italian partners)

Ending date: December 2013

Participating countries/partners:

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Hydrosystems and Bioprocesses Research Unit, Antony and G-EAU, Montpellier (National Research Institute of Science and Technology for Environment and Agriculture, Irstea, France)

EPTB Seine Grands Lacs (Paris, France)

Mediterranean Agronomic Institute of Bari, Land and Water Resources Management Department (CIHEAM-IAMB, Bari, Italy)

Type of R&D: The ClimAware project mainly deals with applied research and development in the fields of Water resources management and Agricultural water use

Programme: 2nd Joint IWRM-NET Call for Research on Integrated Water Resource Management

Web link: http://www.uni-kassel.de/fb14/wasserbau/CLIMAWARE

Anvisierte Artikel der WRRL

Das ClimAware Projekt untersuchte den Einfluss des Klimawandels auf Süßwasserressourcen auf europäischen und regionalen Bezugsskalen, um effiziente Anpassungsstrategien zur Verbesserung der Wasserwirtschaft bei verschiedenen sozio-ökonomischen Rahmenbedingungen zu entwickeln und so zu einer effektiven Umsetzung der Wasserrahmenrichtlinie (WRRL) beizutragen. Der Schwerpunkt des Projekts liegt auf dem WRRL Instrumentarium der Flussgebietsmanagementpläne, der Bewirtschaftungspläne und der Maßnahmenprogramme. ClimAware bezieht sich insbesondere auf die nachfolgenden Artikel der WRRL:

- Art. 4, dieser regelt die Umweltziele, die besagen, dass bis zum Jahr 2015 ein guter Zustand für alle Oberflächengewässer zu erreichen oder zumindest jegliche Verschlechterung der Oberflächengewässer zu verhindern ist.
- Art. 11, der die Maßnahmenprogramme zur Erreichung der Umweltziele beschreibt.
- Art. 14, der sich auf die Information und Anhörung der Praxispartner und beteiligter Interessengruppen bezieht.

Schlüsselwörter

Wasserrahmenrichtlinie, Klimawandel, sozio-ökonomische Entwicklungen, Niedrig- und Hochwasser, Flut und Dürre, Wasserverfügbarkeit und Wasserbedarf, Wasserwirtschaft, Nachhaltigkeit, hydromorphologische Bedingungen, Talsperrenbewirtschaftung, landwirtschaftliche Wassernutzung, Bewässerungsverfahren, Beteiligung von Interessengruppen, Anpassungsstrategien, hydrodynamisch numerische Modellierung, hydrologisch-ökonomische Modellierung.

Projektbeschreibung

Durch die Kombination eines europäischen Modellansatzes mit der Analyse von Fallstudien und regionalem (lokalem) Wissen über Wasserbedarf und Wasserverfügbarkeit wurde sich den Hauptzielen des Projektes zugewandt. Berücksichtigt wurden dabei sowohl klimatische Veränderungen, als auch sozio-ökonomischer Entwicklungen. Eine integrative Bewertung für ganz Europa erfolgte durch eine Betrachtung verschiedener Szenarien und Prognosen zum Klimawandel. Dieser breite Blickwinkel erlaubt den Hinweis auf solche Regionen, die potenziell durch den Klimawandel gefährdet sind. Darüber hinaus wurden regionalspezifische Anpassungsmaßnahmen ermittelt, die EU-bezogen umgesetzt werden könnten. Des Weiteren wurden innerhalb Europas drei Fallstudien ausgewählt, um an diesen Veränderungen des hydrologischen Regimes, der Wasserverfügbarkeit und der branchenspezifischen Wassernutzungen zu erforschen. Diese Fallstudien konzentrieren sich auf drei verschiedene Fragestellungen der Wasserwirtschaft in drei verschiedenen Regionen.

In der ersten Fallstudie wurde für einen Abschnitt der Eder (Deutschland) der Einfluss des Klimawandels auf die hydromorphologischen Bedingungen gemäß WRRL abgeschätzt. Das Untersuchungsziel dieser Fallstudie war, die Erreichbarkeit der Umweltziele der WRRL an einem typischen Flussabschnitt auch unter Berücksichtigung der Auswirkungen des Klimawandels zu erfassen und zu bewerten.

Die zweite Fallstudie untersuchte für das Flusseinzugsgebiet der Seine (Frankreich) die wasserwirtschaftlichen Aspekte, insbesondere die Trinkwasserversorgung und den Hochwasserschutz, die dort teilweise auf dem Betrieb künstlicher Stauseen basieren. Es wurden Szenarien entwickelt, die den Einfluss des Klimawandels auf die Wasserressourcen, den Wasserbedarf und deren Bewirtschaftung verknüpfen.

Die dritte Fallstudie betrachtete für die italienische Region Apulien die quantitativen Auswirkungen des Klimawandels auf die Wasserhaushaltskomponenten und die Wassernutzung im Agrarsektor, um die Einführung von Anpassungsmaßnahmen zu unterstützen. Zurzeit ist die Landwirtschaft in Apulien immer noch Hauptwassernutzer und primäre wirtschaftliche Ressource.

Politischer Fokus

Das ClimAware Projekt verfolgt zwei Ziele: Erstens, die Auswirkungen des klimatischen und des sozio-ökonomischen Wandels abzuschätzen und Anpassungsstrategien zu deren Reduzierung gemäß der relevanten Fragestellungen im Rahmen einer jeden Fallstudie zu entwickeln. Dies unterstützt Wassermanager sowie andere Betroffene und Akteure auf Flussgebietsebene. Zweitens werden in Abhängigkeit der regionalen Wasserproblematik mit ihren jeweiligen Eigenheiten und Beschränkungen anhand dieser Ergebnisse regionaltypische Empfehlungen bezüglich strategischem, taktischem und operativem Management für politische Entwicklungen und Entscheidungen in der EU abgeleitet.

Wichtige Meilensteine, wesentliche Projektergebnisse, Empfehlungen

Im Rahmen von ClimAware wurden verschiedene Aspekte der Wasserwirtschaft auf europäischer- und auf Fallstudienebene untersucht und dabei sowohl sozio-ökonomische Szenarien, als auch Projektionen zum Klimawandel einbezogen. Die Ergebnisse zeigen:

Aus europäischer Perspektive betrachtet muss sich ein Großteil der EU auf eine Zunahme von Wassermangel und Trockenperioden vorbereiten. Wassermangel ist vor allem in Süd- und Südosteuropa ein Problem. Daher müssen sich regionale Anpassungsstrategien auch mit der Steuerung des Wasserbedarfs und einer effizienteren Nutzung von Süßwasserressourcen befassen. Unsicherheiten bezüglich der Klimaprojektionen und der Veränderungen des Nutzungsdruckes (Wasserbedarf) spielen dabei eine wichtige Rolle, da die Auswirkungen des Klimawandels zusätzlich zu bzw. in Konkurrenz mit einhergehenden sozio-ökonomischen Entwicklungen stehen werden. Daher sollten alle Anpassungsstrategien für den Klimawandel Aktivitäten anstreben, die nicht nur auf Grund ihrer Effektivität bezüglich der aktuellen Klimavariabilität und des aktuellen Nutzungsdruck ausgesucht wurden, sondern auch die zukünftigen Bedingungen reflektieren. Der Vergleich verschiedener Szenarien hat zu dem Ergebnis geführt, dass sozio-ökonomische Szenarien die Dynamik von Wasserknappheit dominieren, wobei selbst ein wesentlicher Rückgang der Wasserentnahmen in bestimmten Regionen eine Wasserknappheit, insbesondere während der Sommermonate, nicht verhindern kann. Aus diesem Grund sollten Anpassungen an den Klimawandel nicht isoliert betrachtet werden und der Fokus politischer Handlungen immer auch auf sozio-ökonomischen Einflussfaktoren, wie beispielsweise der Landnutzung oder Produktionsmustern, liegen. Technische Maßnahmen, die vor allem darauf abzielen den gegenwärtigen Zustand aufrechtzuerhalten oder Einwirkungen zu reduzieren, reichen wahrscheinlich für verschiedene europäische Regionen in Zukunft nicht aus, um dort Gewässer zu schützen und die Anfälligkeit für Wassermangel zu reduzieren.

Bezüglich der Verbesserungen hydromorphologischer Bedingungen von Fließgewässern entsprechend der Ziele der WRRL (Fallstudie 1) stellen Renaturierungsmaßnahmen, wie sie an der Unteren Eder umgesetzt wurden, nach wie vor die beste Möglichkeit zur Unterstützung von morphodynamischen fluvialen Prozessen dar. Auch wenn sich letztendlich die sich entwickelnde Gewässermorphologie aufgrund des Klimawandels verändern wird, ist keine Notwendigkeit zur Anpassungen dieser morphologisch eigendynamischen und damit sich selbst-regulierenden Maßnahmen zu erwarten.

Bezüglich des Klimawandels und der Unsicherheiten des gewässerökologischen Leitbildes ist diese Art der Renaturierung die beste Wahl für eine effektive Umsetzung der WRRL. Hydromorphologische Verbesserungen sind ein sehr guter Beitrag für die Aufwertung der biologischen Qualitätskomponenten. Morphologisch statische Maßnahmen, wie die Errichtung und der Betrieb von Fischaufstiegsanlagen, müssen an eine durch den Klimawandel verursachte Verschärfungen der Niedrigwassersituation angepasst werden können. Dies ist in der Regel leicht zu erreichen, sowohl während der Planungs- und Ausführungsphase, als meist auch noch bei bereits im Betrieb befindlichen Anlagen.

Ziel der zweiten Fallstudie (Flusseinzugsgebiet der Seine) war es, den Wassermanagern einen analytischen Rahmen zur Bewertung potentieller Auswirkungen des Klimawandels auf die Hydrologie des Flusseinzugsgebietes zur Verfügung zu stellen und Anpassungsstrategie zu ermitteln, mit denen diese Veränderungen bewältigt werden können. Diese Anpassungsstrategien wurden sowohl auf taktischer (Anpassung der vorgegebenen Stauraum-Füllkurven), als auch auf operativer Ebene (Echtzeit Stauraum-Steuerung) entwickelt.

Das Ergebnis ist eine zentralisierte Echtzeitsteuerung, genannt „Tree-Based Model Predictive Control“ (TB-MPC), entwickelt in Zusammenarbeit mit der TU Delf (Niederlande) und der „Politecnico di Milano“ (Italien). Dieses Werkzeug nutzt für das Flussgebietsmanagement der Seine alle in Echtzeit verfügbaren Informationen, einschließlich Ensemble-Wettervorhersagen und ist damit eine deutliche Verbesserung für die Bewirtschaftung von Dürren und Hochwasserereignissen.

Die Fallstudie Apulien (Fallstudie 3) identifizierte eine ganze Reihe von Maßnahmen zur Anpassung an bzw. zur Begrenzung der negativen Auswirkungen des Klimawandels. Auf betrieblicher Ebene passen die Landwirte ihre Bewirtschaftungsstrategien an: Sie reduzieren die bewässerten Oberflächen und wechseln zu weniger wasserintensiven Techniken. Des Weiteren werden Anbauprodukte ausgetauscht und es kommt zu einem deutlichen Phänomen der Landnutzungsaufgabe, so dass in einem großen Gebiet der Region Flächen nicht mehr bewirtschaftet werden. Auf Systemebene haben Erörterungen mit ortsansässigen Fachleuten der Wasserwirtschaft die Notwendigkeit der Verstärkung gemeinschaftlicher Managementaufgaben verdeutlicht. Diese sind die Erhebung des Bewässerungsbedarfs, die Optimierung der Wasserverteilung im Hinblick auf eine zukünftig geringere Verfügbarkeit, die Entwicklung eines Frühwarnsystems für Dürren und infrastrukturelle Maßnahmen zur Steigerung der Wasserverfügbarkeit. Eine Reduzierung der Anfälligkeit der Bewässerungssysteme gegenüber Dürren könnte durch weitere Verbindungen mit anderen konventionellen und nicht-konventionellen Wasserquellen erreicht werden. Ersteres erfordert den Ausbau der Infrastruktur durch neue Speicher und Zuleitungen, letzteres zuverlässige Wasseraufbereitungsanlagen. Darüber hinaus stößt die Wiederverwendung von Abwasser auf kulturellen Barrieren, wovon auch die Bereitschaft der Landwirte abhängt, dieses Wasser zur Bewässerung einzusetzen.

Die Ergebnisse zeigen, dass die Einkünfte der Landwirte durch zukünftige Klimabedingungen erheblich beeinträchtigt werden, ungeachtet komplexer landwirtschaftlicher Anpassungsstrategien. Diese Ergebnisse stellen die Zukunftsfähigkeit des landwirtschaftlichen Systems in Frage, welches durch eine Steigerung der Produktivität die Lebensmittelversorgung sichern soll. Auch die sozio-ökonomische Nachhaltigkeit ist mit einer Einkommensminderung der Landwirte von etwa 37 % entsprechend gefährdet.

Technische Unterstützung und Wissenstransferprozesse, sowie die Einbeziehung der Ziele und Kenntnisse der beteiligten Akteure in eine gemeinsame strategische Ausrichtung spielen eine entscheidende Rolle, um eine erfolgreiche Einführung von effektiven Anpassungsmaßnahmen zu ermöglichen.

Im Projekt identifizierte Anwendungsgrenzen

Das ClimAware Projekt befasst sich mit dem Einfluss des Klimawandels und sozio-ökonomischer Veränderungen. Aufgrund dessen basieren die Projektergebnisse auf klimatischen und modellbehafteten Unsicherheiten, was eine kontinuierliche Entwicklung und Anpassung in Abhängigkeit der realen Entwicklungen von Wasserbedarfs und Wasserverfügbarkeit erfordert. Des Weiteren sind die ausgewählten Fallstudien individuelle Beispiele deren Ergebnisse immer validiert und falls nötig angepasst werden müssen, wenn sie auf vergleichbare Probleme übertragen werden sollen.

Zusätzliche technische und wissenschaftliche Informationen: Verwandte Ergebnisse

Brouwer, R., Hofkes, M., 2008. Integrated hydro-economic modelling: Approaches, key issues and future research directions. Ecol. Econ. 66:16-22. doi: 10.1016/j.ecolecon.2008.02.009.

Dehay, F., 2012. Etude de l'impact du changement climatique sur la gestion des lacs-réservoirs de la Seine. Master thesis ENGEES, Strasbourg. http://cemadoc.irstea.fr/cemoa/PUB00035975

Dorchies, D., Thirel,, G., Jay-Allemand, M., Chauveau, M., Bourgin, P.-Y., Dehay, F., Perrin, C., Jost, C…, Rizzoli, J.-L., Demerliac, S. and Thépot, R., 2013. Climate change impacts on multi-objective reservoir management: case study on the Seine River basin, France, The International Journal of River Basin Management, accepted.

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Thirel G., D'Agostino D., Dorchies D., Flörke M., Kehr K., Perrin C., Scardigno A., Schneider C., Theobald S., Träbing K. (2014). The Climaware project: Impacts of climate change on water resources management – regional strategies and European view. EGU General Assembly 2014, Wien, Austria.

Weitere Informationen zu dem Projekt:

Projektstart: September 2010 (offiziell Januar 2011 für die französischen und italienischen Partner)

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Beteiligte Länder/Partner:

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EPTB Seine Grands Lacs (Paris, France)

Mediterranean Agronomic Institute of Bari, Land and Water Resources Management Department (CIHEAM-IAMB, Bari, Italy)

Art der Forschung und Entwicklung:

Das ClimAware Projekt befasst sich hauptsächlich mit angewendeter Forschung und Entwicklung auf den Gebieten der Wasserwirtschaft und landwirtschaftlicher Wassernutzung.

Programm: 2^{nd} Joint IWRM-NET Call for Research on Integrated Water Resource Management

Web link: http://www.uni-kassel.de/fb14/wasserbau/CLIMAWARE

Note de synthèse

Les articles de la DCE visés

Le projet ClimAware a analysé les impacts du changement climatique sur les ressources en eau aux échelles continentales et régionales pour identifier des stratégies d'adaptation efficaces, pour améliorer la gestion de l'eau pour divers secteurs socio-économiques et par conséquent, pour contribuer à une implémentation efficace de la Directive Cadre sur l'Eau (DCE). Dans cette optique, l'accent est mis sur les outils fournis par la DCE pour la planification de la gestion des cours d'eau et pour les programmes de mesures. ClimAware s'est en particulier concentré sur les articles suivants de la DCE:

- Art. 4, concernant les objectifs environnementaux pour atteindre un bon état pour toutes les eaux de surface jusqu'en 2015 ou au moins pour prévenir les détériorations éventuelles de l'état des eaux de surface.
- Art. 11, concernant les programmes de mesures pour atteindre les objectifs environnementaux.
- Art. 14, traitant de l'information et de la consultation des pratiques des partenaires et des parties prenantes.

Mots-clés

Directive Cadre sur l'Eau, changement climatique, développements socio-économiques, basses eaux et hautes eaux, crue et sécheresse, disponibilité en eau et demande en eau, gestion des ressources en eau, développement durable, conditions hydromorphologiques, gestion de barrage, utilisation de l'eau pour l'agriculture, pratiques d'irrigation, implication des parties prenantes, stratégies d'adaptation, modélisation numérique hydrodynamique, modélisation économique hydrologique.

Description du projet

Les principaux objectifs du projet ont été adressés en combinant une approche de modélisation européenne avec une analyse de cas d'études et la connaissance régionale (locale) des demandes et disponibilités en eau en considérant le changement climatique ainsi que les développements socio-économiques. Une estimation intégrée pour l'Europe entière a été entreprise en considérant différents scénarios et projections de changement climatique. Cette perspective à large échelle permet d'identifier des régions qui sont potentiellement vulnérables au changement climatique mais aussi d'identifier les mesures d'adaptation qui pourraient être développées au niveau européen. De plus, trois cas d'étude ont été sélectionnés à travers l'Europe pour étudier les changements dans les régimes hydrologiques, la disponibilité en eau, et les usages de l'eau. Ces cas d'étude concernent trois différents problèmes de gestion de l'eau dans trois régions différentes.

Dans le premier cas d'étude, l'influence du changement climatique sur les conditions hydromorphologiques selon la DCE ont été évaluées pour une section de la rivière Eder (Allemagne). L'objectif de ce cas d'étude était d'examiner si l'objectif environnemental de la DCE peut être rempli dans une section typique de la rivière en considérant le changement climatique.

Le second cas d'étude s'est penché sur la gestion de l'eau, plus spécialement de la fourniture en eau potable, et sur la mitigation des crues sur le bassin de la Seine (France), qui est partiellement basée sur l'exploitation de réservoirs artificiels. Des scénarios ont été développés pour évaluer l'impact du changement climatique sur les ressources en eau en testant différents modes de gestion des réservoirs.

Le troisième cas d'étude a évalué les effets quantitatifs du changement climatique sur les composantes du bilan en eau et sur l'utilisation de l'eau sur le secteur agricole de la région des Pouilles en Italie, afin de soutenir l'adoption de mesures d'adaptation. En fait, la région des Pouilles l'agriculture reste le principal utilisateur d'eau et la principale ressource économique.

Objectifs du projet

Les objectifs du projet ClimAware sont doubles: premièrement, évaluer les impacts des changements climatiques et socio-économiques et développer les stratégies d'adaptation pour les réduire en accord avec les questions les plus pertinentes dans le contexte de chacun des cas d'étude. Cet objectif apporte un soutien aux gestionnaires de la ressource en eau et aux autres parties prenantes au niveau du bassin versant. Deuxièmement, ces résultats sont traduits en recommandations à l'attention des responsables politiques au niveau de l'Union Européenne pour une gestion stratégique, tactique ou opérationnelle en fonction du problème lié à l'eau.

Dates importantes de la politique, productions-clés des projets et principales recommandations

Dans ClimAware différents aspects de la gestion des ressources en eau ont été étudiés aux niveaux européens et des cas d'étude en considérant des scenarios socio-économiques ainsi que des projections de changement climatique. Les résultats montrent :

Au niveau européen, la majorité de l'UE a besoin de se préparer à plus de sécheresse et de pénurie en eau. La pénurie en eau est plus spécialement un problème en Europe du Sud et du Sud-Est. Par conséquent, des stratégies d'adaptation doivent s'appliquer à la gestion de la demande en eau et à une utilisation plus efficace des ressources en eau. L'incertitude des projections climatiques et des changements de la pression anthropique (i.e. la demande en eau) joue un rôle majeur puisque les impacts du changement climatique s'ajouteront à, ou seront en concurrence avec, ceux associés aux développements socio-économiques.

Par conséquent, toutes les politiques d'adaptation au changement climatique devraient nécessiter des actions qui ne sont pas seulement choisies sur la base de leur efficacité par rapport à la variabilité actuelle du climat et à la pression anthropique. En comparant différents scénarios, il peut être conclu que les scenarios socio-économiques dominent les dynamiques de la pénurie d'eau ; même une diminution substantielle des prélèvements en eau ne protège pas certaines régions en particulier pendant l'été. C'est pourquoi l'adaptation ne devrait pas être discutée de manière isolée et toute intervention politique devrait aussi se focaliser sur les autres paramètres comme l'occupation du sol et les modèles de production. Les mesures techniques qui ont pour principal but de maintenir l'état actuel ou qui essaient de réduire les impacts ne sont pas suffisant pour économiser l'eau et pour réduire la vulnérabilité à la pénurie en eau dans le futur.

En ce qui concerne l'amélioration des conditions hydromorphologiques des rivières selon les objectifs de la DCE (cas d'étude 1), les mesures de restauration, telles quelles sont implémentées en aval de la rivière Eder, afin de soutenir les processus morphodynamiques fluviaux, restent le meilleur choix pour la restauration des cours d'eau. Bien que le développement final de la morphologie de la rivière puisse se modifier à cause du changement climatique, on ne s'attend pas à ce que ces mesures morphodynamiques auto-ajustables aient besoin d'adaptation.

En termes de challenges liés au changement climatique ainsi que d'incertitudes sur la situation de débits non - ou très peu - altérée par l'homme, ce genre de mesure est le meilleur choix pour une stratégie d'implémentation efficace de la DCE. Les améliorations hydromorphologiques soutiennent très bien l'amélioration de la qualité biologique. Les mesures morphostatiques comme l'installation et l'exploitation de passes à poissons ont besoin d'être adaptables dans le cadre de l'aggravation des étiages lié au changement climatique ce qui est habituellement facile à réaliser pendant la conception et la construction ainsi que, dans les plupart des cas, pour des installations déjà exploitées.

L'objectif du cas d'étude 2 (bassin versant de la Seine) était de fournir une structure d'analyse aux gestionnaires de l'eau pour évaluer les conséquences potentielles du changement climatique sur l'hydrologie du bassin versant et pour évaluer des stratégies d'adaptation pour pallier ces changements. Ces dernières ont été développées aux niveaux tactique (adaptation des courbes d'objectif de remplissage des réservoirs) et opérationnel (gestion en temps réel des réservoirs).

Cela c'est concrétisé avec la réalisation d'un contrôleur centralisé en temps réel appelé Tree-Based Model Predictive Control (TB-MPC) développé en collaboration avec l'université technique de Delft (TU Delft, Pays-Bas) et l'Ecole Polytechnique de Milan (Italie). Pour la gestion des réservoirs sur le bassin de la Seine, cet outil utilise toute l'information disponible en temps réel, ce qui inclue les prévisions d'ensemble météorologiques, et par conséquent, montre une réelle amélioration pour la gestion des étiages et des crues.

Le cas d'étude des Pouilles (cas d'étude 3) a identifié une série de mesures pour s'adapter et / ou réduire les effets néfastes du changement climatique. Au niveau de l'exploitation agricole, les exploitants adoptent différentes stratégies : ils réduisent les surfaces irriguées et se tournent vers des techniques moins utilisatrices en eau. De plus, il y a un effet de substitution des cultures et de manière dangereuse un sérieux phénomène d'abandon des terres puisqu'une zone importante de la région ne sera plus cultivée. Au niveau du système, des discussions avec les experts locaux en gestion de l'eau ont mis en avant la nécessité d'améliorer certaines des tâches de gestion des consortiums, à savoir l'enquête sur la demande en irrigation, l'optimisation de l'allocation de l'eau en vue de la réduction future de sa disponibilité, le développement d'un système d'alerte précoce de la sécheresse et des interventions infrastructurelles pour augmenter la disponibilité en eau. La réduction de la vulnérabilité du système d'irrigation aux sécheresses pourrait être entreprise en améliorant l'interconnexion avec d'autres sources d'eau, à la fois conventionnelles et non conventionnelles. Les premières requièrent le développement de nouveaux stockages et d'infrastructures de distribution. Les secondes nécessitent des stations de traitement des eaux fiables. En outre, la réutilisation des eaux de traitement fait face à des barrières culturelles très implantées chez les exploitants agricoles peu enclins à utiliser cette eau pour l'irrigation.

Les résultats montrent que, malgré les stratégies complexes adoptées, le revenu fermier est sérieusement affecté par les futures conditions climatiques. Ces résultats remettent en question la viabilité générale des systèmes agricoles qui sont supposés améliorer la productivité pour atteindre la sécurité alimentaire. De la même manière, la viabilité socio-économique est aussi vulnérable avec une diminution des revenus des fermiers d'environ 37%.

L’assistance technique et les processus de transfert de connaissances ainsi que l’intégration des objectifs et connaissances des parties prenantes dans une vision stratégique partagée a été un problème majeur pour faciliter la réussite de l’adoption de mesures d’adaptation efficaces.

Les limites identifiées par le projet

Le projet ClimAware s’intéresse à l’impact du changement climatique et des changements socio-économiques. Par conséquent, les résultats du projet sont basés sur des incertitudes liées au climat et aux modèles, ce qui nécessite une évaluation continue et une adaptation qui dépend du vrai développement de la disponibilité et de la demande en eau. De plus, les cas d’étude choisis sont des exemples individuels et les résultats ont toujours besoin d’être validés et ajustés, si nécessaire, quand ils sont transférés à des problèmes similaires.

Informations techniques / scientifiques additionnelles : livrables liés

Brouwer, R., Hofkes, M. (2008). Integrated hydro-economic modelling: Approaches, key issues and future research directions. Ecol. Econ. 66:16-22. doi: 10.1016/j.ecolecon.2008.02.009.

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Schneider C., Flörke M. (2013). Floodplain wetlands at risk: The impact of dams on ecologically important flood flows. GWSP Conference "Water in the Anthropocene: Challenges for Science and Governance", 21.-24.5.2013, Bonn, Germany.

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Thirel G., D’Agostino D., Dorchies D., Flörke M., Kehr K., Perrin C., Scardigno A., Schneider C., Theobald S., Träbing K. (2014). The Climaware project: Impacts of climate change on water resources management – regional strategies and European view. EGU General Assembly 2014, Wien, Austria.

Informations additionnelles sur le projet:

Date de début: septembre 2010 (officiellement janvier 2011 pour les partenaires français et italien)

Date de fin: décembre 2013

Pays / partenaires participant :

Department of Hydraulic Engineering and Water Resources Management, Faculty of Civil and Environmental Engineering (University of Kassel, Germany)

Centre for Environmental Systems Research (CESR, University of Kassel, Germany)

Unités de recherché Hydrosystèmes and Bioprocédés, Antony et G-EAU, Montpellier (Institut national de recherche en sciences et technologies pour l'environnement et l'agriculture, Irstea, France)

EPTB Seine Grands Lacs (Paris, France)

Mediterranean Agronomic Institute of Bari, Land and Water Resources Management Department (CIHEAM-IAMB, Bari, Italy)

Type de R&D: Le projet ClimAware traite principalement de la recherché appliquée et du développement dans les domaines de la gestion des ressources en eau et l'utilisation agricole de l'eau

Programme: 2nd appel joint IWRM-NET pour la recherche sur la gestion intégrée des ressources en eau

Lien internet: http://www.uni-kassel.de/fb14/wasserbau/CLIMAWARE

Sintesi dei Risultati

Il progetto ClimAware e la Direttiva Quadro Acque

Il progetto ClimAware ha analizzato gli impatti del cambiamento climatico sulle risorse idriche a scala continentale e regionale al fine di individuare efficaci strategie di adattamento e migliorare la gestione delle risorse idriche nei vari settori socio-economici. Il progetto ha inteso, quindi, contribuire ad una efficace implementazione della Direttiva Quadro Acque (WFD) attraverso l'individuazione di strumenti, la cui adozione, come previsto nei piani di gestione dei bacini idrografici e nei programmi di misure, contribuiscano al raggiungimento degli obiettivi prefissati. In particolare, ClimAware fa riferimento ai seguenti articoli della Direttiva Quadro:

- Art. 4, che riguarda gli obiettivi ambientali per raggiungere un buono stato delle acque entro al 2015, e impedire il deterioramento dello stato di tutti i corpi idrici.
- Art. 11, che si concentra sui programmi di misure per conseguire gli obiettivi ambientali.
- Art.14, che detta le norme in materia di informazione pubblica e di consultazione dei portatori di interesse

Parole chiave

Direttiva Quadro Acque, cambiamenti climatici, sviluppi socio-economici, inondazioni e siccità, disponibilità e domanda idrica, gestione delle risorse idriche, sostenibilità, condizioni idromorfologiche, gestione delle dighe, uso agricolo dell'acqua, pratiche di irrigazione, coinvolgimento di stakeholder, strategie di adattamento, modellazione numerica idrodinamica, modellazione idrologico-economica

Descrizione del progetto

I principali obiettivi del progetto sono stati perseguiti combinando un approccio di modellazione a scala europea, con l'analisi di casi di studio regionali e la conoscenza della domanda e della disponibilità di acqua a livello locale considerando sia i cambiamenti climatici che gli sviluppi socio-economici. Considerando diversi scenari e proiezioni di cambio climatico, è stata svolta una valutazione integrata per l'intera Europa che ha permesso, da un lato, di identificare le regioni che sono potenzialmente vulnerabili al cambiamento climatico e, dall'altro, di individuare le misure di adattamento che potrebbero essere promosse a livello di UE. Tre diversi casi di studio che affrontano diverse tematiche di gestione delle acque in diverse regioni europee sono stati selezionati al fine di studiare le variazioni nei regimi idrologici, la disponibilità idrica e l'uso settoriale dell'acqua.

Nel primo caso studio è stata valutata l'influenza del cambiamento climatico sulle condizioni idromorfologiche di una sezione del fiume Eder (in Germania) secondo quanto indicato nella WFD. L'obiettivo di questo caso di studio è stato quello di esaminare se gli obiettivi ambientali fissati dalla direttiva quadro possano essere realizzati in una sezione fluviale tipica considerando gli impatti del cambiamento climatico.

Il secondo caso di studio ha analizzato la gestione delle acque, in particolare quelle potabili, e la riduzione delle inondazioni nel bacino del fiume Senna (Francia), che è in parte basato sul funzionamento di bacini artificiali. Gli scenari sono stati sviluppati collegando l'impatto del cambiamento climatico sulle risorse idriche con le variazioni nella domanda di acqua e la sua gestione.

Il terzo caso di studio ha valutato gli effetti quantitativi del cambiamento climatico sulle componenti del bilancio idrologico e sull'uso dell'acqua nel settore agricolo della regione Puglia (Italia), al fine di individuare e supportare l'adozione di appropriate misure di adattamento. Al momento in Puglia, l'agricoltura rimane il principale utilizzatore di acqua e anche la primaria risorsa economica per la regione.

Policy focus

L'obiettivo del progetto ClimAware è duplice:

1. Valutare gli impatti dei cambiamenti climatici e socio-economici sulle risorse idriche e sviluppare strategie di adattamento ai cambiamenti stessi, nei settori e sulle problematiche più rilevanti nel contesto di ogni caso di studio. I risultati del progetto possono supportare i gestori delle risorse idriche e gli altri portatori di interesse a livello di bacino idrografico.
2. Tradurre i risultati in raccomandazioni per i responsabili politici a livello europeo, al fine di fornire loro le basi per una gestione strategica, tattica e operativa della risorsa idrica.

Obiettivi raggiunti, risultati chiave e principali raccomandazioni

Nel progetto ClimAware, sono stati studiati diversi aspetti della gestione delle risorse idriche a livello europeo e di casi di studio, considerando gli scenari socio-economici e le proiezioni di cambio climatico. I risultati mostrano che, dal punto di vista europeo, la maggior parte delle regioni deve prepararsi ad affrontare crescenti episodi di carenza idrica e siccità. La scarsità d'acqua è un problema soprattutto nell'Europa meridionale e sud-orientale. Pertanto, le strategie di adattamento devono riguardare principalmente la gestione della domanda di acqua e l'uso più efficiente delle risorse idriche. L'incertezza delle proiezioni climatiche e dei cambiamenti delle pressioni antropiche (ad esempio la domanda di acqua) svolgono un ruolo importante su quelli che saranno gli impatti dei cambiamenti climatici, in aggiunta o in concomitanza con gli sviluppi socio-economici. Per questo motivo, le politiche di adattamento al cambio climatico devono prevedere azioni che tengano conto della variabilità climatica, delle dinamiche socio-economiche e delle collegate pressioni antropiche. Confrontando diversi scenari, si può concludere che le variabili socio-economiche influenzano il bilancio tra domanda e offerta delle risorse idriche. Pertanto le misure di adattamento e le politiche di intervento sul territorio dovrebbero sempre tenere conto dei driver socio-economici, come l' uso del suolo e le tendenza di produzione. I risultati mostrano anche che, se da un lato, le misure che mirano a mantenere lo stato attuale di un sistema non sono sufficienti a risparmiare acqua e ridurre la vulnerabilità del sistema stesso alla futura carenza idrica, d'altro lato, anche una sostanziale diminuzione dei prelievi di acqua non impedisce ad alcune regioni di sperimentare severe condizioni di scarsità d'acqua, soprattutto durante la stagione estiva

Per quanto riguarda il miglioramento delle condizioni idromorfologiche dei fiumi in funzione degli obiettivi della Direttiva Quadro sulle Acque (Caso di Studio 1), le misure di ripristino che supportano i processi fluviali morfodinamici, così come sono state implementate nel fiume Eder, rimangono la scelta migliore per il ripristino della portata fluviale. Sebbene la morfologia della portata possa comunque cambiare a causa dei cambiamenti climatici, queste misure morfodinamiche di auto-regolazione non necessitano di adattamento e si dimostrano essere la scelta migliore per una efficace strategia di attuazione della direttiva quadro.

In termini di sfide del cambiamento climatico e di incertezze sulla situazione dei corsi fluviali alterati poco o niente dall'antropizzazione, i miglioramenti idromorfologici sostengono molto bene il miglioramento degli elementi di qualità biologica. Le misure morfo-statiche, come l'installazione e il funzionamento delle strutture che favoriscono il passaggio dei pesci, sono inoltre facilmente adattabili ai cambiamenti climatici che inducono una riduzione del deflusso minimo, sia in fase di progettazione e costruzione che di operatività del sistema.

L'obiettivo del Caso di Studio 2 (bacino del fiume Senna) è stato quello di fornire un quadro di analisi ai gestori delle risorse idriche per valutare le potenziali conseguenze dei cambiamenti climatici sulla idrologia del bacino e valutare le strategie di adattamento per far fronte a questi cambiamenti. Queste strategie di adattamento sono state sviluppate a livello tattico (adattamento delle curve di riempimento delle dighe) e a livello operativo (gestione delle dighe in tempo reale).

Il risultato è la messa a punto di un modello di controllo in tempo reale centralizzato per la gestione delle dighe sul fiume Senna, chiamato Modello Tri-Base per il Controllo (TB-MPC) sviluppato in collaborazione con TU Delft (Paesi Bassi) e il Politecnico di Milano (Italia). Questo strumento utilizza tutte le informazioni disponibili in tempo reale, comprese le previsioni meteorologiche, e quindi, apportando un sostanziale miglioramento della gestione della siccità e delle inondazioni.

Il Caso di Studio 3 ha individuato una serie di misure di adattamento e/o mitigazione degli effetti avversi del cambio climatico. A livello aziendale, gli agricoltori adottano diverse strategie nella loro gestione delle aziende: riducono le superfici irrigate e si spostano verso tecniche irrigue meno intensive. Inoltre, vi è un effetto di sostituzione delle colture e anche un importante e grave fenomeno di abbandono della terre coltivate. A livello di sistema, dibattiti e scambi di opinione con gli esperti locali della gestione della risorsa idrica, hanno evidenziato la necessità di migliorare alcuni elementi della gestione da parte dei consorzi di bonifica, quali la rilevazione in campo della domanda irrigua, l'ottimizzazione dell'allocazione della risorsa idrica in vista della futura ridotta disponibilità, lo sviluppo di un sistema di allerta della siccità e interventi infrastrutturali volti ad aumentare la disponibilità di acqua. La vulnerabilità dei sistemi irrigui alla siccità potrebbe, inoltre, essere ridotta migliorando l'interconnessione con altre fonti idriche, sia convenzionali che non convenzionali, laddove, le prime richiedono lo sviluppo di nuove infrastrutture di accumulo e distribuzione, le seconde necessitano di affidabili impianti di trattamento dei reflui e di interventi volti a superare le barriere culturali legate alla predisposizione degli agricoltori all'utilizzo di tali acque in irrigazione.

I risultati mostrano che, nonostante le complesse strategie agricole adottate, il reddito agricolo è fortemente influenzato dalle future condizioni climatiche. Di conseguenza, anche la sostenibilità socio-economica è resa vulnerabile a causa della riduzione del reddito degli agricoltori di circa il 37 %. Questi risultati mettono in discussione la sostenibilità dell'intero sistema agricolo, che si suppone debba aumentare la produttività per sostenere la crescente sicurezza alimentare.

L'assistenza tecnica e il trasferimento delle conoscenze insieme all'integrazione degli obiettivi e delle conoscenze degli portatori di interesse in una strategia condivisa, risultano essere elementi cruciali per facilitare il raggiungimento dell'adozione di efficaci misure di adattamento.

Limitazioni identificate dal progetto

Il progetto ClimAware affronta il tema dell'impatto dei cambiamenti climatici e socio-economici sulle risorse idriche. I risultati del progetto scontano dunque le incertezze connesse alle proiezioni climatiche e ai modelli di simulazione utilizzati, e richiedono, quindi, una continua valutazione e adattamento degli stessi in base al reale sviluppo della domanda e disponibilità di acqua. Inoltre, i risultati ottenuti nei casi di studio scelti dovranno essere validati e, se necessario, adattati qualora si vogliano utilizzare per l'analisi e l' individuazione di misure di adattamento in altri contesti geografici e/o settoriali con problemi analoghi.

Informazioni aggiuntive tecniche/scientifiche

Brouwer, R., Hofkes, M. (2008). Integrated hydro-economic modelling: Approaches, key issues and future research directions. Ecol. Econ. 66:16-22. doi: 10.1016/j.ecolecon.2008.02.009.

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Dorchies, D., Thirel, G., Jay-Allemand, M., Chauveau, M., Bourgin, P.-Y., Dehay, F., Perrin, C., Jost, C., Rizzoli, J.-L., Demerliac, S. and Thépot, R. (2013). Climate change impacts on multi-objective reservoir management: case study on the Seine River basin, France, The International Journal of River Basin Management, accepted.

Schneider C., Flörke M. (2013). Floodplain wetlands at risk: The impact of dams on ecologically important flood flows. GWSP Conference "Water in the Anthropocene: Challenges for Science and Governance", 21.-24.5.2013, Bonn, Germany.

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Informazioni sul progetto

Data di partenza: Settembre 2010 (ufficialmente Gennaio 2011 per i partners Francese e Italiano)

Data di chiusura: Dicembre 2013

Paesi partecipanti/partner:

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Tipo di R&D:	Il progetto ClimAware si occupa principalmente di ricerca applicata e sviluppo nei settori della gestione delle risorse idriche e dell'utilizzo dell'acqua in agricoltura.
Programma:	Seconda Call del “Joint IWRM-NET” per la Ricerca sulla Gestione Integrata delle Risorse Idriche
Web link:	http://www.uni-kassel.de/fb14/wasserbau/CLIMAWARE

1 Introduction/Objectives

Overview of the ClimAware project

Climate projections produced by the intergovernmental panel on climate change (IPCC) in their fifth assessment report (2013, see www.ipcc.ch) indicate that changes in precipitation and temperature are expected to occur throughout Europe in the 21st century, with a likely decrease of water availability in many regions. Besides, water demand is also expected to increase, in link with these expected climate modifications, but also due to socio-economic and demographic changes. This situation may not be sustainable in the current water management perspective. So adaptation strategies may be needed to cope with these evolutions.

In this context, the main objective of the ClimAware project is to analyse the impacts of climate change on freshwater resources at the continental and regional scales and to identify efficient adaptation strategies to improve water management for various socio-economic sectors. This contributes to a more effective implementation of the Water Framework Directive (WFD) and its instruments (river basin management plans, programmes of measures). The results of the project are supposed to be used to develop integrated measures for good freshwater management.

In more details, the objectives of the ClimAware project were to:

- elaborate quantitative projections of changes in river flows and consequences such as flood frequency, drought occurrence and sectoral water uses.
- analyse the effect of climate change on the hydromorphological reference conditions of rivers and therefore the definition of “good status”.
- define management rules/strategies concerning dam management and irrigation practices on different time perspectives.
- investigate uncertainties in climate model – scenario combinations. The research approach considers both European as well as regional perspectives.

To fulfil the objectives of the ClimAware project, the following modelling methodology was implemented (see illustration in Figure 1).

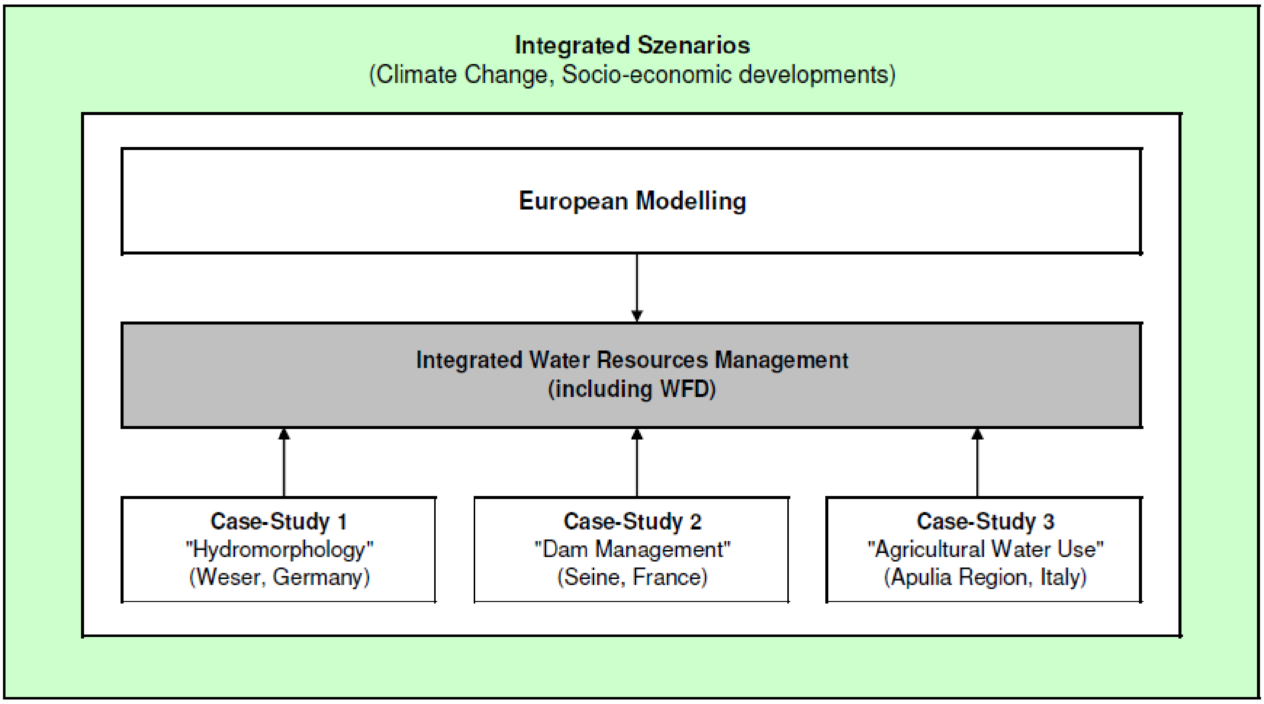


Figure 1: Impact-chain of climate change and water resources management implemented in the ClimAware project

Starting from a European modelling approach of water availability and use based on the WaterGAP model, the changes in the hydrologic regimes and water use of different sectors were analysed. Subsequently three case studies were used to investigate the impacts of climate change at a regional scale. Regional models from three different countries and focusing on three types of water management issues were developed:

Hydromorphology (Weser basin, Germany): By using different scenarios, the influence of climate change on the hydromorphological characteristics of the River Weser river basin according to the WFD, were evaluated. The objective is to examine on typical river sections, how the WFD objectives can be implemented in consideration of climate change.

Dam management (Seine basin, France): Water management on the Seine river basin for water supply and flood alleviation is partly based on the management of artificial reservoirs. The case study developed scenarios linking the impact of climate change on water resources and the expected change on the uses and on the management of the system.

Agricultural water use (Apulia region, Italy): In the Apulia region, economic and demographic changes cause an increase in the demand for good-quality municipal and industrial water. Besides, changes in the agricultural practices increase the demand for water in the agricultural sector. Since water is scarce in this region, the study focused on the agricultural sector, which has the largest water saving potential.

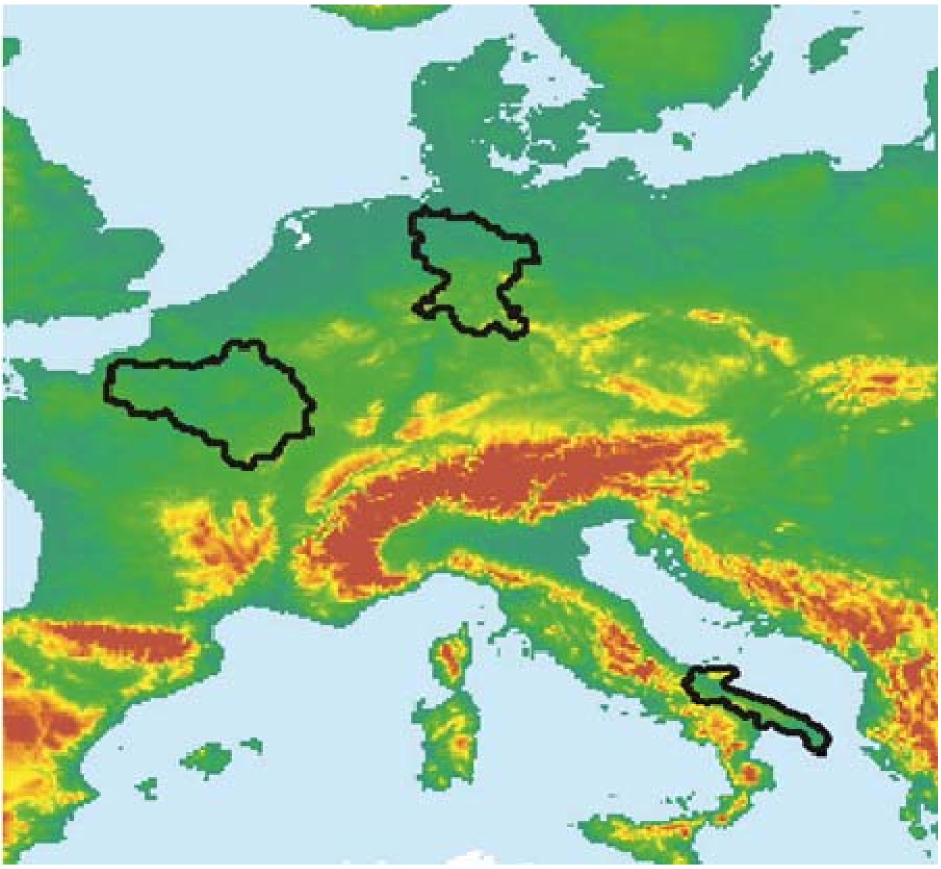


Figure 2: European map with the regions of the three case studies

A cross-scale integration between the European and regional modelling frameworks was implemented.

The project is divided into five work packages (WP):

- WP 1: Climate scenario selection and European modelling
- WP 2: Case studies
- WP 3: Cross-case and cross-scale comparison and integration
- WP 4: Dissemination of results, knowledge transfer
- WP 5: Project coordination

Stakeholders are involved in the project, especially within the scope of three case studies, to help establishing sustainable and integrated water resources management plans. Results are and will be broadly disseminated to policy makers.

The project is coordinated by the Department of Hydraulic Engineering and Water Resources Management, Faculty of Civil and Environmental Engineering at the University of Kassel (Germany) and involves four other partners:

- Center for Environmental Systems Research (University of Kassel, Germany)
- EPTB Seine Grands Lacs (Paris, France) (EPTB: Public river basin authority)

- Institut national de recherche en sciences et technologies pour l'environnement et l'agriculture, Irstea (Montpellier and Antony, France)
- Mediterranean Agronomic Institute of Bari, Land and Water Resources Management Department (CIHEAM-IAMB, Bari, Italy)

2 Research programme

2.1 CLIMATE SCENARIO SELECTION AND EUROPEAN MODELLING

Introduction

The aim of Work package 1 (WP1) is threefold: 1) to set the framework for the whole project, 2) to select appropriate climate change input and 3) to perform the European modelling on current and future water resources. The European modelling shall provide an overall view of continental water resources under changing climate and socio-economic conditions. The selected climate model-scenario combinations are utilized to create long-term quantitative projections of river flows and five different water use sectors which will allow for a holistic assessment. This "big picture" is then compared with scenario results obtained at the case study level in Work Package 3 (WP3, see Chapter 2.3).

Methodology, Modelling Approach

In order to compute the impact of climate change and other important driving forces on future water resources, the global state-of-the-art integrated water model WaterGAP3 (Water – Global Assessment and Prognosis) was applied for the European modelling (Verzano 2009). The model consists of two main components (Figure 3), a hydrology model to simulate the characteristic macro-scale behaviour of the terrestrial water cycle (Alcamo et al. 2003, Döll et al. 2003, 2012), and a water use model to estimate water withdrawals and consumption of different water use sectors (aus der Beek et al. 2010, Flörke et al. 2013). Lately, the model has been refined and performs its calculations now on a global 5 by 5 arc minutes grid cell raster (~6 x 9 km^2 in Central Europe).

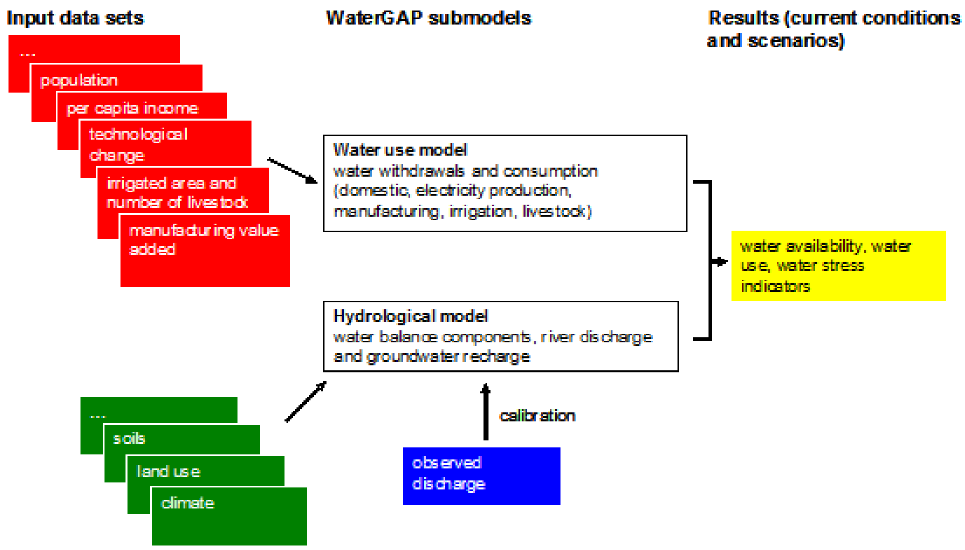


Figure 3: Overview of WaterGAP3 and its components.

The basis of the hydrological model is made up of spatially distributed physiographic characteristics such as land cover, soil properties, topography, permafrost and glaciers, drainage direction, and the location and area of lakes and wetlands. Based on the time series of climatic data, WaterGAP3 calculates daily water balances for each individual grid cell. The vertical water balance of the land area defines groundwater recharge and surface runoff taking into account canopy, soil and snow water storages. The water balance of freshwater areas considers lakes and wetlands, and is affected by precipitation and evaporation. Both, runoff from land and freshwater areas contribute to the total runoff in each grid cell which is routed along a predefined drainage direction map (DDM5; Lehner et al. 2008) to the next downstream grid cell. In Europe alone, the simulated river discharge is calibrated at 221 gauging stations against observed annual river flow data from the Global Runoff Data Centre (GRDC 2004). In the calibration process, described in detail by Döll et al. (2003), only one model parameter (γ) is adjusted, which affects cell surface runoff generation at gauging stations.

In WaterGAP3, 586 reservoirs/dams with a storage capacity of > 100 million m³ are implemented in Europe based on information of the Global Reservoir and Dam (GRanD) database (Lehner et al. 2008; Lehner et al. 2010) and the EEA European Lakes, Dams and Reservoirs Database (Eldred2; Crouzet 2008). So far, the modelling of the dams' management followed the generic algorithm developed by Hanasaki et al. (2006) with minor modifications described by Döll et al. (2009). Because this approach distinguishes only between irrigation and non-irrigation dams, the dam management had to be improved within the ClimAware project in order to assess climate change impacts in case studies 1 and 2. Hence, further dam types such as hydropower generation, flood control, and navigation were implemented in WaterGAP3. For each of these dam types, an objective function is now considered within the model as described by Van Beek at al. (2011) dependent on the main purpose of each dam. The objective functions maximise electricity production (hydropower dams; Equation 1), minimise flood damages (flood control dams; Equation 2), and minimise deviations from the annual mean (navigation dams; Equation 3).

$$\min \sum_{m=1}^{12} \frac{1}{P_m \cdot R_m \cdot \rho \cdot g \cdot h_m} \qquad \text{Equation 1}$$

$$\min \sum_{m=1}^{12} (R_m - Q_{bf})^2, R_m > Q_{bf} \qquad \text{Equation 2}$$

$$\min \sum_{m=1}^{12} (R_m - \bar{Q}) \qquad \text{Equation 3}$$

P_m	*: variations in the price of hydropower*
Q	*: mean annual discharge [m^3/s]*
Q_{bf}	*: bankfull flow [m^3/s]*
R_m	*: reservoir release for month m [m^3/s]*
g	*: acceleration due to gravity (g = 9,81 m/s^2)*
h	*: hydrostatic pressure head (=water height in reservoir) [m]*
ρ	*: density of water (ρ = 1000 kg/m^3)*
m	*: index of month*

In addition, the new optimisation scheme considers different constraints, which foster minimum flow provisions and flood protection. Accordingly, sufficient storage capacity is reserved to absorb larger floods Q_{max} for seven days (flood protection; Equation 4) and sufficient storage is kept to maintain a minimum flow Q_{min} for thirty days (minimum flow provision; Equation 5).

$$C - S_{m+1} > 7 \cdot Q_{\max} \cdot \Delta t \qquad \text{Equation 4}$$

$$S_{m+1} > 30 \cdot Q_{\min} \cdot \Delta t \qquad \text{Equation 5}$$

C : *maximum reservoir capacity [m³]*
S_{m+1} : *reservoir storage of next month [m³/s]*
Q_{max} : *7-day maximum flow [m³/s]*
Q_{min} : *7-day minimum flow [m³/s]*
Δt : length of day [86400s]

Given current reservoir storage and monthly inflow data of the upcoming year, the overall modelling strategy is to find the monthly target storages (and corresponding monthly reservoir releases) that would ensure optimum functioning of the reservoir for a predefined period. This strategy has been realized in WaterGAP3 by applying deterministic dynamic optimization according to Bellman (1957) and a discretisation of the storage by the Savarenskiy's scheme (Milutin, 1998). As inflow data, forecasted values based on average simulated flows during the last 5 years (rather than simulated future discharge) are applied. This reflects more realistically the hydrological situation, where water managers have to deal with uncertain forecast as well (van Beek et al. 2011). The monthly target storages together with the actual incoming flow are subsequently used to calculate the daily reservoir releases (Equation 6). Here, another soft constraint is that daily releases should be higher than Q_{min} and lower than bankfull flow.

$$R_{mi} = \max(0, \frac{S_{m,i-1} - S_{m+1}}{(n-i)\Delta t} + Q_{mi}) \qquad \text{Equation 6}$$

R_{mi} : *updated daily release [m³/s]*
Q_{mi} : *expected average daily inflow [m³/s]*
$S_{m,i-1}$: *actual storage at the end of the previous day [m³]*
n : total number of days for the current month
i : *number of days passed*

River discharge is also affected by water withdrawals and return flows. In WaterGAP3, natural cell discharge is therefore reduced by the consumptive water use in a grid cell as calculated by the water use sub-models of WaterGAP3. Spatially distributed sectoral water withdrawals and consumption are simulated for the five most important water use sectors: irrigation, livestock based agriculture, manufacturing industry, thermal electricity production, and households and small businesses. In this context, water withdrawals depict the total amount of water used in each sector while the consumptive water use indicates the part of withdrawn water that is consumed by industrial processes or human needs or lost by evapotranspiration. For most water-related sectors, except irrigation, only a small amount of water is consumed. That means most of the water withdrawn is returned, partly with reduced quality, to the environment for subsequent use. Water use for the agricultural and electricity production sectors were calculated on a 5 by 5 arc minutes grid scale, but for domestic and manufacturing sectors on country scale. The countrywide estimates of water use are calculated based on data from national statistics and reports, and are then allocated to the grid cells within the country based on the geo-referenced population density and urban population maps (Flörke et al. 2013).

The amount of cooling water withdrawn for thermal electricity production is determined by multiplying the annual thermal electricity production with the water use intensity of each power station, respectively. Input data on location, type and size of power stations are based on the World Electric Power Plants Data Set (UDI 2004). The water use intensity is impacted by the cooling system and the source of fuel of the power station. Four types of fuels (biomass and waste, nuclear, natural gas and oil, coal and petroleum) with three types of cooling systems (tower cooling, once-through cooling, ponds) are distinguished (Flörke et al. 2012).

Net and gross irrigation requirements, which reflect an optimum supply of water to irrigated plants, are computed based on a digital global map of areas equipped for irrigation (Siebert et al. 2005, 2006) as a starting point for simulations. Irrigation water requirements are then calculated for each grid cell based on the spatial extend of the irrigated area, dominant crop type, climatic conditions, and irrigation project efficiency. Lately, irrigated areas were adjusted in WaterGAP3 to national statistics and reported areas actually irrigated (aus der Beek et al. 2010). The model simulates cropping patterns, growing seasons and net and gross irrigation requirements and distinguishes 21 different crop types (aus der Beek et al. 2010). Regarding livestock water demands of the agricultural sector, WaterGAP3 computes the associated water withdrawals by multiplying the number of animals per grid cell by livestock-specific water use intensities (Alcamo et al. 2003).

Data

In order to drive WaterGAP3 for the baseline, the WATCH-forcing data (Weedon et al. 2011) were employed as climate input. It consists of a set of daily, 0.5 by 0.5 degree gridded meteorological forcing data, which are, next to others, precipitation, air temperature, and long- and shortwave radiation. The WATCH-forcing data was chosen because it is the reference dataset for the bias-correction of the future Global Circulation Model (GCM) projections used in the project. For the ClimAware-analyses, the gridded meteorological forcing data has been simply disaggregated to the 5 arc minute resolution as required by the model.

Land-use data for the base year 2005 are derived from the Corine Land Cover map (CLC2000; EEA 2007) for EU countries and the Global Land Cover Characterization map (GLCC; USGS 2006) for the other countries of Europe.

Scenarios

Climate scenarios

The effect of a changing climate on river flow regimes was taken into account by driving WaterGAP3 with bias-corrected daily GCM projections (precipitation, air temperature, long- and shortwave radiation) as developed in the EU FP6 project WATCH (Water and Global Change) (Harding et al., 2011). In order to consider the uncertainty in current climate modelling, bias-corrected time series from three different state-of-the art GCMs were applied: (i) ECHAM5/MPI-OM model from the Max-Planck Institute for Meteorology, Germany, (ii) IPSL-CM4 model from the Institute Pierre Simon Laplace, France, and (iii) CNRM-CM3 model from Centre National de Recherches Meteorologiques, France. The application of different GCMs is of particular importance as the deviations of results among models have a larger variation than among the different emission scenarios (Kaspar 2004, Déqué et al. 2007).

In combination with each GCM, two highly distinctive emission scenarios were used as a basis of the modelling process. To depict the whole bandwidth of climate change, the IPCC SRES emission scenarios A2 and B1 were selected (described in IPCC 2007). The SRES A2 scenario describes a very heterogeneous world with high population growth, slow economic development and slow technological change. Under the A2 scenario, the global greenhouse gas emissions (in the absence of further climate policies) are projected to grow steadily during the whole twenty-first century and may double by 2050 compared to the year 2000. The SRES B1 world is a convergent world with a global population that peaks in mid-century and rapid changes in economic structures towards a service and information economy. The trend in global greenhouse gas emissions increases slightly (~40 %) until 2040 and decreases till 2100.

Socio-economic scenarios

In order to take into account socio-economic developments as well as changes in future water use and land use the ClimAware project makes use of outcomes of the EU FP6 project SCENES (Water Scenarios for Europe and for Neighbouring States) (Kämäri et al. 2008). SCENES' overall objective was to develop and analyse a set of comprehensive scenarios of Europe's fresh waters up to 2050 through a participatory process. These scenarios were chosen to be applied in ClimAware because they are i) the most recently developed scenarios for Europe, ii) water related, and iii) consistent with the modelling framework. The methodology of scenario analysis in SCENES was based on the story-and-simulation (SAS) approach (Alcamo, 2008) that combines both qualitative and quantitative information of possible futures. The qualitative scenarios were constructed during three consecutive stakeholder workshops. They comprise a set of plausible futures in the shape of narrative storylines which address both socio-economic and environmental drivers and consequences for water quantity and quality. The quantitative scenarios in turn are based on modelling results taking up information on drivers provided by the storylines and questionnaires filled out by the stakeholders. Four narrative storylines, namely Economy First (EcF), Fortress Europe (FoE), Policy Rules (PoR) and Sustainability Eventually (SuE) were developed (Kok et al. 2011). Results indicate that the stories are complex, integrated, and rich in detail. A characteristic feature in all storylines is the focus on climate change impacts as a major trigger to changes in human and thus societal awareness and behaviour. For the analyses in ClimAware, climate realisations were linked to the respective socio-economic scenarios from the SCENES project, i.e. the SRES A2 climate realisations were linked to the "Economy First" scenario (A2-EcF), and the SRES B1 climate realisations to the "Sustainability Eventually" scenario (B1-SuE).

More information on the scenarios as well as national time series on the main drivers is accessible at the SCENES WebServer, a functional cross-referencing scenario web-service, which is open for public (http://www.cesr.de/SCENES_WebService/).

Summary of EcF storyline

In the EcF scenario, the economy develops towards globalisation and liberalisation so innovations spread but income inequality, immigration and urban sprawl cause social tensions. All energy production alternatives are considered, international consortia are financed to find high-tech alternatives to fossil fuels. Global demand for food and biofuels drives the intensification of agriculture with increasing need for irrigation and new cultivation area. As the CAP reform (Common Agricultural Policy) is weakened farms are abandoned where crop production is uneconomic. Slow adoption of water-efficient technologies due to peoples' limited income, low water-saving consciousness, more single-person households, increase in tourism and lack in training using new irrigation technologies lead to higher water use. Only the higher water prices dampen this trend. It is economic to treat and re-use irrigation return flows thus this practice also reducing diffuse pollution is adopted. Water ecosystems providing ecological goods and services for economies and society (e.g. tourism) are preserved and improved. Thus the WFD (Water Framework Directive) changes its conceptual focus from the good ecological status to preserving socio-economically worth ecological services. Pollution load increases due to curtailed infrastructure, poor treatment and intensified agriculture. Poisoning incidents catch the interest of media and public. Scientific findings and public protests are being finally heard. Even if governments and European institutions are weak in EcF they are the last straw after recession and social upheaval in 2040s to start working with NGOs, industries and other representatives of civil society to restore economic prosperity and make ground for social coherence.

Summary of SuE storyline

Within the SuE scenario, Europe transforms from a globalised, market-oriented to an environmentally sustainable society, where local initiatives are leading and quality of life becomes a central point. Internal migration will be very strong, ageing of population, longevity, and fading borders within the EU result in movements of people into countries with enjoyable climate conditions. Economic growth is an important factor but is characterized by slow growth. Improvements in technology lead to increases in water use efficiency and investments in water-related R&D activities are initiated to share technological benefits within Europe. Direct agriculture subsidies are phased out and replaced by policies aimed at environmental services by farmers, such as support for farmers in less favourable areas with high-nature value farmland and accompanied by effective spatial decentralisation policies. Decreasing food demand and increasing crop productivity lead to a decrease in the sum of cropland plus grazing land. Land-use changes in general promote greater biological diversity. Efforts are made to share technological benefits so that the overall benefit is felt. European inspired environmental standards are also introduced in Eastern Europe. Water demand is strongly reduced by water savings and behavioural changes. These two opponent scenarios were selected to show the effect of adaptation measures.

Results

European modelling results

Water availability

The visual comparison of the model results, depicted as relative change of water availability from the climate normal period (1971-2000) to the scenario period (2050s represented by 2041-2070), shows a clear division according to the direction of change of northern and southern Europe, and western to eastern Europe, respectively (Figure 4 to Figure 6). In northern Europe, an increase in water availability is very likely while all other regions, except the region around Azerbaijan and Armenia, may face a negative change in water availability. The strongest reduction of water availability is anticipated for Southern Europe (the Mediterranean region) as well as in the southern region of Eastern Europe, around Romania. With regard to the different climate scenarios used and the time period selected, the model results show that, in general, change in mean annual water availability in Europe is slightly lower under the SRES B1 scenario than under the SRES A2 scenario (compare Figure 4 to Figure 6).

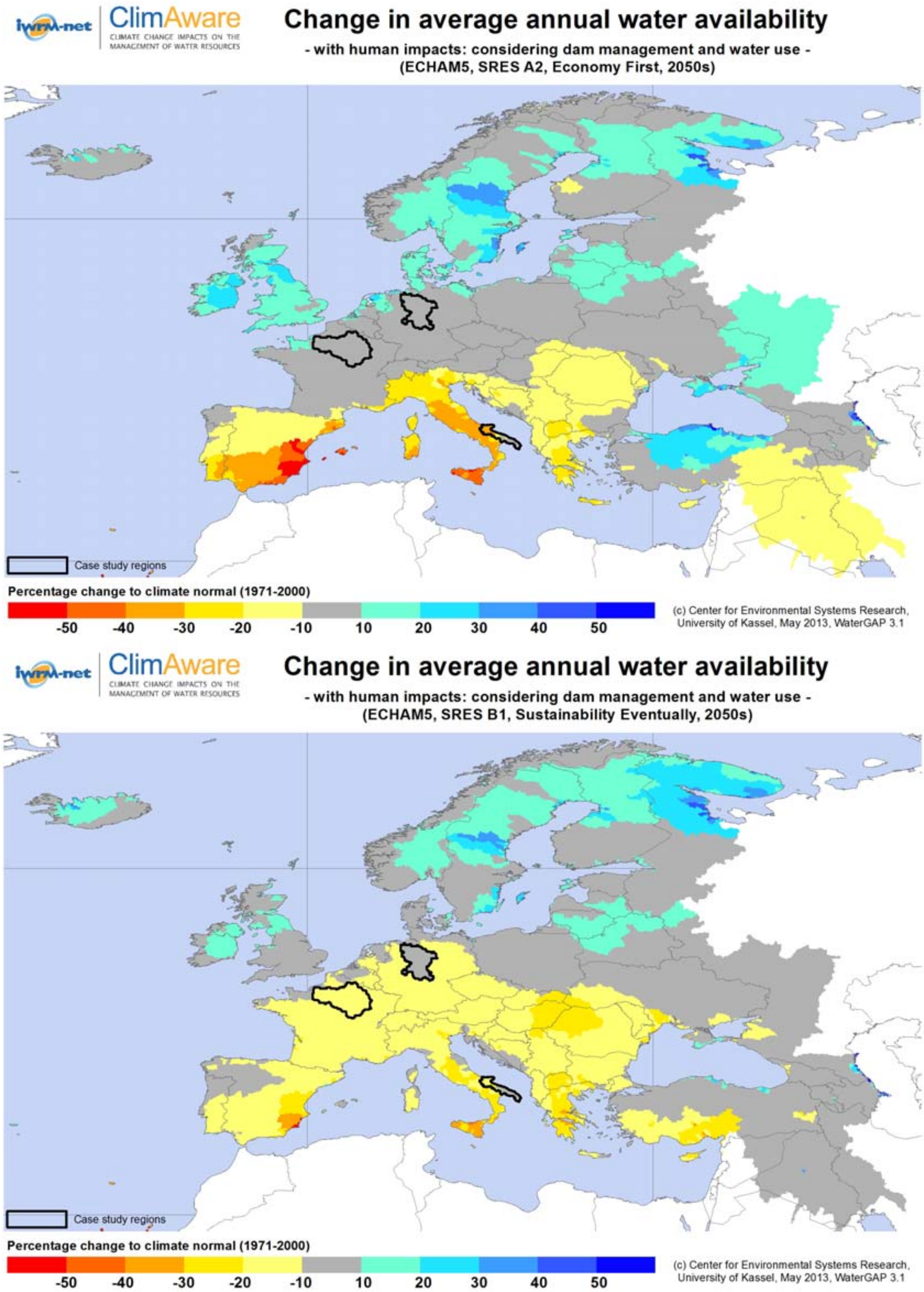
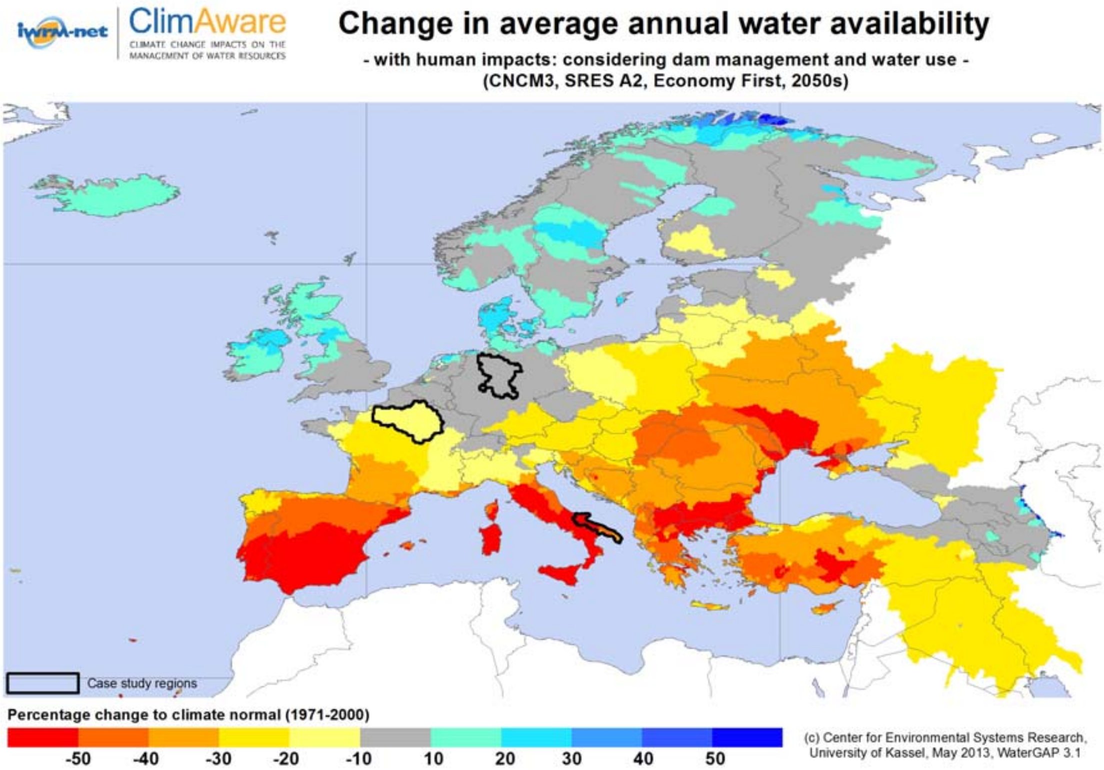


Figure 4: Relative change in water availability between the climate normal period and the 2050s as calculated by WaterGAP3 forced with ECHAM5 climate input. SRES A2 scenario depicted above, SRES B1 scenario below.



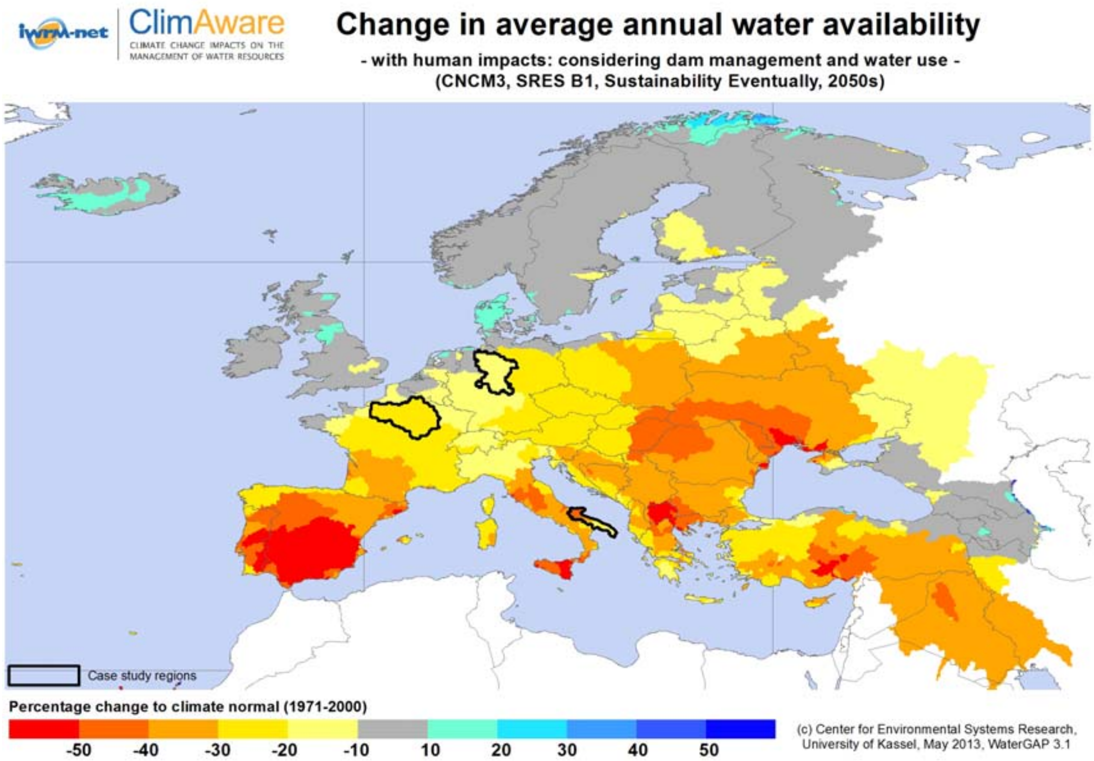
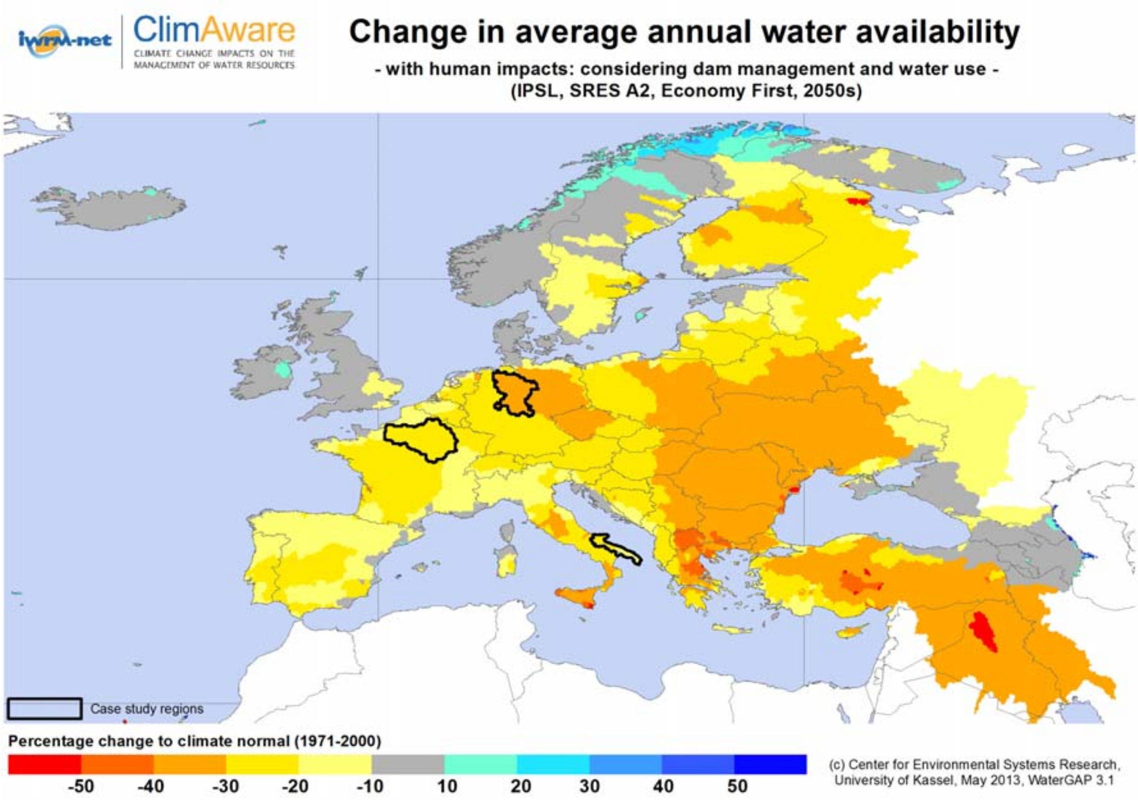


Figure 5: Relative change in water availability between the climate normal period and the 2050s as calculated by WaterGAP3 forced with CNCM3 climate input. SRES A2 scenario depicted above, SRES B1 scenario below.



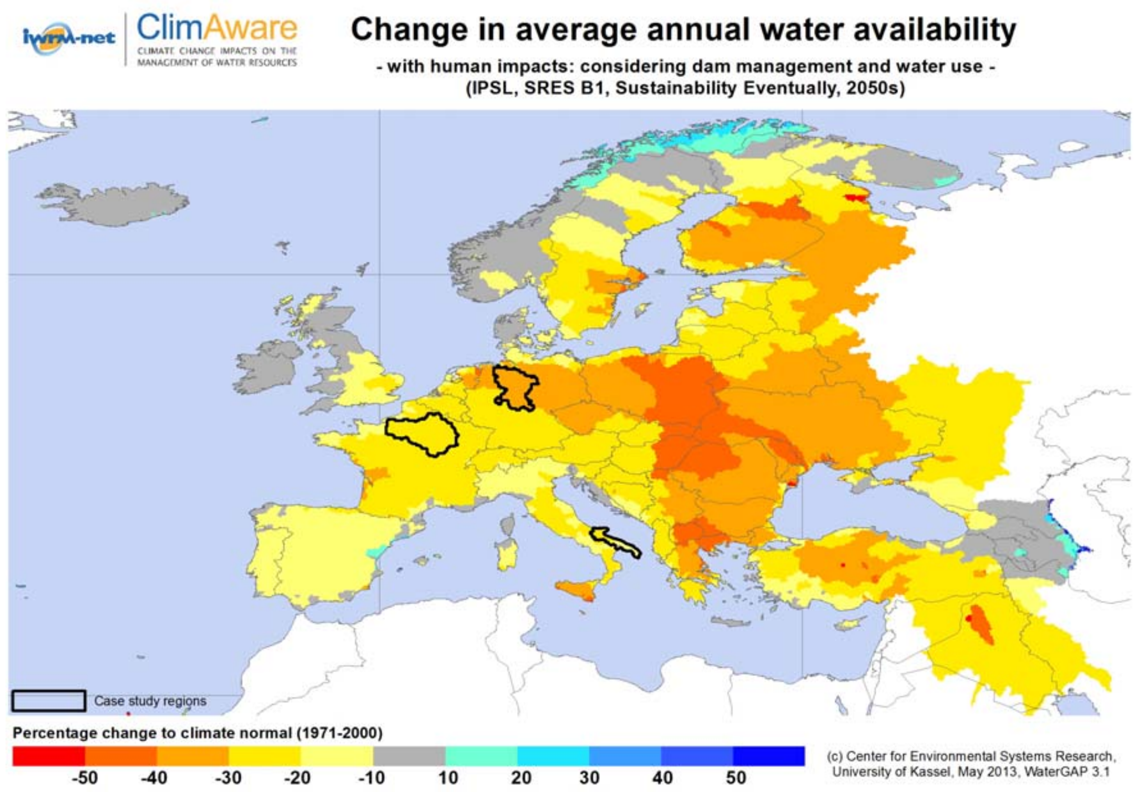


Figure 6: Relative change in water availability between the climate normal period and the 2050s as calculated by WaterGAP3 forced with IPSL climate input. SRES A2 scenario depicted above, SRES B1 scenario below.

Differences between the WaterGAP3 model outcomes according to the climate realisations:

ECHAM5: In general, the water availability is expected to change moderately all over Europe, represented by an increase in Northern Europe, a moderate decrease in Southern Europe and no change in large parts of Central Europe. In comparison to the other two GCMs applied, the change in water availability is lowest under ECHAM5, especially regarding reductions. The decrease of water availability is most pronounced in the south parts of Southern Europe (Figure 4). Largest discrepancies between ECHAM5 driven model outcomes and the other GCM based results are evident in Russia as well as Turkey at the Black Sea. Here, the ECHAM5-based results show a positive change in water availability whereas CNCM3 and IPSL results lead to a partially strong decrease of water availability.

CNCM3: WaterGAP3 results driven by this model output show a strong reduction in water availability in Southern Europe, Eastern Europe and Western Asia, except the region around Azerbaijan and Armenia. An increase in water availability is evident only for Northern Europe and Spitsbergen as well as for the region around Azerbaijan and Armenia (Figure 5).

IPSL: At large the hydrological modelling driven by climate data from the IPSL model presents the strongest decrease in water availability among the applied GCM outputs. Here the reduction in water availability is especially pronounced in Western Asia and Eastern Europe up to Scandinavia (Figure 6) and less pronounced in the Mediterranean region as compared to the CNCM3 model.

Consistencies among the WaterGAP3 model outcomes according to the climate realisations:

In agreement with all climate realisations, the strongest decrease in water availability until the 2050s can be expected in southern Italy and Israel with a reduction of more than 30 % in relation to the climate normal period. Further, agreement in negative or no change (-5 % to +5 %) of water availability among the GCMs is evident in all Southern Europe as well as the western part of Western Asia and the south of Finland. The highest increase in water availability with more than 30 % appears in the north of Spitsbergen under all three GCM climate realisations. Except for the IPSL model combined with the SRES B1 scenario, an increase up to 30 % or no change in water availability is evident in Denmark and Great Britain as well as in Iceland. Changes in water availability in the region around Azerbaijan and Armenia are very low to positive with all three GCMs, with local exceptions (compare Figure 4 to Figure 6).

It should be noted that for the analysis of impacts on short to medium time scales the differences between different emissions scenario-based climate scenarios are relatively small since they only start to diverge in the second half of the century. More important for further analysis at the given time scale (2050s) is to take into consideration different GCMs which show an even broader variation.

High and low flows

Next to changes in mean annual water availability indicating climate change impacts, low and high flow conditions of Europe's rivers were of interest for assessing future water resources. Low flows usually occur in Europe in late-summer and early-autumn. Especially in regard to the focus of the three case studies, changes in low flows could affect the possibility of navigation, competition between different water use sectors, freshwater supply to large metropolitan areas, provision of cooling water, and irrigation of crops during these times. The Q95, which constitutes the discharge that is exceeded by 95 percent of all discharge values, was considered as indicator and calculated for each GCM-scenario realisation on a grid cell level, taking into account daily river discharges which were reduced by water consumed from other water use sectors (domestic, manufacturing and agriculture). Figure 7 represents the direction of changes in Q95 in Europe as ensemble mean for the 2050s as projected by WaterGAP for the A2-EcF and B1-SuE scenario.

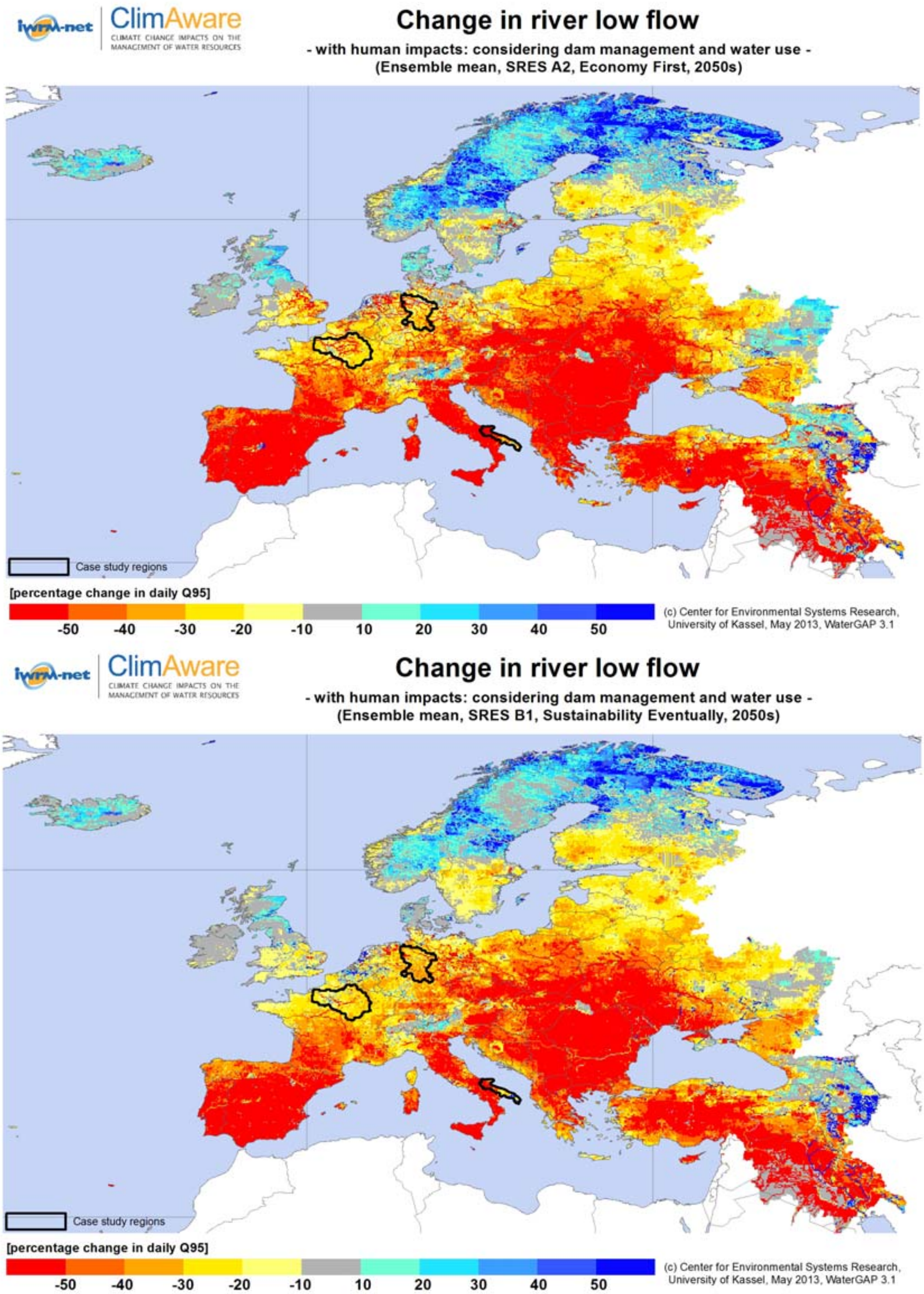
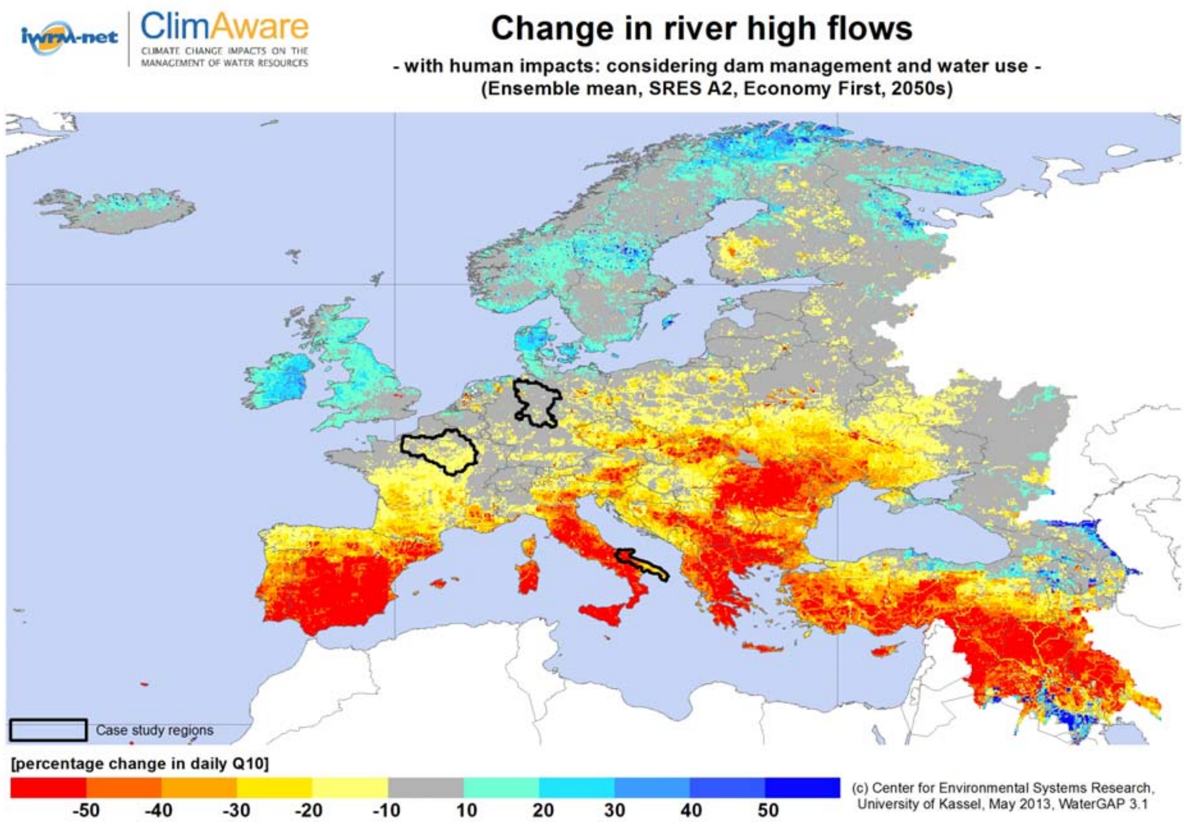


Figure 7: Projected changes of Q95 low flows for the 2050s represented by the ensemble mean for the SRES A2 emission scenario in combination with an Economy First socio-economic scenario (upper map) and for the SRES B1 Sustainability Eventually scenario combination (lower map).

The quantification of the scenarios shows a decrease in Q95 over large parts in Europe, especially for the Mediterranean rim countries and the Black Sea region with more than 50 %. However, even in Southern UK, central Europe, and up to Southern Sweden and the Baltic States, a decrease in Q95 is expected by the model simulations. On the contrary, the scenarios show an increase of Q95 in Northern Europe and the Alps. Comparing the two different scenario combinations, a slightly stronger increase of low flows in the north and a stronger increase in the south of Europe are obvious under the A2-EcF scenario combination.

The impact of climate change on Europe's freshwaters does not only cause changes in water availability and water scarcity, but also affects the occurrence of floods which can have negative (i.e. flood damages) and positive impacts (i.e. inundations of natural flood plain areas). Additionally, surpluses of water during times of high flows can be stored in reservoirs for times of less water availability during dry seasons. However, in the Mediterranean rim countries (Spain, Italy, Greece, and Turkey) as well as in the Carpathians and Balkan mountains even high flows are likely to decrease in the 2050s due to the strong decreases in precipitation throughout the year (Figure 8). Here, the Q10 high flow was used as indicator, which constitutes the discharge that is exceeded by only 10 percent of all discharge values. While no or only minor changes (i.e. within ±10 %) can be found in Germany, Switzerland, the Baltic States, Belarus, Russia and Finland, increases in high flows are indicated for Ireland and the UK, Denmark, as well as parts of Norway and Sweden (especially in the far North due to projected increases in winter precipitation). Again, changes in high flows are stronger under the A2-EcF combination in the North and South of Europe. However, high flows are slightly more decreasing in Central Europe under the B1-SuE scenario combination.



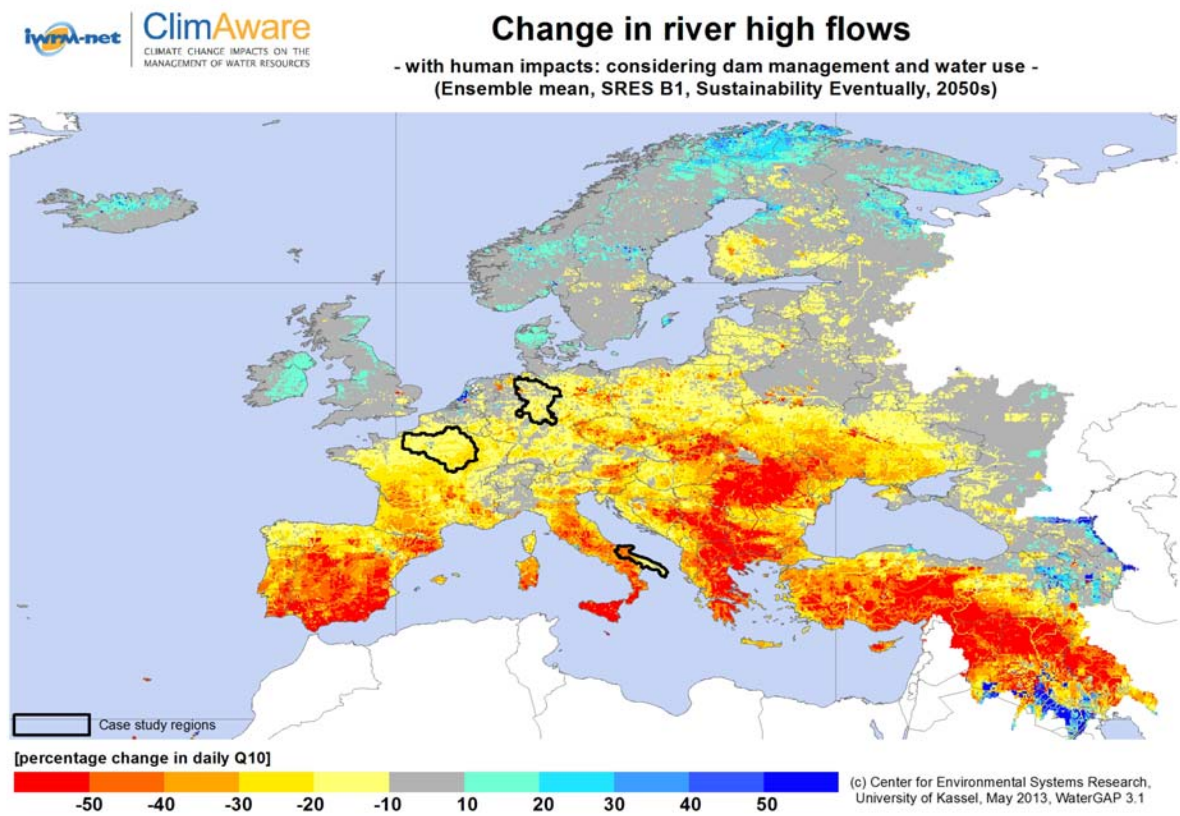


Figure 8: Projected changes of Q10 high flows for the 2050s represented by the ensemble mean for the SRES A2 emission scenario in combination with an Economy First socio-economic scenario (upper map) and for the SRES B1 Sustainability Eventually scenario combination (lower map).

Water withdrawals

Large volumes of water are withdrawn each year from Europe's freshwater reservoirs by society and industry. Major water users are households, manufacturing factories, thermal power plants and irrigation projects. Considering the European regional extension, about 395 km³ of water was abstracted from freshwater resources to be used in the domestic, industry and agriculture sectors in 2005. In Europe, most of the water was abstracted for industrial purposes (52 %), i.e. for cooling of power plants (37 %) and as process water in the manufacturing sector (15 %), followed by the agricultural sector (30 %) whereas almost all of the water accounted for irrigation purposes and only a minor part for livestock uses. A share of 18 % was withdrawn for households and small businesses. Figure 9 depicts the total water withdrawals for the year 2005 in Europe in mm per river basin area. Most intense abstractions of freshwater resources (>100 mm per year) can be observed in UK, Benelux countries, Germany, and Northern Italy. Here, most of the water is abstracted by the industrial or agricultural sectors, except UK where the dominant part of the water is used in the domestic sector. At the Weser basin, large amounts of water (>100mm) are withdrawn for cooling purposes in the industrial sector. Depending on the cooling system (tower cooling, once-through cooling or ponds), most of the water withdrawn is returned back to the river, however, with higher temperatures which can negatively affect especially during hot and dry summers.

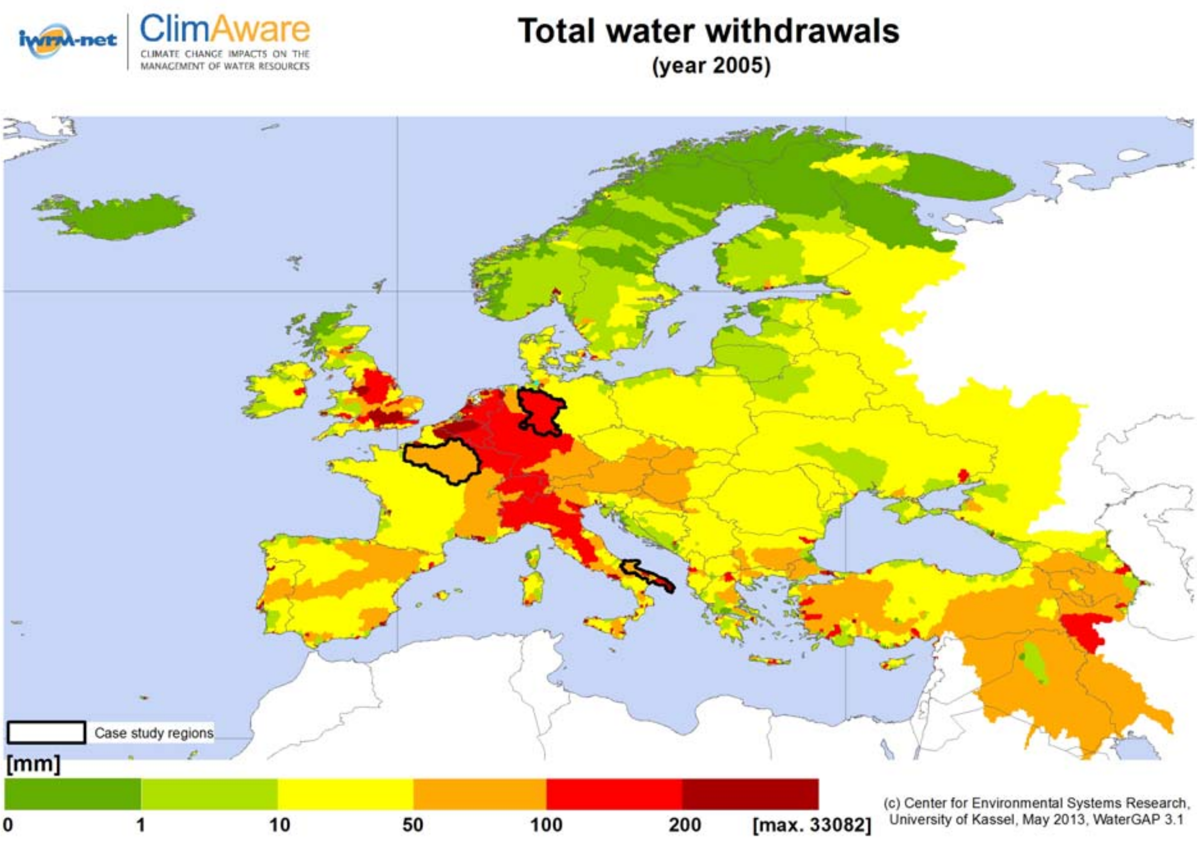


Figure 9: Total water withdrawals on a river basin scale in pan-Europe (2005).

Within the scenario developments process in SCENES, the main drivers and assumptions for estimating future water withdrawals and consumption were elaborated between stakeholders and experts. Future socio-economic developments as well as technological change rates or assumed structural changes according to the four different scenarios pathways are presented in the SCENES Web Service, which can be accessed at http://www.cesr.de/SCENES_WebService/.

The amount of water used in the future varies between the four SCENES scenarios (Figure 10). An increase in water withdrawals up to 578 km³ is expected in the Economy First (EcF) scenario until 2050; and for Fortress Europe (FoE) up to 417 km³, respectively. Water withdrawals of all sectors increase in EcF, particularly of the industrial sector where water abstractions may double in the future. The same trend can be observed in FoE but not as extreme as in EcF. Over the same period it is more likely that the water abstractions decrease under Policy Rules (PoR) by 54 % compared to the base year or even 66 % under the Sustainability Eventually (SuE) scenario conditions. The reductions compared to the base year relate to all sectors and are mainly driven by assuming structural and technological changes, i.e. behavioural change and improving efficiencies.

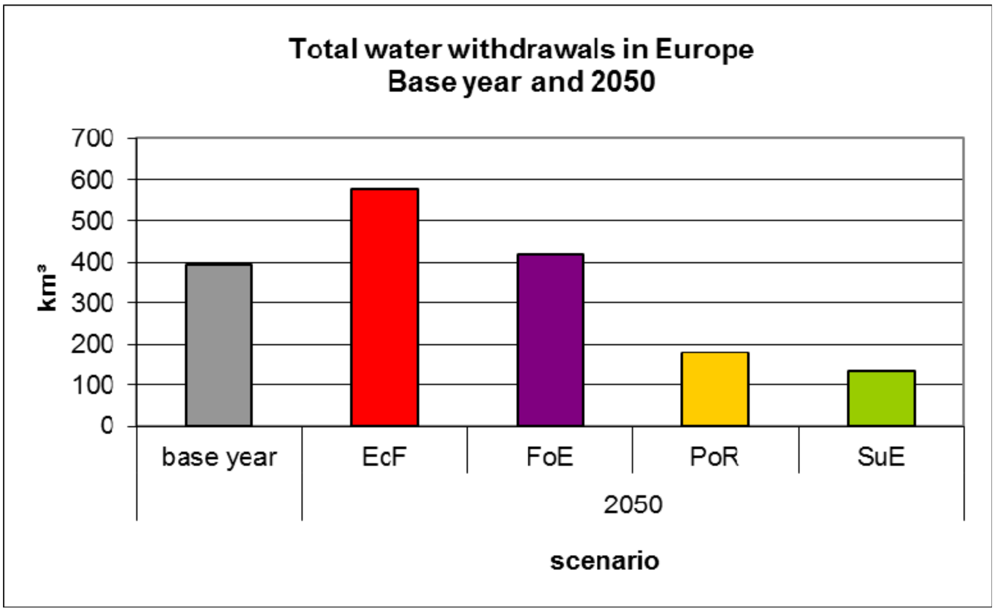


Figure 10: Total water withdrawals for the SCENES scenarios in Europe.

Figure 11 shows that, overall, water withdrawals are expected to increase by more than 50 % over most of Europe until 2050 under EcF scenario conditions combined with the ensemble mean of the A2 climate realisations. Exceptions are river basins in Scandinavia, Iberian Peninsula, Italy, Greece, Cyprus, and Turkey. In Southern Europe, this development is mainly driven by a decrease in irrigation water withdrawals due to land-use changes, while the building of more efficient power plants lead to decline in Northern Europe. For the SuE scenario together with the ensemble mean of the SRES B1 climate realisations, a decrease in total water withdrawals of more than 50 % is simulated for almost all of Europe. The main reason leading to this sharp decline in total water withdrawals are technological innovations to save water and an increasing commitment to save water in all sectors.

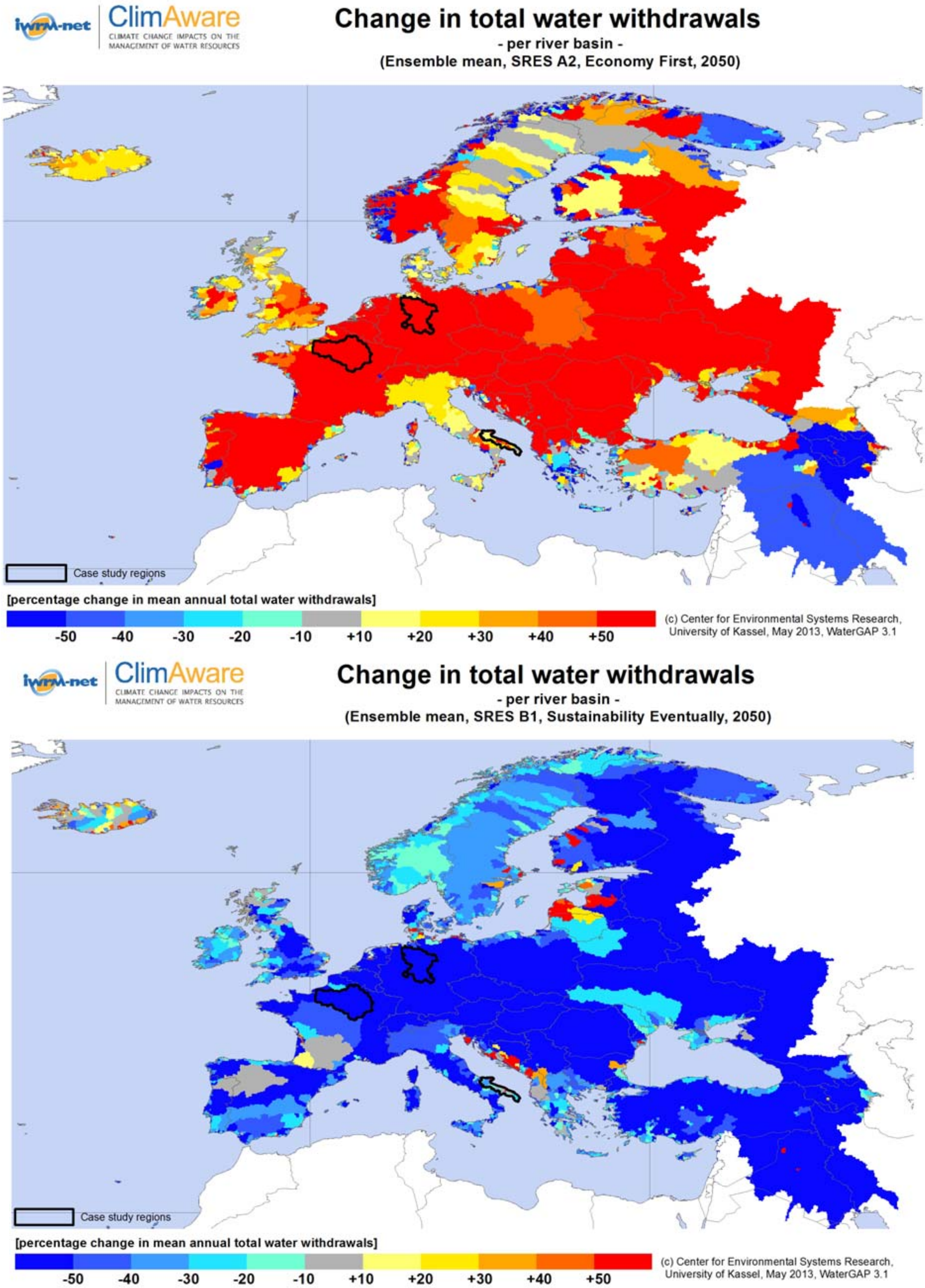


Figure 11: Change in total water withdrawals between the base year and 2050 for the two scenarios: (left) Economy First, (right) Sustainability Eventually.

Water stress

Building up on the results for water availability and water withdrawals presented in the previous sections, the projections of water stress in the summer period are presented in the following. Water stress is represented with the withdrawals-to-availability ratio (w.t.a.), however, only water consumption was considered for the electricity production sector as most of the water withdrawn for cooling purposes is returned back to the river. Water stress is a measure of the amount of pressure put on water resources and aquatic ecosystems by the users of these resources, including households, industries, thermal power plants and agricultural users (Alcamo and Henrich 2002, Alcamo et al 2007, Raskin et al. 1997, Vörösmarty et al. 2000). A drainage basin is assumed to be under low water stress if w.t.a. ≤ 0.2; under medium water stress if 0.2 < w.t.a. ≤ 0.4 and under severe water stress if w.t.a. > 0.4. With respect to Figure 10, the maximum deviations to the base year conditions are obvious for the EcF and SuE scenarios. For that reason, further analyses are carried-out for these two rather than four scenarios.

Since water scarcity is particularly high during the summer months (June, July, and August), the analysis of the summer w.t.a. provides a more meaningful picture regarding water scarcity. For the base year, high summer water stress occurs in the Mediterranean Basin, in the UK, Belgium, and Ukraine (Figure 12). In the future, summer w.t.a. is expected to increase under the A2-EcF scenario conditions and decrease in B1-SuE (Figure 13). Monthly water availability has been calculated as the ensemble mean of the SRES A2 and SRES B1 climate driven model simulations. In summer, decreasing water availability is of higher importance than in the analysis of annual averages (not shown). As a result, there are fewer river basins where the sensitivity to changes in water withdrawals dominates the increase of water stress. Under SuE, some areas in France suffer from an increase in water stress during summer next to those in the Mediterranean Basin. Here, decreasing water availability is again dominant since water withdrawals are rather low in this scenario.

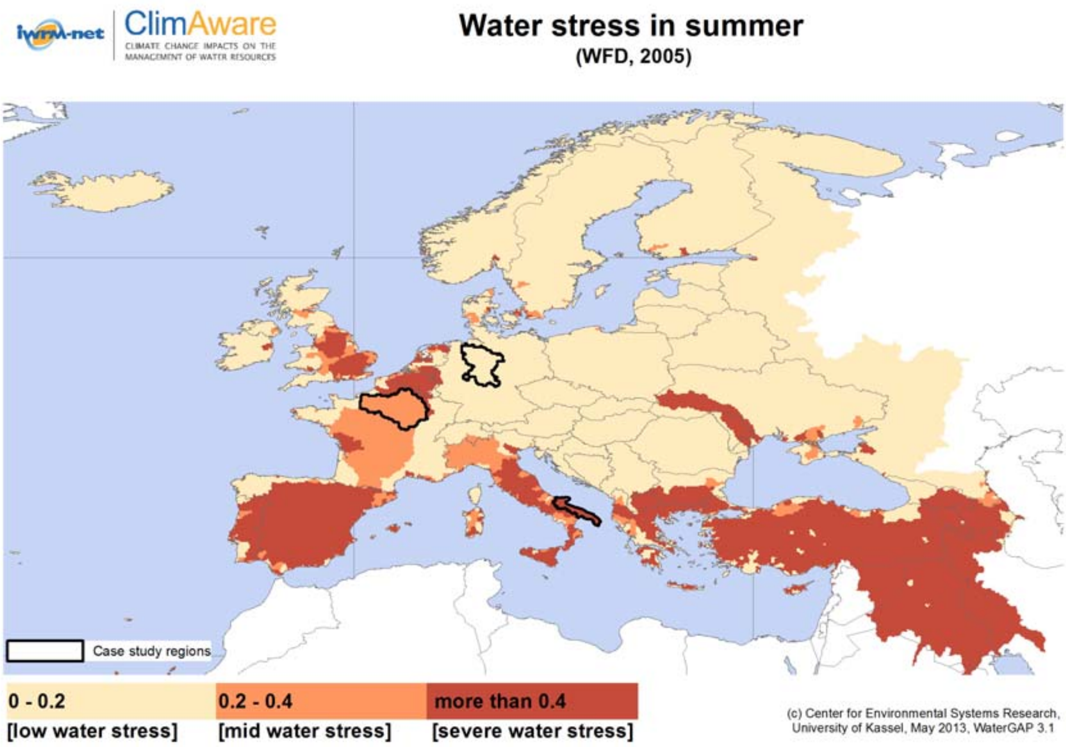


Figure 12: Water stress in summer in the year 2005 represented by the withdrawal-to-availability ratio

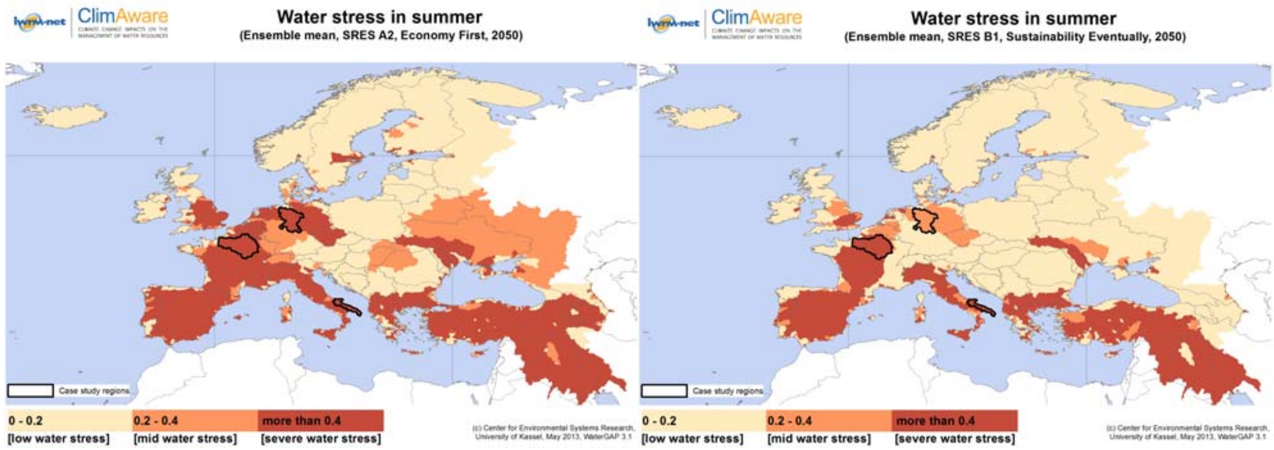
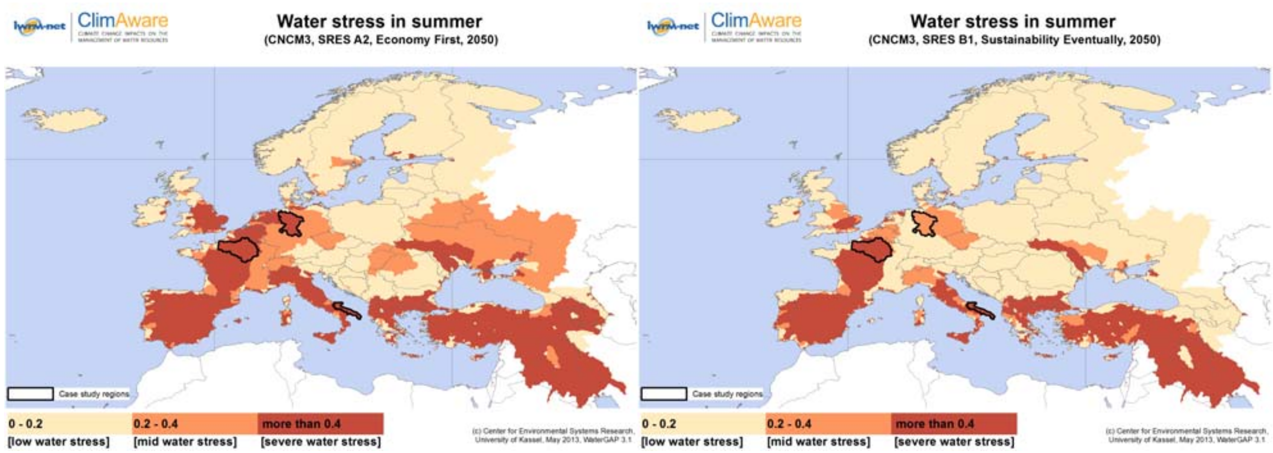


Figure 13: Mean water stress projections for the year 2050 based on an ensemble mean of GCMs for the SRES A2 scenario coupled with the EcF scenario for land and water use (left map) and the SRES B1 scenario coupled with the SuE scenario for land and water use (right map).

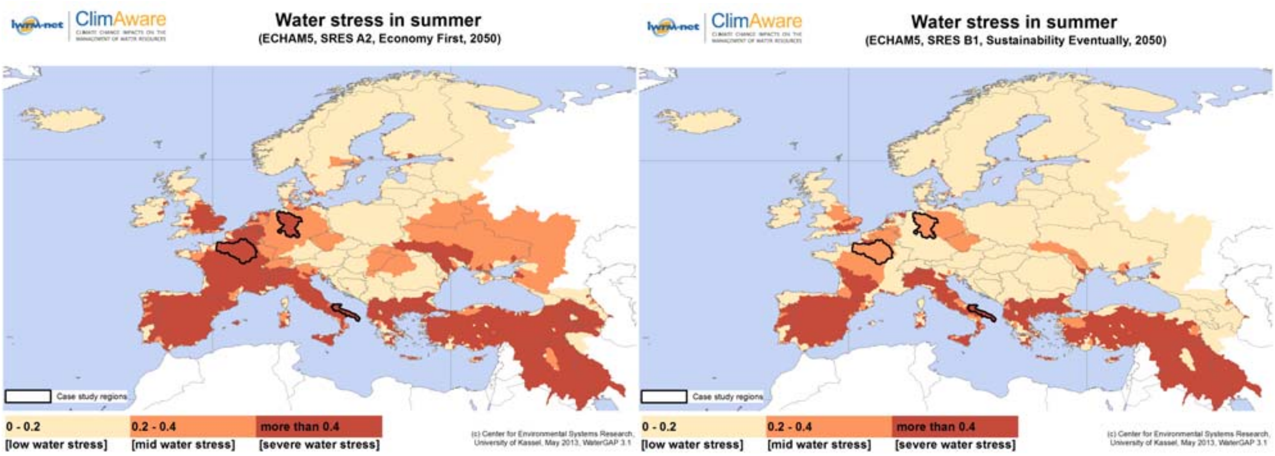
It is obvious from the results that the areas under the most severe water stress are Southern and Western Europe in the EcF scenario. Approximately three quarters of the area of Southern and Western Europe is expected to be under severe water stress during summer. In Southern Europe, the area under water stress increases by 25 % although the total water withdrawals decrease, driven solely by reduced irrigation requirements. At the same time, water availability also decreases (by about -28 %) due to less rain and higher evaporation. Here, the decreasing water withdrawals cannot compensate for the reduction in water availability. A high increase in water-stressed area is expected for Western Europe, where both an increase in total water withdrawals and a decrease in water availability occur. In this region, especially the industrial and agricultural water abstractions increase. Water stress increases in Northern Europe as well, but only a very small part of the area is under severe water stress. In Eastern Europe, the area under severe water stress in summer remains at the same level as the baseline conditions. However, a large part of the area is under mid water stress in the A2-EcF scenario.

The projections using the A2-EcF scenario combination show more pronounced dissimilarities among the models compared to the B1-SuE scenarios. In general, the ECHAM5 model projects the mildest and the IPSL the strongest water stress. With the SRES A2 climate scenario all models project an increase in water stress in Southern and Western Europe as well as the eastern part of Eastern Europe where it is even projected as being severe for wider areas under the CNCM3 model. The IPSL model even projects an increase in water stress for wide ranges of the western part of Eastern Europe (Figure 14). Comparing the different GCMs using the SRES B1 scenario input it becomes obvious that the changes among the models are less pronounced. Major differences are visible for the IPSL-based results as compared to the other two GCM-driven outcomes. For example, summer water stress in Germany is projected as severe instead of mid and mid water stress is also seen in Poland as well as in small areas of Norway and Finland. Looking at Europe only the ECHAM5 model projects the least water stress in the summer period for 2050.

a)



b)



c)

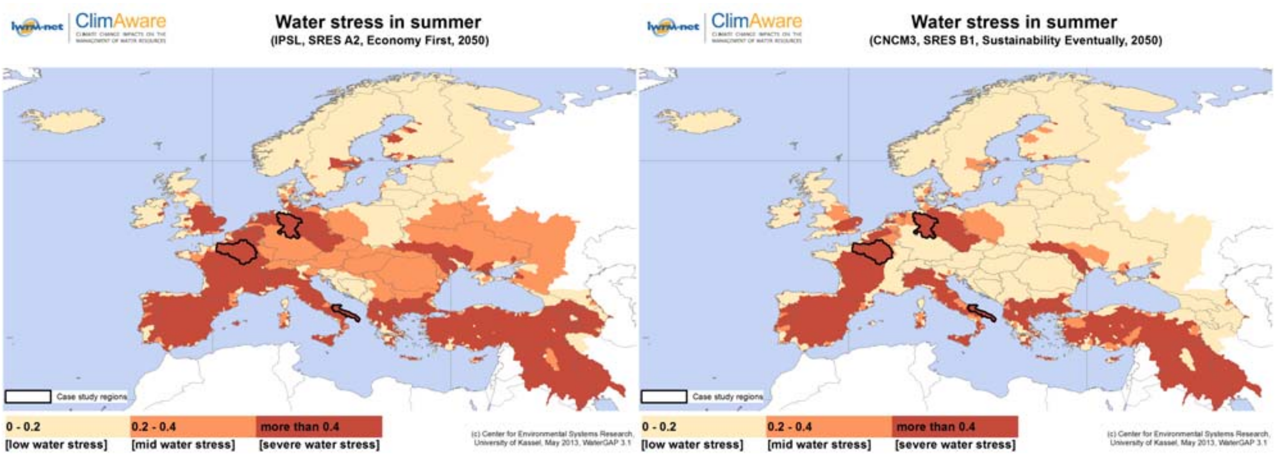


Figure 14: Summer water stress in 2050. WaterGAP3 results based on long-term monthly water availability calculated with climate input from a) CNCM3, b) ECHAM5, and c) IPSL. The A2-EcF scenario combination is depicted on the left side, B1-SuE on the right.

Modelling results for the case studies

One part of the European modelling was to improve, validate, and analyse WaterGAP simulations in each of the three case studies especially in regard to their main research focus (i.e. monthly discharge time series, dam management, specific impact indicators, and irrigation water demands). These steps were undertaken in close collaboration with all partners from the three case studies who provided specific case study information. The consultation with the project partners was helpful as most of the information have only been available in French or Italian language, respectively.

Case study 1 – Eder River, Germany

The flow regime of the Eder River is highly influenced by the Ederdam. According to information provided by the CS1 partner, the main purpose of the Ederdam is low flow regulation to support navigation on the Weser River. Therefore, a flow level of at least 120 cm shall always be provided at the gauging station in “Hannoversch Münden” during the summer months. Within the winter months, snow melt often contributes substantially to high flow situations at the Eder River. Hence, flood protection is another purpose of the Ederdam. Further but less important functions of the dam are hydropower generation and tourism (Cemus & Richter 2008).

The Eder River is a relatively small river in regard to the large-scale focus of the WaterGAP3 model. In addition, the new dam algorithm realised within the ClimAware project was applied and needed to be tested. Therefore, a validation of WaterGAP3 flow data was conducted at the gauging stations Schmittlotheim and Fritzlar. Schmittlotheim is located in upstream direction of the Ederdam with an upstream catchment area of 1178 km^2 and Fritzlar is in downstream direction of the Ederdam with an upstream catchment area of 1806 km^2. Consequently, river flows in Schmittlotheim represent reservoir inflows, while Fritzlar represents reservoir releases. Therefore, simulated mean monthly flow data of these two gauging stations for the time period 1971-2000 have been compared to observed data (Figure 15).

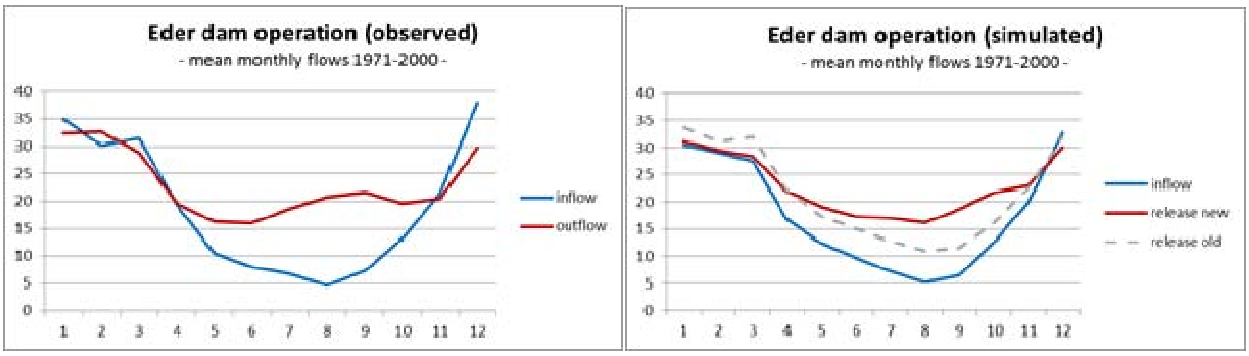


Figure 15: Mean monthly reservoir inflow (blue lines) and releases (red lines) simulated by WaterGAP (right chart) in comparison to observed data (left chart). Simulated release data from the former applied dam operation scheme (i.e. the Hanasaki algorithm) are contained as well (grey dashed line).

The results show that WaterGAP3 can mimic the mean monthly flow regime at the Ederdam quite well and an improvement could be gained at the Eder River with the newly implemented dam operation scheme. In comparison to the former applied operation scheme, the new one achieves a stronger modification of the flow regime which reflects more reality. In addition to this validation, monthly discharge data of the entire baseline were compared to observed flow data at Fritzlar

(Figure 16). Accordingly, monthly flow data can be simulated in Fritzlar with a Nash-Sutcliffe efficiency (NSE) of 0.69 and a weighted correlation (ωR^2) of 0.7. The regression line with a gradient of 0.98 shows that values centre around the 1:1 line, however, the mean percentage error (MPE=+13.5 %) indicates that flows tend to be slightly overestimated. A graphical example of the validation is given in Figure 17. All in all, WaterGAP3 provides satisfactory results for the Eder River for the monthly and mean monthly resolution despite the focus on large-scale assessment. This enabled a cross-scale comparison in WP3 of the project for the Eder River (see Chapter 2.3).

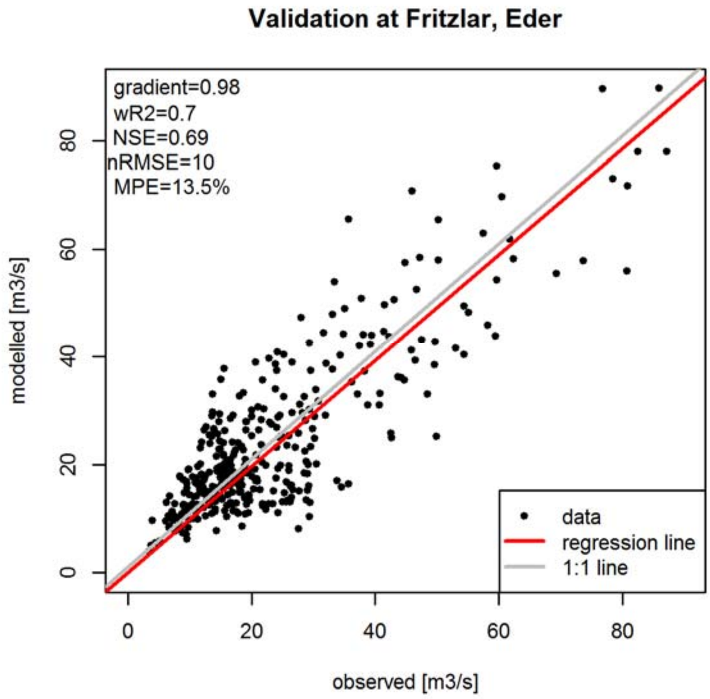


Figure 16: Scatter plot between simulated and observed monthly discharge values at the gauging station Fritzlar for the complete baseline 1971-2000 including efficiency criteria.

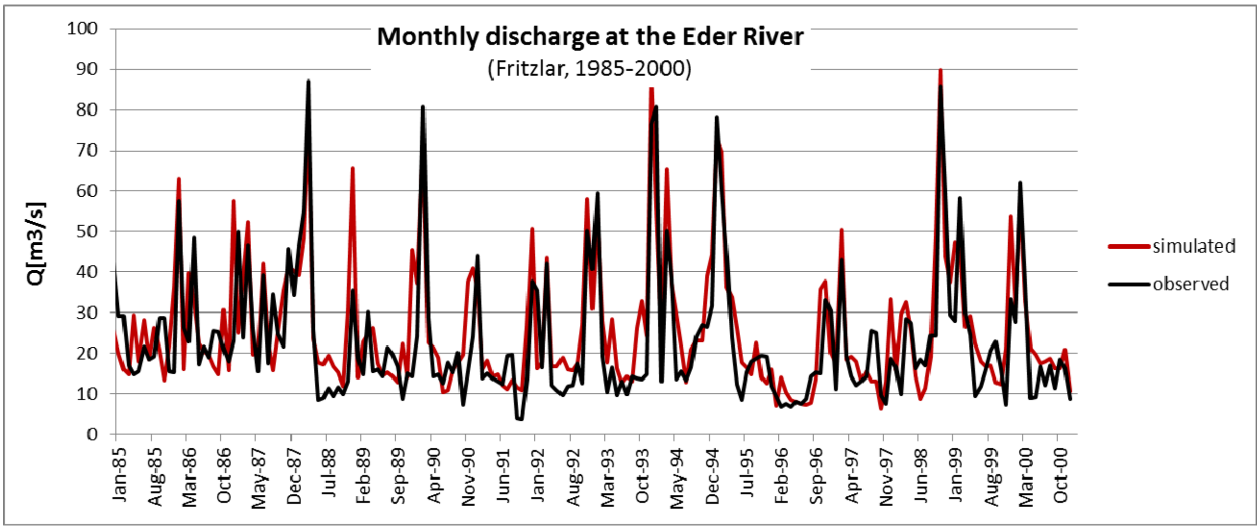


Figure 17: Comparison of monthly simulated discharge (red line) against observed flow data (black line) for the Eder River at the gauging Station Fritzlar exemplarily depicted by the time series 1985-2000.

Case study 2 – Seine River basin, France

Of special importance at the Seine River basin is the low and high flow situation. On the one hand, Paris, a large metropolitan area with approximately 10 million people, needs to be supplied with freshwater even during times of low flows. Thereby, competition with other water use sectors such as industry and agricultural could increase under climate change. On the other hand, floods could occur more often under climate change leading to flood related damages in adjacent settlements. Hence, indicators of special interest which are important to describe impacts in the Seine River basin have been exchanged between CESR and CS2 partners. Furthermore, the management of the Seine River basin is strongly influenced by dam management. Seine Grands Lacs operates 4 different reservoirs (Aube, Marne, Pannesciere-Chaumard, and Seine) in the catchment. CS2 partners could provide important information about dam operation, purpose, capacity and location. Some of the constraints applied at these reservoirs such as minimum flow provision, flood control, as well as minimum and maximum volume of the lake can be covered by the new dam operation scheme in WaterGAP as well.

For the Seine River basin, a validation was conducted at Paris-Austerlitz for the entire baseline period 1971-2000. This gauging station was chosen as the discharge here is impacted by all 4 dams and Paris is of importance in the catchment in regard to water supply. A 15-year graphical example of simulated versus observed monthly flow is depicted in Figure 19, while a scatter-plot including different efficiency criteria for the entire validation period are provided in Figure 18. The scatter-plot shows that in general flows are slightly overestimated by WaterGAP3 (Mean percentage error MPE=+12.3 %), however, high flows tend to be underestimated (gradient=0.92). All in all, the Nash-Sutcliffe efficiency (NSE=0.76), the weighted correlation (wR2=0.7), and the normalised root mean square error (nRMSE=9) indicate that WaterGAP3 simulates monthly flows at Paris-Austerlitz satisfactorily.

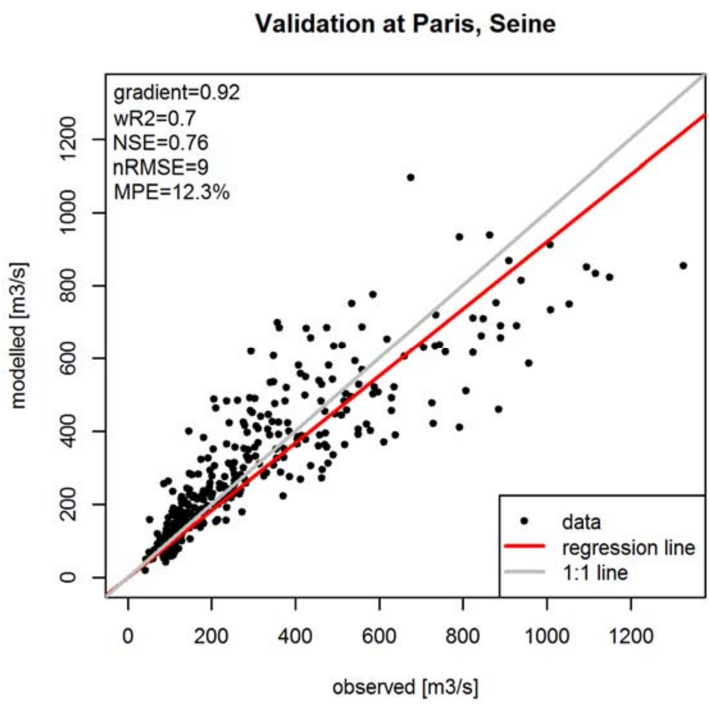


Figure 18: Scatter plot between simulated and observed monthly discharge values at the gauging station Paris-Austerlitz for the complete time series 1971-2000 including efficiency criteria.

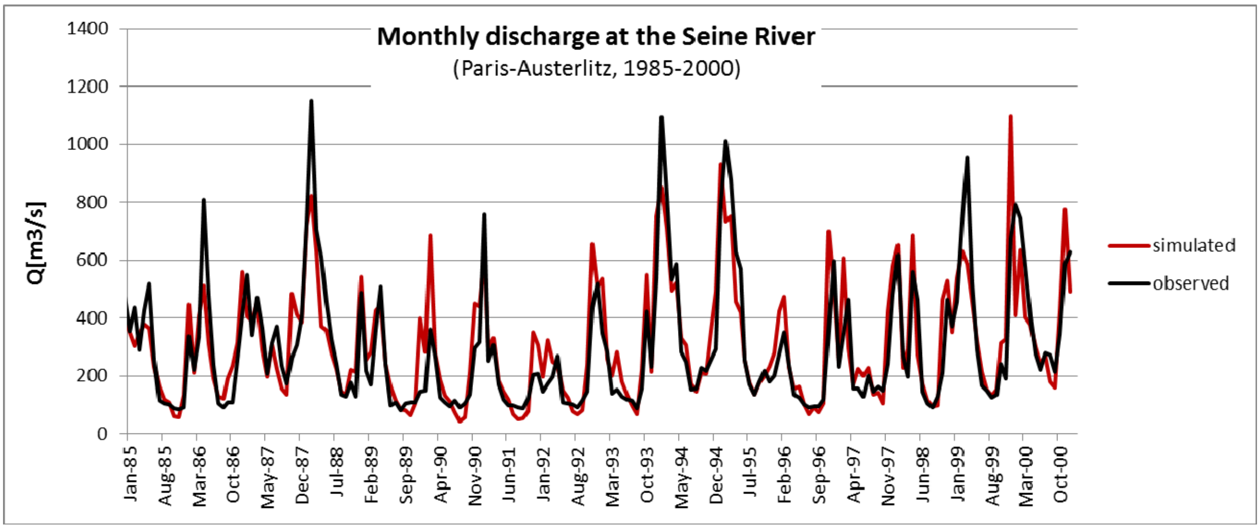


Figure 19: Comparison of monthly simulated discharge (red line) against observed flow data (black line) for the Seine River at the gauging Station Paris-Austerlitz for the time series 1990-2000.

<u>Case study 3 – Apulia region, Italy</u>

A case study analysis together with a validation was performed for the Apulia region in Italy analysing irrigation water use for the baseline period (1971-2000). Here, CESR collaborated with the Mediterranean Agronomic Institute of Bari (CIHEAM) who provided relevant data such as irrigated area, dominant crop type, and irrigation project efficiency for Apulia. A comparison of the applied irrigated areas for Apulia showed that patterns of irrigated area implemented in WaterGAP match quite well with patterns provided by CIHEAM on the basis of the land use map of CORINE (2006) (Figure 20). However, regarding total numbers, the total irrigated area was underestimated by -39 % in WaterGAP. While 240,673 ha of irrigated area were implemented in WaterGAP for Apulia, the CORINE map gave a value of 394,224 ha.

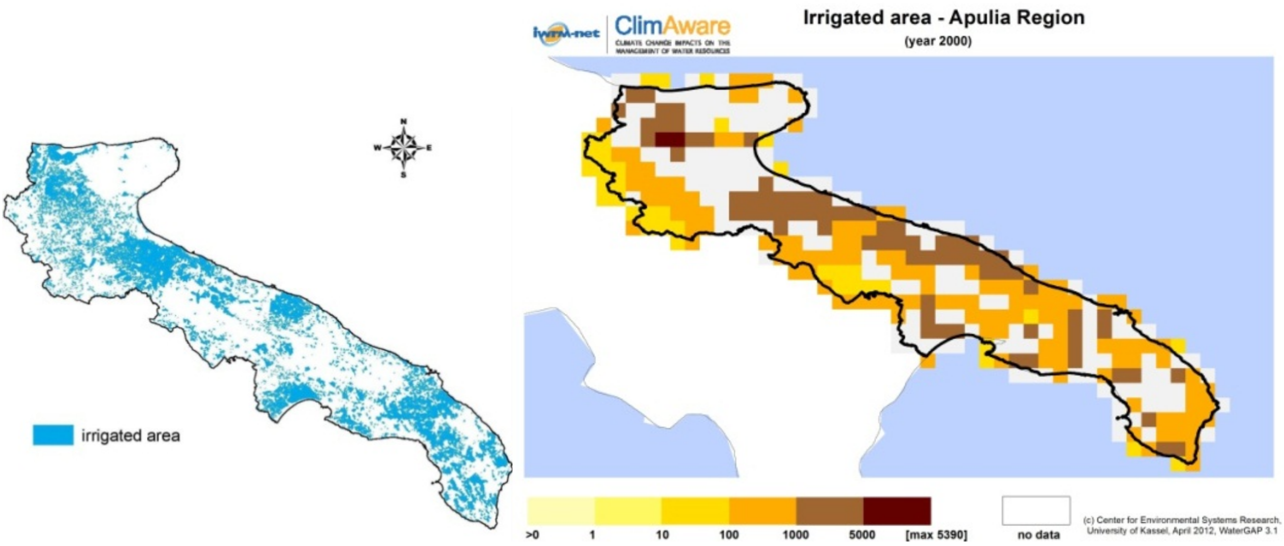


Figure 20: Irrigated area in the Apulia region , CORINE map, (left map) and prepared for WaterGAP based on national statistics for the year 2000 (right map).

Subsequently to the validation, irrigated area was adapted in WaterGAP3 for the Apulia region in order to provide sound data for the cross-scale comparison in WP3. Therefore, location and extend of irrigated area as well as crop specific information were implemented in WaterGAP3 according to information provided by the CS3 partner (Figure 21).

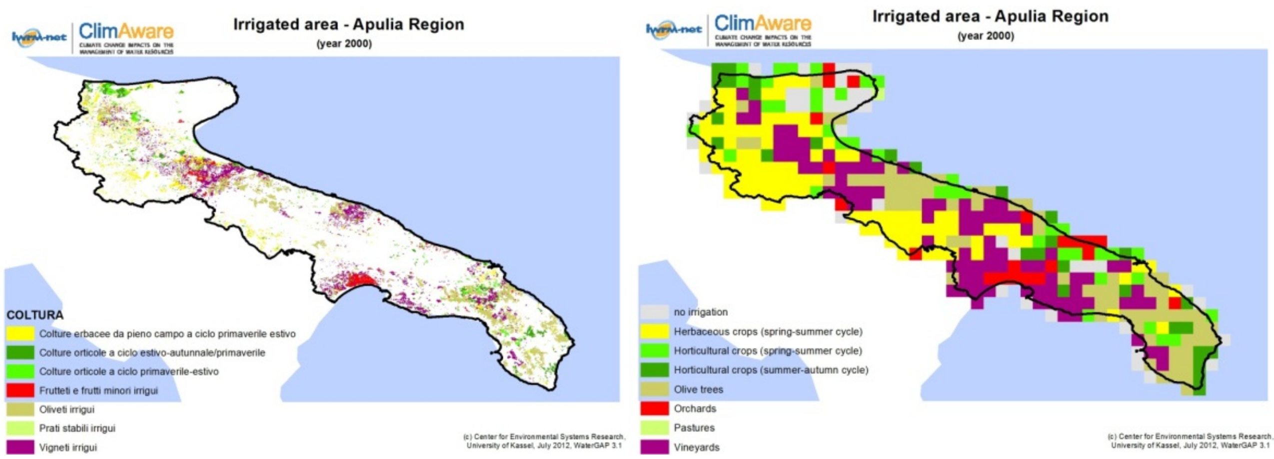


Figure 21: Crop-specific irrigated area information for Apulia as provided by CIHEAM (left map) and the dominant crop type of each grid cell in WaterGAP3 after the adjustment (right map).

Before the adjustment of the irrigated area in WaterGAP, model results for the baseline period provided a value of 350.3 million m^3 for mean annual irrigation water consumption which accounts for 64.0 % less compared to the value provided by CIHEAM (973.2 million m^3). With implementation of the crop-specific irrigated area, WaterGAP results could be significantly improved (Figure 22).

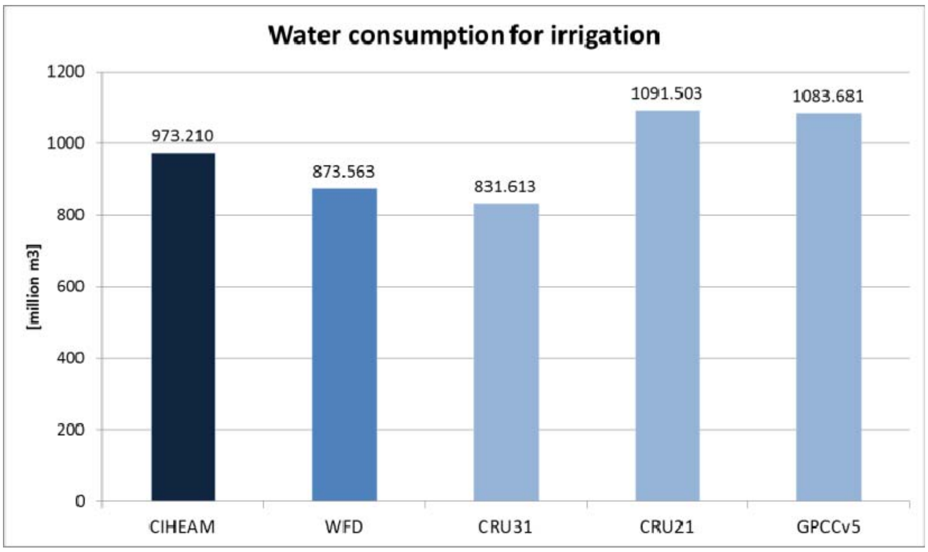


Figure 22: Water consumption for irrigation in Apulia as provided by CIHEAM and calculated by WaterGAP driven with different climate forcing data (WATCH-forcing data, CRU31, CRU21 and GPCCv5)

Applying the WATCH forcing data, which have been selected for the ClimAware project, mean annual irrigation water consumption is now estimated at 873.5 million m^3 for the baseline period, which accounts for an underestimation of only 10 %. In addition, further model runs for the baseline period were conducted with other climate forcing data sets (i.e. CRU21, CRU31 and GPCC v5) to assess the uncertainty range due to the chosen climate data. This comparison showed that results vary from –15 % (CRU31; 831.6 million m^3) to +12 % (CRU21; 1091.5 million m^3) depending on the chosen climate forcing data.

2.2 CASE STUDIES

2.2.1 CS 1 – HYDROMORPHOLOGY, GERMANY

Introduction

Present efforts in stream restoration in Germany focus on the aims of the WFD (European Parliament of the Council 2000) to establish the good ecological status in surface waters of not heavily modified water bodies. The aims of the investigation are to describe indications for the adjustment and the continuity of the river basin management plans based on the WFD considering hydromorphology and the hydrological regime.

Figure 23: Impression of a typical River in Central Germany after implementing a restoration measure

Within the frame of the case study “Hydromorphology” the total objective is to examine how the hydromorphological WFD-objectives can be achieved in consideration of climate change. This objective is distinguished into three separate objectives. The first aim is to investigate the hydromorphological situation under the consideration of climate change induced pressures on hydromorphology in comparison to the human impact due to stream training or other hydromorphological effective works. The second aim is to investigate the dependence of measures to improve the hydromorphological situation under the influence of climate change. The third aim is the evaluation of the natural (non- or very-minor anthropogenic altered) hydromorphological state under climate change pressure since it is as the state of reference the goal of future stream management. All three aims are necessary to evaluate climate change effects on the streams hydromorphology and to find reliable concepts for the adaption of measures concerning WFD-objectives.

The most preferable method and therefore the main focus of case study 1 in the framework of ClimAware is modelling the stream flow using input of climate change induced discharge changes as investigated in WP 1. By using different scenarios the influence of the climate change on the hydromorphological characteristics according to the WFD is evaluated and proposals for implementation were developed.

The Eder River is located in the middle of Germany as part of the Weser catchment area. Especially the Lower Eder reach downstream of the Ederdam is a very well suited example since there is a combination of the aim of hydromorphological improvement under the condition of dam management opportunities. Therefore the German case study 1 focuses on the Lower Eder River, a 44 km long river section, which starts downstream the Ederdam and flows into the Fulda River near Kassel (Figure 24). The Lower Eder River is a regulated river with a mean annual low of MNQ = 6 m³/s, mean annual flow MQ = 23.8 m³/s and mean annual flood MHQ = 135 m³/s in the river section downstream the Ederdam (Theobald et al., 2013; http://wrrl.hessen.de/viewer.htm). After the inflow of the tributary of the Schwalm River at stream km 17 the typical values for the discharge regime are composed by mean annual low of MNQ = 8.3 m³/s, mean annual flow MQ = 32 m³/s and mean annual flood MHQ = 208.6 m³/s. These discharge values result from summing up the discharges according to the hydrological main values from the “Gewässerkundliches Jahrbuch” (HLUG Wiesbaden 2009) for the gauging stations of the River Eder River and Schwalm River upstream the tributary. The headwaters of Weser river basin like the Eder River are mainly situated in a low mountain range.

Data

Required data for a reliable hydraulic model are mainly information on discharge, stream geometry, flow resistance and hydraulic structures.

Hydrological data are observed runoff data from the current state and data resulting from the modelling based on climate projections implemented by CESR. Geometry data and hydraulic data are resulting from the “Retentionskataster Hessen” (RKH) of the HWRMP Fulda (www.hlug.de) including third-party local measurements and own recoveries.

Morphological information are based on the results of the initial analysis according to the WFD (MULV 2009; www.flussgebiete.hessen.de) as well as own estimations. The design of the measure is based on already implemented restoration measures according to the WFD and additional own estimations. The location of the measure is oriented on an already partly established measure at the investigated site. The design of the measure was selected in discussions with local consultants experienced in similar restoration activities.

The calibration of the models parameters for flow resistance is based on the gauge data observed at the gauging station in Fritzlar which are published by HLUG (HLUG Wiesbaden 2009). Additionally it is based on measured water levels for the complete project area from the year 2005.

All external data were extended by internal synergies with further projects, for example KLIMZUG Nordhessen (Theobald et al., 2013). Majorly the used data was available in the administration for water resources management or other water related authorities like municipalities and should be obtainable also for similar situations. So limited data availability is not expected to limit the transfer of the method to comparable situations.

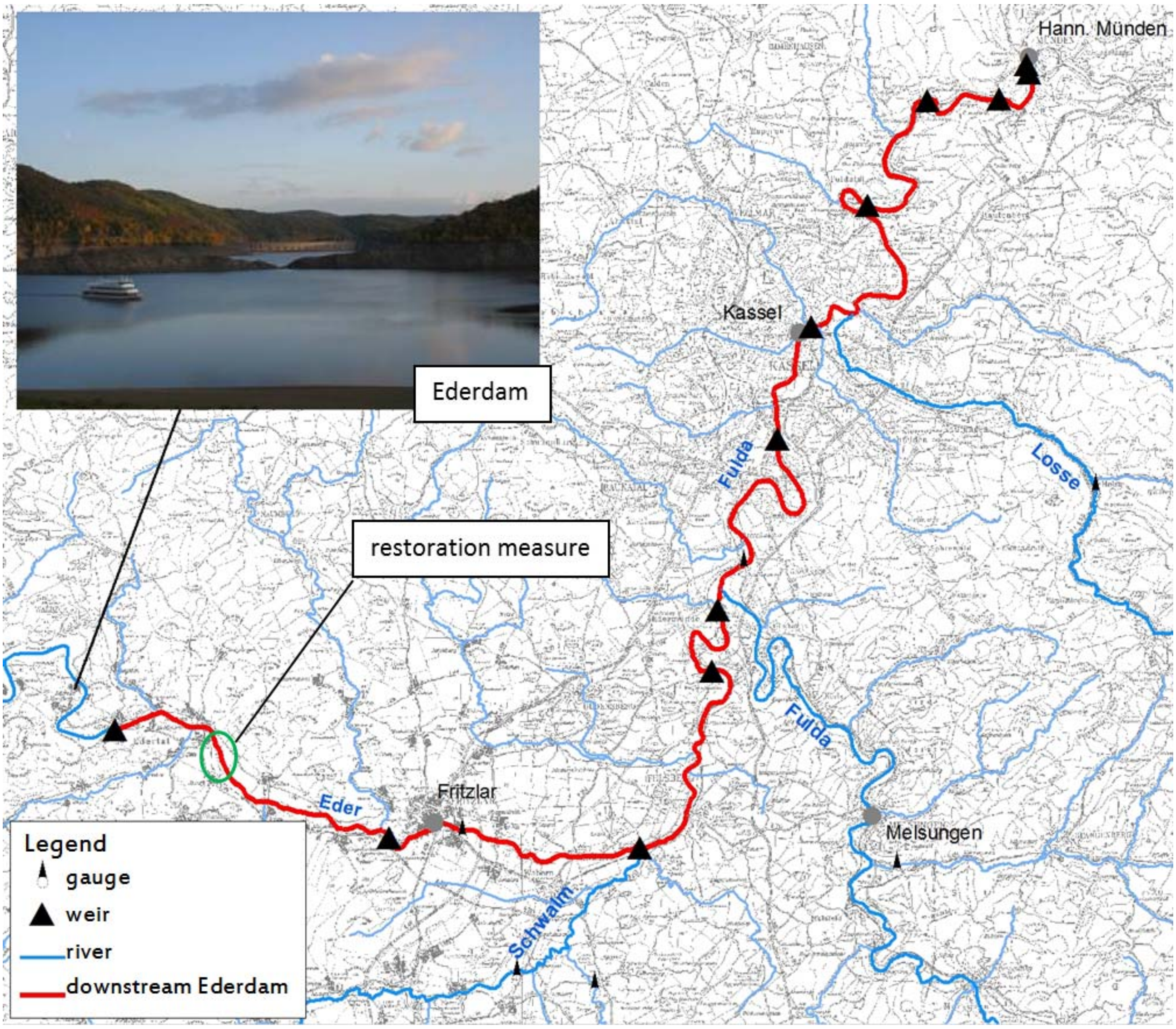


Figure 24: Lower Eder River and Fulda downstream the Ederdam

Methodology, Modelling Approach

Implementing WFD

Within the frame of the case study "Hydromorphology" planning and implementation of the WFD is supported by the use of hydrodynamic-numerical modelling.

On the basis of hydrological and hydraulic parameters, the impact of climate change on the hydromorphological conditions of watercourses and hence two groups of quality components of the WFD (hydrological regime, morphological conditions) can be quantified. Having the knowledge of this impact chain, it can be estimated to what extent the impact of climate change also influences the hydromorphological assessments of waters and which actions regarding the aims of WFD are needed to guarantee a "good status". In this context the influence on abiotic or water structure relevant parameters are of relevance. It can be estimated whether the current programmes of measures and river basin management plans are still adequate taking account of climate related changes or whether an adaptation needs to be done. In this case adaptation strategies of the mentioned impact chain can be made at the following positions:

- Measures regarding hydromorphological enhancement may have to be changed (e.g. restoration measures have to be adapted to a changed mean water flow, in order to increase the potential of self-dynamic development of more near-natural river structures)
- Adaption of the use and management of water courses (adaptation of the Dam management on a changed seasonal cycle of inflow)
- Adaption of the reference conditions, which define the “good ecological status” according to the global changes, in particular according to the climate change

The functional chain described above runs on the exemplary selected river section in the Weser catchment, the Lower Eder River. This 44 km long river section was selected in working step one in close cooperation with the practice partners, due to the terrestrial measurements which actually are taking place, as well as river bearings and the advanced planning of implementation projects according to the WFD. This procedure ensures that practice partners directly incorporate project results in their daily work. Thus the project responds to their demands. The objective of this study is to present possible consequences of climate change according to the objectives of the WFD to the stakeholders in environmental protection and nature conservation, hydropower, navigation and flood control and to develop common recommendations.

Basic considerations

Major influences on the biocoenosises in streams are besides others like the characteristics of chemical and physico-chemical elements supporting the biological elements (incl. temperature and pollutants) the characteristics of substratum and flow field (Bohle 1995, Schönborn & Risse-Buhl 2013). Substratum is mainly controlled by flood events and human impacts like stream training so flow may be assumed as the major remaining direct or indirect effect. This is controlled by morphology and discharge resulting in characteristic spatial-temporal variability on the scale of pool-riffle-sequences and days. Processes like incision or aggradation of alluvial channels usually have their cause also in human impact at that scale e.g. the installation or operation of weirs. Smaller scales in the magnitude of the length-scale of grain-sizes or the time-scale of turbulence are hydraulically controlled by the mentioned larger scales. Larger scales like reach-length-scales between main tributaries or geological units are only under indirect hydromorphological effective human impact.

Since the ecological status is described by the characteristics of the biocoenosis in terms of species composition and abundance (European Parliament of Council, 2000) it may be assumed to describe the options for the development of specific biocoenosis by hydraulically related parameters. The ecological status in the absence of major limnological-chemical deficits is affected by deficits in the performance of the hydromorphological situation.

To investigate the effect of reduced discharges due to climate change some basic assumptions on the relation between hydrological conditions, morphological conditions and the ecological status may be found. It has to be emphasized that low flow reductions due to climate change or human impact may cause increased concentrations of pollutants as well as increased temperatures. For the investigated reach of the Lower Eder River these effects are assumed to be negligible since water temperature is dominated by the relatively cold outflow of the deep-water from the Ederdam or may not be modified by hydromorphological effective measures.

From the ecological point of view on low flow hydraulics its ecological significance at gravel bed rivers like the Lower Eder River is based on the following basic assumptions:

Organisms and biocoenosis are adapted to natural conditions like

- Discharge regime, described by typical values like mean annual low-flow discharge MNQ and its seasonal distribution of occurrence
- Main morphological parameters like gradient, channel planform patterns, longitudinal curvature, bed forms, cross sectional forms or floodplain vegetation which are mainly not influenced by low flow hydraulics and are assumed to suffer negligible climate-change-induced modifications in the region of the Weser basin
- Seasonal clogging of the substratum's interstices (colmation) which is a commonly observable pattern in stream pools during low flow situation and which is washed out (decolmation) due to turbulence and/or sediment movement during periods of increased discharges and flooding. Natural clogging is established in regular cycles during low flow periods.
- Hydraulic situation (flow field) which is determined by discharge and hydromorphologically significant structures

Human impact related to hydromorphology usually effects aspects like

- Discharge regime, i.e. by water release by hydro power, dam management etc.
- Hydromorphologically significant structures, i.e. by stream training, flood protection measures, damming etc.
- Connectivity between stream water and groundwater by additional clogging which is reinforced by anthropogenic input of fines e.g. like wastewater inflow or soil erosion of farmland or by decolmation because of increased or more frequent flooding.

Consequently the climate-change influenced environmental situation at low flow may be described by typical parameters like

- Low flow discharge regime, described by typical values like mean annual low-flow discharge MNQ
- Hydraulic situation described by typical parameters like flow depth, velocity, width of water table, bottom shear stress

Climate change may effect in addition to the mentioned human impact stream ecology by main aspects like

- Discharge modification, e.g. changed mean annual flow, mean annual low flow or mean annual floods
- Temperature, e.g. water temperature in the water volume or air temperature in the floodplain
- Radiation balance

Obviously considering climate-change induced low flow reduction is very much related to instream flow investigations since the variation of discharge changes abiotic factors in stream ecology. This means that severe decreases of low flow discharge e.g. may change abiotic factors in stream ecology, lead to severe loss of lotic aquatic habitat and change biocoenosis. In similar ways the other climate-change induced effects may be considered in the investigation e.g. increased flooding in its effects on stream incision or hydraulic stress for organisms.

Creating DTM

For hydraulic modelling a high-resolution digital terrain model (DTM), with additional maps and further information being integrated, was built for the investigated area. The available topographic information were combined on interpolation technique to be able to describe exactly characteristic contour lines and scarps respectively for the HN-modelling and the calculations on geometries relevant for floodplains such as the cross profile of waters, of shore lines, of flood protection or foothills.

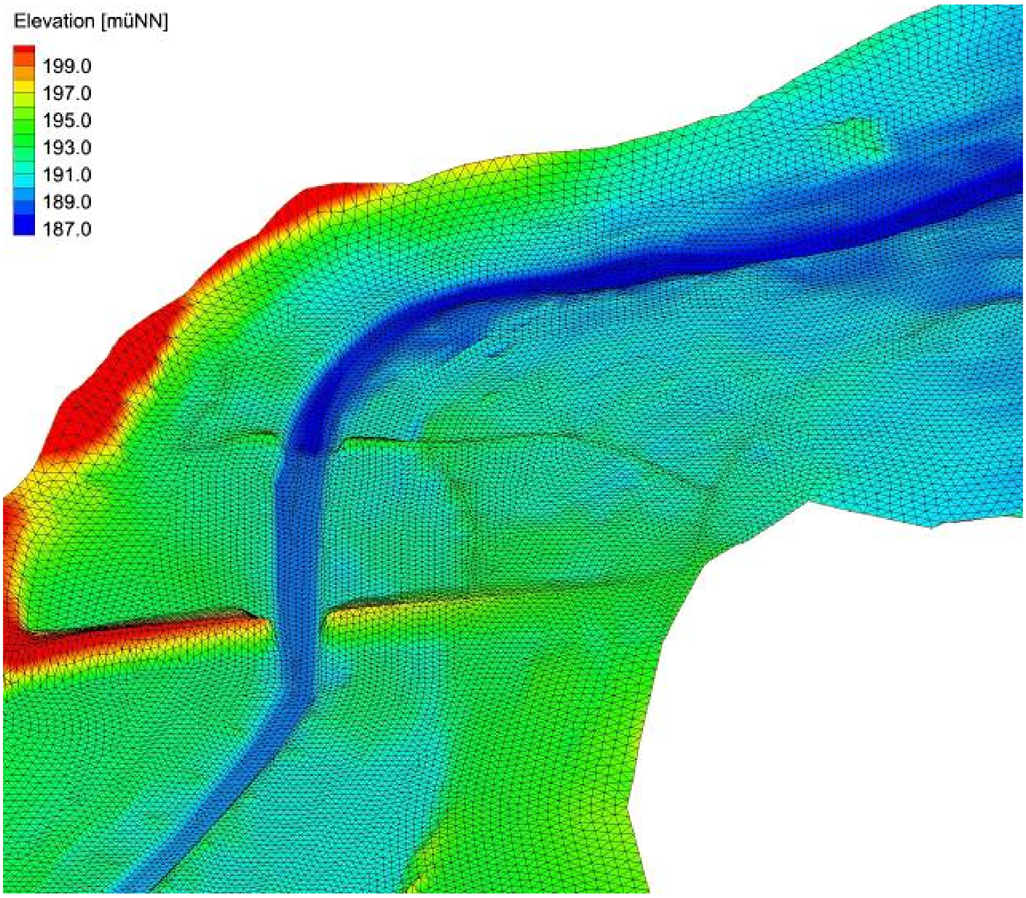


Figure 25: DTM view on part of the Lower Eder River in present state just upstream of the restoration measure and the evaluation area, looking downstream direction

For the investigation of the exemplary restoration measure the DTM and its expected morphodynamic self-adjustment several geometric scenarios were extended accordingly.

In streams like the Lower Eder River flow resistance is mainly dominated by surface roughness due to grain roughness, bed form resistance because of pool-riffle-sequences and drag resistance of vegetation. The flow resistance is described in areas of similar character like stream bed consisting of gravel, floodplain meadows composed by grasses or riparian vegetation like willows, alder or ash.

Stream flow Modelling

Based on the DTM, a two-dimensional hydrodynamic-numerical-model of the Lower Eder River was implemented. Basics are the shallow water equation as a simplification of Navier-Stokes-equation (Equation 7, DVWK 1999).

$$\frac{\partial uh}{\partial t}+\frac{\partial u^2h}{\partial x}+\frac{\partial uvh}{\partial y}=-\frac{g}{2}\frac{\partial h^2}{\partial x}+\frac{h}{\rho}\frac{\partial \sigma_x}{\partial x}+\frac{h}{\rho}\frac{\partial \tau_{yx}}{\partial y}-gh\frac{\partial z_b}{\partial x}-\frac{\tau_{bx}}{\rho}$$

$$\frac{\partial vh}{\partial t}+\frac{\partial v^2h}{\partial y}+\frac{\partial uvh}{\partial x}=-\frac{g}{2}\frac{\partial h^2}{\partial y}+\frac{h}{\rho}\frac{\partial \sigma_y}{\partial y}+\frac{h}{\rho}\frac{\partial \tau_{xy}}{\partial x}-gh\frac{\partial z_b}{\partial y}-\frac{\tau_{by}}{\rho}$$

$$\frac{\partial h}{\partial t}+\frac{\partial hu}{\partial x}+\frac{\partial hv}{\partial y}=0$$

Equation 7

Main assumptions of the applied 2D-HN-model are unsteady flow, neglected vertical components of acceleration (2D-approximation) and fully rough turbulent flow. Parameters for input are bed elevation $z_0(x,y)$, Stricklers value of flow resistance $k_{St}(x,y)$, inflowing discharge Q_{in} at the upstream boundaries, water surface elevation $z_{Wsp,out}$ at the outflow boundaries and for cross-sectional reference the definition of longitudinal coordinate s and normal-lateral coordinate b for objective definition of (s,b) = fct(x,y).

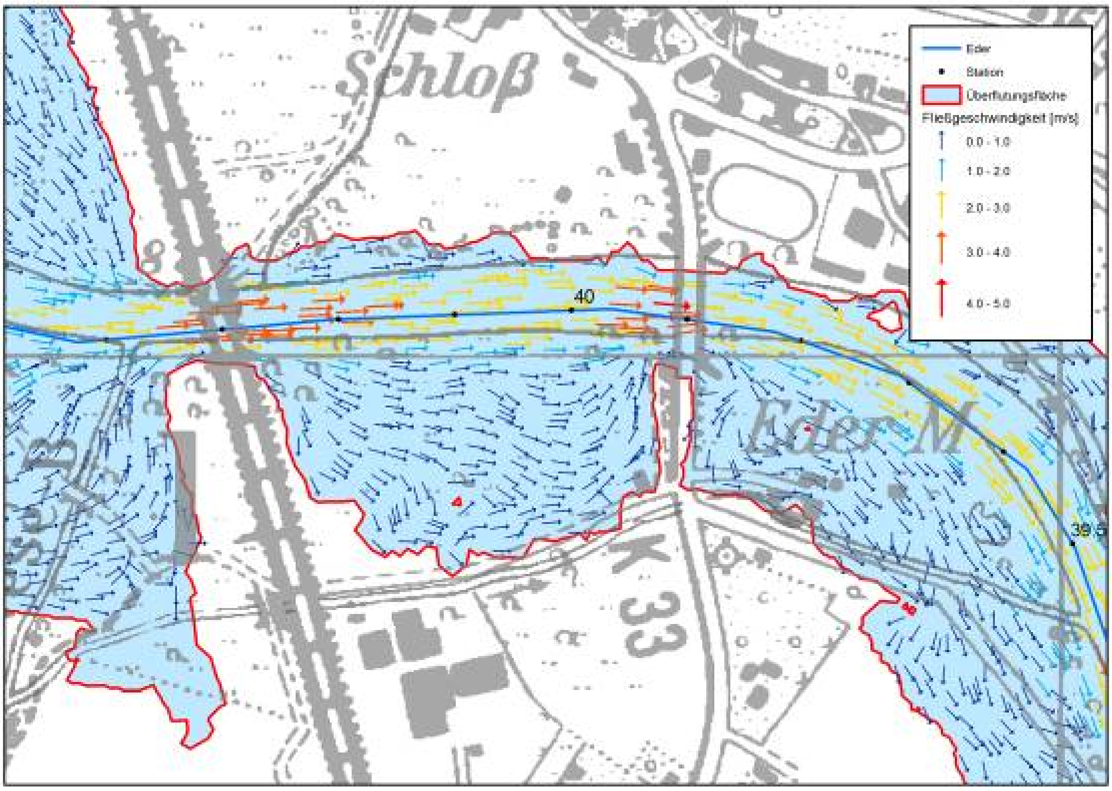


Figure 26: Example view for 2D-HN-model results just upstream of the restoration measure and the evaluation area

Hydraulic structures may either considered directly with their geometrical properties or indirectly as internal boundary conditions based on classical calculation approaches of hydraulic engineering like stage-distribution relations (Nujic, M. 2006). Calibration was not needed since the 2D-HN-model was applied already in other synergistic investigations were calibration was performed on the basis of available local measurements and experiences (Theobald et al. 2013; RP Kassel 2010, www.hlug.de).

Output parameters in the area of computation with Cartesian x,y-coordinates are water surface elevation $z_{Wsp}(x,y)$ and depth-mean-velocity in x- respectively y-direction $v_{mx}(x,y)$, $v_{my}(x,y)$ as well as after transformation in natural coordinates $z_{Wsp}(s,b)$, $v_{mx}(s,b)$, $v_{my}(s,b)$

Bottom shear stress τ_0 calculated by the approaches of Darcy-Weisbach and Gaukler-Manning-Strickler (DVWK 1999) as function of local depth h, depth-mean-velocity v_m, Stricklers value k_{st} (=1/$n_{Manning}$ reciprocal value of Mannings value) und gravitational acceleration g (see Equation 8 and Equation 9)

$$\tau_0 = \frac{\lambda}{8} \rho v_m^{\ 2}$$ Equation 8

including

$$\frac{\lambda}{8} = \frac{g}{k_{St}^{\ 2} \cdot h^{1/3}}$$ Equation 9

Concerning the three aims of this case study the following models were established and applied.

Stream training and other hydromorphological effective human impact may be observed along the total 44 km long reach of the Lower Eder River (Figure 27). For the investigation of the effects of climate change on hydromorphology in comparison to human impact by stream training (1st aim) it is reliable to extract cross-sectional-referenced 1-D-parameters from the 2-D-HN-model. Extracted 1-D-parameters regarding abiotic factors are such as mean and maximum water depth (h_m, h_{max}), cross-sectional mean flow velocity v_{mA} and bottom shear stress $\tau_{0,m}$ (see Equation 10 to Equation 15) including their longitudinal variance/diversity in dependence of the 1-D-coordinate (s).

$$h(s,b) \equiv \text{Max}\{z_{Wsp}(s,b) - z_0(s,b); 0\}$$ Equation 10

$$A(s) \equiv \int_{\min b}^{\max b} h(s,b)\, db_{Wsp}$$ Equation 11

$$h_m(s) \equiv A(s)/b_{Wsp}(s)$$ Equation 12

$$h_{max}(s) \equiv \text{Max}\ \{h(s,b)\}$$ Equation 13

$$v_{mA}(s) \equiv Q(s)/A(s)$$ Equation 14

$$\tau_{0,m} \equiv \frac{\lambda}{8} \rho v_{mA}^{\ 2}$$ Equation 15

To achieve the 1st aim the actual state was simulated for several discharge situations. This was done to identify the impact of climate change induced discharges on the hydromorphological conditions and to be able to assume the hydromorphological conditions under the projected climate change. It has to be emphasized that in this step three anthropogenic-altered situations of different intensity of hydromorphological effective human impact are investigated. The results are compared with the state of least anthropogenic alteration which is the free flowing situation.

The simulations for the complete Lower Eder River were calculated with discharges of ¼·MNQ up to 2·MNQ-situation (typically 1.5 m³/s to 12 m³/s for the upper reach from the Ederdam to the confluence of the Schwalm River and 2.1 m³/s to 16.6 m³/s from the Schwalm River confluence to the confluence of the Lower Eder River into the Fulda River). The discharges were selected with respect to low flow situations which are expected to be most sensitive to climate change since more and extended low flow periods are expected to appear (see also WP 1).

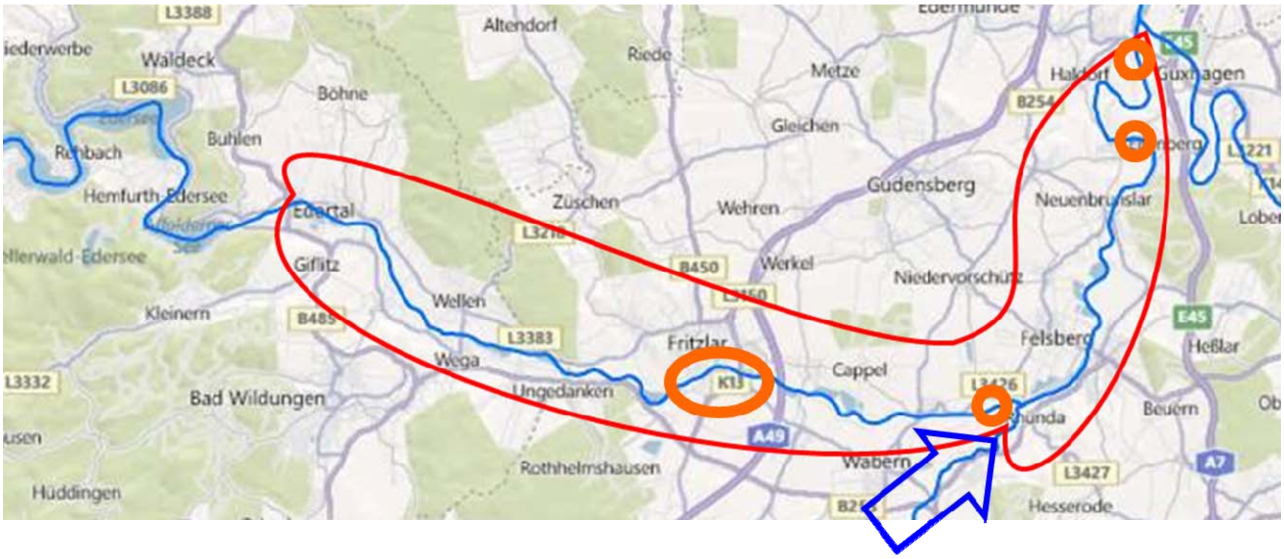


Figure 27: Map of the total 44 km long reach of the Lower Eder River including water releases and the confluence of Schwalm River investigated for effects of climate change on hydromorphology in comparison to human impact by stream training

The next step considers the measures under the influence of climate change (2nd aim). These simulations concentrate on an exemplary typical restoration measure and its reach-specific section. The Hessian implementation of the WFD recommends for the “good ecological status” at least 35 % of the river to be in good hydromorphological conditions (MULV 2009, see flussgebiete.hessen.de). According to this an evaluation area was defined, which represents a length of 100 % in comparison to a length of approximately 35 % for the measure. The measure represents a newly created 450 m long floodplain channel left-hand-sided from the main channel (km 39.25 to km 38.75, Figure 28) and is investigated in the context a 1.3 km long representative section (evaluation area from km 38.2 to km 39.5) of the 44 km total length 2D-HN-model. The section length was selected with respect to the length of the measure as well as to cover multiple pool-riffle-sequences which are usually expected to occur in average at six bankfull widths b_{BQ} (Knighton & Wharton 2014; Yalin & Silva 2001). Approximating the bankfull width by about 50 m means that about five pool-riffle-sequences are included in the evaluation area.

The investigated exemplary measure was simulated for different states of the natural morphodynamic self-adjustment due to sedimentation processes as they are observed in similar measures. In comparison to the actual state three further morphological scenarios of morphodynamic self-adjustment were developed and evaluated. These morphological scenarios represent different states during the morphodynamic self-adjustment due to sedimentation of such a typical restoration measure beginning with

a) the starting situation before the measures realization takes place,

b) the initial state of restoration directly after shaping the measure by dredging,

c) an intermediate state of beginning sedimentation at the upstream inflow range of the floodplain channel as an example of morphodynamics and

d) a final state with a significant higher level of the floodplain channel bed (see also Figure 36)

The periods for which the three typical states (b) to (d) exist depend very much on individual stream and flood regime after initialisation of the measure. In hydraulic engineering practice it may often be observed that the initial state (b) is shifted within one or two flooding period to the intermediate state (c) which may last for a number of years. In the on-going morphodynamic process of self-adjustment the establishment of bushy vegetation from natural succession may increase the sedimentation at the upper inflow reach of a newly created branch.

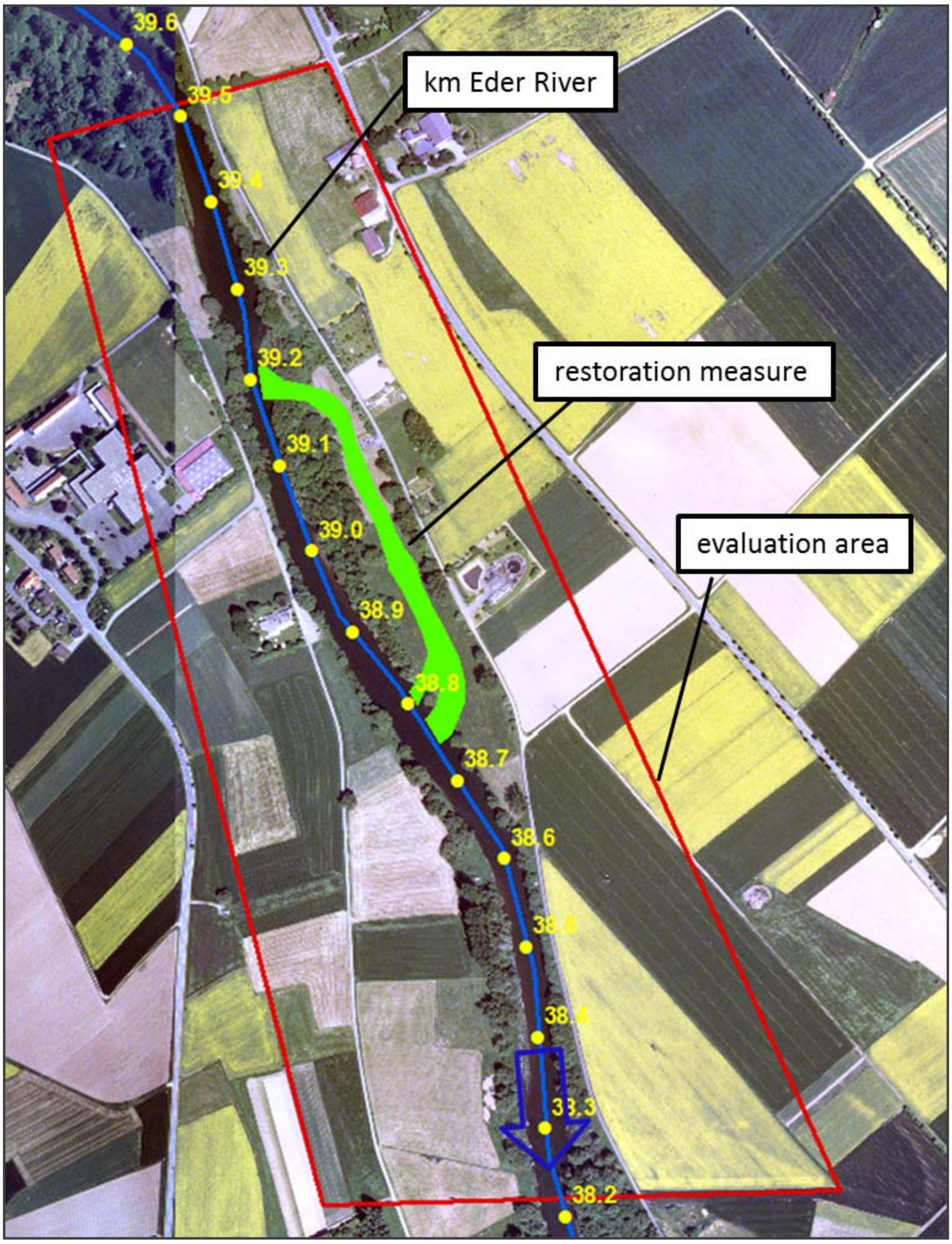


Figure 28: Aerial view on the restoration measure and the evaluation area

In combination with the different states due to morphodynamic self-adjustment several different discharges regarding the main effect of climate change were investigated in the model. The initial design of the measure was oriented to start the upstream side inflow at total discharges between mean annual low flow MNQ = 6 m³/s and the mean annual flow MQ = 23.8 m³/s. Consequently the simulations were performed with the mean annual low flow MNQ = 6 m³/s (non-exceeding approx. 40 d/yr), the double mean annual low flow 2·MNQ = 12 m³/s (non-exceeding approx. 150 d/yr), the mean annual flow MQ = 23.8 m³/s (non-exceeding approx. 270 d/yr) and the approximate bankfull discharge BQ = 50 m³/s (non-exceeding approx. 340 d/yr). Discharge less than the mean annual low flow MNQ was not investigated because there are no differences in the extreme low flow stream geometry. The simulations of the measure were evaluated two-dimensional for the representative section defined as “evaluation area”. Regarded abiotic factors are such as local water depth, depth-mean flow velocity and local bottom shear stress (h, v_{mh}, τ_0; see Equation 16 to Equation 18) in dependence of the 2D-coordinates (x, y).

$$h(x,y) \equiv z_{Wsp}(x,y) - z_0(x,y) \qquad \text{Equation 16}$$

$$v_{mh}(x,y) \equiv \left\{ v_{mx}^2(x,y) + v_{my}^2(x,y) \right\}^{1/2} \qquad \text{Equation 17}$$

$$\tau_0(x,y) \equiv \lambda \rho v_{mh}^2(x,y)/8 \qquad \text{Equation 18}$$

All measures according to the WFD are oriented on a **n**on- or very-minor **a**nthropogenic altered **s**tream **s**ituation (NASS) as a state of reference for future streams development aiming at sustainable management and protection of freshwater resources. For the hydromorphological aspects this may be described by parameters like width/depth ratio or the mean and variability in the distributions of depth, width, flow velocity or substratum. Several of these parameters are evaluated in the steps of investigation for the 1st and 2nd aim showing the effects of climate change in comparison or in combination with human impact on present hydromorphology. Consequently the 3rd aim (climate change induced state of reference) is investigated with a focus on the morphodynamic limitation of the measures and its climate-change-induced dependence of discharge (WP 1) and flow (this CS 1). Discharge dependence for this kind of measures may be investigated by the results of the 2D-HN-Model.

Simulation of Scenarios

The simulation of scenarios of climate change with regard to the streams hydromorphological situation are performed by considering discharge changes in their effect on hydraulics and morphodynamics. The future variation of discharges reliably expected is focused on decreasing low flow discharges and perseverative low flow periods. There exists no reliable proof for a change of flood flow with multi-year reoccurrence intervals in the region of the Lower Eder River so this aspect was not investigated further in detail. Nevertheless basic considerations are extracted from synergetic results of similar investigations like KLIMZUG Nordhessen (Theobald et al. 2013).

The investigation of the total reach with 1D-evaluation focuses on low flow situations while the analysis of the representative measure (2D-evaluation) targets on low flow and morphodynamic more important larger bankfull flows.

Results

Effects of low flow reduction on the hydromorphology of the total reach of the Lower Eder River (1D-evaluation)

To describe the effects of flow reduction due to climate change on stream hydraulics the approach considers the set of representative hydraulic parameters along different typical reaches. In the first step cross-section-oriented parameters are chosen, these are maximum water depth in the cross-section, mean flow velocity and width of the water table. In gravel-bed streams like the Eder River the morphology is caused by sediment transport during floods. This results in a spatial variety of different water depths, widths and flow velocities even for a constant discharge. In the selected approach this spatial variety is described by probability distributions of the hydraulic parameters P and their statistical parameters arithmetic mean M, standard deviation S and skewness C (see Equation 19 to Equation 23). To reduce severe skewness it may be useful to transform the hydraulic parameters P into their logarithmic value R = ln(P). For R the statistical parameters M, S and C are also calculated.

$$P_{Ci} \text{ in } \left[h_m(s_i), h_{max}(s_i), v_m(s_i), ...\right] \qquad \text{Equation 19}$$

$$R_{Ci} \text{ in } \left[\ln(h_m(s_i)), \ln(h_{max}(s_i)), \ln(v_m(s_i)), ...\right] \qquad \text{Equation 20}$$

$$M_P \equiv \frac{1}{n_C} \sum_{n_C}^{i=1} P_{Ci} \qquad \text{Equation 21}$$

$$S_P^{\ 2} \equiv \frac{1}{n_C - 1} \sum_{n_C}^{i=1} (P_{Ci} - M_P)^2 \qquad \text{Equation 22}$$

$$C_{,P} \equiv \frac{n_C}{(n_C - 1) \cdot (n_C - 2)} \cdot \frac{\sum_{n_C}^{i=1} (P_{Ci} - M_P)^3}{S_P^{\ 3}} \qquad \text{Equation 23}$$

n_C: *Number of cross sections*

It should be emphasized that the arithmetic mean of an ln-transformed sample is equivalent to the ln-transformation of the geometric mean of the non-transformed sample.

To describe the effect of changing discharges the probability distributions and their statistical parameters are investigated for some typical low flow situations. Since the number of measured situations is very limited the hydraulic situation was simulated in a hydrodynamic-numerical model. The hydraulically most significant gradients of human impacts on the Lower Eder River are releases of water at hydropower stations and corresponding backwater situation due to weirs. In addition to these human impacts there is the afflux of the Schwalm River, which is a major tributary increasing the natural discharge downstream from the confluence. This results in a number of different classes of reaches preliminary distinct by the hydrologic situation (upstream/downstream Schwalm River, with/without water release) and the hydraulic situation (free flowing/anthropogenic backwater reaches).

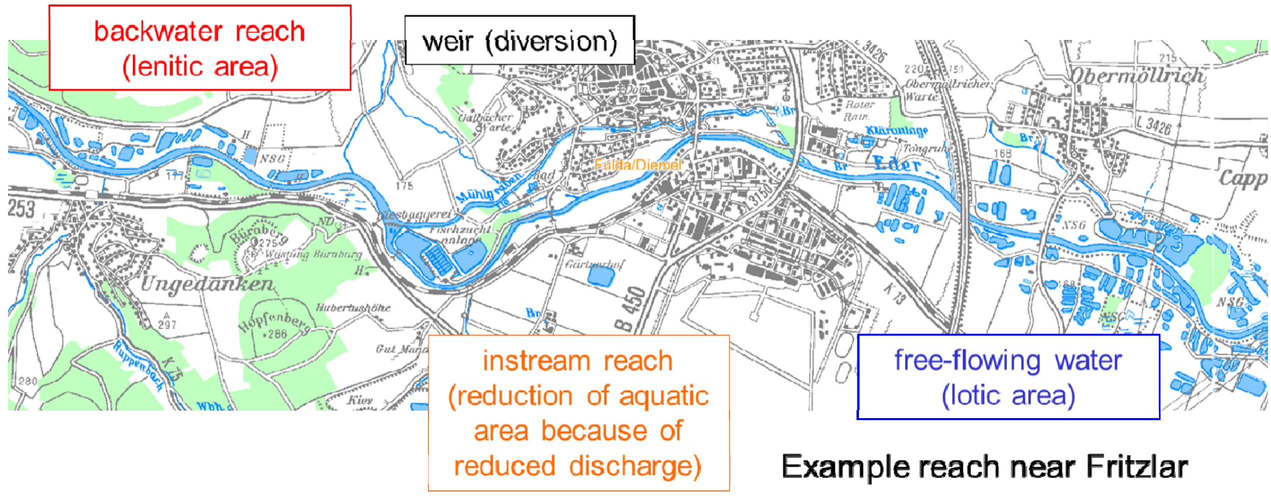
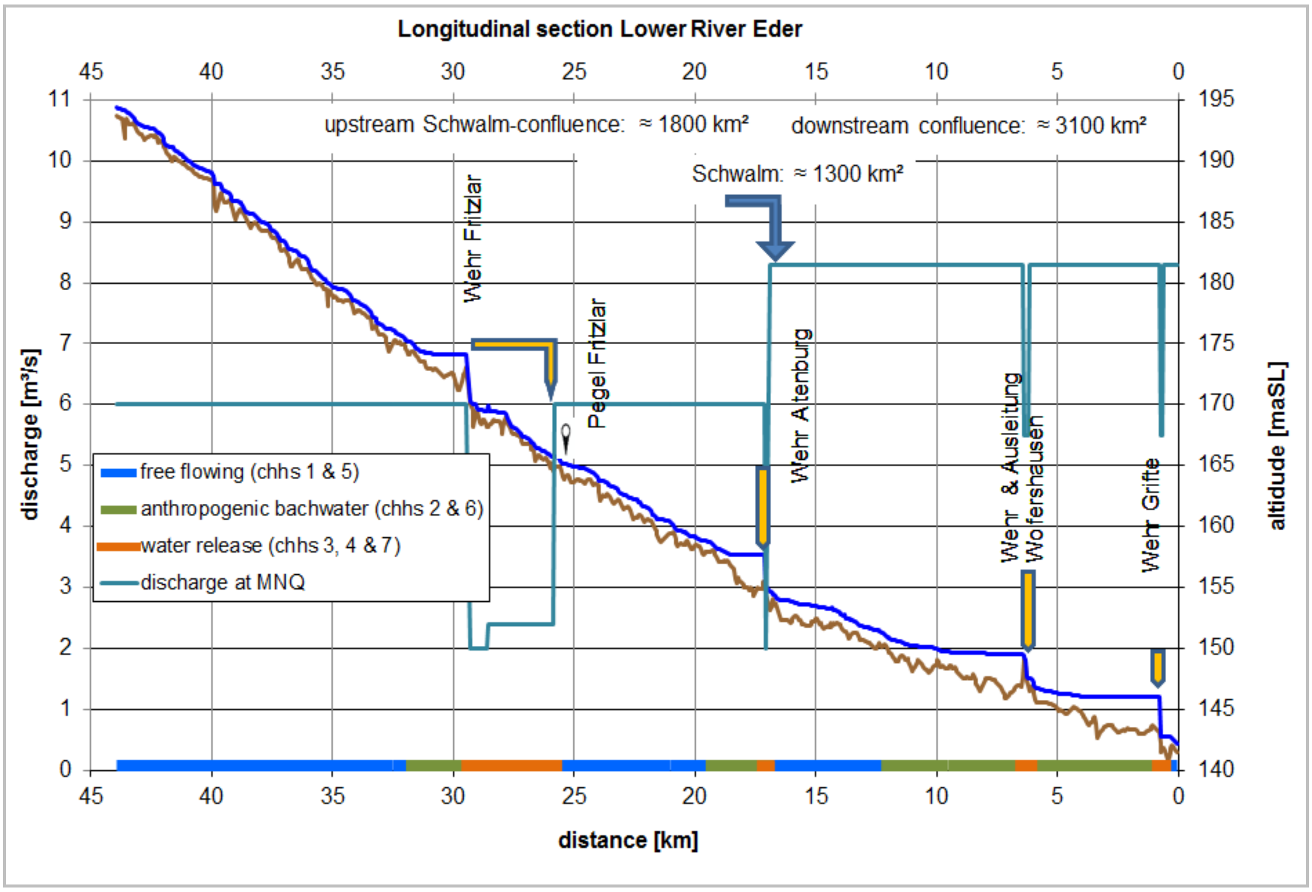


Figure 29: Example of different hydraulic situations at the Lower Eder River

The HN-model was used to simulate the following four different low flow situations in relation to the mean annual low flow discharge MNQ: ¼·MNQ, ½·MNQ, 1·MNQ, 2·MNQ (Eichendorff 2012). The example shows the longitudinal section along the Lower Eder River. The backwater effects are obviously observable by larger flow depths and lower velocities. The evaluation along the different typical reaches of the Lower Eder River (free flowing/anthropogenic backwater reaches) was based on cross profiles in a one-dimensional parameter view.



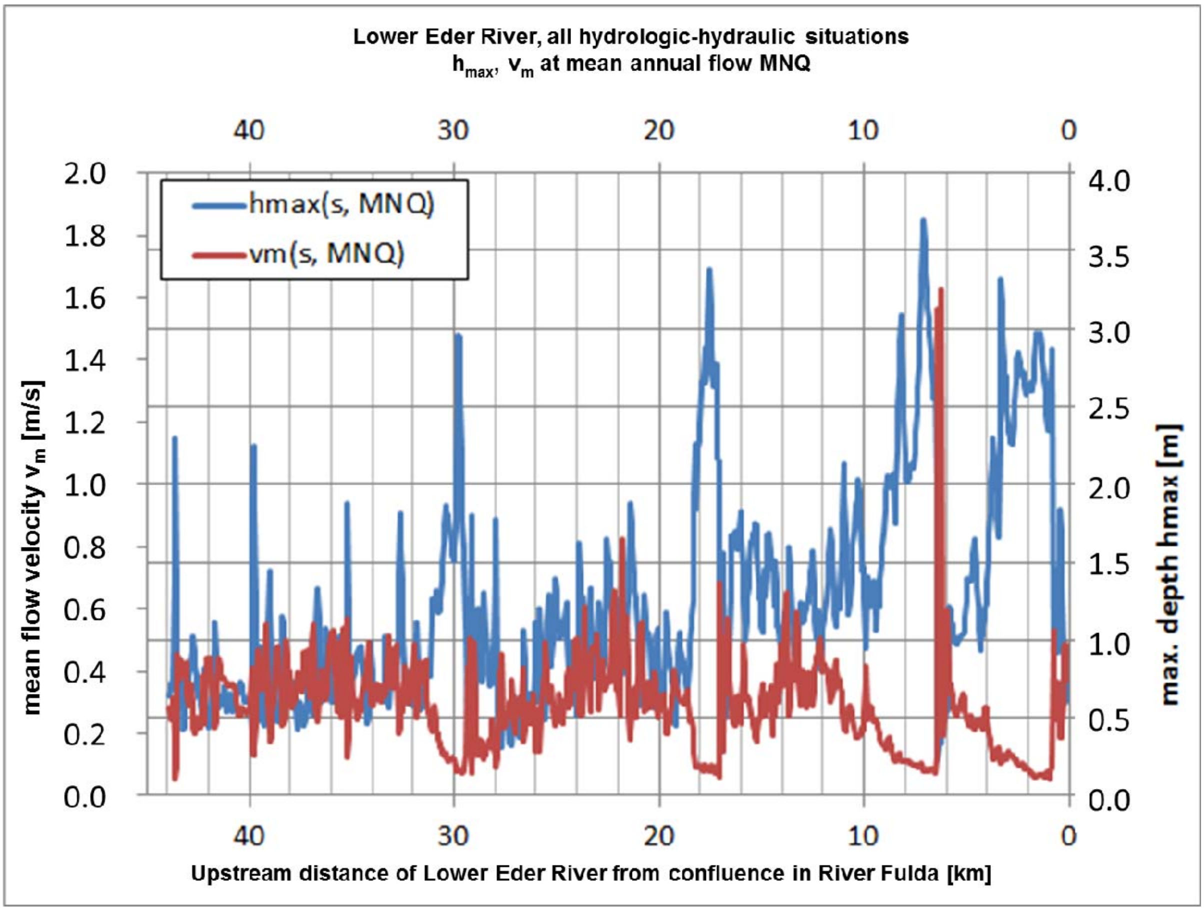
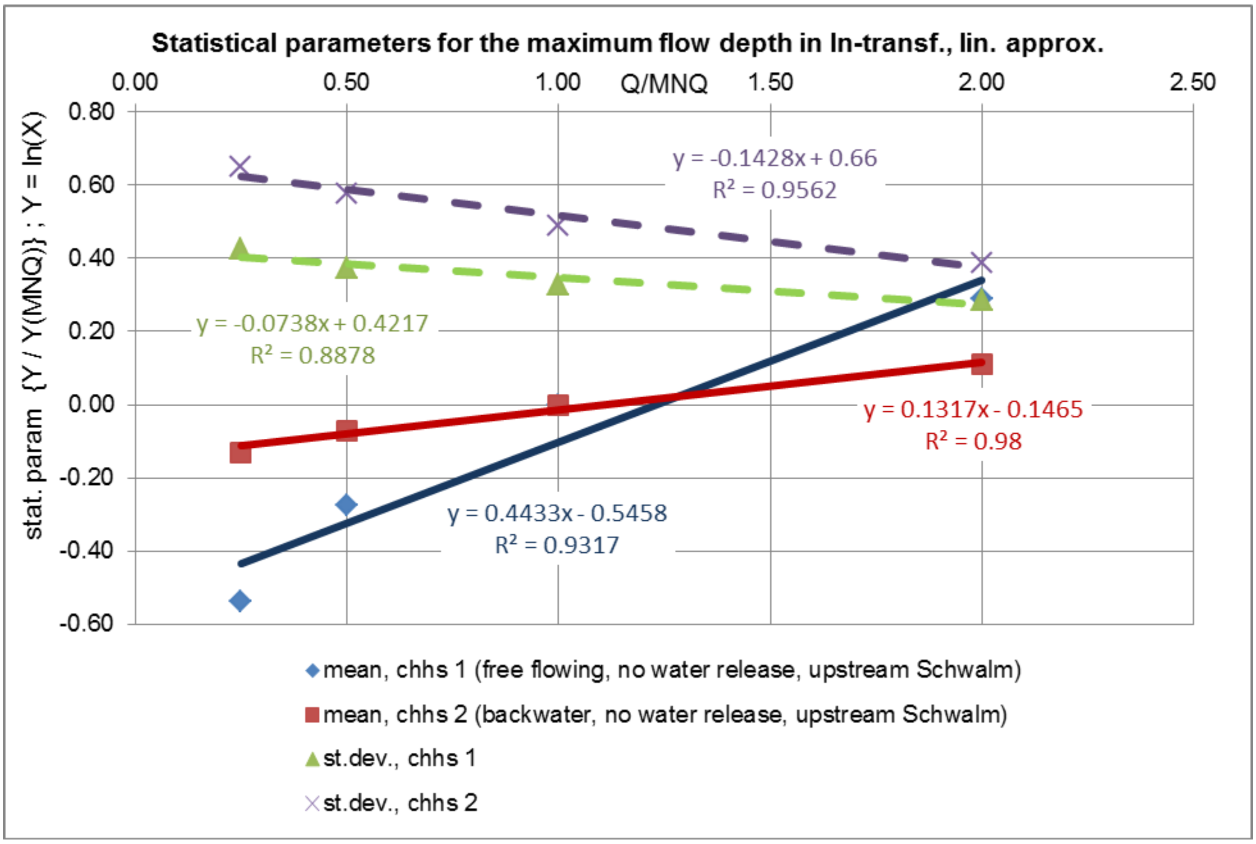


Figure 30: Longitudinal section along the Eder River, water surface, and stream bottom (above); maximum flow depth h_{max} and mean velocity v_m (below)

The statistical parameters mean, standard deviation and coefficient of skewness were calculated for the seven different hydrologic-hydraulic situations. The resulting statistical distributions of the empirical data from the hydraulic modelling are compared with the parameter-based distributional functions according to Gauß and ln-Gauß. The ln-Gauß-distribution is preferred for the evaluation based on cross-sections parameters because of better fitting and avoidance of absurd negative values for the physical parameters.

A comparison of the statistical parameters for the ln-transformed flow depth is shown in the following figure. The coefficients of determination show very good values for all statistical parameters, so the chosen method is valid for further work.



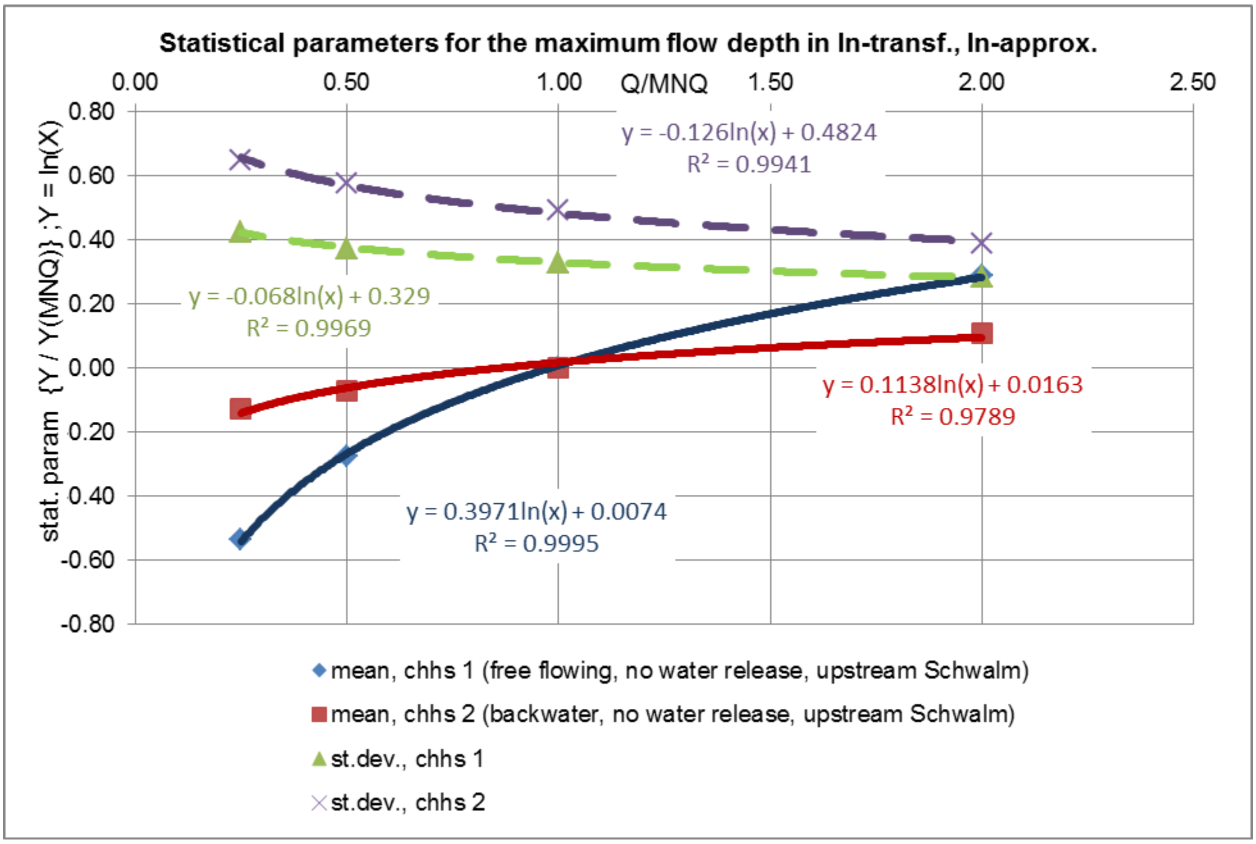


Figure 31: Statistical parameters cross-section-referred maximum flow depth in two different discharge-dependent approximations as an example for 1D-evaluated discharge dependence of hydromorphology

It can be seen that in the backwater reach the influence of discharge on flow depth is less intense than in the free flowing reach. This may be explained by the low dependence of the more or less constant water table due to the weir. This result is not surprising since it is well known that the effects of weirs are not only acting on river continuity (longitudinal connectivity of freshwater habitats) but also on flow field and related sediment transport because of backwater impact. In contradiction to the results on flow depth are the results on flow velocity since in weir backwater reaches the cross-sectional area at low flow is more or less constant resulting in an equivalent more or less discharge proportionality of the flow velocity.

Nevertheless it is necessary to compare climate-change induced alteration of the low flow regime with anthropogenic impacts due to alternated stream hydromorphology. For this comparison the discharge dependence of the statistical parameters of the hydromorphological quality elements like flow depth may be used by representing different situations in different probability functions and compare these. Figure 32 shows exemplary the results of this situation-dependent probability functions for a discharge decrease of 20 % and the hydromorphological situation of a free flowing reach in comparison to the weir-induced backwater reach. Obviously the distinction between the hydromorphological situations is much larger than the differences due to the discharge decrease.

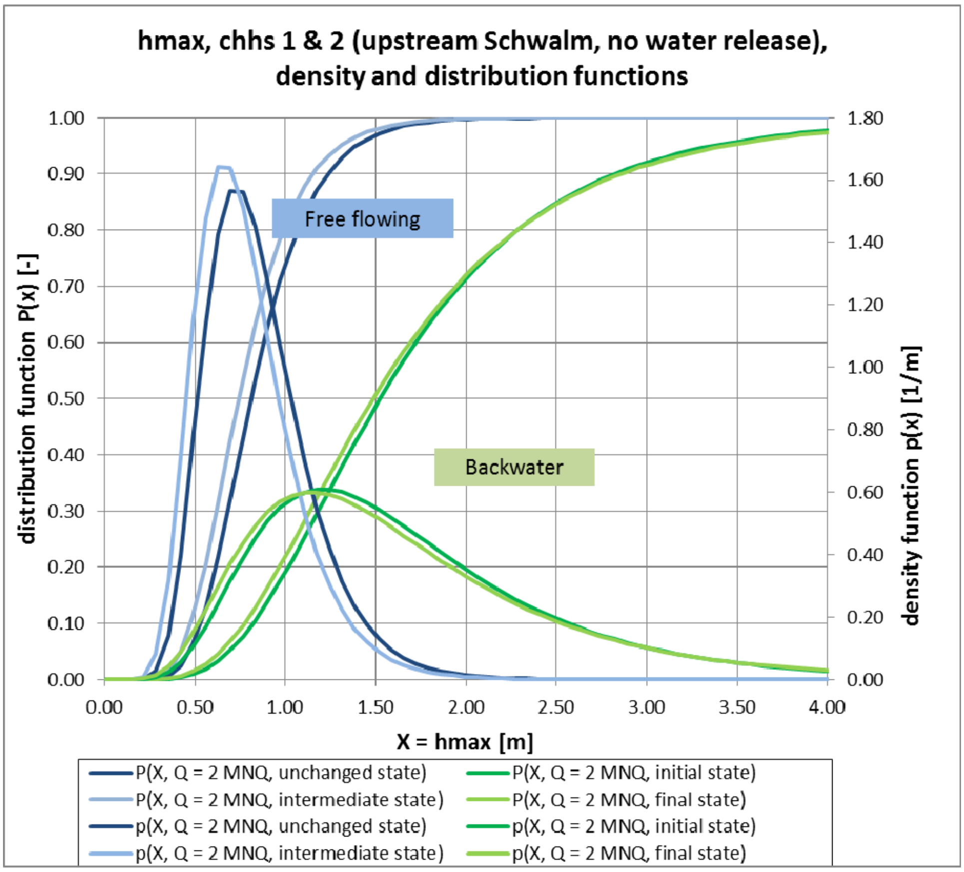


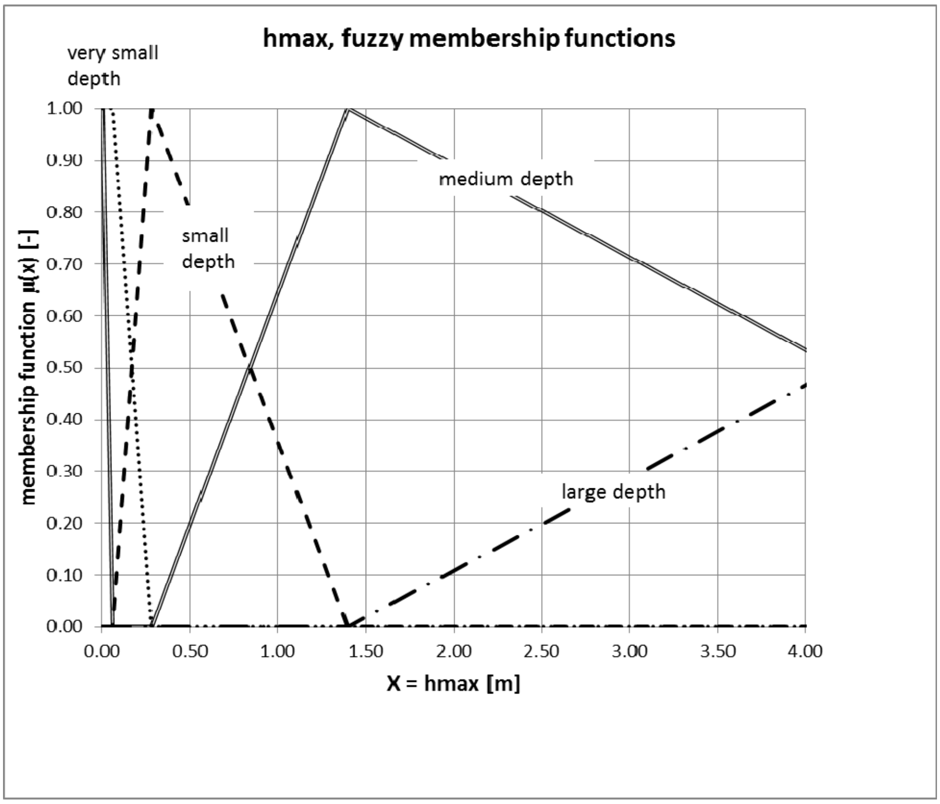
Figure 32: Effect of discharge variation on the probability density and distribution functions of 1D-evaluated hydromorphological parameters shown at the example of the maximum flow depth

To gain a set of illustrative numbers on that effect the probability functions are interpreted verbally by the use of triangle fuzzy-membership functions μ (Bothe 1995) with preliminary selected typical values for each considered class (Figure 33). The typical values for medium conditions are equivalent on the samples geometric mean at mean annual flow MQ. The relation of the typical values of adjacent membership functions, e.g. medium and small depth, is characterised by the preliminary set factor 5, e.g. typical medium depth = 1.4 m resulting in typical small depth = typical medium depth/5 = 1.4 m/5 = 0.28 m. Applying these membership functions μ on the probability density functions p of a parameter X calculates the share S of each investigated class C (Equation 24).

$$S_C \equiv \int_{\min X}^{\max X} p(X)\,\mu_C(X)\,dX \qquad \text{Equation 24}$$

With regard to the flow depth (X=h) shows approximately one half each for the class of medium and the class of small depths for the mean annual low flow MNQ as a representative low flow situation for the Lower Eder River (Figure 34). Reducing the discharge from mean annual low flow MNQ by 20 % to 0.8·MNQ increases the portion of small depths by about 5 % and decreases the share for the medium depth by the same amount. In comparison to this is the hydromorphological backwater effect more drastic since the flow depths at low flow are increased. Due to the backwater effect there is a reduction of small depths by more than two third of its free flowing share. So the backwater effect reduces lotic habitats by the same portion because at a constant discharge situation smaller flow depths mean larger flow velocity (Figure 35). Although this particular result on lotic habitats under backwater influence is not surprising it shows nevertheless that the effect of climate-change induced discharge alteration by decreased low flows is of less significance than the anthropogenic-altered structure due to the weir. Consultations with stakeholders of this project as well as by similar schemes show the awareness on these results since it is comparable to outcomes in similar restoration activities.

In summary the results of the 1D-evaluated investigation of a representative low flow situation for the Lower Eder River show that the streams anthropogenic-altered structure are at present as well as for future climate-change of major importance for the hydromorphological elements supporting biological quality elements. According to the WFD implementation strategy these presented results on climate-change altered low flow do not justify a necessity for the adaption of measures. Nevertheless adaption measures for the discharge operation of the Ederdam according to its aims of improving low flow situations in downstream navigation reaches of the Weser River are implemented since the year 2012 in a testing operation mode to consider increasing low flow variability.



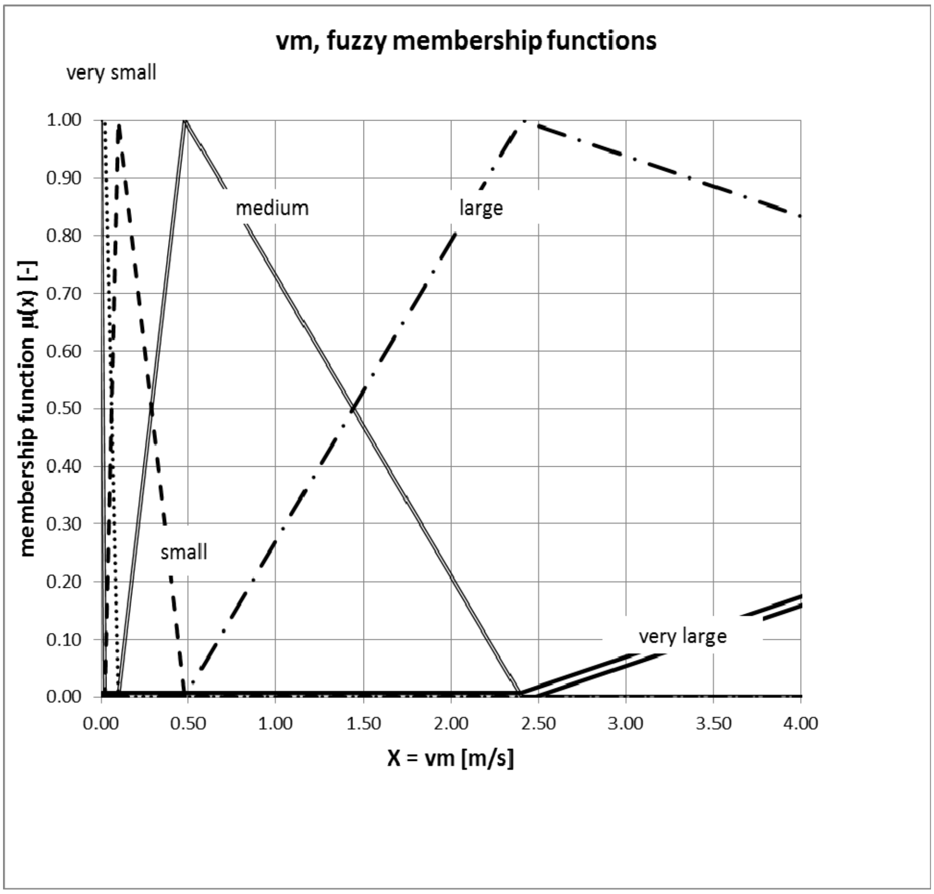


Figure 33: Membership functions for verbal interpretation of 1D-evaluated hydromorphological parameters shown at the example of the maximum flow depth (above) and velocity (below)

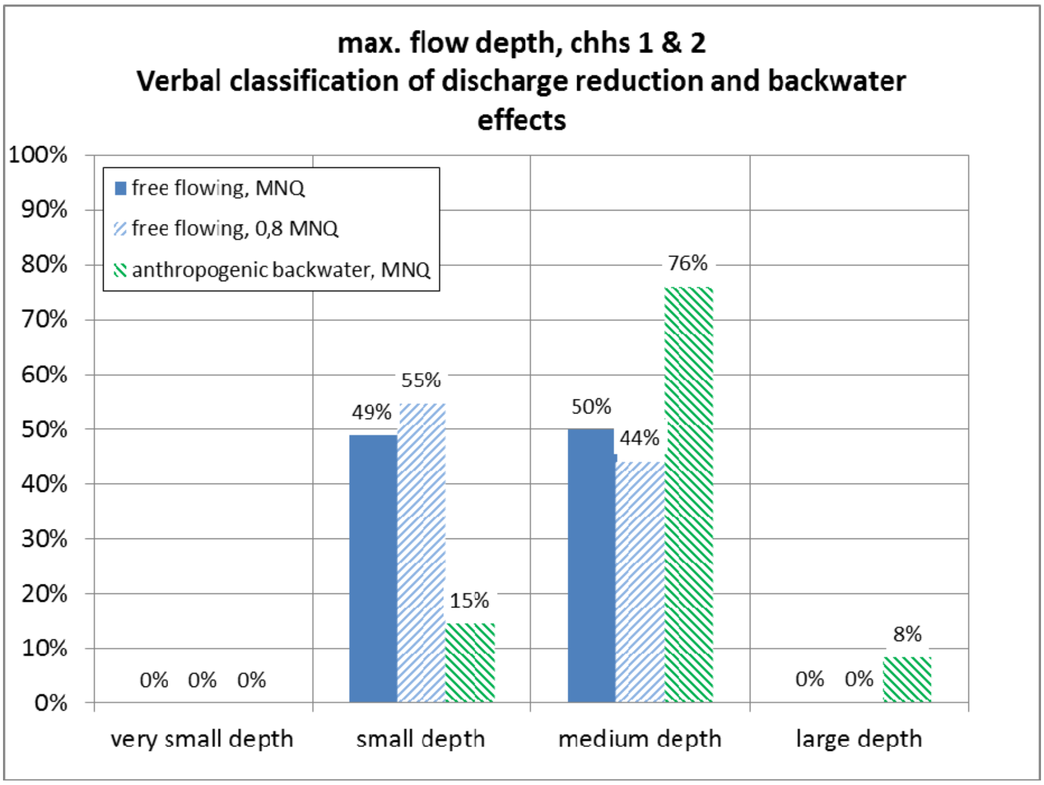


Figure 34: Comparison of climate-change induced discharge alteration and anthropogenic altered hydromorphological situation for verbal classified maximum flow depth

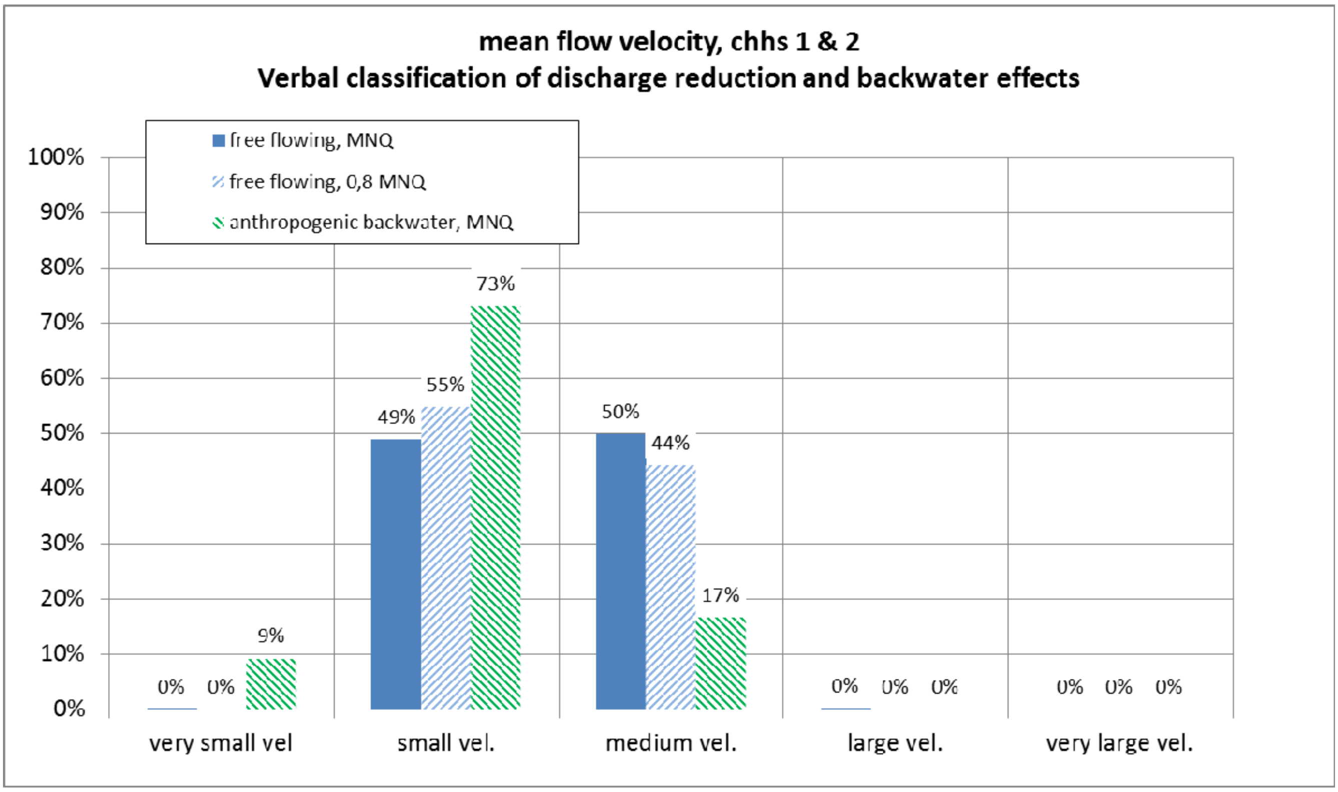


Figure 35: Comparison of climate-change induced discharge alteration and anthropogenic altered hydromorphological situation for verbal classified mean flow velocity

Effects of low flow reduction on the hydromorphology of the exemplary measure at the Lower Eder River (2D-evaluation)

The longitudinal section (Figure 36) concentrates on the discharges when the water starts to flow through the measure, depending on the state of the restoration. So for example the discharge of double mean annual low flow 2·MNQ = 12 m³/s flows only through the initial state of the measure. After beginning sedimentation even the mean annual flow MQ = 23.8 m³/s just trickles through the restoration measure and only a discharge of BQ = 50 m³/s flows through the restoration measure in its final state.

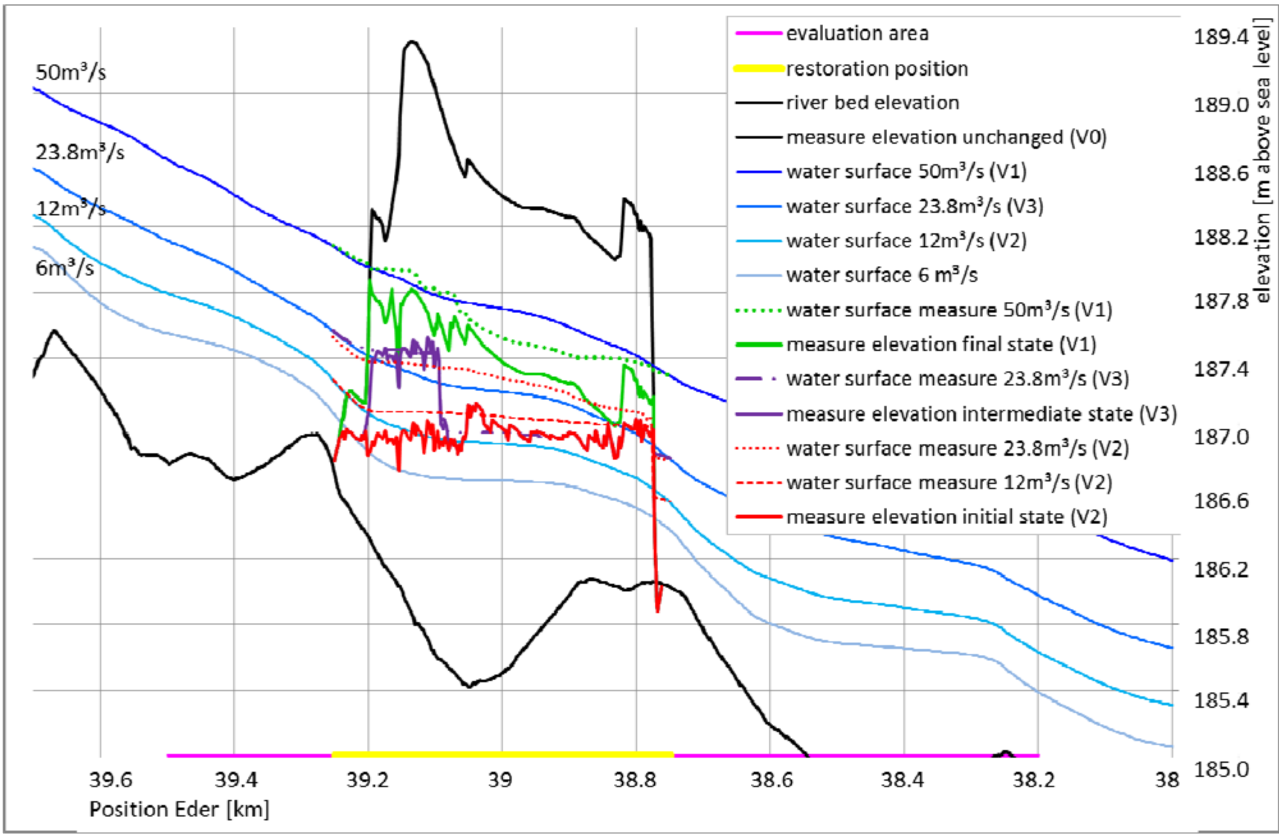


Figure 36: Longitudinal section with the different states of the restoration measure

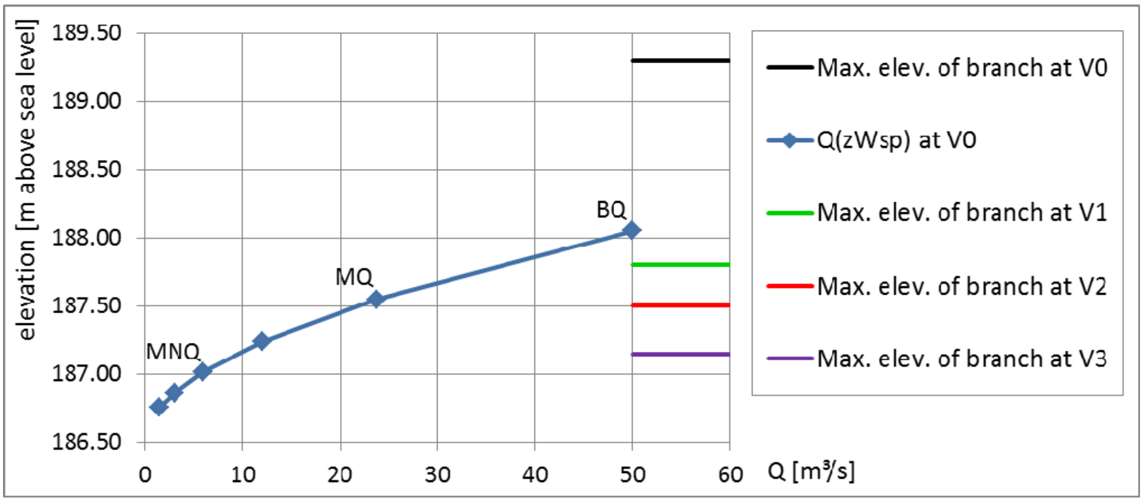


Figure 37: Rating curve of the inflow area of the measure (km 39.24)

Since the hydrodynamic numeric simulations for the case study are two-dimensional also the results in form of the different hydraulic parameters may be evaluated in a two-dimensional view. For the defined “evaluation area” (Figure 28) around the measure a two-dimensional evaluation has been carried out in this case study for the parameters water depth, flow velocity and shear stress. By doing this a sample size of 6000 up to 9000 elements for each parameter is reached, depending on the size of the wetted areas, respectively the discharge. The HN-model is based on a calculation mesh with equidistant nodes and the hydraulic parameters are calculated for each node of the mesh. So the complete information, the model offers for the “evaluation area” is included in this two-dimensional evaluation. This facilitates a statistical evaluation taking into consideration the aim to reach good hydromorphological conditions for at least 35 % of 100 % of the stretch of water based on strong data basis.

The variety of different water depths, velocities and bottom shear stresses in dependence of the discharge and the state of the restoration measures can be described by the distribution of these hydraulic parameters and by their statistical parameters.

Figure 38 shows the parameter “water depth” for all scenarios for a discharge of MNQ = 6 m³/s in comparison to a discharge of BQ = 50 m³/s. For lower flows (MNQ = 6 m³/s) only the initial state of the restoration measure influences the variety and the range of the water depths, but in the intermediate state, when there were first sedimentations in the measure inflow area, there is nearly no more difference in the distribution of the water depth in comparison to the state without the restoration measure. For nearly bankfull flows (BQ = 50 m³/s) it is viewable, that due to sedimentation the amount of low water levels also gets reduced in the course of time but there are significant effects of the measure also after a period of sedimentation.

The sample sizes for the different discharges and scenarios are different depending on the wetted area. To make it possible to compare all results, they were weighted with the wetted area of the hydrological/morphological situation of the initial-state at bankfull discharge BQ (Friedrich 2013). Accordingly it is shown an increase of wetted area due to the initial-state restoration measure by about +5 % for the mean annual low flow MNQ = 6 m³/s and +15 % for the bankfull discharge of BQ = 50 m³/s. The additionally created water depths are in the range of small depths less than approximately 0.5 m at MNQ (almost negligible) and less than 1 m at BQ. Also the expected morphodynamic self-adjustment of the side-channel keeps the wetted area from the initial to the assumed final morphological state unchanged for BQ. At discharges around the mean annual low flow MNQ = 6 m³/s all initially created wetted areas get lost in the final state due to morphodynamically self-adjusted aggradation while at bankfull discharge of BQ = 50 m³/s the wetted area stays unchanged.

The following figure shows the according distribution for the flow velocity. The results were also weighted with the wetted area of the hydrological/morphological situation of initial-state at BQ. The initial-state measure shows at BQ an increase of non-stagnant flow behaviour with non-zero flow velocity by about 15 % which is in accordance to the wetted area (Figure 38). At MNQ only a small percentage of non-stagnant flow area is added in the initial state, which gets lost within the morphodynamic self-adjustment.

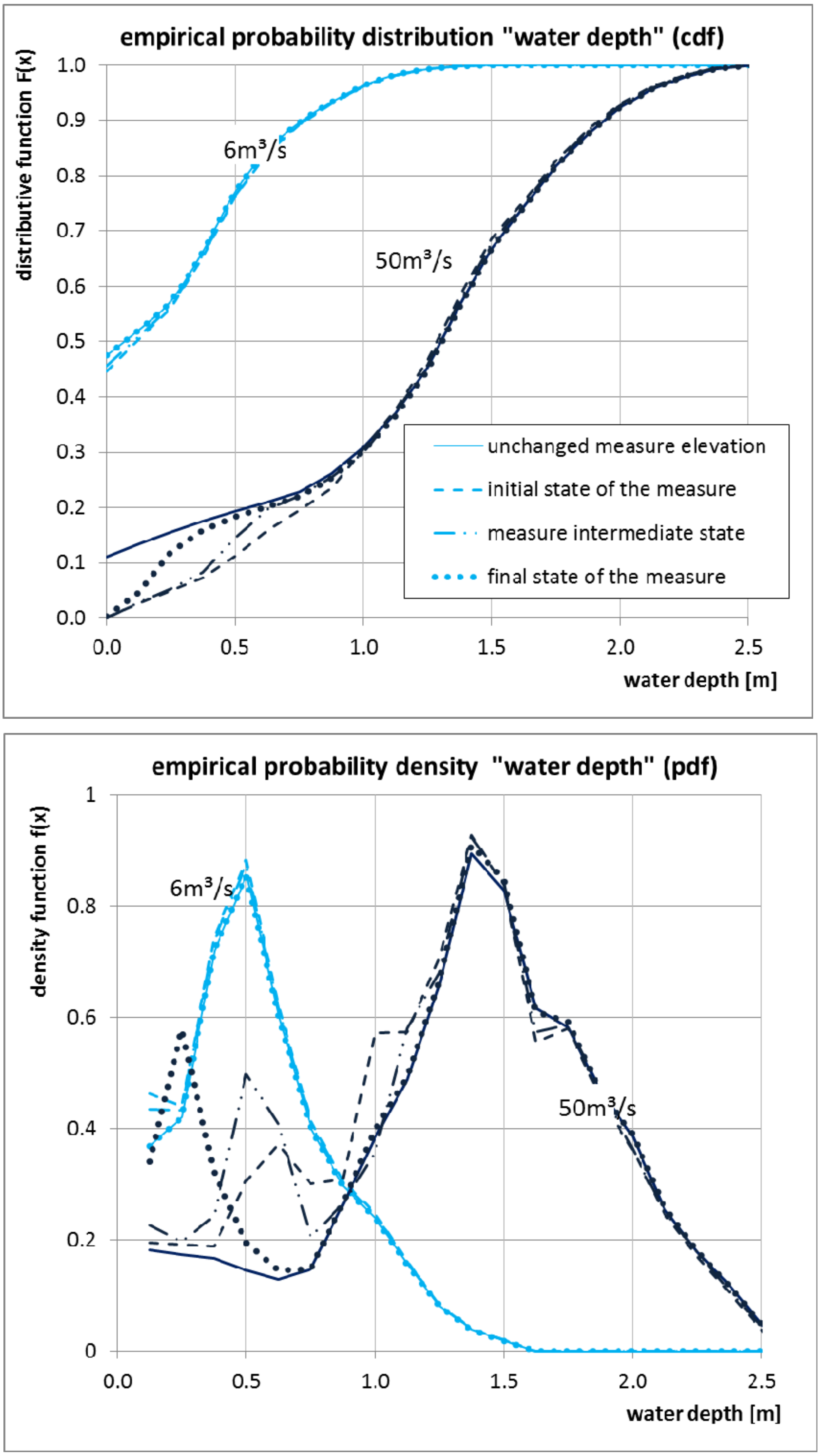
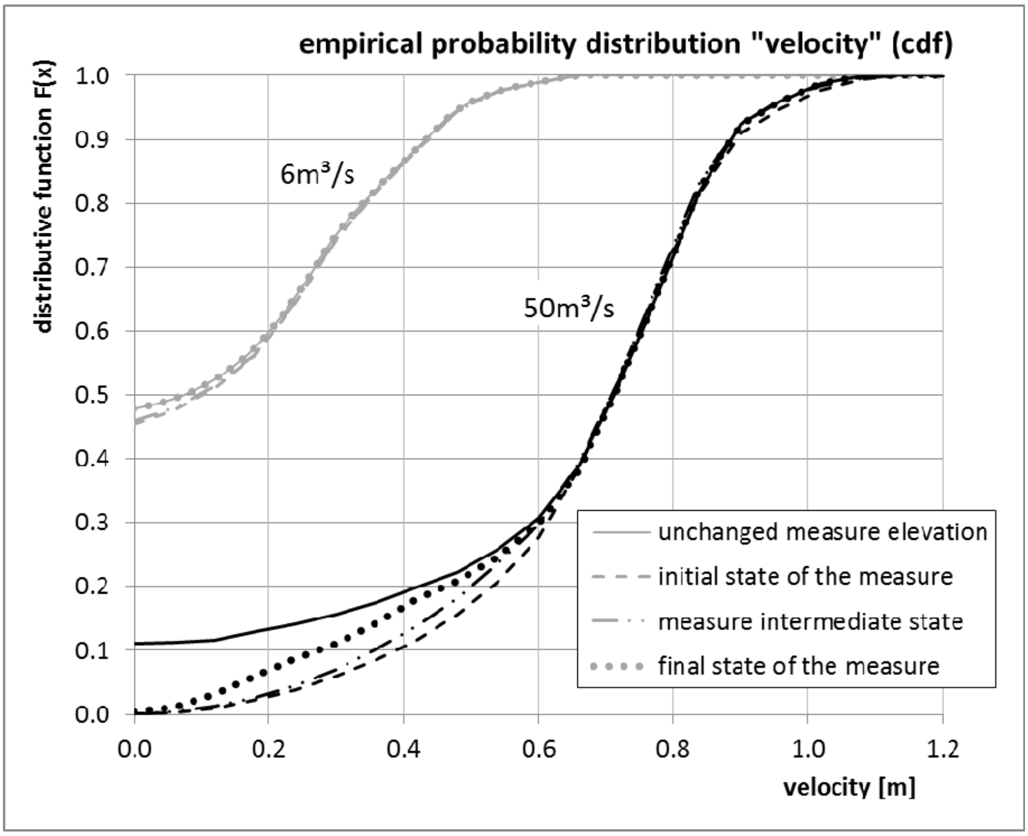


Figure 38: Empirical probability (above) and density (below) distribution “water depth” for all scenarios and the discharges of MNQ=6 m³/s and BQ=50 m³/s



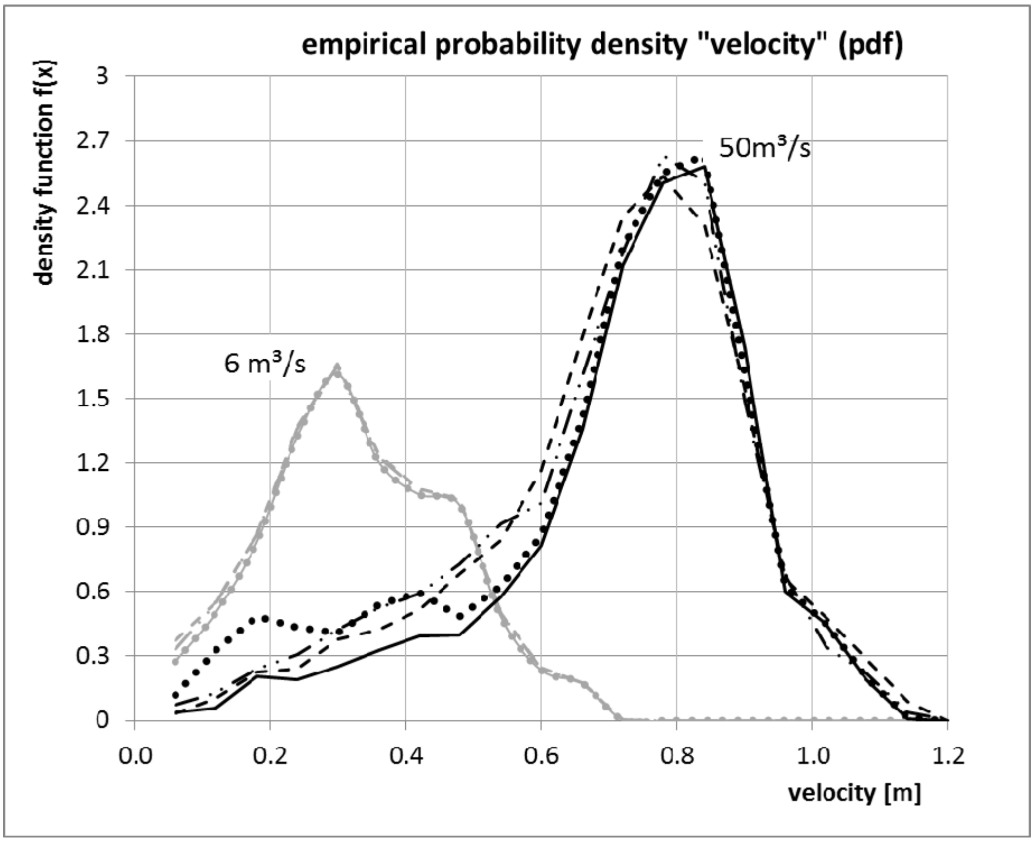


Figure 39: Empirical probability (above) and density (below) distribution “velocity” (Q=6 m³/s and Q=50 m³/s)

For the “evaluation area”, as well as for the evaluation based on cross profiles, the statistical parameters mean, standard deviation and coefficient of skewness were calculated. The resulting statistical distributions of the empirical data from the hydraulic modelling are compared again with the parameter-based distributional functions according to Gauß and ln-Gauß. In contrast to the 1D-evaluation based on cross sections the two-dimensional evaluations distributions fit better with the Gauß-distribution.

A comparison of the statistical parameters for the flow depth is shown in the following figure.

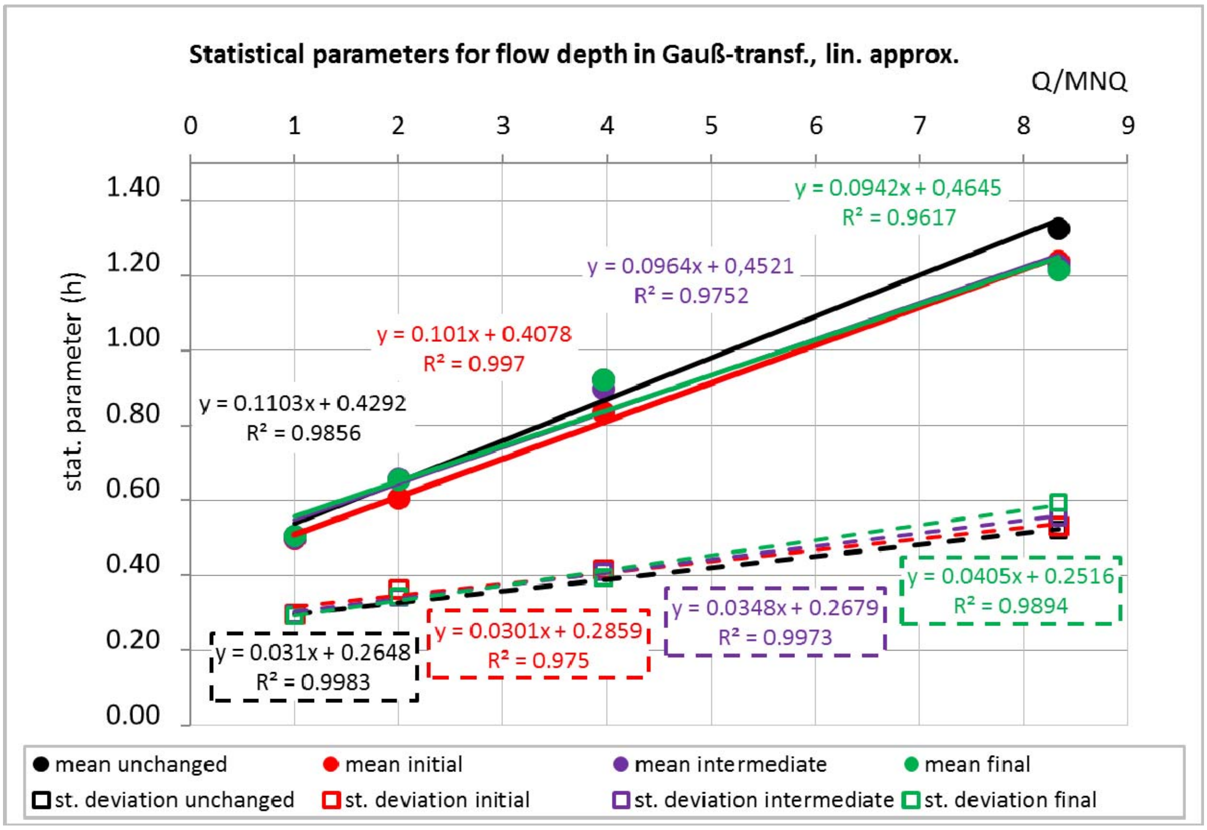


Figure 40: Statistical parameters for flow depth for the different scenarios

This site-specific study shows that the influence of the measure on the hydraulic parameters variety depends on the discharge and the morphodynamic state of the restoration measure. This can be explained by the level of the inflow area into the measure and depending on this by the amount of flow through the measure. Due to flow and morphological dynamics including the resulting sedimentation of the branch this type of restoration measure changes its shape in the course of time. The channel bed elevation in the measure rises and as expected the influence of the measure on the distribution of the aquatic hydraulic parameters in the water volume decreases. Due to climate change an extension of low flow periods is expected. During these periods the measures influence on aquatic volume decreases since the threshold for inflow increases and the measure is wetted less often. In addition the semi-aquatic area increases which gives room for the development of flood plain vegetation including flood plain forests. This type of vegetation is under the special attention of the Council Directive 92/43/EEC (on the conservation of natural habitats and of wild fauna and flora) summarized in the habitat type 91E0* (Annex I). For aquatic fauna like several age-structured fish species these semi-aquatic habitats may be very valuable during flooding since their area of low flow may give shelter against hydraulic stress due to stronger flow velocities in the river bed.

The results for flow depth and velocity due to the typical floodplain restoration measure show minor effects at low flows and considerable consequence at near bankfull flows. This is not surprisingly but may be observed in most cases of newly created floodplain channels in the region of Northern or Central Hesse e.g. the Upper Lahn restoration at Sterzhausen. Measures like these are very valid for mobile fauna needing shelter from strong flood flow situation (some fish species or special stages of life) as well as pioneer vegetation and floodplain woods demanding this kind of hydrological regime.

According to land use the longitudinal section Figure 36 and Figure 37 show that flooding is sensitive to the measure. For the final state of the measure a discharge of $Q = 50\ m^3/s$ causes the water level to rise locally at the inflow area of the measure. This applies just as much for the other states of the restoration measure (initial state, intermediate state) and is a result of the local enlargement of the total cross-sectional area at subcritical flow conditions and resulting in local reduction of flow velocity. An increase of roughness may support such an effect. This effect has to be kept into consideration when planning restoration measures. Although for the Northern Hessian region there is no reliable proof by measured data so far it is reasonable that an increase of flood events due to climate change may not be neglected for other regions. So the aspect of rising water table elevation may become even more relevant.

The investigated measure is based on the concept of self-adjusted morphodynamics. It is well known by stakeholders like water authorities or consultants in fluvial morphology that the self-adjustment and resulting processes of aggradation or degradation may not be avoided. Discussions with relevant stakeholders in this project as well as in similar ones show the awareness of these morphodynamic processes. So consequently a so-called final state is not everlasting but will be changed within fluvial development. In that context sustainability means the initial start of morphodynamics and continuous ensuring the conditions of an anthropogenic minor-limited morphological process. The influence of climate change on typical measures like the investigated floodplain channel establishment are negligible in the context of slightly changing low flow situations. An adaption of such measures founded on the principle of minor-limited morphodynamic self-adjustment may not be justified by the investigated results of this case study or other considered experiences. Under these conditions of morphodynamic self-adjustment the climate change is of low influence for the WFD implementation strategy for the investigated Lower Eder River.

Adaption of the non- or very-minor anthropogenic altered stream situation on climate-change

A widely assumed basic principle for the non- or very-minor anthropogenic altered stream situation (NASS) is the self-adjustment of streams and their surrounding environment towards a balancing between a morphodynamic equilibrium state and the repeatedly occurring random disturbance due to floods and other exogenic fluvial factors (e.g. storms with impact on riparian vegetation). Main elements are besides discharge, valley gradient and form, genuine sediments for bed and suspended load, stream gradient, channel planform and cross-sectional pattern also biological factors like riparian forests, woody debris or beaver activities. A change of NASS occurs if climate-change induced modification of fluvio-morphological factors emerges. Besides discharge there has to be given attention to the vegetation.

Today exists along the Lower Eder River in the region of Northern Hesse typical riparian and river-in vegetation like transitory grassy and herbaceous pioneer vegetation at banks or more persistent riparian softwood forests in floodplains. It seems very reasonable to expect under slightly warmer climatic situations changes in the vegetation species composition but not in its fluvial oriented effects. So for potamal streams it is relatively reliable to assume a shift in species composition despite of the sustainment of fluvio-morphological functions of the biological factors of flora as well as fauna.

For rhithral streams the situation is much more complicate. In natural streams of this kind there exist large woody debris jams (LWD) and beaver dams (BD) that cause drastic impact on stream morphology including severe damming effects (Figure 41). These are under certain conditions undeniably comparable to temporal small weirs. This kind of natural damming as a natural discontinuity may cover temporal scales of months to decades and spatial scales of multiples of the bed width. The effects may include the obvious temporal hindering or interruption of longitudinal connectivity for fish populations as well as sediment transport. Although beaver are known to be temperature sensitive it is also reliable to assume that LWD and BD still exist for the NASS under a moderate climate change as it is expected for the investigated region of Northern Hesse. Though and despite of this more complicate situation in rhithral streams it is not expected to see significant shifts of the aspects of morphology or river continuity of the NASS due to climate change.

Figure 41: Rhithral discontinuities in German streams due to beaver dams or large wood jamming (photos by K. Träbing)

The discharge flood regime as one of the most decisive morphodynamic factors was investigated in its influence by climate-change within the last to steps of this case study for the total reach of the Lower Eder River as well as a representative reach including a typical restoration measure. It is shown that the effects of climate change via discharge modification on representative hydraulic parameters of the Lower Eder River do exist but are negligible in their effect on the achievement of the WFD aims.

Along the Lower Eder River as well as numerous other streams in the investigated region of Northern Hesse two main kinds of hydromorphological effective restoration measures may be distinct. The distinction is caused by the use of the stream which is commonly a restriction for morphodynamic self-adjustment. The reaches with hydromorphological deficits underlie different intensities of restrictions.

As already mentioned measures are oriented on the NASS and ideally should give space to the streams morphodynamic self-adjustment under a non- or minor-limited situation. Consultations of stakeholders active in similar projects at all levels of water resources management mainly show the consensus on that concept under ideal conditions although in real implementation processes the restrictions may be judged differently sometimes. Hydromorphologicaly effective measures which fulfil this ideal minor-limited morphodynamic self-adjustment will not have to be checked according to climate change effects on NASS since adaption of the measure on climate change is an inherent element of these measures. A good example is the investigated typical exemplary measure at the Lower Eder River. Measures which do not fulfil the condition of minor-limited morphodynamic self-adjustment are based on stable framework condition. For this kind of measure climate-induced changes may give reason for adaption.

Major restrictions for limited morphodynamic self-adjustment may be non-removable weirs with corresponding backwater effects or reaches inside of intensely used urban areas. Such reaches may not be developed into a less anthropogenic altered situation by initialized morphodynamic self-adjustment if the risk due to non-regulated change is to detrimental in terms of basic impossibilities or ecological efficiency of possible measures. In these reaches restoration measures need to be morphodynamicly stable and will be further on called “morphostatic”. The morphostatic measures should consider climate change or should be constructed in an anthropogenic adjustable design. Excellent examples are measures to ensure river continuity in terms of undisturbed migration of fish populations. If migration barriers may not become removed (e.g. to minimize groundwater table decrease or channel incision) it is necessary to install fish passage facilities like fish ladders. These have to consider slightly decreasing water surface elevations at low flow situations for their correct functioning since the anthropogenic non-altered potamal streams are assumed to be longitudinally full connected. In rhithral streams fish passage facilities should to be installed and operated to function equivalently to the NASS. This may be a problem in practice, e.g. for the design of fish passage facilities, unless natural hydromorphological discontinuities as described above are considered correctly. Climate-change induced discharge modification by reduced low flow may shift local biocoenosises towards more low-flow-tolerant characteristics. Under these conditions it would be reasonable to check instream flow requirements also for a careful lowering of instream flows.

Results of the case study with regard to WFD

The transfer of the results of the case study on hydromorphology at the Lower Eder River to other reaches, streams or regions is limited by the basic assumptions as follows:

- Similar expected changes of low or flood flow regime without influence on the sediment yield of the watershed give reason to assume similar fluvial processes as described for the Lower Eder River and therefore results may transferable to such streams.
- Similar restrictions for limited morphodynamic self-adjustment. This means under conditions of intensely used streams or floodplains the assumed non- or minor-limited morphodynamic self-adjustment may cause damage to human health, the environment, cultural heritage and economic activity and has to investigate separately.
- According to measures like the investigated newly established floodplain channel the results are transferable to other situations concerning the last two aspects. A separate investigation should be performed if a major rise of the discharge passing the floodplain channel compared to the main channel is to be expected because this may mean a

significant abrupt shift of the main channel into the floodplain with possible sudden and severe consequences to human use of the floodplain e.g. infrastructure installation.

- The effect of stream size according the difference between potamal and rhithral characteristics of river continuity (large woody jams, beaver dams) and the increasing effects of large woody debris (LWD) causing drifting wood with an increased risk of flooding. It has to be emphasized that hydromorphological effective stream restoration measures using LWD are one of the most efficient strategies as far as flood risks for downstream reaches are not ignored. Otherwise failures of this strategy may cause lost of public confidence not only for this special kind of measure but will also harm to the acceptance of the total WFD implementation process.
- The consultations of stakeholders active at all levels of water resources management in this or similar projects mainly show the consensus on the basic concepts and outcomes of this project under ideal conditions. Nevertheless it has to be emphasized that in real implementation processes the restrictions e.g. on land use adaptions may be judged different.

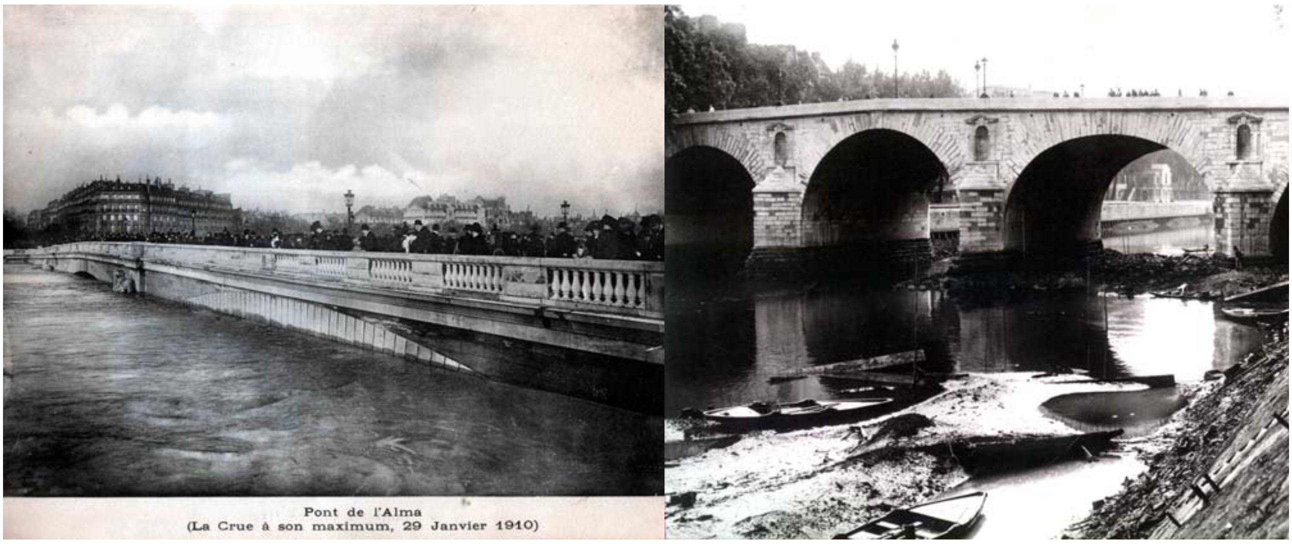
The connection between the river bed and the groundwater bodies under consideration of the NASS is rarely effected by climate change since the major exchange processes are dominated by hydrologically dominated hydraulic parameters like the gradients between the water table of the stream and its surrounding groundwater body. Effects of clogging (colmation) of the stream bed may be expanded due to extended low flow periods and may be influenced by washload or suspended load of fines originated in the watershed e.g. from wastewater inflows or eroded farmland soil. Washing out clogging material (decolmation) is caused by turbulence and/or sediment movement during floods. Morphological effective measures for stream restoration usually do not deteriorate the connectivity between stream and groundwater body unless they constantly deliver fines downstream direction. The connectivity of groundwater and surface water may be improved by additional morphodynamics as supported by self-adjustable measures. Therefore this kind of restoration is a very good possibility not only for the improvement of the ecological status of the streams and floodplains but also for the hyporheic biocoenosis.

The hydrological regime and its impact due to climate-change may change significantly downstream from dams in case of substantial modifications of low flow or flooding regime. For the region of Northern Hesse exits no reliable justification for climate-change induced flooding regime modifications although the range of uncertainties remains relatively large. Therefore measures and strategies of the WFD implementation should consider these lacks in knowledge in the case of possible options by selecting the choices with the least flood sensitivity. The testing operation mode of the Ederdam to prevent negative impact on navigation on the downstream reaches of the Weser River due to low flow variability does not affect these measures. In this case study’s region of investigation of the Lower Eder River in the Weser basin the human impact caused by stream training, weir-induced backwater situations and flood plain use is expected to remain more severe than the expected effects of discharge modifications induced by climate change. The measures concerning the aims of the WFD (Annex V, Table 1.2) are generally oriented on anthropogenic-non-altered streams (European Parliament of the Council, 2000). So these kinds of measures, which are supporting morphodynamic fluvial processes, remain the best choice for stream restoration. Though the finally developing stream morphology may change due to climate change these morphodynamic self-adjustable measures are not expected to need adaption. In terms of climate-change challenges as well as uncertainties on the non - or very-minor anthropogenic altered stream situation this kind of measure is the best choice for an effective WFD implementation strategy. Hydromorphological improvements support the improvement of the biological quality elements very well. Morphostatic measures like the installation and operation of fish passage facilities need to be adaptable for climate-change induced low-flow aggravation which is usually easy to achieve during design and construction as well as in most cases also in an already operating installation.

2.2.2 CS 2 – DAM MANAGEMENT, FRANCE

Introduction

Paris and its region totalled 11.79 million inhabitants in 2010 and 29 % of French GDP. It is crossed by the River Seine whose basin concerns 30 % of French population. Thus, there are critical socio-economic issues in this basin where major events already happened in the past as illustrated in Figure 42.



(a) **(b)**

Figure 42: The River Seine at Paris during historical extreme events. (a) : View of the Alma bridge during the flood in January 1910, (b) View of the Marie bridge during the drought of 1943

The first objective of the case study is to provide the managers of the River Seine basin reservoirs with an analysis framework to evaluate the possible consequences of climate change on the basin hydrological behaviour. The second objective is to assess possible adaptation strategies they could consider in the future. Focus is laid on the River Seine basin upstream Paris (43,800 km2), with 25 gauging stations spread over the main stream and its tributaries (Figure 43).

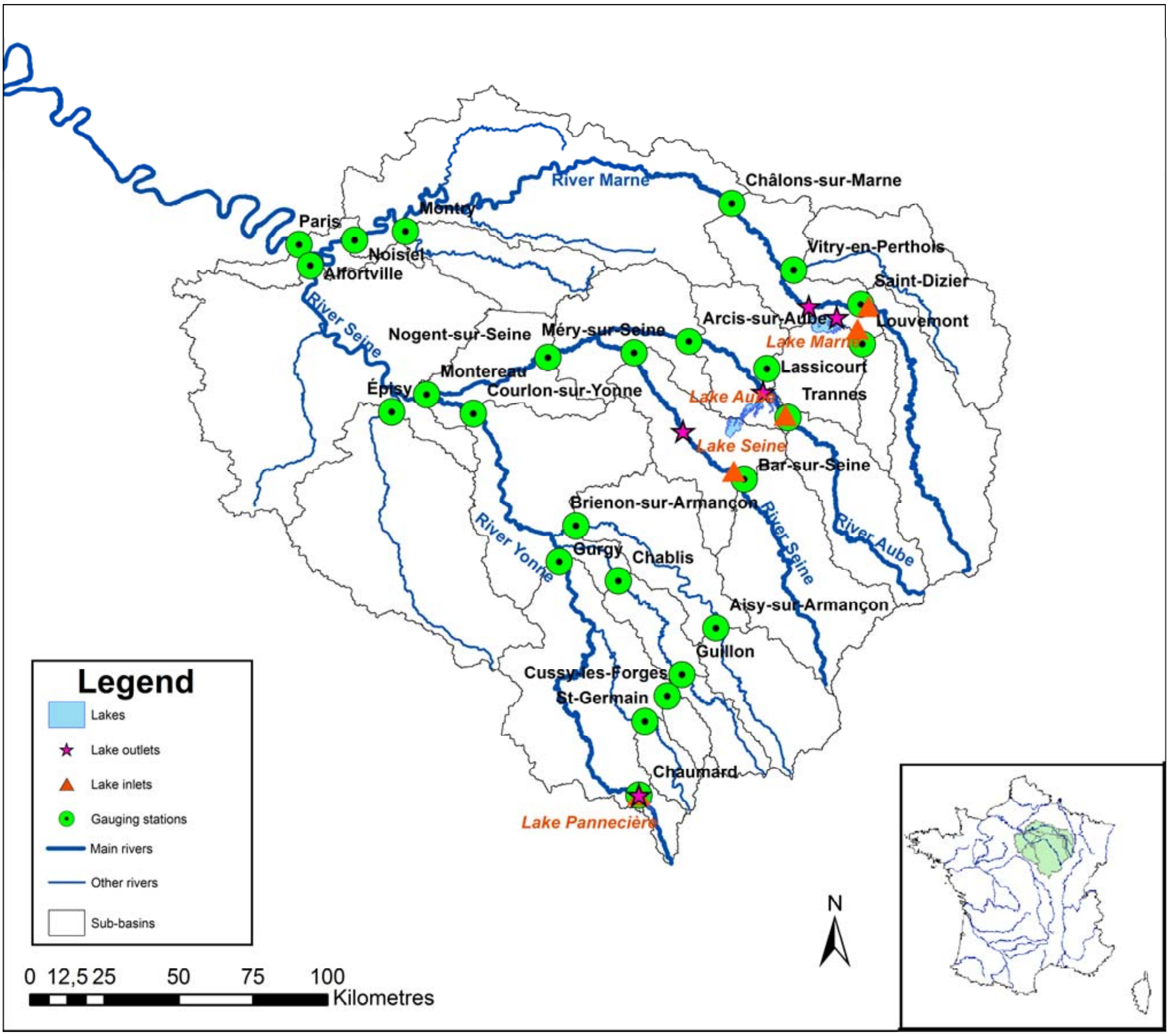


Figure 43: Contour map of the River Seine basin at Paris, with gauging stations, main hydrographic network and reservoirs

The main rivers of the basin are regulated by four large artificial reservoirs managed by public territorial basin authority (EPTB) Seine Grands Lacs (SGL) on the Rivers Marne, Aube, Seine and Yonne (Figure 44), totalling a water storage capacity of 805 hm3. On the River Yonne, the dam is a run-of-the-river type, while the three others bypass the rivers with inlet and outlet connections. The four reservoirs were built between the 1950s and 1980s and all the infrastructures were designed according to the known historical flood events and low-flow periods on the catchment. The reservoirs control 17 % of the basin area at Paris.

Figure 44: Aerial view of the Pannecière lake and dam on the River Yonne (Credits: Office de tourisme de France)

Extreme hydrological events can have strong impacts on the sustainability of the system in terms of water resources (low flows) or risk (floods) and therefore are critical to study. The aim of the case study is to develop future scenarios linking the impact of climate change on water resources and the expected changes regarding the water uses and the management of the system.

The key aspects of this case study are:

- to develop an integrated model of the basin, including the artificial influences of dams;
- to define climatic as well as socio-economic changes over the basin by the mid-21st century;
- to evaluate the sustainability of current reservoir management rules (use of target reservoir filling curves and local reservoir constraints);
- to define adaptation strategies at tactical (adaptation of target reservoir filling curves) and operational (real-time reservoir management) levels.

A special attention was put on evaluating the uncertainties linked to the different steps of the modelling chain.

Data

Flow and climate data in current conditions

Twenty-five gauging stations spread over the main stream and its tributaries (see Figure 43) were used. Daily observed flow time series were collected from the national HYDRO database (www.hydro.eaufrance.fr). Naturalized flow data were provided by Seine Grands Lacs (Hydratec, 2011). Naturalized flow data provide an estimate of natural flows, i.e. flows that would have been observed if none of the four main reservoirs had been built.

Observed meteorological data (precipitation and temperature) were obtained from the Météo-France SAFRAN re-analysis (Vidal et al., 2010). SAFRAN provides daily grid data at an 8×8-km resolution that were lumped over the catchments. The potential evapotranspiration was obtained using the Penman-Monteith formula (Penman, 1948).

Historical management data of the reservoirs (i.e. inflow and outflow values) provided by SGL were used and withdrawals data on the river from BIPE (Bureau d'Informations et de Prévision Economique; Office of information and economic forecast) studies were obtained.

Scenario and climate models

Here a classical approach to derive hydrological projections based on climate scenarios was adopted. The A1B greenhouse gas (GHG) emission scenario built by the Intergovernmental Panel on Climate Change (IPCC, 2007) was chosen. It is considered as a medium scenario, which means that it is not among the most optimistic ones either among the most pessimistic ones. Seven GCMs outputs were used: CCCMA-CGCM, ECHAM5-MPI, GFDL-CM2.0, GFDL-CM2.1, MRI-CGCM2.3.2, GISS-MODEL-ER and ARPV3. They provide daily precipitation, temperature and potential evapotranspiration scenarios for the 08/01/1961–07/31/1991 period chosen as a reference for current conditions (hereafter called present period and noted PST) and the 08/01/2046–07/31/2065 target period for future conditions (hereafter called future period and noted FUT). Since the spatial resolution of GCMs is too coarse to be used over the study basin, data downscaled at an 8×8-km resolution using a weather-type statistical method (the DSCLIM algorithm, Boé et al., 2006; Boé et al., 2007) were used.

Concerning the withdrawals evolution in the basin, the two trend scenarios elaborated for all the catchments in France within the Explore 2070 project (Chauveau et al., 2013) by BIPE was used:

- a “Concentration” scenario based on the assumption that the human housing will become more and more concentrated as the population increases,
- a “Spread” scenario which assumes the housing will become more and more spread out in the future.

These two scenarios are not intended as a forecast of a future pressure on the resource but they provide a range of uncertainty around a mean scenario used in this project.

Methodology, Modelling Approach

In order to evaluate the possible impact of climate change on the River Seine basin, a modelling suite to produce daily streamflow simulations for naturalized and influenced conditions was used (see Figure 45).

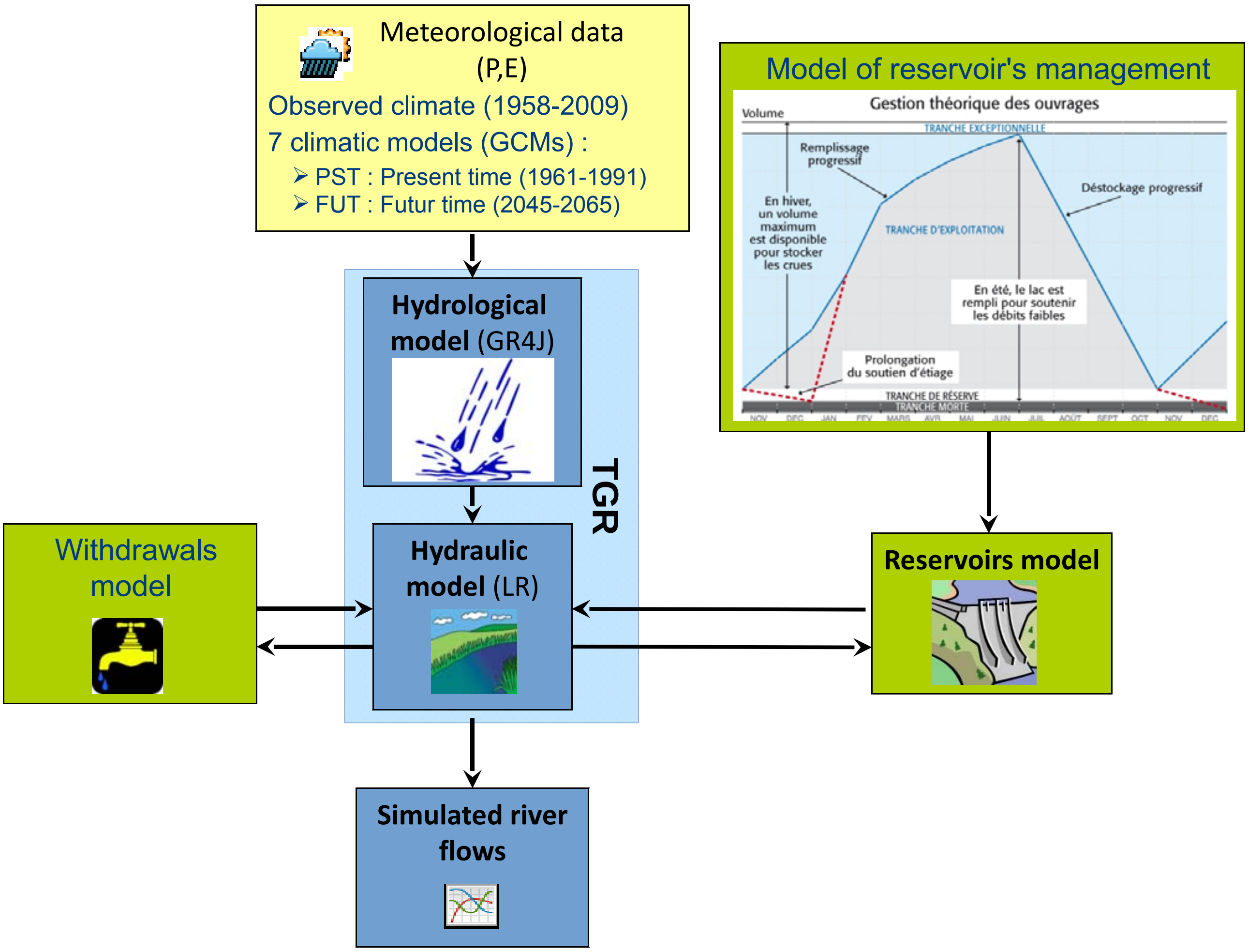


Figure 45: The modelling suite used to produce daily streamflow simulations for naturalized (without green boxes) and influenced conditions (with green boxes)

Two conceptual rainfall-runoff models were used:

- the lumped and conceptual GR4J model;
- the semi-distributed TGR model which is composed of GR4J models for each sub-catchment and uses a linear lag and route (LR) method to propagate the flow between the sub-catchments (Figure 46).

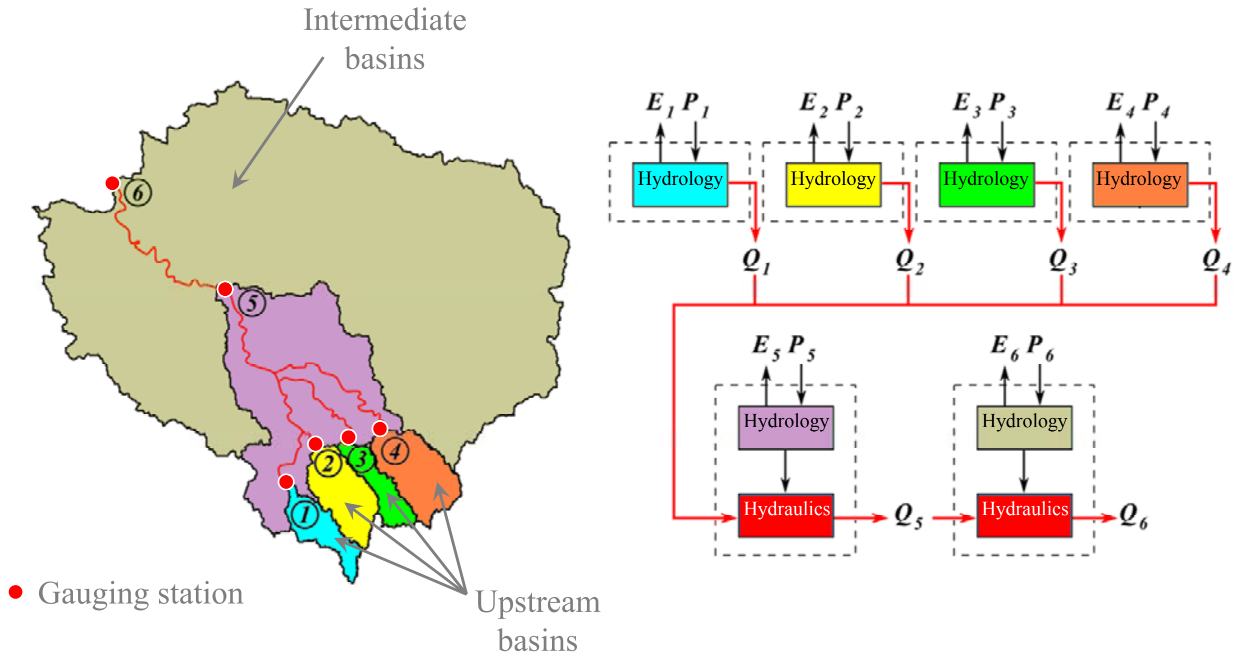


Figure 46: Schematic representation of the TGR model implementation for six gauging stations, coupling hydrological modelling of the upstream and intermediary basins and hydraulic routing (adapted from Munier, 2009)

The methodology for assessing the impact of climate change involves several steps:

- First, the hydrological and hydraulic models were calibrated with naturalized flows on the period 1958-2009 using the SAFRAN observed meteorological data.
- Because downscaled GCM scenarios showed quite significant biases compared to observations over the present period, a quantile-quantile mapping method to precipitation, potential evapotranspiration and temperatures variables on a monthly basis was applied. The aim of this method is to fit the distributions of climate variables to the distributions of observations over PST and to apply the same transformation to GCM variables over FUT.
- The model was then forced with downscaled GCM variables in PST and FUT to quantify the possible hydrological trends on the River Seine basin.
- A model simulating the current management rules of the reservoirs and a model of the withdrawals on the river were developed.
- Flows simulations were done under influenced conditions and the performance of the reservoirs management was assessed for PST and FUT using performance indicators related to flow objectives defined downstream the reservoirs by the stakeholders.

Scenarios of adaptation

To introduce the reservoir's management adaptation, three management levels should be distinguished:

- Strategic level: it relates to infrastructure design. An adaptation example would be to build a new reservoir.

- Tactical level: it addresses the general management objectives and characteristics of the reservoirs. The reservoirs serve for low-flow augmentation and flood alleviation following pre-established filling curves designed from an analysis of historical low-flow and floods. The current tactical management is decentralized, i. e each reservoir is managed independently from the others.
- Operational level: it addresses the day-to-day operations. The reservoir manager is allowed to depart from the theoretical filling curves to adapt to specific hydrological events. For example, in flood conditions, if flow values observed in the river exceed a given threshold, the amount in excess over this threshold is diverted to the reservoir.

The adaptation at the strategic level was not considered in the project because the investigation of new infrastructures was beyond the scope of this project. Thus, two perspectives for improving and adapting the management and make it more robust to climate change are proposed:

- at the tactical level, to design new objective filling curves of the reservoirs considering the climate change.
- at the operational level, to implement a centralized real-time controller for the four reservoirs by using a model predictive control driven with mid-term meteorological forecasts (9-day lead time).

The two perspectives will be tested separately and simultaneously to determine their respective levels of efficiency in a climate change adaptation perspective. They both have the particularity to explicitly take into account the downstream objectives described below.

Objectives and performance indicators used for benchmarking the quality of the management

To evaluate the impact and efficiency of reservoir management, flows are monitored at several gauging stations downstream from the four reservoirs. At each gauging station, several thresholds were defined.

In low-flow conditions, they are regulatory thresholds used to restrict water uses:

- Vigilance threshold: there is no restriction of water use but the river is highly sensitive to pollution events;
- Alert threshold: 30 % restriction of water use;
- Reinforced alert threshold: 50 % restriction of water use;
- Crisis threshold: the use of water is prohibited except a minimum use for drinking water.

In high-flow conditions, the selected thresholds correspond approximately to three critical levels defined by the following colours:

- Yellow: Risk of flooding or rapidly rising waters not causing significant damage, but requiring special vigilance in the case of seasonal and/or exposed activities.
- Orange: Risk of flood generating large spills that could have a significant impact on community life and the safety of property and people.
- Red: Risk of major flood. Direct threat and widespread safety of persons and property.

The monitoring stations and their thresholds are detailed in Table 1. All thresholds were chosen in agreement with the operational services responsible for low-flow and flood management on the basin.

Table 1: Monitoring stations downstream from the reservoirs, influence of the reservoirs (A=Aube, M=Marne, P=Pannecière, S=Seine) and low-flow and high-flow thresholds

Monitoring stations				**Low-flow thresholds (m^3/s)**				**High-flow thresholds (m^3/s)**		
	Gauging station	**River**	**Influenced by Reservoirs...**	**Vigilance**	**Alert**	**Reinforced alert**	**Crisis**	**Yellow**	**Orange**	**Red**
24	Arcis-sur-Aube	Aube	A	6.3	5.0	4.0	3.5	110	260	400
22	Méry-sur-Seine	Seine	S	7.3	5.0	4.0	3.5	140	170	400
13	Nogent-sur-Seine	Seine	A+S	25.0	20.0	17.0	16.0	180	280	420
02	Gurgy	Yonne	P	14.0	12.5	11.0	9.2	220	340	400
23	Courlon-sur-Yonne	Yonne	P	23.0	16.0	13.0	11.0	550	700	900
16	Alfortville	Seine	A+S+P	64.0	48.0	41.0	36.0	850	1 200	1 400
21	Châlons-sur-Marne	Marne	M	12.0	11.0	9.0	8.0	330	520	700
17	Noisiel	Marne	M	32.0	23.0	20.0	17.0	350	500	650
05	Paris	Seine	A+S+P+M	81.0	60.0	51.0	45.0	950	1 600	2 000

Reservoir management intends to maintain downstream flows within the limits defined by the thresholds, i.e. above the low-flow chosen threshold and below the chosen high-flow threshold. Hence the efficiency of the reservoir management can be evaluated based on two sets of conditions at the target downstream station: the set of satisfactory cases, noted S, when flow at the station remains within the limits defined by the chosen thresholds, and the set of failures, noted F, when flow is outside these limits.

The failure rate can be defined as the complementary of reliability. Reliability is the probability for flow Q_i at time i to be in the satisfactory state S (Hashimoto et al., 1982). Hence, the failure rate *fr* is defined as:

$$fr = 1 - \text{Prob}\left[Q_i \in S\right] \quad \text{Equation 25}$$

A failure event is defined by the consecutive days when Q_i is in the failure state. The frequency of a failure event is equal to:

$$freq = \frac{365{,}25j}{n} \qquad \text{Equation 26}$$

Where *freq* is the frequency in years^{-1}, *n* is the number of days of the study period and *j* the number of failure events during the period.

The average length of a failure period was also used defined by:

$$d_{mean} = \frac{1}{j}\sum_{t=1}^{j} d(t) \qquad \text{Equation 27}$$

Where *d(t)* is the duration of the t^{th} failure period.

Last, the vulnerability indicators defined by Kjeldsen and Rosbjerg (2004) was used. In case the reservoir management fails to maintain downstream flow under a high-flow threshold (respectively, above a low-flow threshold), vulnerability is defined as the volume that should have been taken (respectively, released) by the reservoirs to avoid this situation during the event considered. This can be calculated for each failure event. Here two statistical indicators calculated from the set of the vulnerability values computed for all the events were used: the mean value, and the value of the 90th percentile of the distribution of vulnerabilities.

Adaptation of tactical management: design of new objective filling curves

The search for tactical management adaptation strategies was based on the method developed on the Manantali dam (Bader, 1992). This method provides optimal filling curves for one objective downstream one lake. A flow to subtract or to add to the naturalized flow to permanently reach the objective at a downstream station was calculated. The generated time series corresponds to the total flow to store in the upstream reservoirs and is further divided between the reservoirs by taking into account the propagation times. After some verification, the flow to store is used in a reverse chronological calculation for getting an optimal control of the reservoirs along the study period (a dynamic programming approach is used to achieve this objective). At this step, some impossibility to reach the flow to store can be observed due to the limited reservoir capacity. Finally, the time series of optimal volumes is statistically analysed for defining annual series of volume for different chance probability to achieve the objective. These series of volume are called iso-frequency curves. In the example given in Figure 47, the different curves on the graph give the probability to be able to face on a 180 m^3/s flood alleviation objective at the gauging station of Nogent-sur-Seine in the future. If the current volume of the reservoir is between the 80 % and 90 % curves, it means that there is a 10 to 20 % probability that the reservoir will be full in the future and the downstream objective will not be reached.

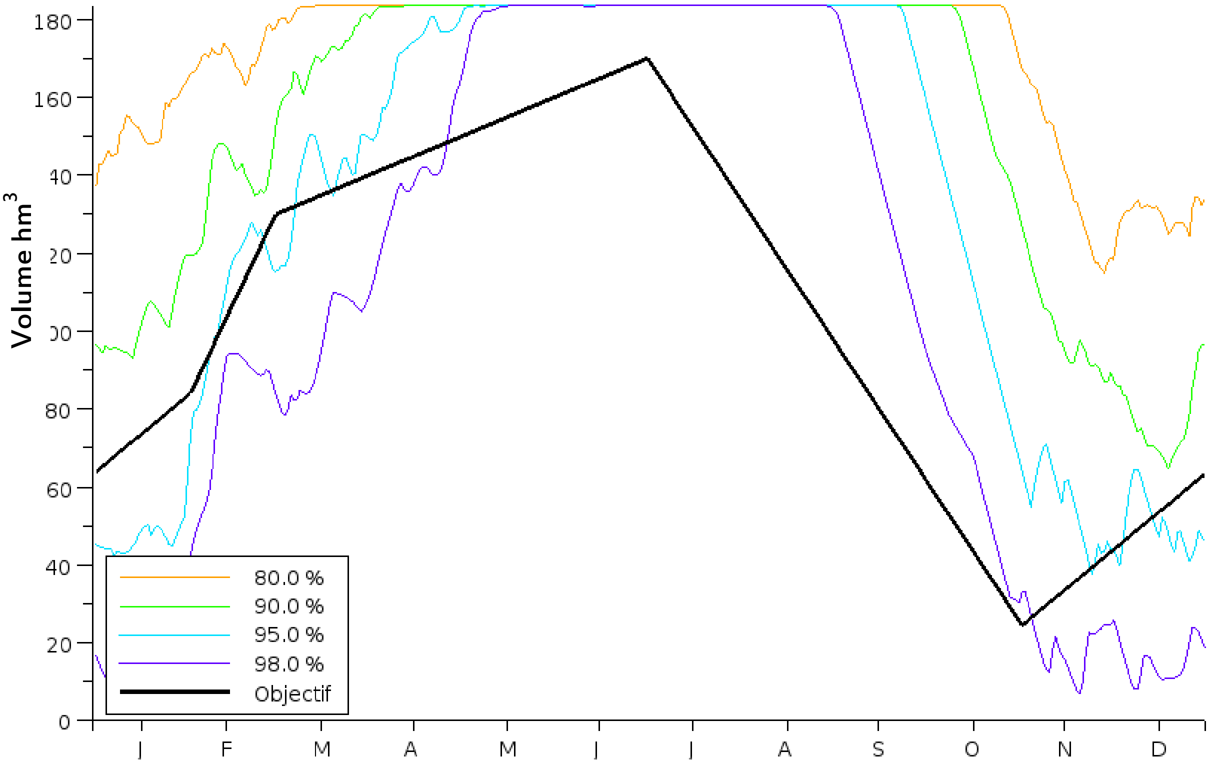


Figure 47: Annual iso-frequency curves for a maximum volume on the lake Aube for a flood objective of 180 m3/s (Yellow threshold) at Nogent-sur-Seine station (coloured curves) and current objective curve (black). Calculation done on the period 1900-2009.

This method can be classified among the Dynamic Programming algorithms which are very powerful for defining the optimal management on a known time series for one or few objectives. However, this method is not adapted to consider a large number of objectives especially when they are contradictory (like in the case of low-flow and flood management).

Instead of solving multiple objectives at the same time with the method used, it was chosen to combine a large set of iso-frequency mono-objective curves to define a multi-objective curve on each lake. As shown in Figure 48, the current objective filling curve (in black) crosses some mono-objective curves at different periods of the year. For maximizing the chance to achieve the objective, the design of this filling curve should minimize the areas where the mono-objective curves are above the current objective filling curve. The idea developed here is to minimize these areas for all the objectives (which can be contradictory) at all the considered downstream stations. For a given multi-objective filling curve, a weighted sum of these areas is calculated. The multi-objective filling curve is the result of an optimization minimizing the weighted sum of the areas. Then this curve is smoothed in order to get only one filling and releasing period during the year.

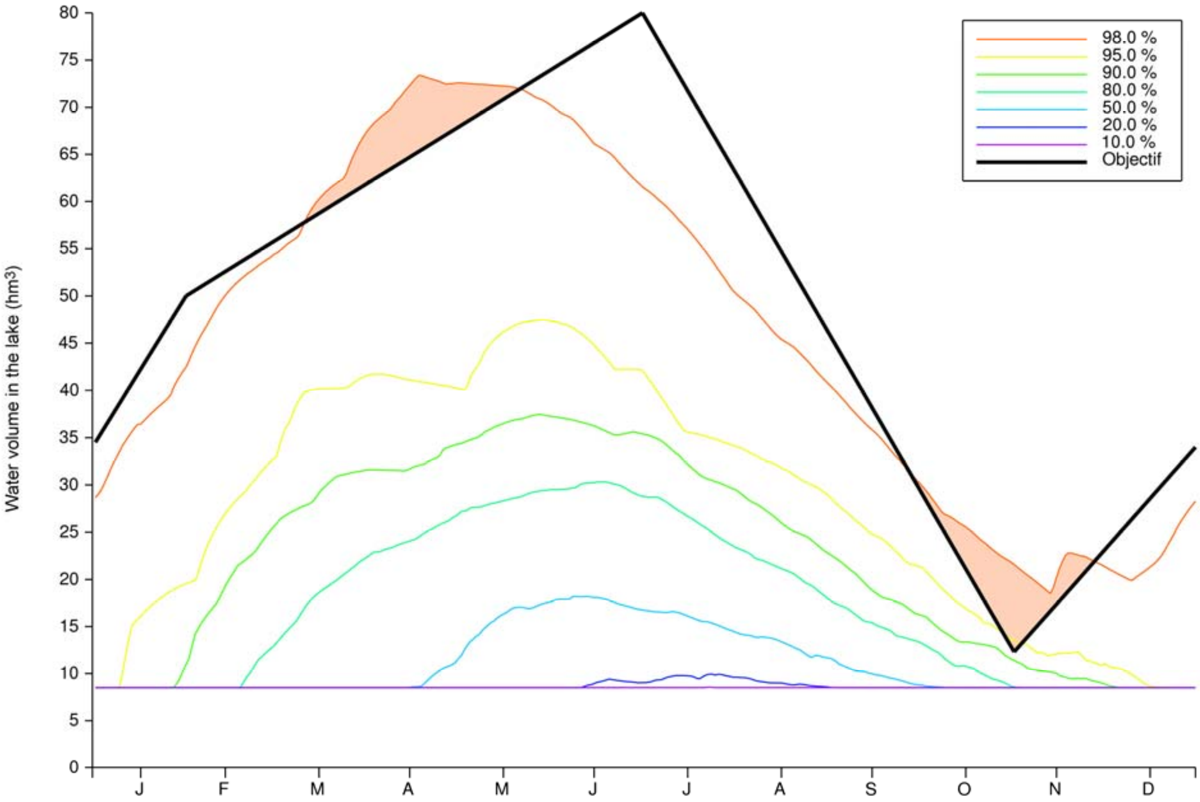


Figure 48: Annual iso-frequency curves for a minimum volume on the lake Pannecière for a low-flow objective of 64 m^3/s (vigilance threshold) at Alfortville station (colored curves) and current objective curve (black). Calculation done on the period 1900-2009.

Adaptation of operational management: Use of Tree-Based Model Predictive Control

For the real-time control, a centralized Tree-Based Model Predictive Control (TB-MPC) in collaboration with TU Delft (Netherlands) and Politecnico di Milano (Italy) was developed. This method uses all the information available in real-time, including ensemble weather forecasting, to obtain an adaptive control. In TB-MPC, a tree is generated from an ensemble of weather forecasts. The tree structure summarizes the information contained in the ensemble, specifying the time, along the optimization horizon, when forecast trajectories diverge and thus uncertainty is expected to be resolved (see Figure 49). This information is then used in the model predictive control framework, to optimize an objective function over a finite receding horizon, using a model to predict the evolution of the system in response to the forecasted inputs.

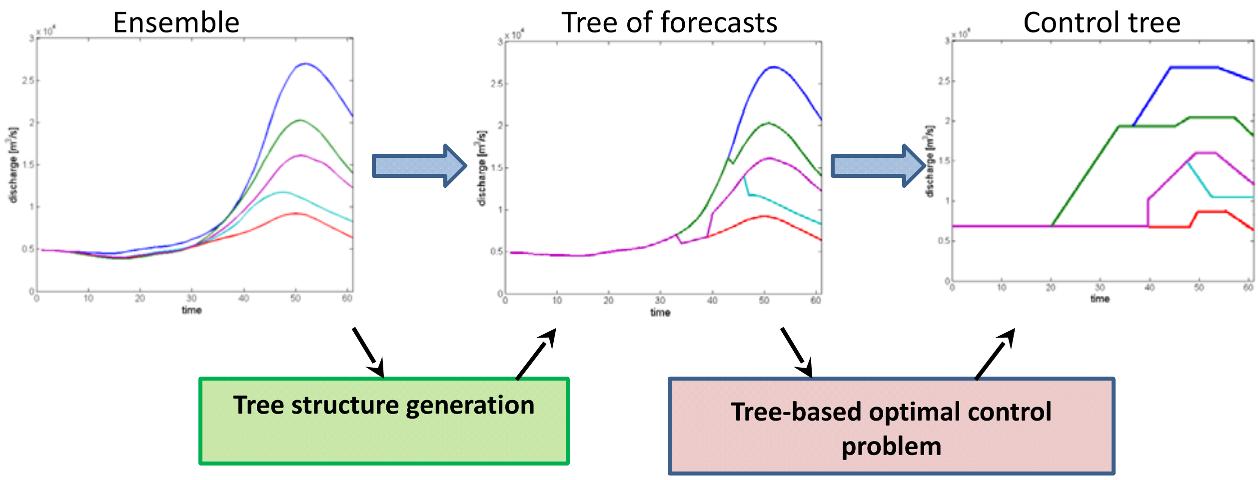


Figure 49: Scheme of the generation of a control tree from an ensemble forecast

The TB-MPC controller was implemented in combination with the existing integrated model of the River Seine basin. The controller optimizes a global cost function that takes into account the costs associated to high and low flows, based on thresholds at some key downstream stations described in Table 1 and a penalty cost based on the final reservoir storages, to guarantee a sustainable management in the long-term.

As the TB-MPC needs ensemble forecasts as input of the optimization, it was necessary to generate ensemble forecast corresponding to the GCMs simulations. A multivariate error model to produce "ensemble-dressing" of GCMs scenarios was used. The error model was calibrated on the error of real ensemble forecasts from ECMWF (9-day ahead forecasts available from 2005 to 2008). Several deterministic and probabilistic statistical scores were used for verifying that the generated ensemble forecasts have "realistic" errors and correct probabilistic skills.

The reservoirs' management model was tested under changing hydro-climatic conditions, using the seven GCMs scenarios. The performance of the TB-MPC was evaluated and compared to the performance of the current decentralized management under present and future scenarios.

Results

Assessment of hydrological models

The evaluation of the rainfall-runoff models (GR4J and TGR) was done under current conditions using available daily flow and meteorological observations (1961-2009), in order to assess their quality and to quantify the uncertainty associated to the choice of the hydrological model. The transferability of the models parameters for periods for which they have not been calibrated is a key issue for climate change applications. Indeed, it is likely that in the future the climate conditions will be very different from the current conditions in which models have been calibrated, and that could result in poor performance of the hydrological simulations. Since no observations are available for the periods on which the future climate projections are done, it is now a common practice to perform calibration and validation over different periods included in the available observation period (Klemes, 1986). In the case study, the 1961–2009 observation period was split into two sub-periods P1 (1961–1984) and P2 (1985–2009). First, P1 was used for calibration and P2 was used for validation; then the roles of P1 and P2 were reversed. The results were evaluated on the two validation periods aggregated together.

Several efficiency measures were used to evaluate the performance of the models under current conditions. C2MQ is a bounded version (see Mathevet et al., 2006) of the Nash and Sutcliffe (1970) criterion (NSQ) calculated on discharge:

$$C2MQ = \frac{NSQ}{2 - NSQ} \qquad \text{Equation 28}$$

Two other criteria based on the same formula as C2MQ were used: C2MLnQ and C2MIQ, which are computed using log-transformed and inverse-transformed streamflows, respectively. They emphasize model performance on low and very low flows, respectively (see Pushpalatha et al., 2012). The results are presented for each of the 25 stations and for both models in Figure 50. Except for one station (the Grand Morin at Montry, station 18), C2MQ and C2MLnQ criteria are larger than 0.6. The average performance of the 25 stations is quite satisfactory: the two models simulated the hydrological behaviour of the catchments quite well, including low-flow periods.

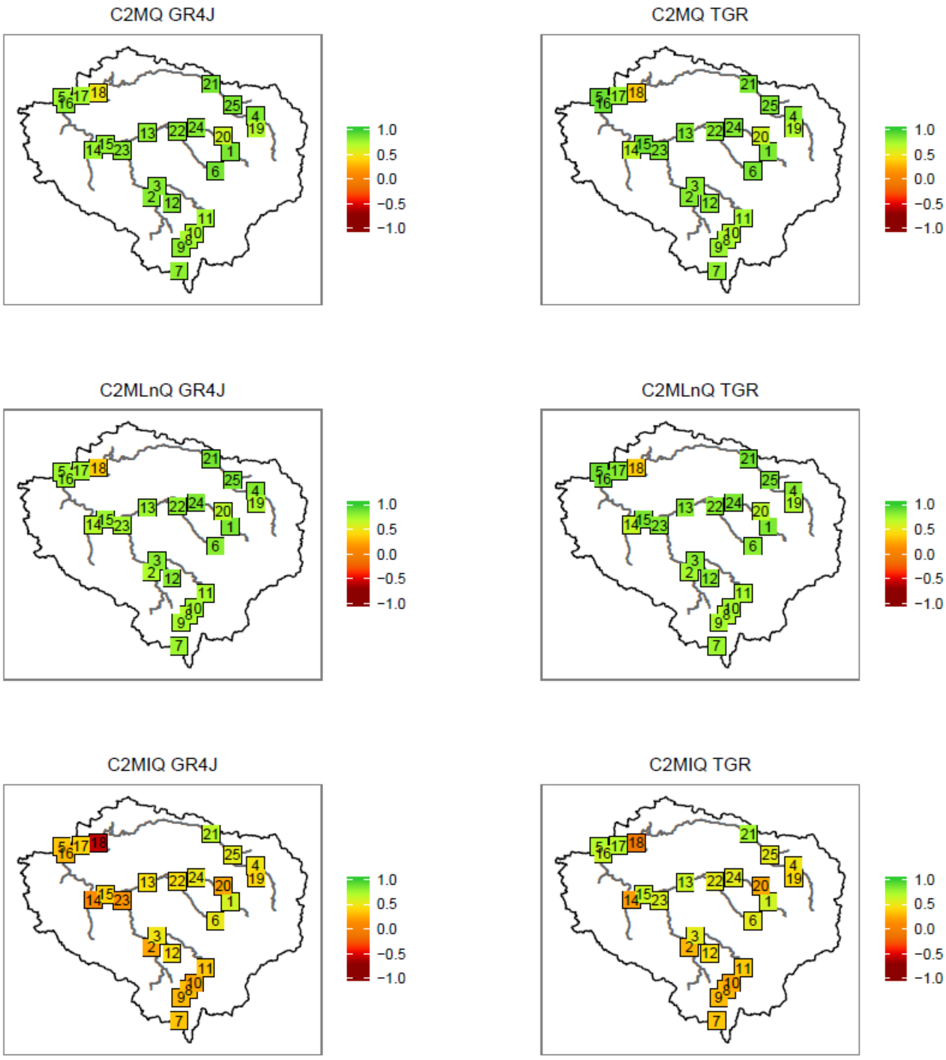


Figure 50: Efficiency criteria in validation (top: C2MQ; middle: C2MLnQ; bottom: CMIQ) obtained by the GR4J (left) and TGR (right) models in current conditions considering naturalized flows for the 25 gauging stations

The average performance on the 25 stations is quite satisfactory: the two models can quite well simulate the hydrological behaviour of the catchments including low-flow periods (see red curves in Figure 51 for results at Paris).

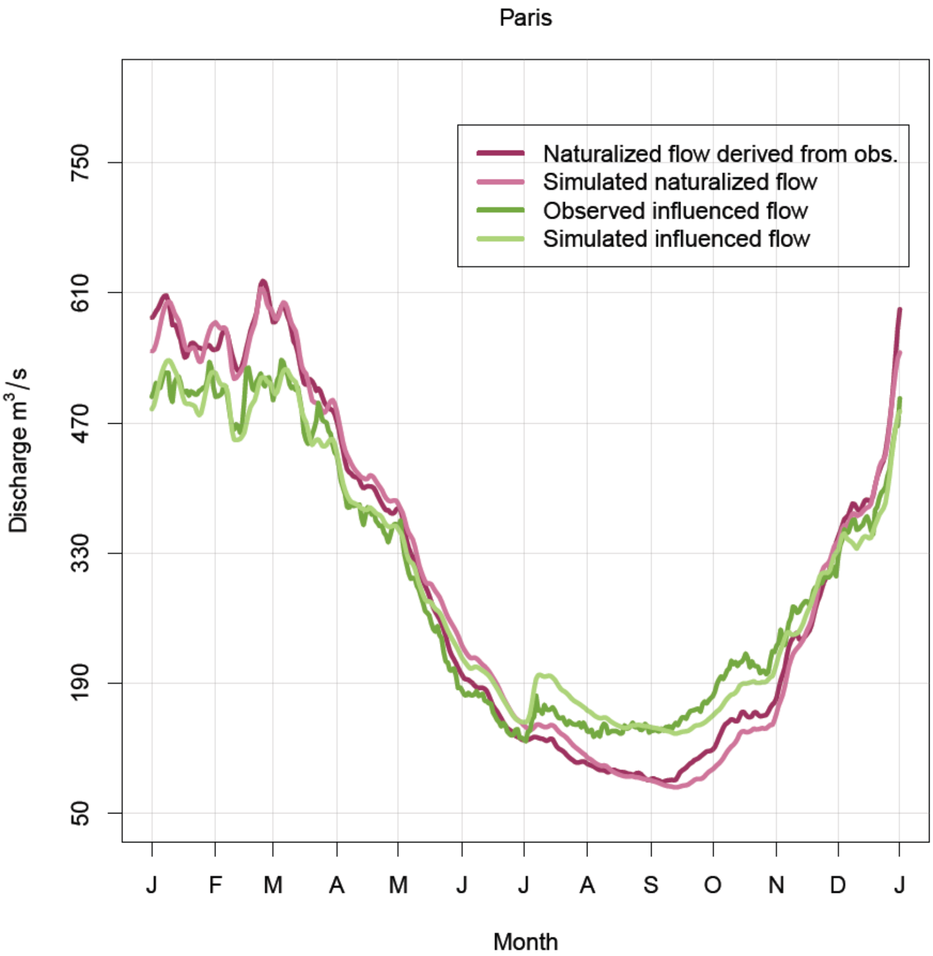


Figure 51: Mean daily flows for the River Seine at Paris-Austerlitz. Influenced and naturalized flows are shown for the 1991-2008 period. Simulations are produced by the TGR model in validation.

Climatic trends

The analysis of climatic trends is based on climatic simulations at the scale of the River Seine basin upstream Paris.

Precipitations

Most models predict a marked decrease of rainfall from May to September (see the two plots of the first column of Figure 53. For the rest of the year, the different GCMs differ on their assessment of the evolution of precipitations.

Temperatures and Potential Evapotranspiration

Climatic simulations from the seven GCMs indicate an increase of average annual temperature between +1.8°C and +2.9°C over the basin, between the 1961-1990 and the 2046-2065 periods (column 2 of Figure 53). The deviation between the seven simulations is about 1°C to 3°C for average monthly temperatures, and is especially significant during winter. As a direct consequence of the evolution of temperature, the GCMs indicate an increase of potential evapotranspiration.

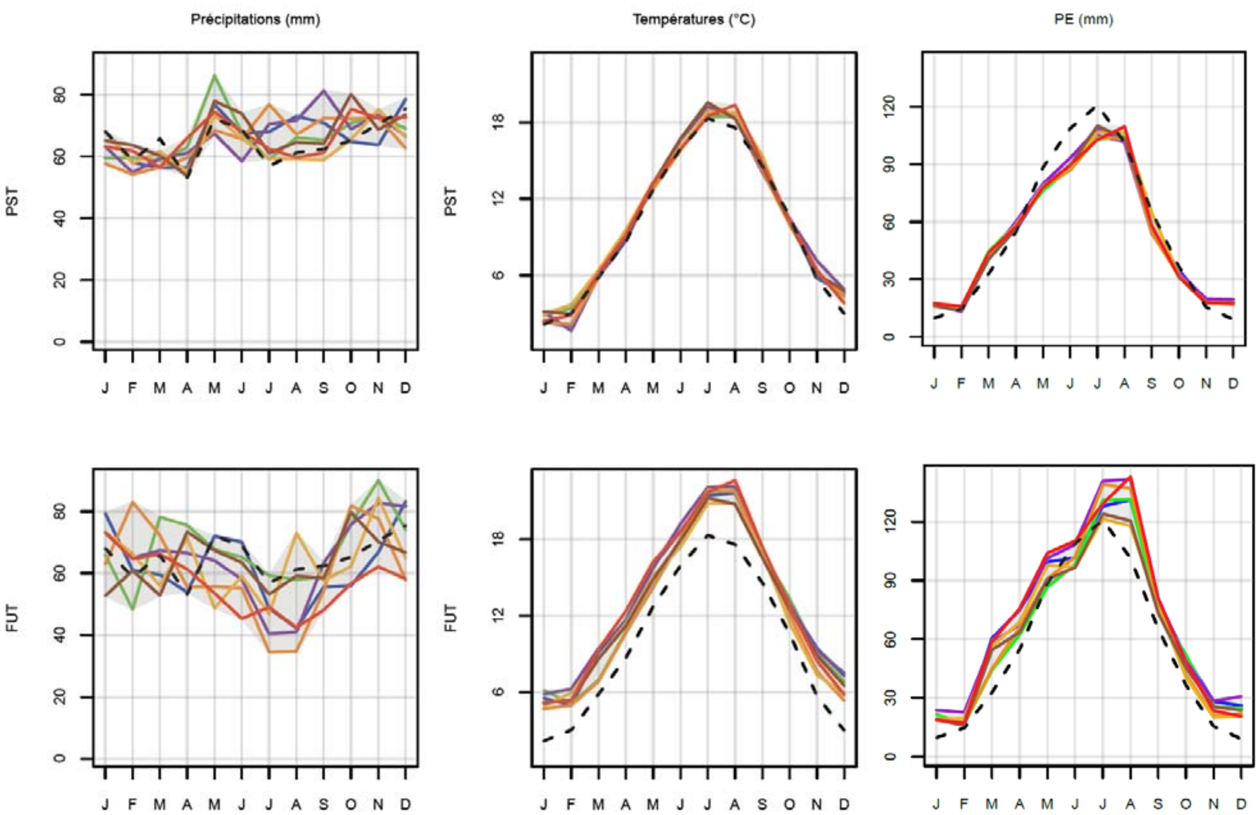


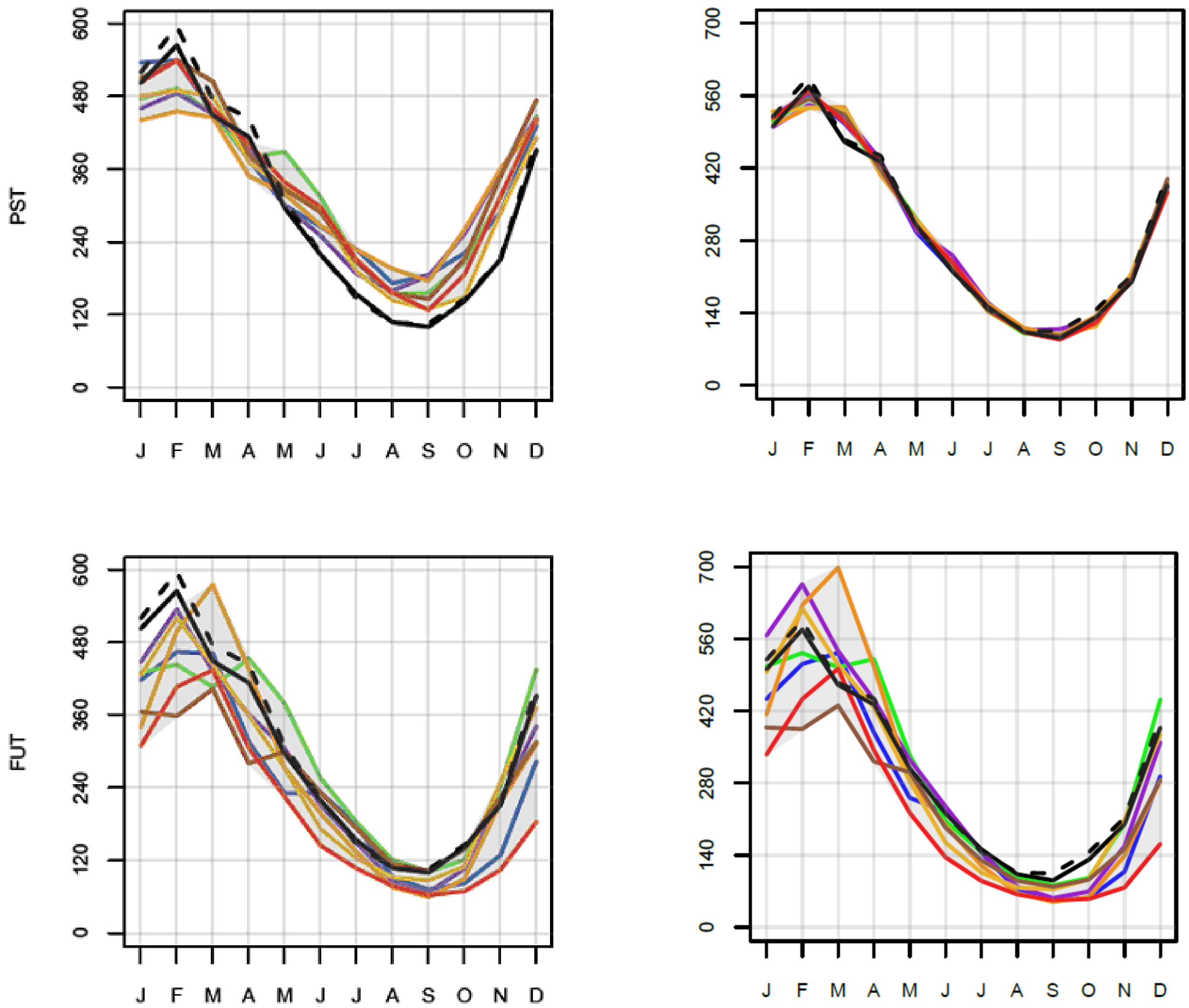
Figure 52: Monthly average of precipitation, temperature and potential evapotranspiration variables over the PST period (1961–1991, top row) and FUT period (2046-2065, down row) for the River Seine basin at Paris. The dashed lines represent SAFRAN observations and the coloured lines are the seven downscaled climate simulations without bias correction

Bias correction

The GCM outputs downscaled over the River Seine basin showed quite significant biases compared to observations over the PST period, mostly during the summer season: precipitation was overestimated from July to November and potential evapotranspiration was underestimated from May to July (see the top row of Figure 52).

To cope with these biases, the commonly adopted approach is to hypothesize that the impact of input biases on hydrological simulations will remain the same between present and future conditions and therefore to consider only differences between future and present conditions to quantify changes in hydrological variables. This approach had a major drawback in case study 2, since it was aspirated to quantify the evolution of the dam management reliability between present and future conditions, using biased scenarios would consequently strongly bias the estimation of management reliability, with results that would be difficult to interpret. In case study 2, the overestimation of precipitation over the summer period caused an underestimation of drought periods by the hydrological models, and as a consequence of the utility of the reservoirs.

Therefore it was decided to correct the bias in the downscaled climate simulations. The quantile-quantile mapping (QQ mapping) method for the study was selected. This method aims to fit the distribution of climate variables to the distribution of observations over a given period (here PST) and applies this transformation to the future time (Panofsky and Brier, 1968). The QQ mapping to precipitation, potential evapotranspiration and temperature variables on a monthly basis was applied. The relative impact of QQ mapping on the evolution of the climate variables was not changed compared with what is described in the “Climatic trends” subsection. The result on the mean monthly discharges at Paris is shown in Figure 53. This figure shows that the QQ mapping allows reproducing the mean monthly discharges at Paris over the PST period, and that a decrease of discharges is projected over most of the year except in winter, which shows uncertain projections.



Without bias correction

With bias correction

Figure 53: Monthly mean naturalized discharge over the PST period (1961–1991, top row) and FUT period (2046-2065, down row) for the River Seine basin at Paris without (left column) and with (right column) bias correction. The dashed black lines represent observations, the plain black lines represent simulated discharges with TGR and the coloured lines are the seven downscaled climate simulations without bias correction simulated with TGR

Hydrological trends

Water resources

75 % of the simulations indicate a decrease of the average annual discharge between 15 % and 30 %, for the FUT period compared to the PST period while 25 % of the simulations show a slight

increase or no trend (Figure 54a). This result can likely be linked with the increase of temperature over the basin, meaning an increase in the evaporation losses.

Low flows

The decrease in QMNA5 (lowest monthly mean discharge reached every five years) and Q95 (the low flows quantile exceeded 95 % of the time) is the most striking result of the study. This decrease is observed for all 14 simulations on the 25 stations. More than 75 % of them show a decrease greater than 25 %. This evolution of QMNA5 and Q95 is related to the evolution of mean discharge during the dry months of the year (June to November, Figure 54b. These results indicate that the increase of the severity and length of low-flow events may have strong impacts on future reservoir management during summer.

High flows and floods

Regarding high flows, the evolutions of QJXA10 (maximum daily discharge with ten-year return period) and Q10 (the high-flow quantile exceeded only 10 % of the time) seem to be uncertain, given the divergence between simulations: some of them show an increase of these hydrological descriptors, while the reverse can also be true for others. Even if QJXA10 values tend to increase, strong conclusions are difficult to draw given that 25 % of the simulations exhibit a decrease. The winter high-flow period also indicates an uncertain evolution of monthly discharge: the simulations diverge and the spread is substantial.

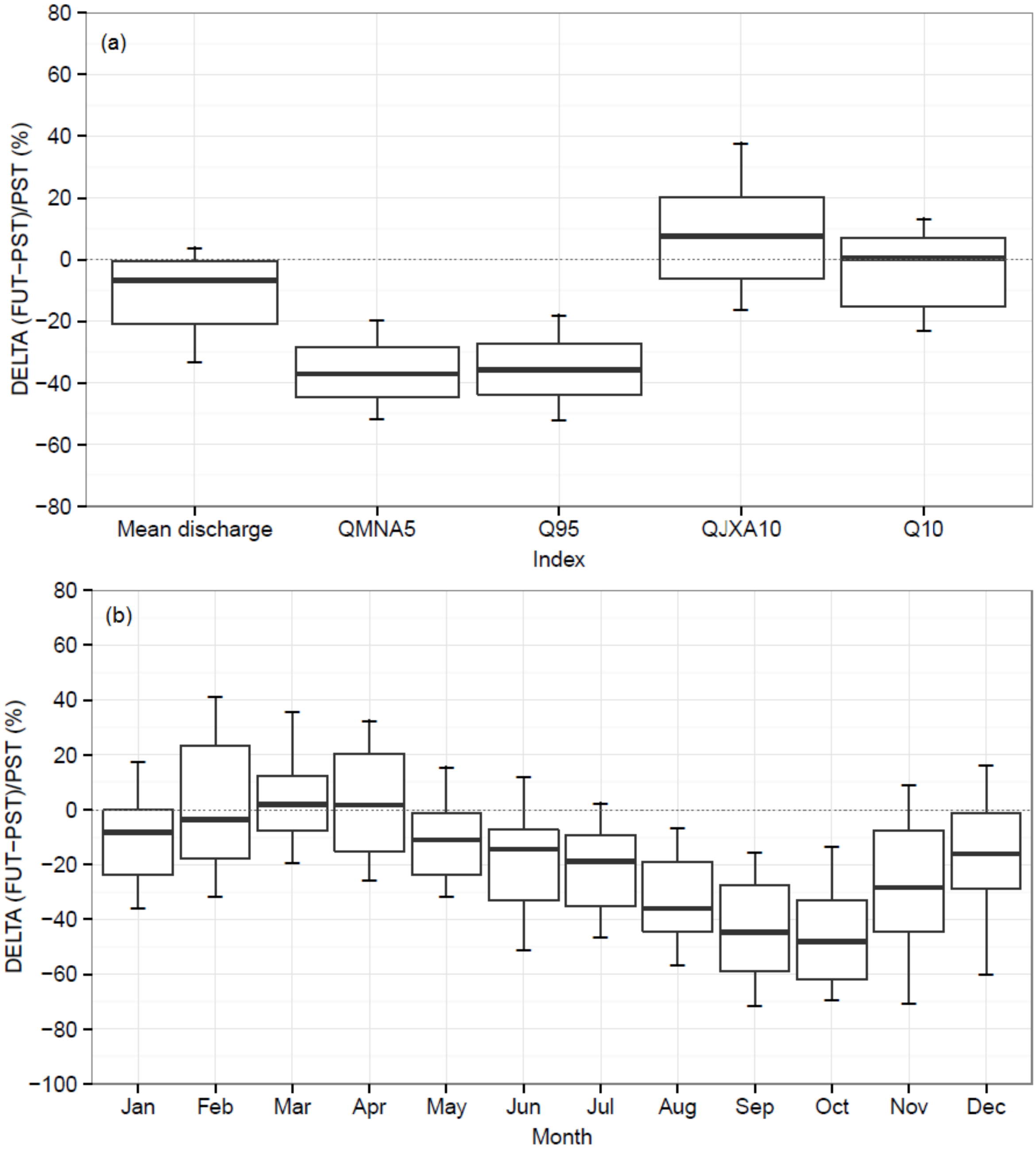


Figure 54: (a) Relative evolution (Δ) of the hydrological descriptors computed by the two hydrological models using the seven climate simulations on the 25 stations. The boxplots show the 5, 25, 50, 75, and 95 % percentiles of the 14 simulations. (b) Relative evolution (Δ) of the monthly discharge for the 14 simulations

Uncertainties on hydrological trends

Uncertainties on the results of this impact study are linked to the strong hypotheses made about future conditions (future concentration of GHG, future land cover, etc.), the lack of knowledge of hydrosystem behaviour in present and future conditions, and limits of climatic and hydrological modelling. First, all modelling steps imply a part of uncertainty due to the imperfect ability of models to reproduce reality. This is especially true for GCMs, rainfall-runoff models and downscaling methods. Second, there is an uncertainty due to the intrinsic variability of hydroclimatic systems.

- The use of a multi-model approach aims at quantifying a part of the uncertainties due to GCMs and hydrological models, but does not allow characterizing all the uncertainties of the results. Thus it can be shown that decrease in low flows is the most consistent result and that decrease in mean flows is not fully significant due to the divergence between GCM simulations;
- Trends on high flows are uncertain due to divergence between GCM simulations.

Performance of the hydrological model with reservoirs influence

To evaluate the performance of the integrated TGR model (with reservoir modelling), simulated flows with the historical observed flows at the gauging stations were compared (see Figure 51 green curves for the results at Paris station). Flows simulated at the gauging stations downstream the reservoirs, at the reservoir inlets and outlets and also volumes of the reservoirs themselves, show that the model correctly mimics the current behaviour of the basin as influenced by the reservoirs, especially in the Paris region (downstream area of the basin).

Impact of climate change on the efficiency of the reservoirs using current management rules

Results are illustrated in Figure 55 (red curves) for the Paris-Austerlitz station. The evolution between PST and FUT periods looks quite similar as in non-influenced conditions (blue curves), i.e. consistent decrease of low flows and uncertain evolution of high flows. Interestingly, however, in low flow conditions, a clear gap appears in simulated ranges between PST and FUT periods, stressing the dramatic decrease of low flows between PST and FUT and the difficulty to maintain low flows at present levels with current management rules.

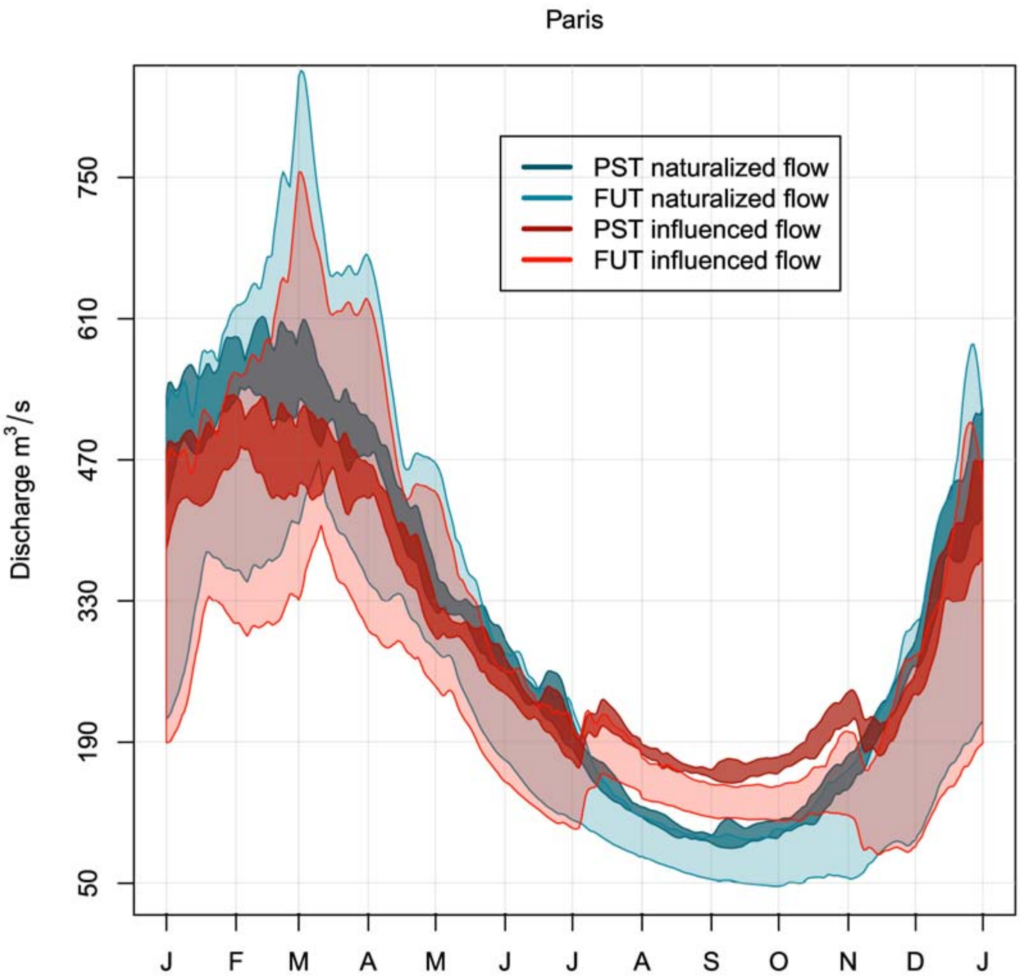


Figure 55: Evolution of daily mean discharge between present (PST) and future (FUT) conditions at the Seine River at Paris-Austerlitz. Discharge simulations are obtained using the TGR model run with the 7 climate simulations. The shaded colours represent the band widths of the 7 simulations. Discharge simulations are shown in natural and influenced conditions.

Adaptation of objective filling curves

The following graphs (Figure 56 to Figure 59) show mono-objective iso-frequency curves of all objectives for a selection of downstream stations for each lake. The iso-frequency curves are drawn with thin lines from yellow to red for low-flows objectives and from green to blue for high-flows objectives. Dark iso-frequency curves represent short return period and the lighter ones figure long return period. These shades of luminosity correspond to the weight applied for each mono-objective iso-frequency curve in the multi-objective optimisation. The bold lines represent the result of the multi-objective optimisation. The first one takes into account all the objectives. For the following multi-objective curves (resp. 2, 3 and 4), the optimisation was done by removing successively 1st, 2nd, and 3rd low-flow objectives.

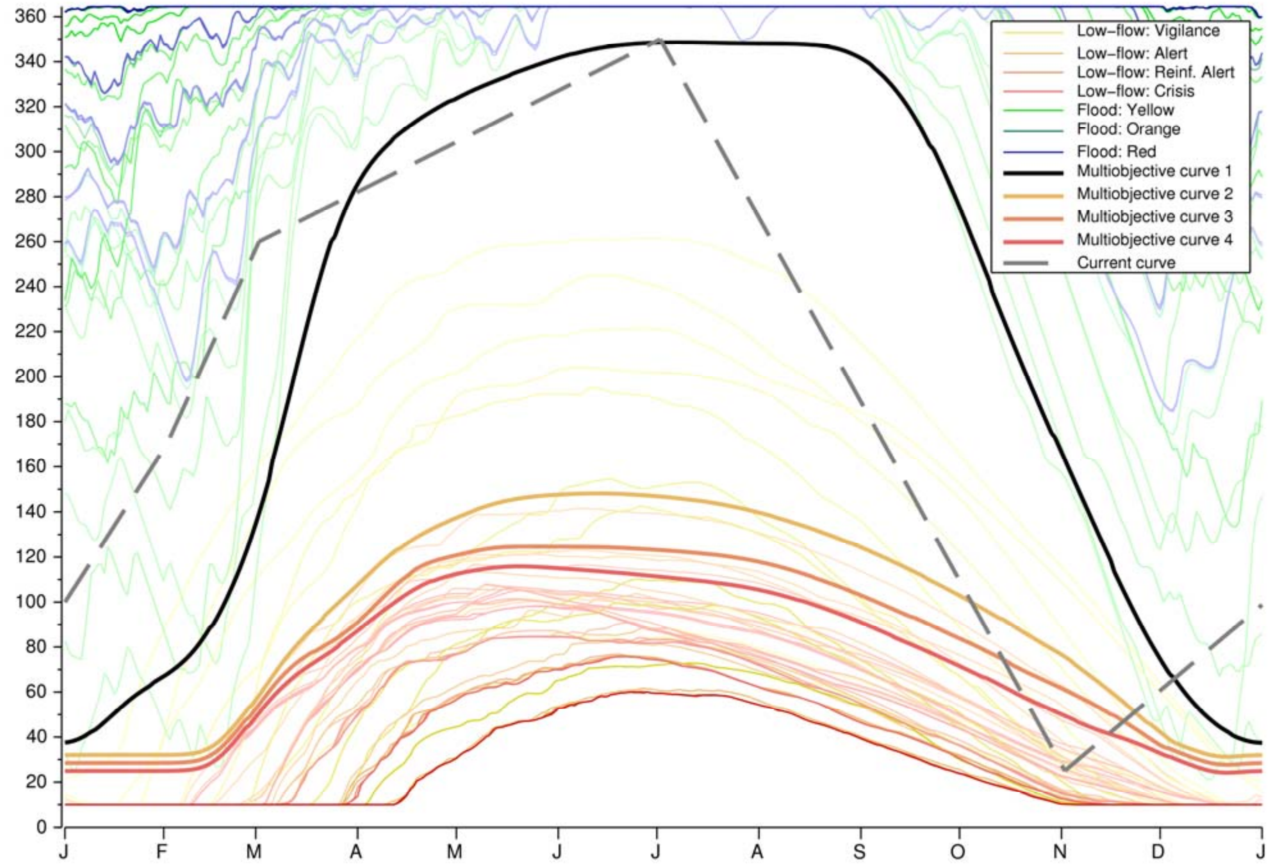


Figure 56: Result of multi-objective optimisation of the filling curve for Marne Lake calculated from present (PST) simulated flows (7 GCMs scenarios x 1961-1991). Volumes (hm^3). Multi-objective filling curves in bold, current filling curve in dotted grey, low-flow and high-flow constraints in thin line.

The results with 1961-1991 and 2046-2065 simulations of all GCMs scenarios show that the new filling curve (noted Multi-objective curve 1) is shifted to the right relative to the current filling curve.

The design of current filling curve naturally carries the support of low water, the only feedback control in the current management rules happens in November to check if it is necessary to continue emptying the reservoir because the flow at a downstream gauging station is under the vigilance threshold. On the contrary, the new filling curve should only be followed when downstream gauging stations are in a satisfactory state and a feedback control must be defined to satisfying objective at downstream. For flood, it is done in the current management by using a flood threshold at reservoirs outlets and this rule is still relevant for the new filling curve.

For low flows it was decided to use the four low-flow thresholds at one downstream station for each reservoir (Arcis-sur-Aube for Aube Lake, Nogent-sur-Seine for Seine Lake, Gurgy for Panneciere Lake and Châlons-sur-Marne for Marne Lake). Accordingly, four objective curves are calculated for each lake (noted Multi-objective curves 1 to 4). Each curve corresponds to the volume required to support the respective downstream four thresholds (vigilance, alert, reinforced alert and crisis). According to the state of the reservoir and its ability to durably support a low-flow threshold, the manager targets the appropriate threshold at the downstream station.

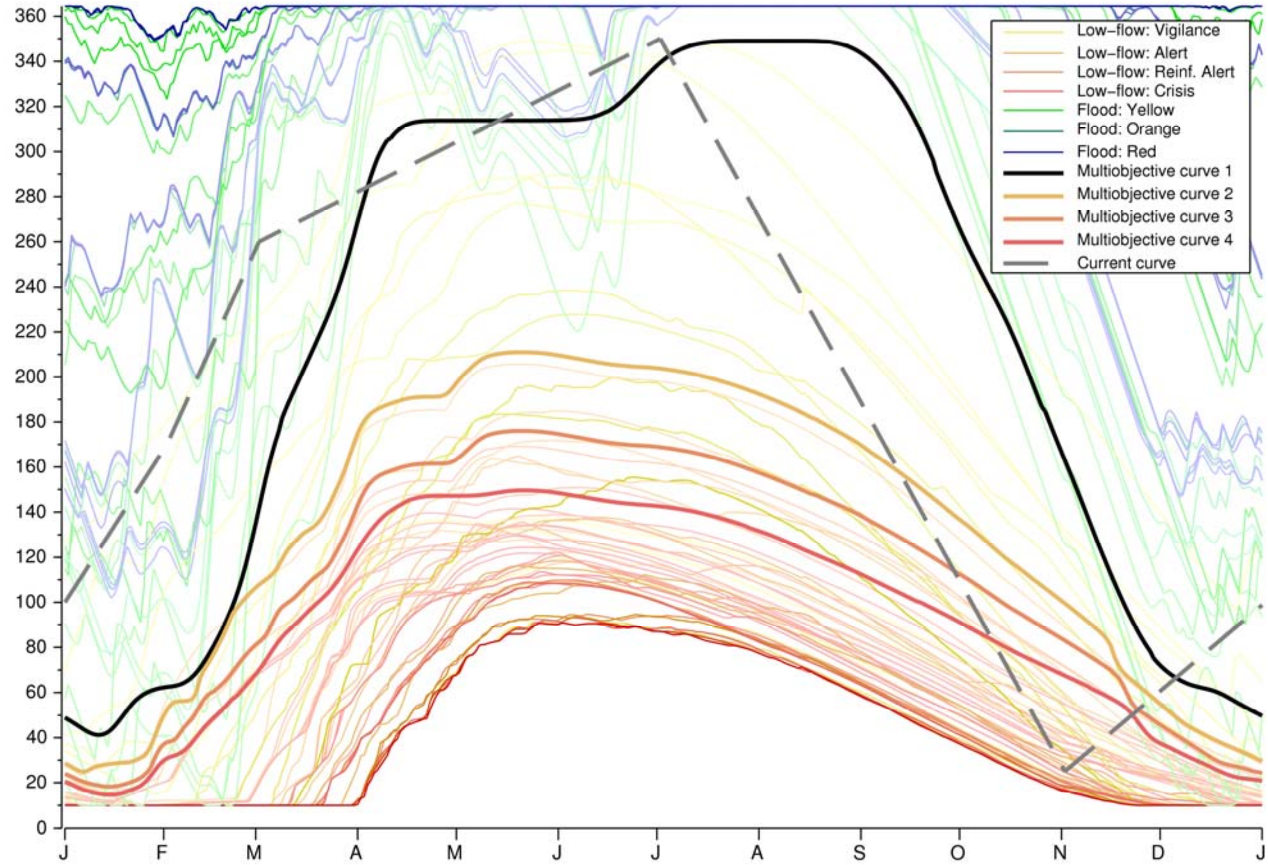


Figure 57: Result of multi-objective optimisation of the filling curve for Marne Lake calculated from future (FUT) simulated flows (7 GCMs scenarios x 2046-2065). Volumes (hm^3). Multi-objective filling curves in bold, current filling curve in dotted grey, low-flow and high-flow constraints in thin line.

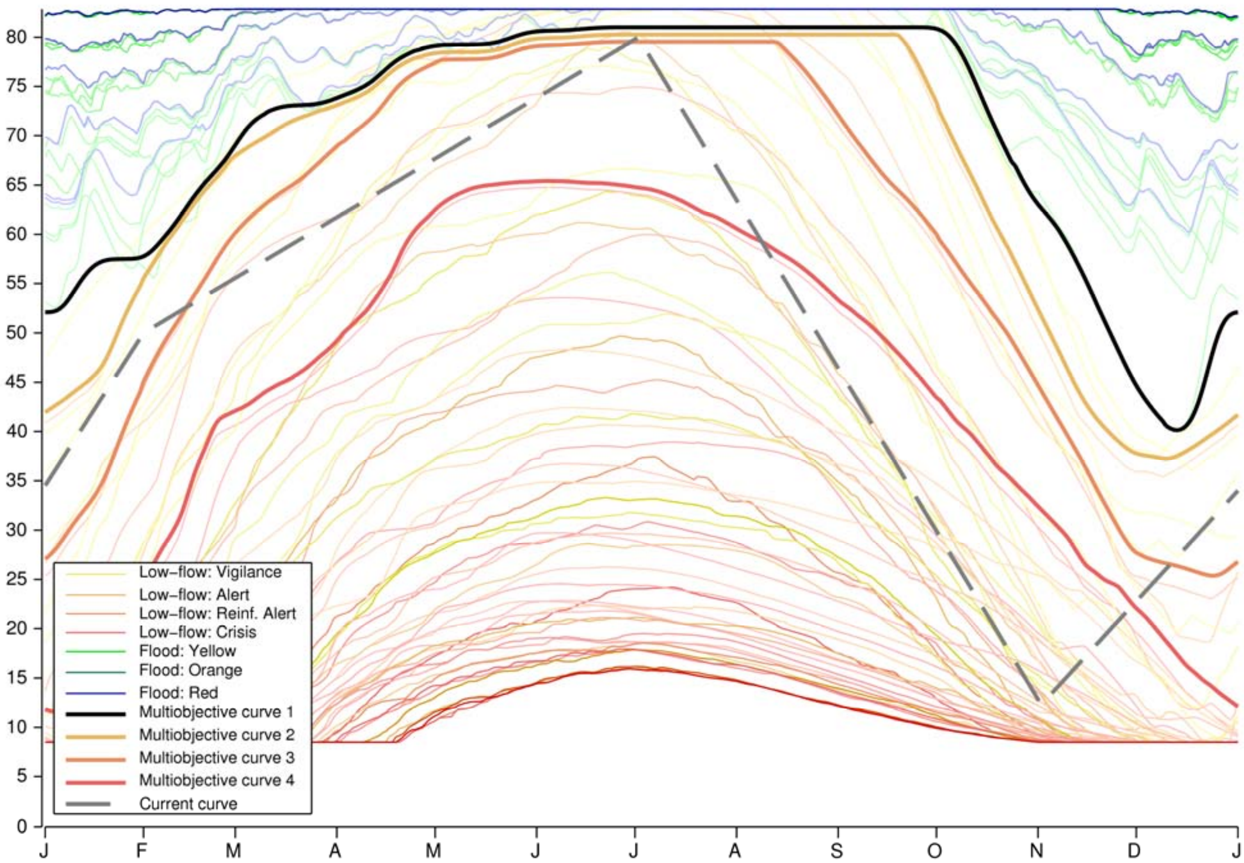


Figure 58: Result of multi-objective optimisation of the filling curve for Pannecière Lake calculated from present (PST) simulated flows (7 GCMs scenarios x 2046-2065). Volumes (hm^3). Multi-objective filling curves in bold, current filling curve in dotted grey, low-flow and high-flow constraints in thin line.

The curves calculated for the four objectives from future (FUT) GCMs scenarios show a raising for each lake. This is especially visible on Pannecière Lake (Figure 58 and Figure 59) where the four curves are blocked at the top of the reservoir volume during the drought period and low-flow and high-flow mono-objective curves cross each other during the rest of the year. On this reservoir, that means that low-flow objectives are unreachable. Hopefully, high-flow objectives are preserved by the multi-objective curves because their weights are more important than the ones for low-flows.

One major consequence with these new filling curves on Pannecière Lake will be that the 1st and the 2nd thresholds in both PST and FUT times and even the 3rd low-flow threshold in FUT time will not be supported by the management in order to maximise the probability to be able to support the 3rd or only the 4th low-flow thresholds until the end of the drought season.

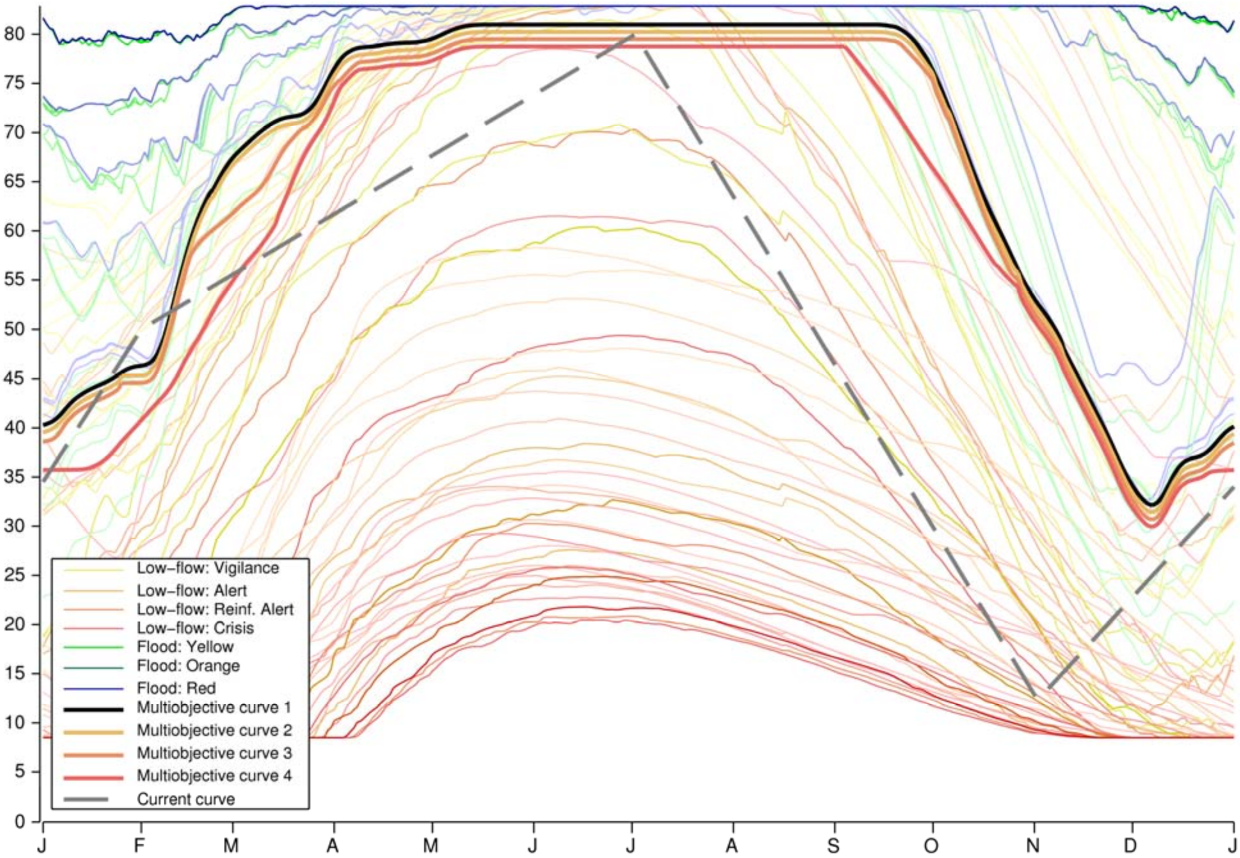


Figure 59: Result of multi-objective optimisation of the filling curve for Pannecière Lake calculated from future (FUT) simulated flows (7 GCMs scenarios x 2046-2065). Volumes (hm^3). Multi-objective filling curves in bold, current filling curve in dotted grey, low-flow and high-flow constraints in thin line.

Benchmarking of the different adaptations of the management

The benchmarking is done using the performance indicators described above and with four management adaptations mixing the current management and the proposed adapted management at operational and tactical levels:

- Current management rules with current filling curve (hereafter CUR CFC);
- Current management rules with new multi-objective filling curves (hereafter CUR NFC);
- Tree-Based Model Predictive Control with current filling curve (hereafter TBMPC CFC);
- Tree-Based Model Predictive Control with new multi-objective filling curve (hereafter TBMPC NFC).

Simulations have been run for these four management adaptations for the 7 GCMs scenarios in present time (PST: 1961-1991) and future time (FUT: 2046-2065). The indicators below have been calculated for the 9 downstream monitoring stations and are represented in the form of boxplots combining data from the 7 GCMs scenarios and the 9 monitoring stations. These boxplots figure the minimum, 1st quartile, median value, 3rd quartile and maximum values. The dot drawn on each boxplot represents the mean value. The graphs below compare each management adaptation in PST and FUT periods for one considered threshold.

As shown above in Figure 54, there is no real trend between PST and FUT periods in high-flow conditions. As a consequence, performance indicators for high-flow thresholds do not show an evolution between PST and FUT periods.

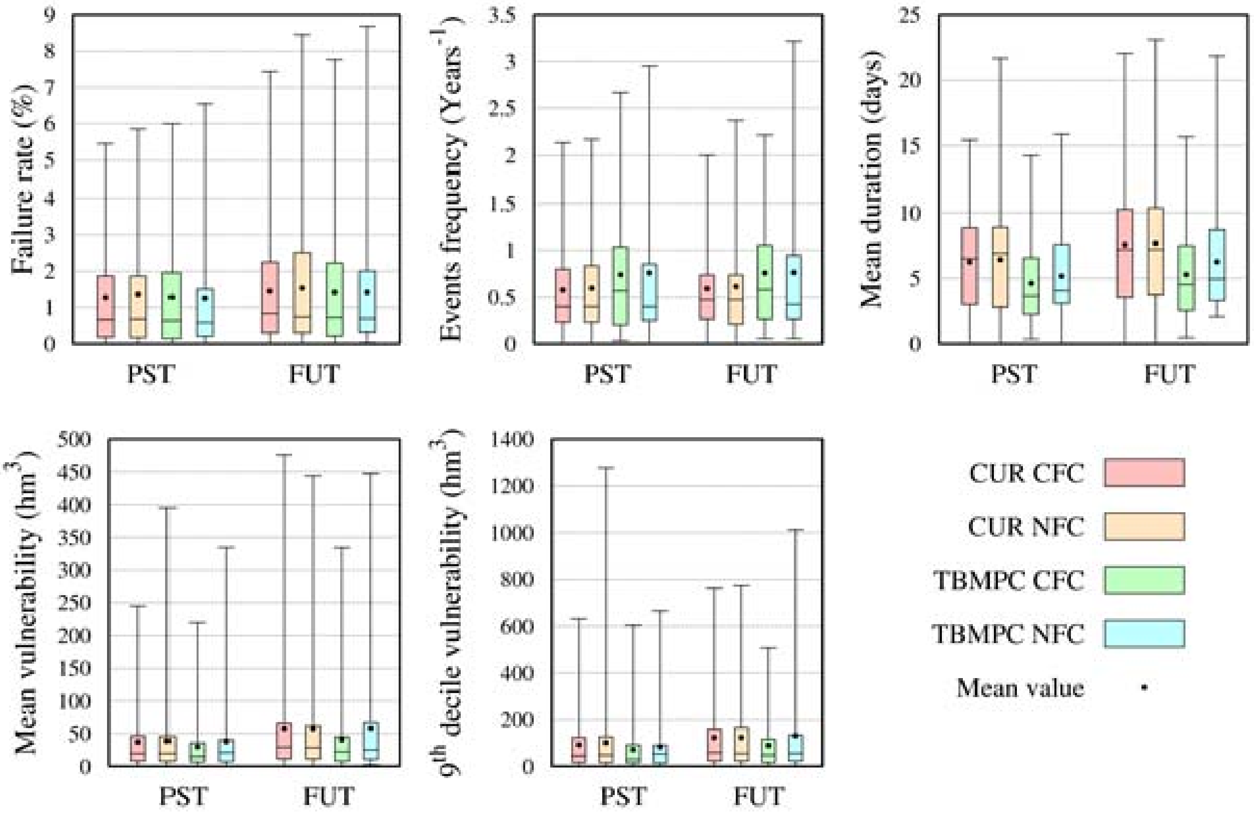


Figure 60: Performance indicators (Failure rate, events frequency, mean duration, mean vulnerability and 9th decile vulnerability) for the 1st high-flow threshold (Yellow) calculated from 7 GCMs scenarios in present (PST) and future (FUT) time for 4 management adaptations.

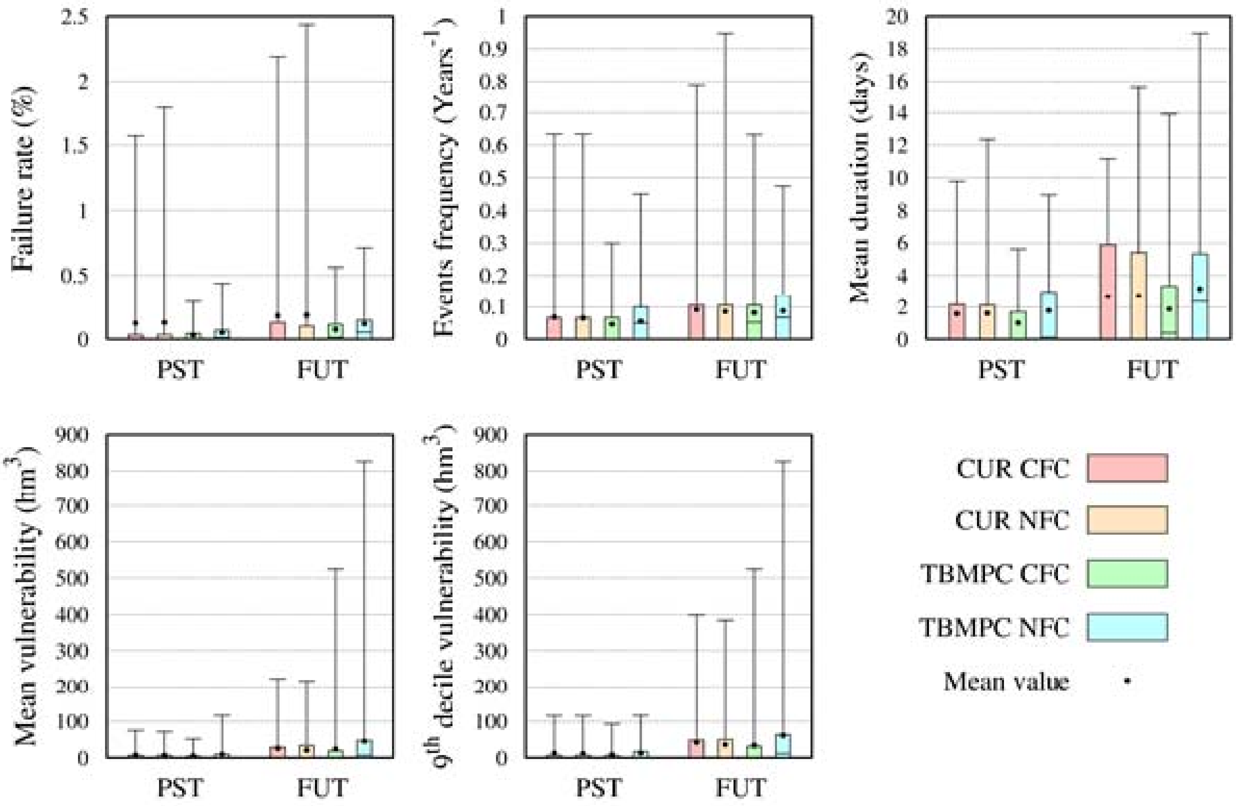


Figure 61: Performance indicators for the 2nd high-flow threshold (Orange) calculated from 7 GCMs scenarios in present (PST) and future (FUT) time for 4 management adaptations.

For the first high-flow threshold (Yellow), differences between management adaptations are quite unimportant. TB-MPC only shows more frequent unsatisfactory events but these events are shorter and the vulnerability indicators are a bit reduced compared with the current management rules (CUR).

Considering the 2nd high-flow threshold (Orange), both mean and extreme values of failure rate (see the dots and the upper bound of the boxplots in the upper left panel of Figure 61) are significantly reduced by TB-MPC for both PST and FUT periods. The use of the current (CFC) or the new multi-objective curves (NFC) does not affect the results except for TB-MPC NFC where the extreme value of the vulnerability underperforms in FUT time compared to others adaptation managements.

It is difficult to conclude with the 3rd high-flow threshold because only few stations are affected for one event in both PST and FUT time and then the uncertainty on the indicators due to small number of events is really important. It seems that TB-MPC is less efficient than the current management rules (see Figure 62). This may be a direct consequence of the fact that this management outperforms the current management on the 2nd high-flow threshold in that it uses more the available capacity of the reservoir for managing this threshold without keeping flexibility to manage the 3rd threshold. In all cases, that shows that the total capacity of the reservoirs is insufficient for managing an exceptional flood as the one encountered in GFDL-CM 2.0 GCM scenario in FUT time. Depending on the management, the vulnerability (i.e. the missing capacity of the reservoirs) on this event fluctuates between 105 to 350 hm^3.

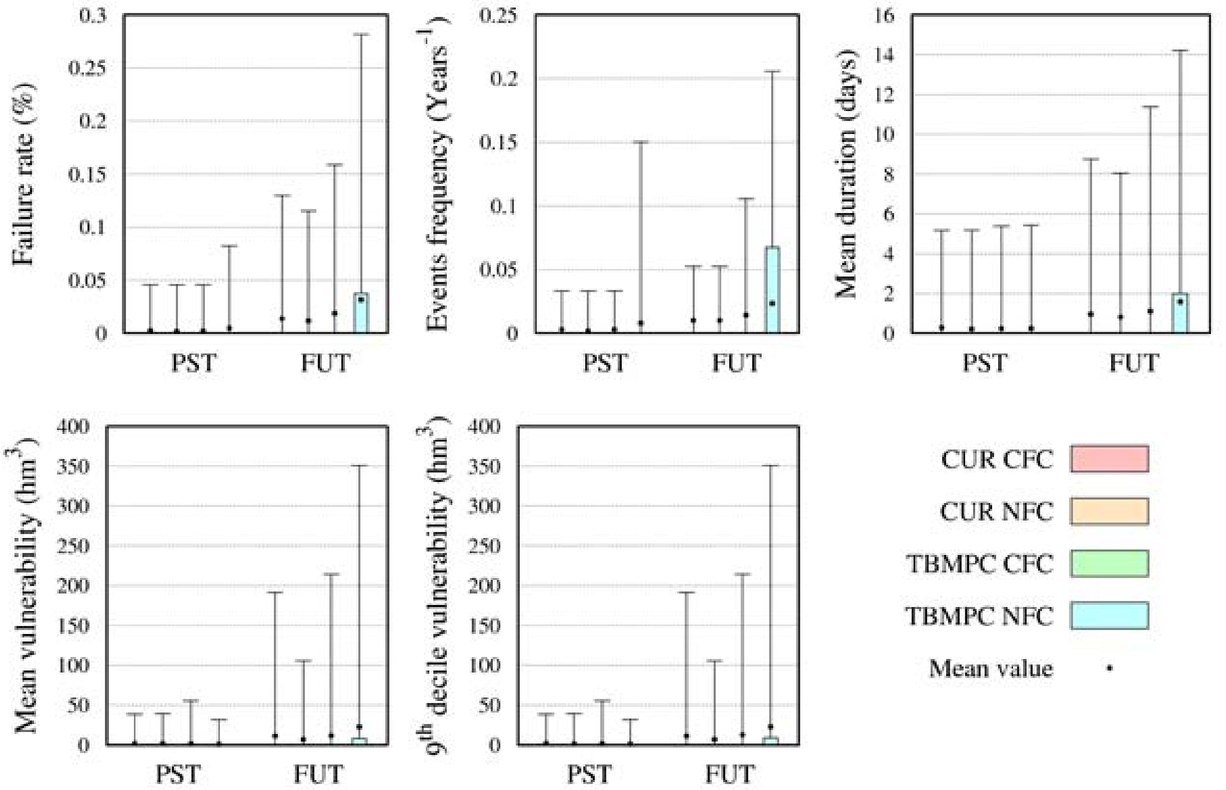


Figure 62: Performance indicators for the 3rd high-flow threshold (Red) calculated from 7 GCMs scenarios in present (PST) and future (FUT) time for 4 management adaptations.

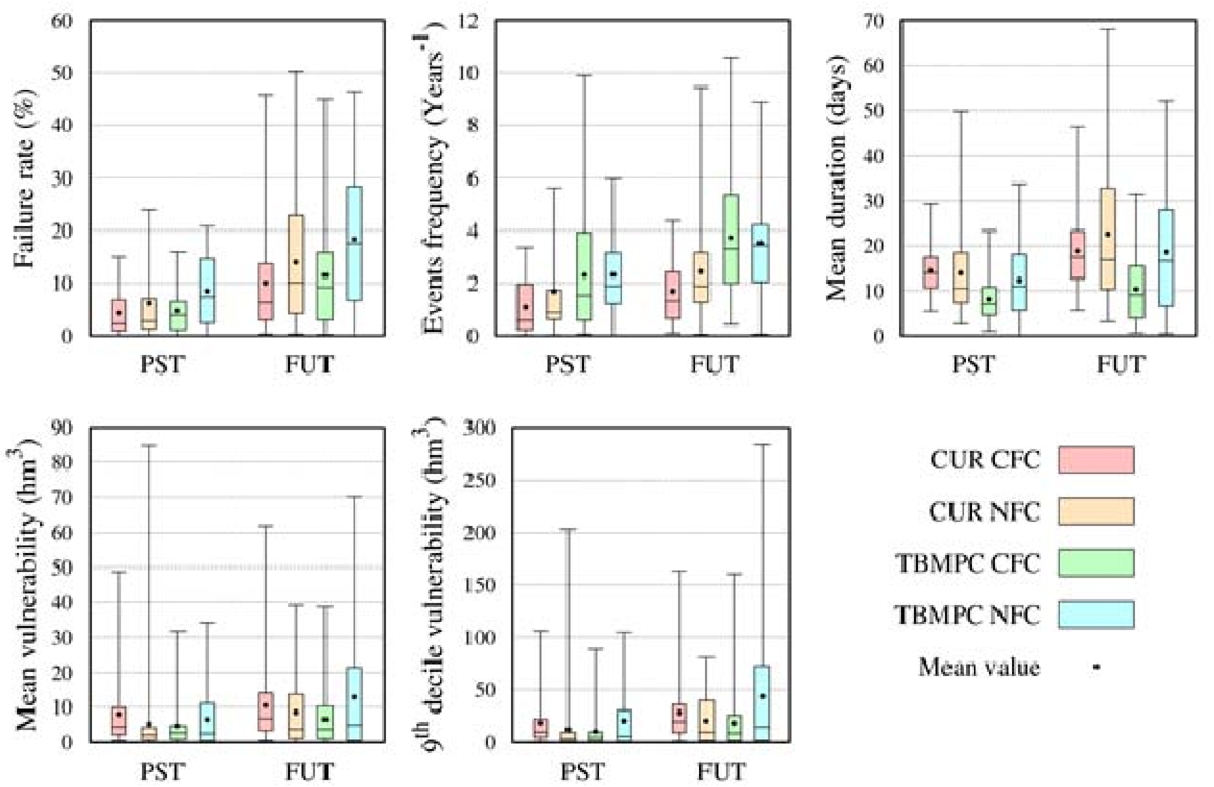


Figure 63: Performance indicators for the 1st low-flow threshold (Vigilance) calculated from 7 GCMs scenarios in present (PST) and future (FUT) time for 4 management adaptations.

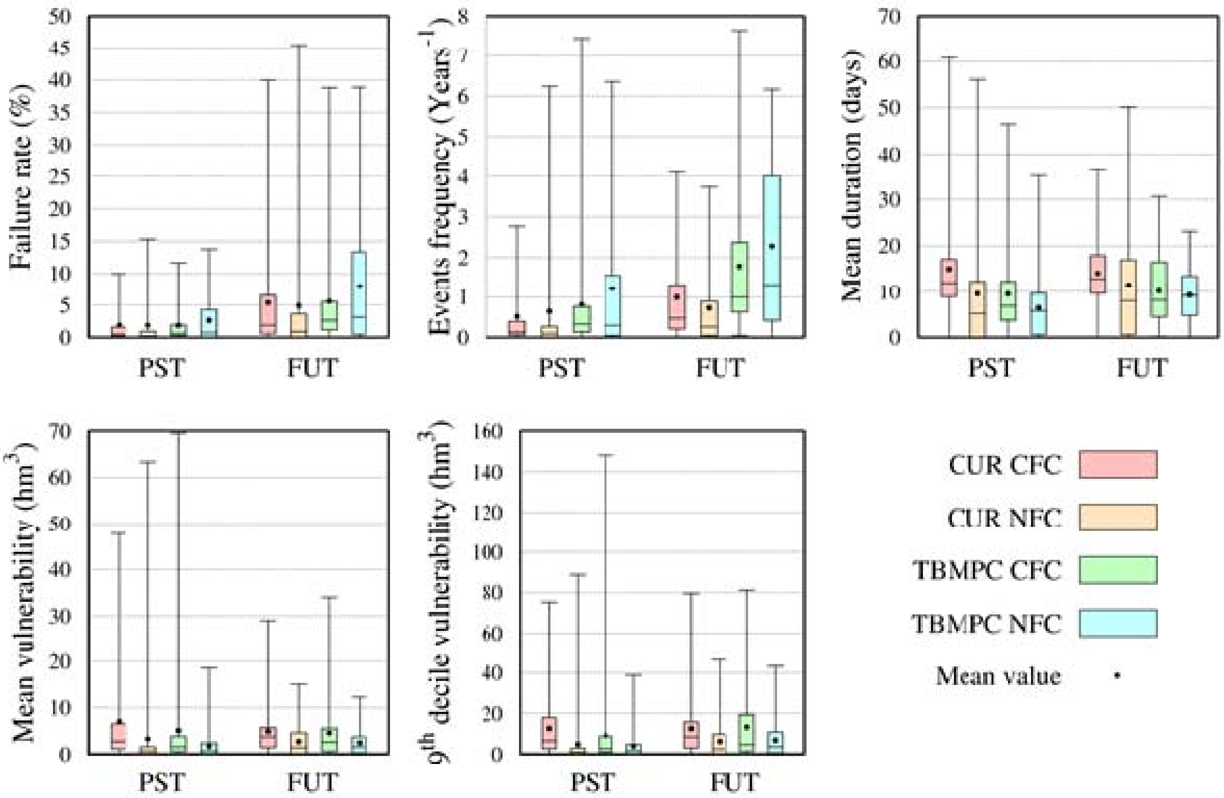


Figure 64: Performance indicators for the 2nd low-flow threshold (Alert) calculated from 7 GCMs scenarios in present (PST) and future (FUT) time for 4 management adaptations.

In Figure 63 and beyond, contrary to high-flow performance indicators, the results concerning the low-flow thresholds show that the indicators are all worse in FUT time: drought events will be more frequent, longer and their vulnerability will increase whatever the adaptation management used.

For the 1st low-flow threshold (Vigilance), TB-MPC doesn't outperform current management rules. This is partially due to the fact that this threshold was not considered as an objective in the multi-objective optimisation. In term of failure rate and events frequency, it seems that the best management in PST and FUT periods is the current one both at an operational level (CUR) and tactical level (CFC). However, TB-MPC CFC is the more efficient in term of vulnerability.

Even if the CUR NFC management takes explicitly care of the 1st low-flow threshold, the failure rate and events frequency are worse than the one of CUR CFC which does not use any feedback control during drought period. This is explained by the weak capacity of Pannecière Lake (See Figure 58 and Figure 59) that orientates the control to support only more important thresholds on this lake.

Figure 64 shows for the 2nd low-flow threshold (Alert) that the current management rules with new filling curves (CUR NFC) is the best management considering the failure rate and the events frequency. The management reducing the most the vulnerability is even so the TBMPC NFC closely followed by CUR NFC. Managements using the new multi-objective filling curves show here their efficiency. Exactly the same conclusions can be drawn for the 3rd low-flow threshold (Reinforced alert) with the indicators in Figure 65.

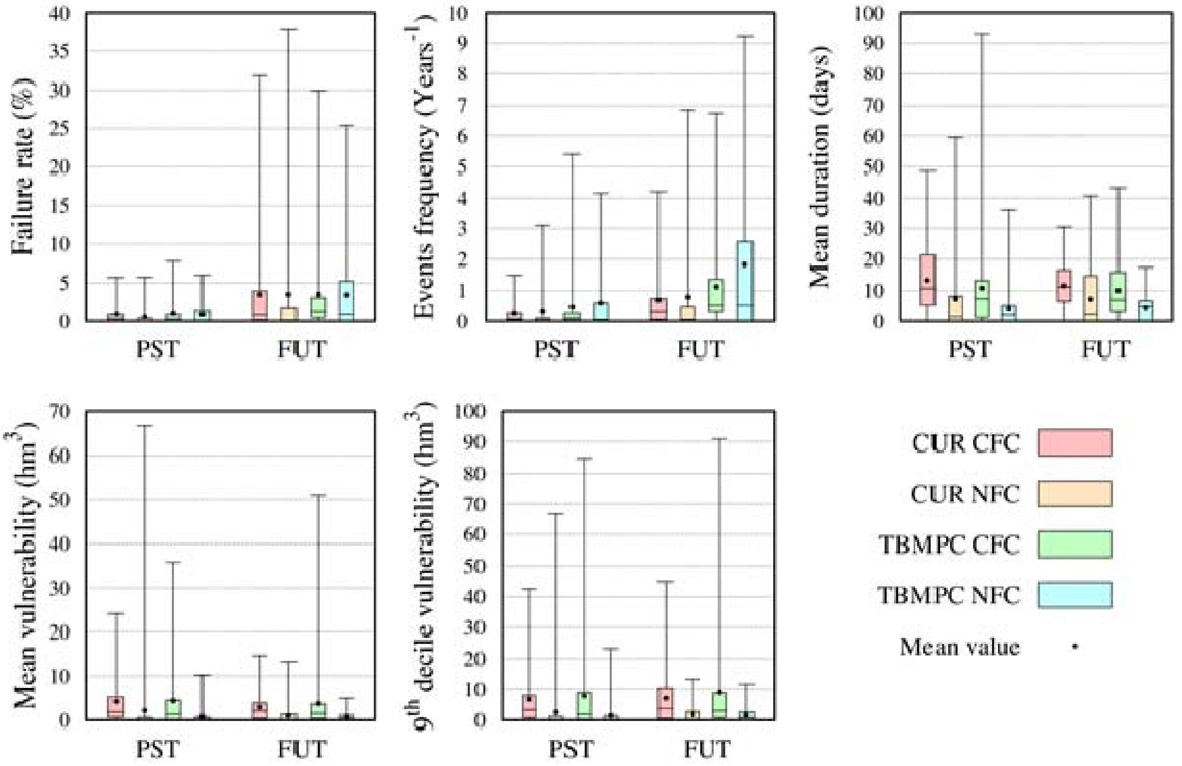


Figure 65: Performance indicators for the 3rd low-flow threshold (Reinforced alert) calculated from 7 GCMs scenarios in present (PST) and future (FUT) time for 4 management adaptations.

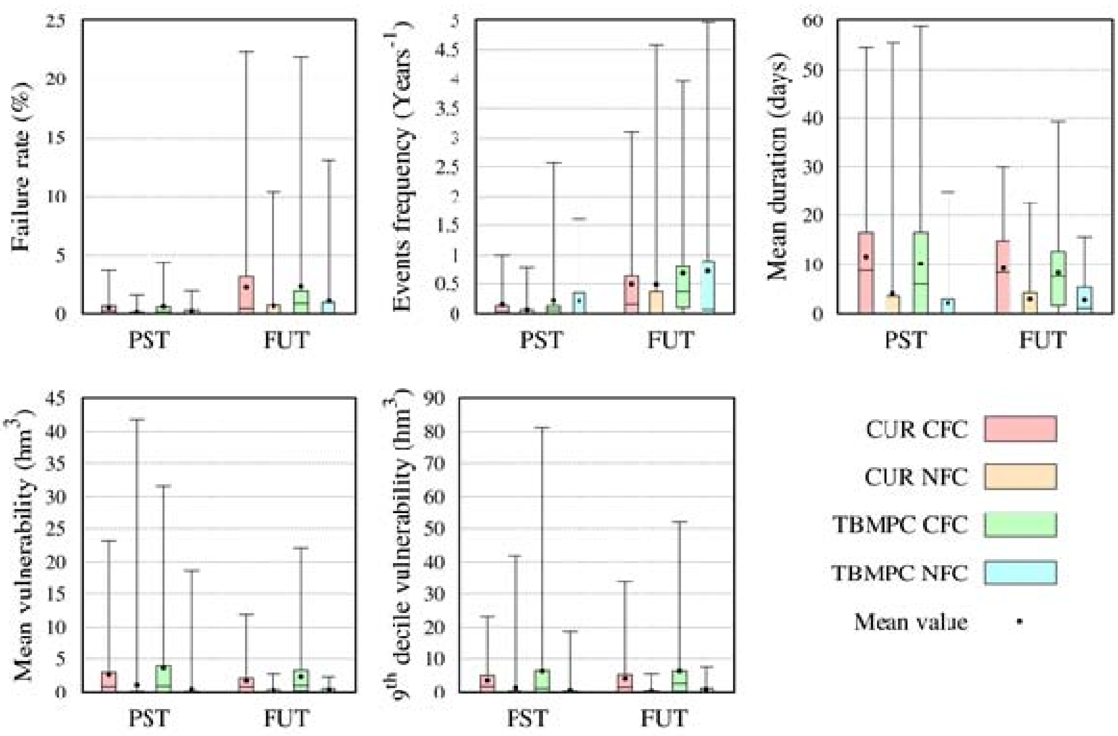


Figure 66: Performance indicators for the 4th low-flow threshold (Crisis) calculated from 7 GCMs scenarios in present (PST) and future (FUT) time for 4 management adaptations.

Concerning the last threshold for low-flow (Crisis) which can be considered as dramatic in term of water use restrictions, most of stations where the discharge goes beyond this threshold are downstream Pannecière Lake. This is because the capacity of this reservoir is weak and because low-flow thresholds at Gurgy gauging station are very high considering the natural regime of the river at this location. However, Figure 66 shows that the two management adaptations using new multi-objective filling curves (CUR NFC and TB-MPC NFC) are the most efficient in term of failure rate and vulnerability. They also considerably reduce the mean duration of these events which is a very important aspect considering water use restrictions.

2.2.3 CS 3 – AGRICULTURAL WATER USE, ITALY

Introduction

The knowledge of the variability of water balance components is a crucial information to face with water resources management and planning issues in semi-arid areas affected by climate changes and to achieve a more sustainable balance between water demand and water availability, through both short and long-term strategies. The assessment of climate change impacts requires the integration of physical and behavioural dynamics into a water balance framework able to face with problems of inter-sectoral supply and demand for water resources, and calls for a multidisciplinary approach. Coupled hydrologic-economic modelling has been used in literature for such aims and recent applications analysed profit optimization for different water use scenarios with respect to groundwater and surface water at basin level (Frede et al., 2002; Lanini et al., 2004; Ahrends et al., 2008; Varela-Ortega et al., 2011; Barthel et al., 2012; Dono et al., 2012).

Based on these premises, in the framework of CLIMAWARE project an integrated hydrological-economic model is proposed with the main objective of assessing the quantitative effects of climate change on water balance components and water use in the agricultural sector of the Italian Apulia region, in order to support the adoption of adaptation measures.

The proposed tool integrates a hydrologic GIS based model implemented in visual basic and MapWindow and a non-linear optimization model encoded in GAMS (General Algebraic Modelling System). The development and implementation of the hydrological model allows defining the water balance components (groundwater recharge, surface runoff, river flow, etc) at regional scale, referring in particular to water demand for irrigation scope. The model also allows estimating indirectly the groundwater abstraction.

The integration with the economic model allows simulating the real farmers' decision process in response to any changes both in the constraints and in the boundary conditions. The tool provides a comprehensive information framework including: water balance components, crops irrigation requirements, farmers choices in terms of cropping patterns and techniques; economic results (revenue, costs and incomes); environmental impacts (use of factors and resulting pressures on the system) .

As anticipated, the Italian case study focuses on the Apulia region (Figure 67), located in the southern part of Italy. The main physical and socio-economic features of this area are common to many Mediterranean parts with similar climate type, whereas agriculture is the primary resource for the local economy, and water related issues are closely interrelated: the increasing gap between water demand and supply, the water quality deterioration.

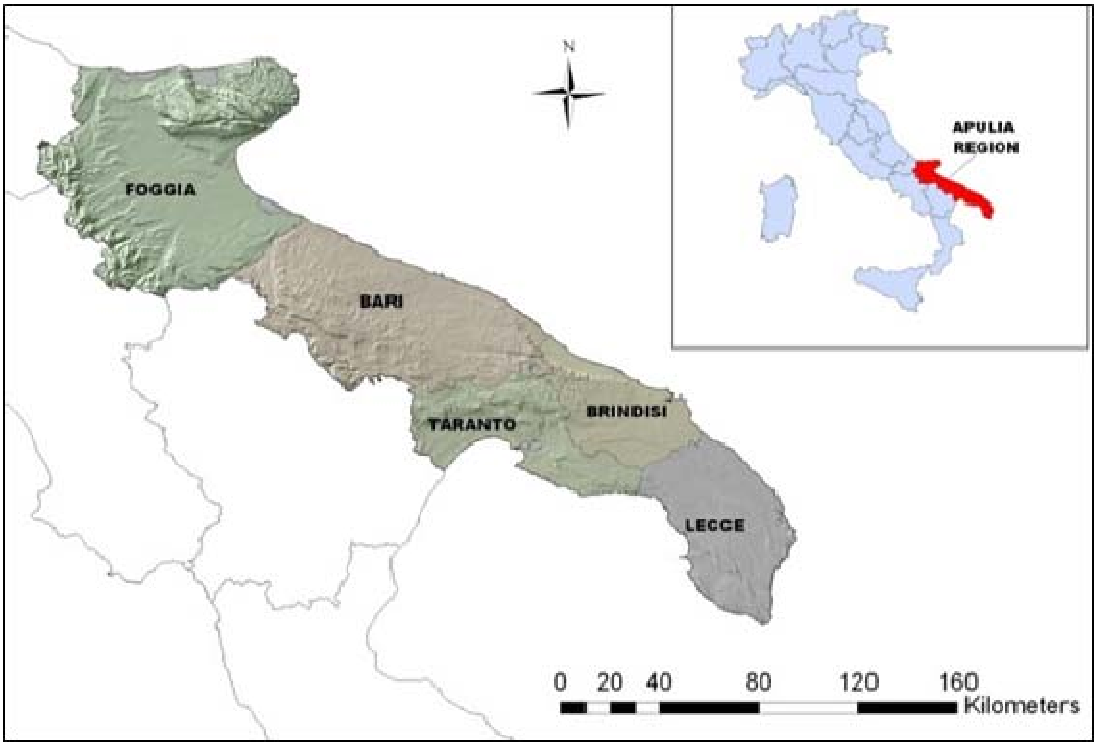


Figure 67: Location of Apulia region and its provinces: Foggia, Bari, Taranto, Brindisi and Lecce

In Apulia, the relatively flat landscape is largely occupied by agriculture; approximately 72 % of the total area is agricultural lands, the largest part is occupied by cereals (33 %) and olive trees (25 %) while the rest is mainly dominated by vineyards, fruit trees and vegetable crops. Cereals and vegetables are mainly grown in the fertile northern zone of the region, where water is made available to farmers through a large irrigation infrastructure managed by the Consortium of “Capitanata”, while olive trees and vineyards dominate the central and southern parts of the region, where surface water is almost completely absent and irrigated crops rely mainly on groundwater abstraction. As a result, groundwater levels are showing a decline with time (De Girolamo et al., 2002) and in some coastal areas sea water intrusion is observed (Polemio and Limoni, 2001).

In this final report the results obtained in the current conditions, considered as the baseline, and under different policy and climatic scenarios are presented. Results have been analysed in terms of water balance (crops irrigation water requirement, groundwater recharge, etc.) and agricultural sector performance.

The final results aim at making better use of water resources and at addressing the policy of water resources management for an efficient solution to the continuously aggravating drought problem.

The obtained results can add pertinent knowledge on the economics of adaptation to climate change impacts on agriculture and can be a support tool for the design of frameworks regulations and policy incentives effective and equitable for the society adapting to climate change.

Data

Climatic dataset

A climatic database is very important for the estimation of the water balance and it has to be representative of the area of interest. For the present study a representative database for one year, defined as a typical meteorological year (TMY) has been calculated starting from the available data period 1950-2007, called long-term measured data series. In the following figures are represented the annual precipitation and average temperature, respectively, referred to the TMY and spatialized over the entire region, using the Spline technique.

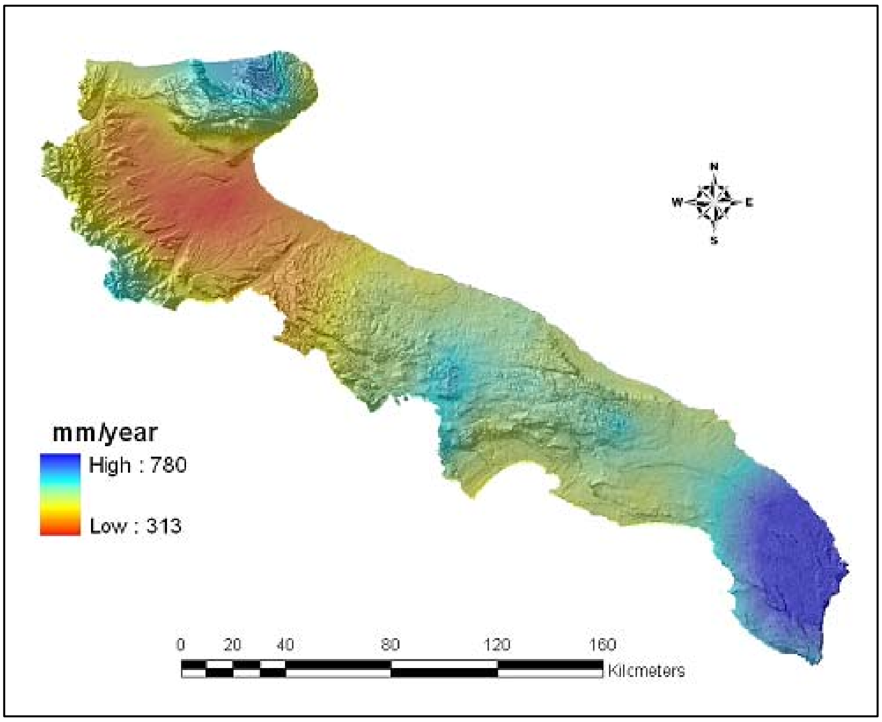


Figure 68: Annual precipitation for the TMY

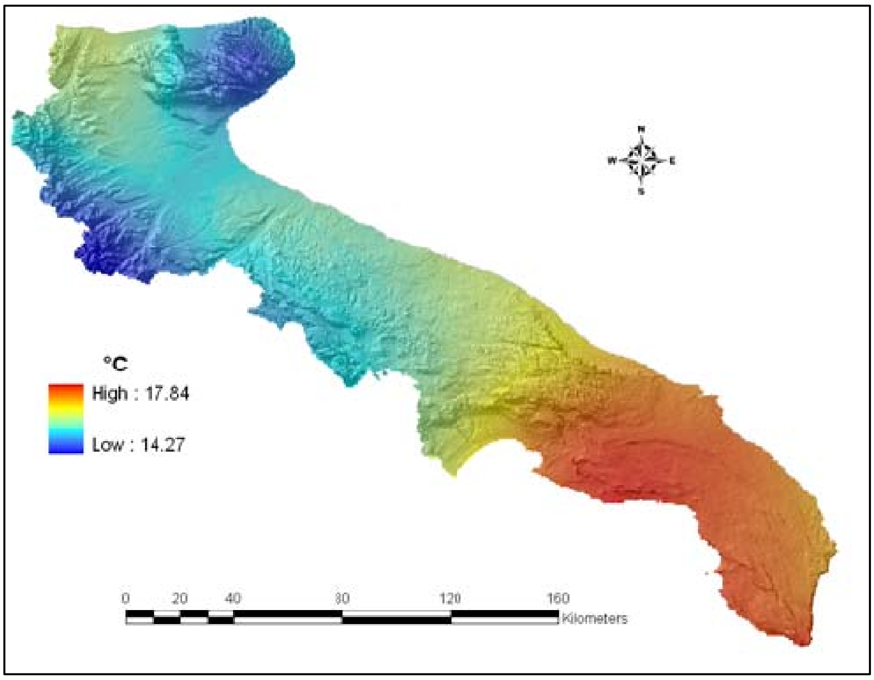


Figure 69: Annual mean temperature for the TMY

Soil dataset

The soil database of Apulia region consists of more than 4,000 sample collected within the ACLA2 project (Steduto et al., 1999; Steduto and Todorovic, 2001) to represent the soil of the entire region. Each sample contains general information on the site, such as slope, stoniness, morphology, texture, parent material, soil color, layer depth, permeability, etc.

Cainarca (1998) has estimated for a number of these samples the hydraulic characteristics of the soil using different pedotransfer function (Gupta and Larson 1979; Rawls et al. 1982; De Jong 1982; Saxton et al. 1986; Vereecken et al. 1989; Rawls et al. 1991), he has validated the obtained results against laboratory measurements and recommended for each soil type a specific pedotransfer function. Based on Cainarca (1998) study, the water holding capacity of the top 1 m soil depth was estimated for all soil samples starting from data of texture, bulk density and organic matter content, when available. To represent spatially the soil hydraulic characteristics, the average value of the total soil samples within each soil classification unit was assigned to that unit. As a result, a map of the Available Water Content (AWC) was obtained as illustrated in Figure 70.

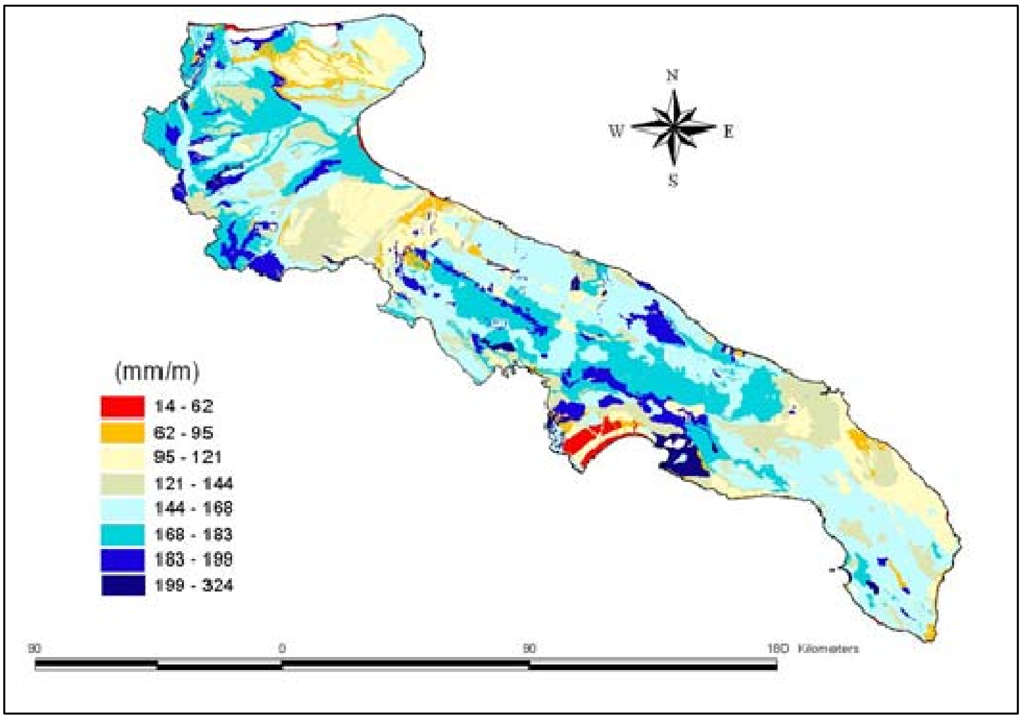


Figure 70: Available Water Content (AWC) per 1 m soil depth

Land cover dataset

For the land cover definition of the Apulia region, the CORINE map (European Environment Agency, 2006) has been used (Figure 71).

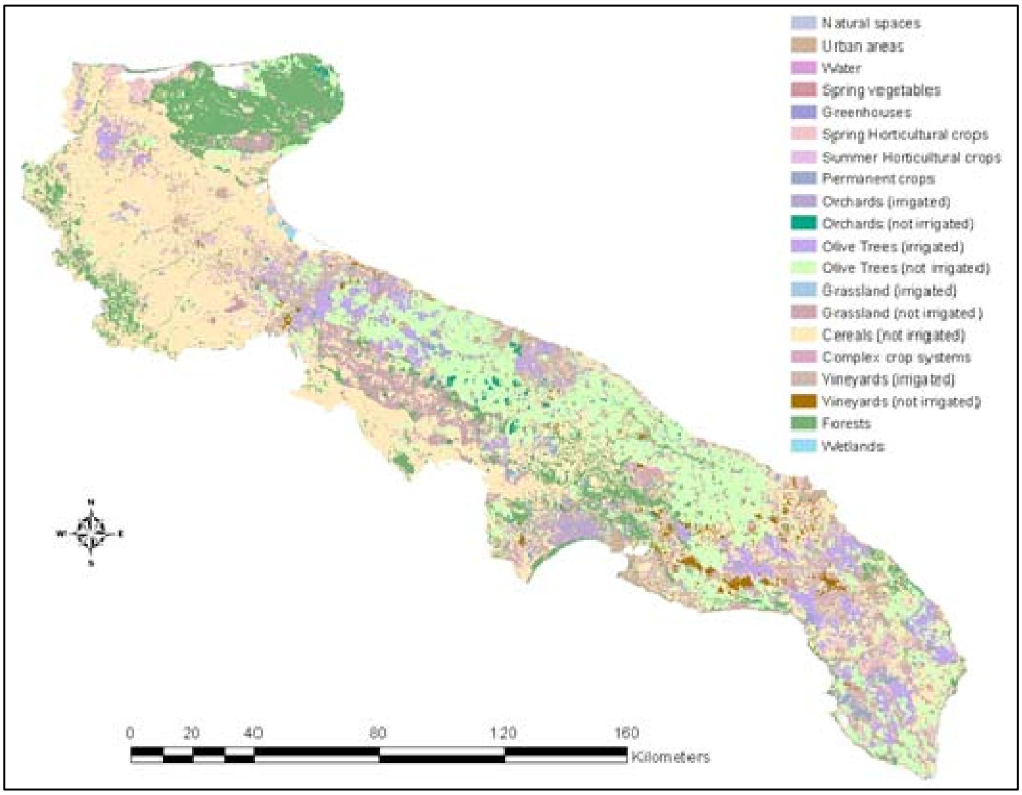


Figure 71: CORINE land cover map, 2006

Most of the land cover units *j* (i.e. vegetables…/ fruit trees….) enclosed in the map, refer to a series of individual crops *i* (tomato, potato, lettuce… / apple, peach…) that can have different growing season, cropped area and water requirement.

For that reason, the cropping area of each crop grown in the province (Foggia, Bari, Taranto, Brindisi and Lecce) was obtained from the national agricultural census (ISTAT, 2007) and appended to the land cover map in a way that every land cover unit j is assigned an average value of crop coefficient (Kc_j) and root depth (PR_j) that is weighted according to the area occupied by each crop *i* within that unit, as following:

$$\overline{Kc_j} = \frac{\sum_{i=1}^{N} Kc_i * A_i}{\sum A_i} \qquad \text{Equation 29}$$

$$\overline{PR_j} = \frac{\sum_{i=1}^{N} PR_i * A_i}{\sum A_i} \qquad \text{Equation 30}$$

PR_j	: *root depth of crop i within the land cover unit j (m)*
Kc_j	: *crop coefficient (Allen et al., 1998) of crop i within land cover unit j*
N	: *number of different crops i within the land cover unit j*
A_i	: *Surface area occupied by each crop i within the correspondent province (ha)*

Socio-economic parameters

Fixed costs, variable costs and prices were collected for the main crops in order to implement the economic model. Further, according to the water tariff scheme most used in the region, the cost of irrigation has been also considered.
The regional Farm Accounting Data Network (FADN) database, as the primary source for the structural and economic farm data, was combined with the data from the Ministry of Labour and Social Security on labour requirements for the different crops and the data provided by the reclamation and irrigation boards present in the Region.
All the data used were adequately integrated and checked both with experts and stakeholders and basing on the scientific literature during the preparation and calibration of the model.
The main economic parameters were collected for each type of farm and for each crop.

Methodology, Modelling Approach

The proposed integration between the two models includes different stages as represented in the following framework: i) The climatic data have been used for the calculation of the water response curves of different crops using the FAO crop model CropWat; the obtained curves have been then inserted in the economic model for the optimization of the crop water demand; ii) A linear programming model has been implemented for the identification of the optimal land use; iii) The new cropping pattern has been spatialized over the entire region using an automatic program developed in Excel and implemented in GIS for the production of the land use map; iv) The climatic data and the land use map have been used in the GIS based hydrologic model for the calculation of the water balance components (groundwater recharge, surface runoff and potential irrigation requirement).

The simulations are referred to the current conditions and to the future scenario of climate change.

In the following figure is represented the scheme showing how the proposed model works.

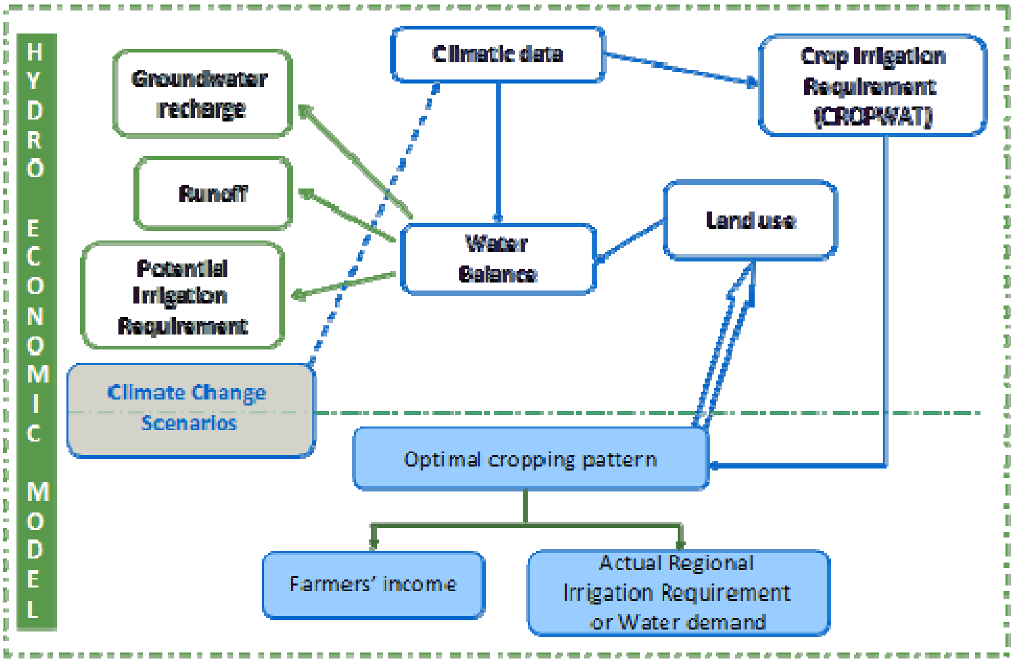


Figure 72: Framework of the proposed integrated model

Crop Irrigation Requirement

In order to implement the farm optimisation model, Net Irrigation Requirements (NIR) and yields for different crops grown in the case study area have been estimated. The NIR, expressed at monthly basis in m^3 ha^{-1}, were calculated using the FAO crop model CropWat, a tool designed by the Food and Agriculture Organization of the United Nations (FAO) to carry out standard calculations for design and management of irrigation schemes, and for improving irrigation practices. It is based on the approach of the daily water balance calculations used in the Irrigation and Drainage Paper Series 33 and 56 (Allen et al., 1998; Doorenbos et al., 1986). The curves of the crop response to water were obtained by applying different irrigation scenarios, starting from full irrigation that corresponds to the maximum (optimal) yield, and then reducing progressively the irrigation input until reaching rainfed conditions.

The economic model

To estimate agricultural water needs in Apulia region under future scenarios, the identification of the land use is required. Yet, farmers' decision in terms of cropping pattern and irrigation techniques is clearly affected by numerous factors such as climate conditions, water availability and market situation. Given the complexity of this decision process, farmers' decision-making should take into account the production methods, the seasonal periods and the quantities produced. Thus, farmers' decisions are subject to the prevailing farm physical and financial constraints, and often to a considerable uncertainty related to yields, prices and input costs. All these factors have been considered in the simulated scenarios. A linear programming model written in GAMS language was developed, integrating agricultural and institutional parameters such as crop production systems, cropping season, irrigation requirements, and water and labour costs. It aims at the identification of the optimal land use allocation of the Apulia agricultural surface as basis for estimation of the potential irrigation requirement.

The adopted methodology is widely applied in socio-economic analysis of agricultural farms and irrigated agriculture (Gómez-Limón and Berbel, 2000; Blanco Fonseca and Iglesias Martinez, 2005; Borresh et al., 2005; Buisson, 2005; Blanco Fonseca, 2007; Janssen and Van Ittersum, 2007; Saraiva and Pinheiro, 2007, Scardigno and Viaggi, 2007; Arfini and Donati, 2008; Marchand et al., 2008; El Chami et al., 2011; Louhichi et al., 2010; Varela-Ortega et al., 2011) to simulate farmer's decision process under different scenarios.

In this work, a non-linear, stochastic, single-year static mathematical programming model, named Climaware_2012, has been used to maximize expected farmer's utility taking into consideration several conditions such as: climate conditions; irrigation requirements and management techniques; monthly and total water availability/supply; prices of the products and agricultural input cost; water tariffs.

Agricultural farms in Apulia region have been distinguished by farm typology according to their structural specifications – average size, capital and labour availability – as well as socio-economic features as defined and identified in the Farm Accounting Data Network (FADN). Therefore, the optimization model used is a block aggregated model that represents all the area, where each block is referred to a macro-farm standing for the group of farms of the same type present in the area (Dono el al., 2008).

Climaware_2012 includes five sub-regional models, one for each of the following provinces: Bari, Brindisi, Foggia, Lecce and Taranto (BA, BR, FG, LE, and TA). Each sub-regional model comprises two components: a macro level component that corresponds to all the farms located in the province and a micro level component that corresponds to the blocks of the different types of farms present in the area. Eight specialist farm types have been considered: Field crops, Horticulture, Wine grapes, Table grapes, Olive, Fruits (including citrus), Livestock and Mixed. The adopted approach allows the analysis of the macro area highlighting though the differences and the specificities of the farms. The analysis of the agricultural system is performed by pursuing total economic efficiency, which leads to identifying the optimal solution for the system as a whole.

Climate conditions and soil properties were used to define the set of the crops that can be cultivated in the area while technical and agronomic considerations allowed defining the possible combinations among crops (C), irrigation techniques (T) and irrigation method (I). Twenty-six crops have been considered and grouped in six main classes as showed in the following table.

Table 2: Land use classes and corresponding crops

Land use classes	Crops
Field crops	durum and soft wheat, barley, oat, broad bean, sugar beet, maize, sunflower and grass meadows
Vegetables	broccoli, cabbage, celery artichoke, lettuce, potato, tomato, watermelon and zucchini
Orchard	cherry, peach, almond and citrus
Vineyard	table and wine grape
Pasture	/
Olive trees	/

Crops can be differently distributed over the year according to the planting and harvesting dates.

Four irrigation techniques (dry, complementary, partial and full irrigation) were considered, where: full irrigation is relative to the full satisfaction of the crop water requirements; partial irrigation is relative to the satisfaction of 75-85 % of the total crop water requirements; and complementary irrigation is relative to the satisfaction of 45-55 % of the total crop water requirements. Two irrigation methods (drip and sprinkler) with different field application efficiencies were also considered.

The model maximizes farmers' utility defined as the expected revenue minus its standard deviation due to risk averse towards price and yield variation (Equation 31).

$$\mathrm{MaxU} = \sum_{f} Z_f - \phi \cdot \sigma \qquad \text{Equation 31}$$

Where U is the expected utility; Z_f is the average net income (€) per farm type, f; φ is the risk aversion coefficient and σ is the standard deviation of the income distribution (€).

The average net farm income per farm type Z_f is defined as the difference between the gross margins and fixed and variable costs, except for the cost for irrigation water (Blanco Fonseca, 2007) and it is equal to the summation of the incomes resulting from different farm activities. The value of production refers to the product sold for final consumption or processed. Existing coupled subsidies have been also considered. Variable costs are given by the specific cropping expenses.

They correspond to the summation of specific crop expenses with costs for temporary labour and mechanization. Specific crop expenses include costs for seeds, fertilizers and pesticides; hire charges and so forth (fuel, insurance, and electricity). Labour costs exclusively include costs for wage-earning labour and not implicit costs relative to the family work.

Costs of irrigation water are separately considered. According to the water tariff scheme most used in the region, cost of irrigation included in the model consists of two different components: i) “the cost of water” given by the volume of water used multiplied by the price of water per cubic meter of water used for the considered crop; ii) a fixed water tariff to be paid for each hectare of irrigable land. Two different water sources were considered: in addition to the water supplied by the collective distribution network, the possibility of self-supply through wells was also taken into consideration. A binomial water tariff consisting of a fixed fee per hectare of irrigable land and a volumetric fee depending on the consumption was considered for the public water source. The cost for private water follows a similar structure with the cost of extraction rising with quantity, due to higher pumping costs for the progressive lowering of the water table level.

Prices were collected from records of the wholesale local market, and were integrated to generate the “endogenous prices” of different crops. The equilibrium price of a good in a supply and demand model is actually endogenous because it is set by a producer in response to consumer demand. Therefore, an “endogenous prices” formula taking into consideration the elasticity of crop price for any change in the demand has been considered.

The obtained income (Z_f) is the remuneration to factors of production of the family (Equation 32), i.e. land property, labour and capital. It is given by the following equation:

$$Z_f = \sum_{c,t,f,i} \left(Pr_c \cdot Y_{c,t,i} - V\cos t_{c,t,i} \right) \cdot X_{c,t,f,i} + \sum_{c,t,f,i} \left(Dpay_{c,t} \cdot X_{c,t,f,i} \right) - \sum_{c,t,f,i} \left(K\cos t_c \cdot X_{c,t,f,i} \right) - \left(Wtarif \cdot ILand_f \right) - \left(Pr\,Wat \cdot QW_f \right) - \left(Pr\,Lab \cdot QLab_f \right) \quad \text{Equation 32}$$

Where $X_{c,t,i,f}$ are the decision-making variables representing the area cultivated by crop type (c), irrigation technique (t), irrigation method (i) and farm typology (f); Pr_c is the average crop price (€ ql^{-1}); $Y_{c,t,i}$ is the crop yield (ql ha^{-1}); $dpay_{c,t}$ subsidies under the Common Agricultural Policy (€ ha^{-1}); $Vcost_{c,t,i}$ are the variable costs (€ ha^{-1}); $Kcost_c$ is plantation cost (€ ha^{-1}); $Iland_f$ is irrigable land (ha); Wtarif is the fixed water tariff per unit area (€ ha^{-1}); PrWat is volumetric water tariff (€ m^{-3}); QW_f is the annual amount of used water (m^3); PrLab is the labour salary (€ hr^{-1}); $QLab_f$ is the annual amount of used labour (hr).

Two different sources of risk were considered: a “market risk” affecting commodity prices and a “nature risk” affecting yields and standard deviation of farm income (€) is given by the following (Equation 33):

$$\sigma = \sqrt{\sum_{kp,ky} \frac{\left(ZK_{kp,kp} - z \right)^2}{N_{kp,ky}}} \quad \text{Equation 33}$$

Where $ZK_{kp,ky}$ is the random income (€); $N_{kp,ky}$ is the number of states of market and nature; Kp are the states of market [1-10] and ky is the state of nature [1-10].

The random net income $ZK_{kp,ky}$ is calculated using the same equation applied for calculating the expected income Z; the unique difference was the average price ($price_c$) replaced by the random price ($price\_k_{c,kp}$) over state of market (kp) where $price\_k_{c,kp}$ is the vector of independent random numbers normally distributed (i.e. they are calculated using a normal distribution function based on the average and the standard deviation of price (Pr_c) and average yield ($Y_{c,t,i}$) is replaced, by the random yield ($Yield\_k_{c,ky}$) over state of nature (k_y) where $yield\_k_{c,ky}$ is the vector of independent random numbers normally distributed (i.e. they are calculated using a normal distribution function based on the average and the standard deviation of yield). The main constraints adopted by the model include: total and irrigated land constraint; agronomic constraints; labour and water constraints. A specific constraint is considered for olive trees since they are protected by law for the historical and cultural value they reflect.

The Risk Aversion coefficient was used for calibration using the mean standard deviation approach. The model was run for different values of the coefficient in a range between 0 and 1.65 and the simulated results were compared with the observed data. The percentage absolute deviation (PAD) parameter was used to validate the parameter between observed at 2007 (ISTAT, 2010) and predicted values (Equation 34).

$$PAD = \sum_{i=i}^{n} \left| X_i^o - X_i^P \right| \div \sum_{i=i}^{n} X_i^o \qquad \text{Equation 34}$$

Where X_i^o is the observed value of the variable and X_i^P is the predicted value.

The Risk Aversion coefficient that gives the lower PAD value is used for scenario testing (Janssen et al., 2010). The PAD values obtained are lower than 9 % for all the provinces, indicating a good level of the model calibration. The regional Farm Accountancy Data Network database has been used as primary source for the structural and economic farm data and combined with the data from the Ministry of Labour and Social Security on labour requirements for the different crops. All the data used were adequately integrated and checked both with experts and stakeholders and basing on the scientific literature during the preparation and calibration of the model. The model has been built and calibrated toward 2007 data and validated towards 2006.

For each simulation, optimal farmers’ choices related to cropping patterns and agri-techniques have been identified, and the effects of such choices on farm revenues, costs and incomes have been estimated. Results have been obtained for each provincial model and then aggregated on the regional scale.

Further, the information about land use re-allocation were spatialized over the entire region using an automatic program developed in Excel and implemented in GIS for the production of maps.

The hydrologic model

The model used is GIS based and implemented in visual basic and MapWindow (Lamaddalena et al., 2008). It has a simple structure since keeping the number of parameters as low as possible allows both a more accurate determination of the parameters and a more reliable correlation of the values obtained (Dooge, 1977). The model combines information coming from different cartographic layers, and as outputs it produces thematic maps illustrating the parameters of the water balance and the volumetric irrigation needs.

The simulated soil water balance is composed of two connected subsystems: the first represents the water dynamics in the root zone while the second represents the phenomenon of the natural groundwater recharge. The monthly soil moisture content variation is summarized hereafter:

$$\delta w / \delta t = P - ET_c - RO - RO_{sub} - GW_r + Irr \qquad \text{Equation 35}$$

Where: P is the monthly precipitation (mm); ETc is the crop monthly evapotranspiration (mm); RO is the monthly surface runoff (mm); ROsub is the monthly subsurface runoff (mm); GWr is the monthly groundwater recharge (mm) and Irr is the monthly irrigation applied (mm).

The reference evapotranspiration (Equation 36) is calculated using the modified version of the Hargreaves-Samani equation (Raziei and Pereira, 2013):

$$ET_0 = 0.0135 \cdot k_{RS} \cdot \frac{R_a}{\lambda} \sqrt{(T_{max} - T_{min})}\,(T + 17.8) \qquad \text{Equation 36}$$

Where Ra is the extraterrestrial radiation, and is the latent heat of vaporization (MJ kg-1) for the mean air temperature T (°C), that is commonly assumed equal to 2.45 MJ kg-1. 0.0135 is a factor for conversion from American to the International system of units and kRs is the radiation adjustment coefficient, commonly equal to 0.17 (Samani, 2004).

Crop evapotranspiration (ETc) is estimated using Allen et al. (1998) methodology (Equation 37), where reference evapotranspiration (ET0) is adjusted by a correction factor known as crop coefficient (Kc) which depends mainly on the crop type, variety and growth stages:

$$ET_c = K_c \cdot ET_0 \qquad \text{Equation 37}$$

The climatic data and the reference evapotranspiration were imported into the GIS and transformed into a continuous surface of 2 km^2 resolution. These maps were finally intersected with the map containing the land use information, referred to the land cover classes, where each class encloses a series of crops with different growing season, cropped area and water requirement. An average value of weighted crop coefficient and root depth according to the area occupied by each crop within the corresponding class was then assigned to each class. Irrigation requirements for each class of crops (Equation 38) are estimated by applying the soil water balance, through the following equation:

$$NIR = ET_c - P_{eff} \qquad \text{Equation 38}$$

Where P_{eff} is the effective precipitation (mm), i.e. the amount of precipitation effectively used by crop excluding the runoff and deep percolation losses.

The surface runoff is calculated based on the SCS curve number method (US Soil Conservation Service, 1972), which estimates the amount of runoff based on local land use, soil type and

antecedent moisture condition. Curve number is computationally efficient and does not require detailed information on soil surface conditions or rainfall (Connolly, 1998). The infiltration below the root zone is partitioned into groundwater recharge and sub-surface runoff, using the coefficients of potential infiltration which depends on the lithology of the soil (Celico, 1986).
The hydrologic model was calibrated by varying the coefficients of potential infiltration (Celico, 1986) (Table 3) that directly influences the rate of the infiltration below the root zone.

Table 3: Coefficients of potential infiltration for each hydrogeological complex

Hydrogeological Complex	Coefficients of potential infiltration (%)
Limestone	90-100
Dolomitic limestone	70-90
Dolomite	50-70
Marly limestones	30-50
Coarse debris	80-90
Alluvial deposits	80-100
Clay-marly-sandy deposits	5-25
Lavas	90-100
Pyroclastic deposits	50-70
Pyroclastics and lavas	70-90
Intrusive rocks	15-35
Metamorphic rocks	5-20
Sands	80-90
Clayey sands	30-50

A satisfactory calibration was considered to be when the coefficient minimized the difference between the simulated and the observed level of groundwater recharge.

Based on the available data, monthly groundwater recharge volumes for the representative aquifer of Tavoliere (Figure 73), situated in the province of Foggia, and for three different years of observations 2008-2009-2010 were selected for calibration.

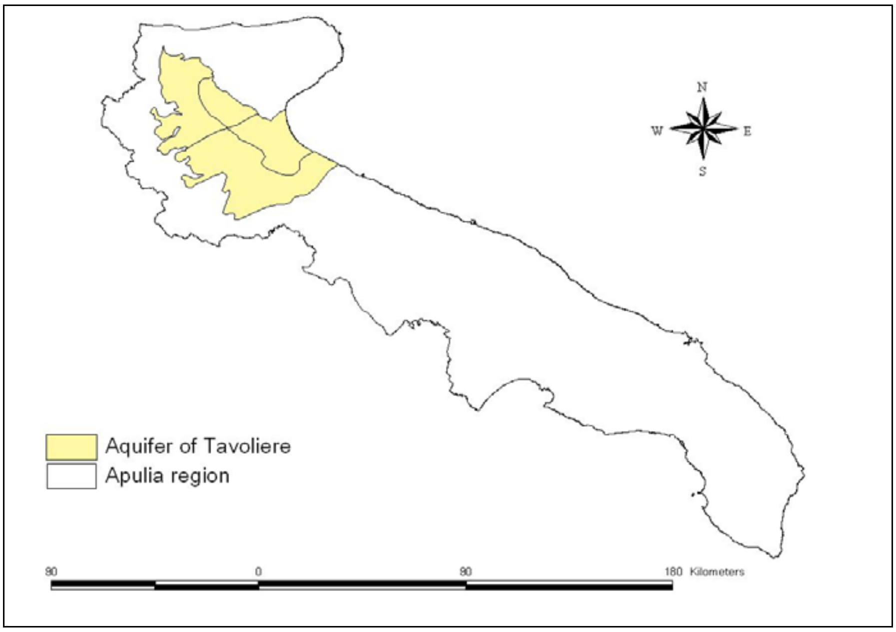


Figure 73: Location of the aquifer of Tavoliere

The observed data of groundwater recharge were available for the 56 sampling points showed in Figure 74.

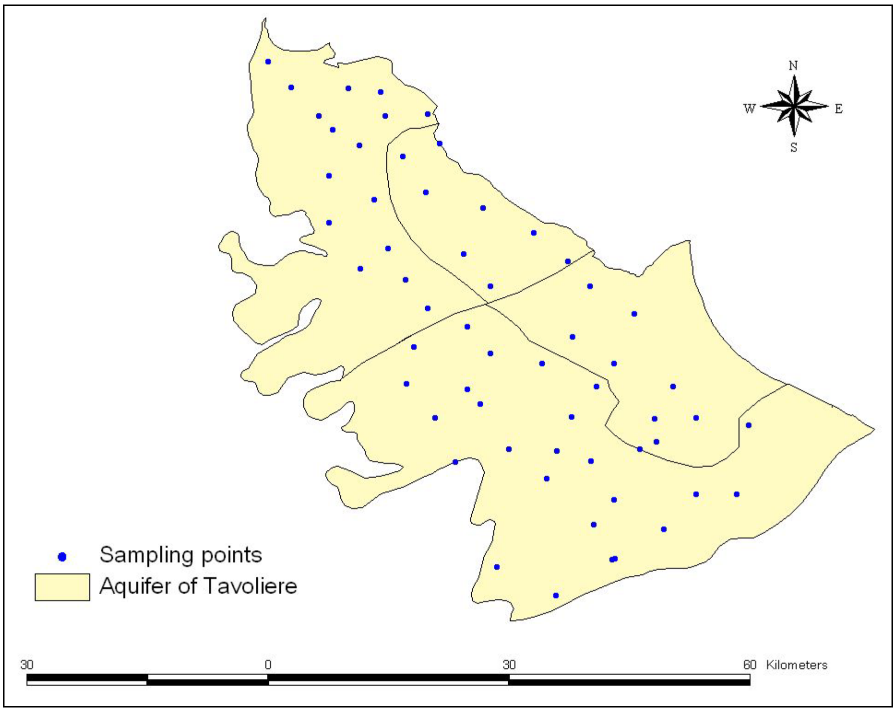


Figure 74: Location of the sampling points in the aquifer of Tavoliere

The simulation results were compared to the observed recharge volumes and each of the coefficients' values were varied as necessary to reach a good fit. The goodness of the fit between the simulated versus observed monthly recharge was assessed using the square regression equation R^2.

As an example, Figure 75 shows the measured and simulated monthly recharge for the test period May-November 2008, for each of the sampling points having a recharge value different from zero.

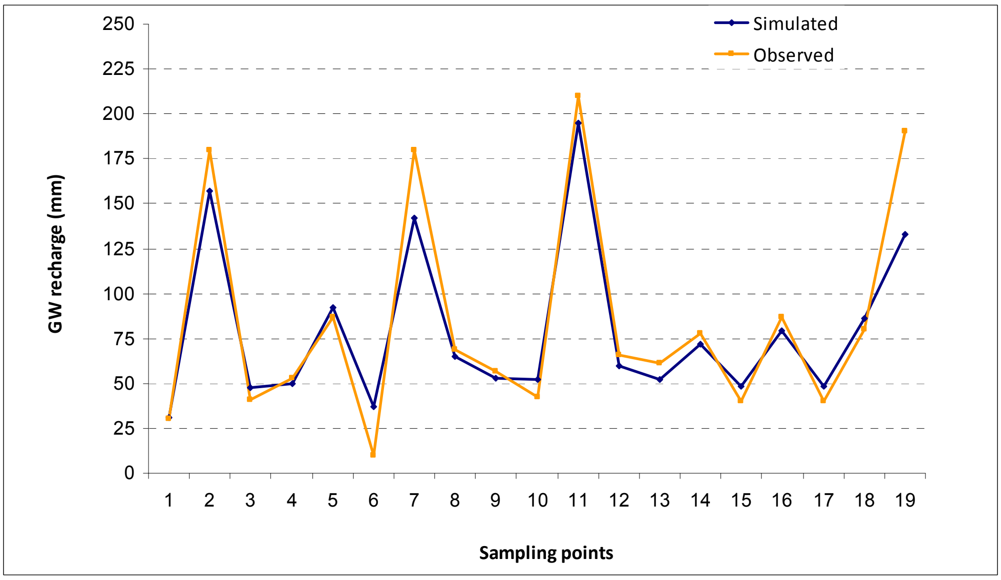


Figure 75: Measured and simulated monthly recharge for the test period May-November 2008

The graphical comparison highlights a general degree of agreement between the observed and simulated trends, which illustrates the ability of the model to simulate the hydrological behaviour of the aquifer.

The model was run after calibration and validation for the whole Apulia region to simulate the water balance components under actual conditions and future scenario of climate change. For the simulation of the water balance under the scenario of climate change, the land use generated by the economic model was used as input.

Climate change Scenarios

A climate change scenario was adopted and applied to the case study in order to analyse water balance components under different climate conditions. The selected scenario was based on the results of the CIRCE project that assessed the climate change projections and impacts in the Mediterranean area (Gualdi et al., 2013), adopting the A1B emission scenario of the IPCC-SRES for greenhouse gases and anthropogenic aerosol concentrations (Nakićenović and Swart, 2000).

The global high-resolution model used to perform the climate change projections generated in CIRCE is the AOGCM, implemented by INGV-CMCC. It is composed by the model ECHAM 5.4 (Roeckner et al., 2003) as atmospheric component and the model OPA 8.2 (Madec et al., 1998) as oceanic component. The atmospheric model is implemented with a horizontal resolution of about 80 km.

Climate change projections of temperature and precipitation have been extrapolated and data have been spatialized over the entire region using the geostatistical technique of Kriging (Figure 76 and Figure 77).

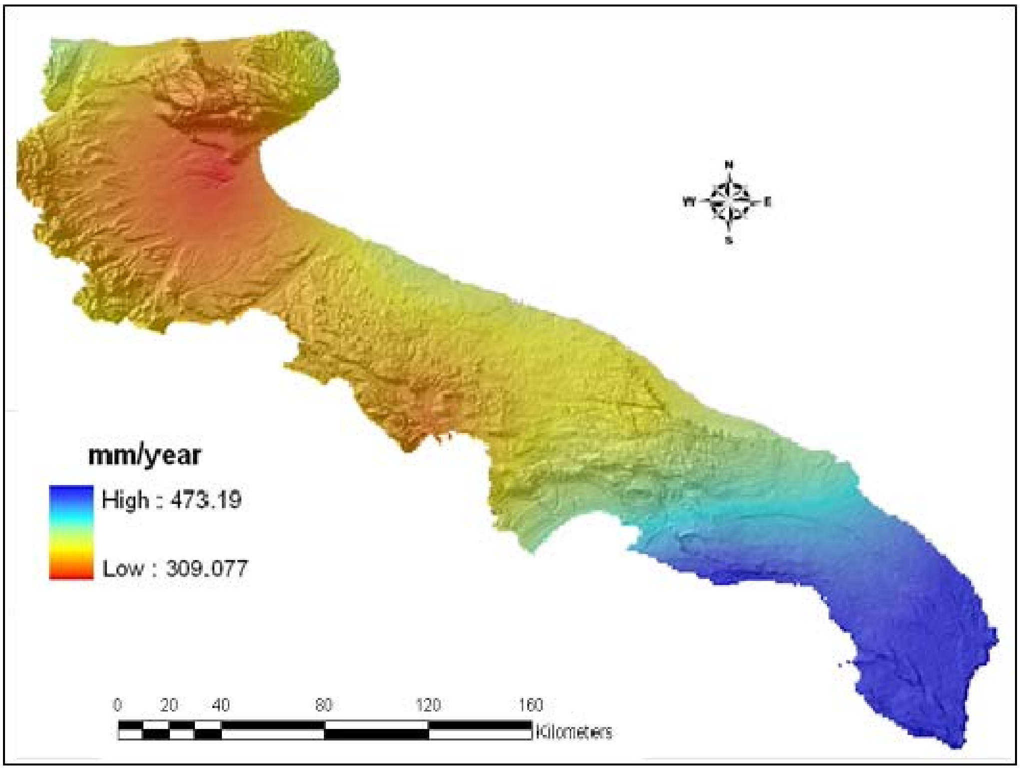


Figure 76: Projections of annual precipitation (mm/year)

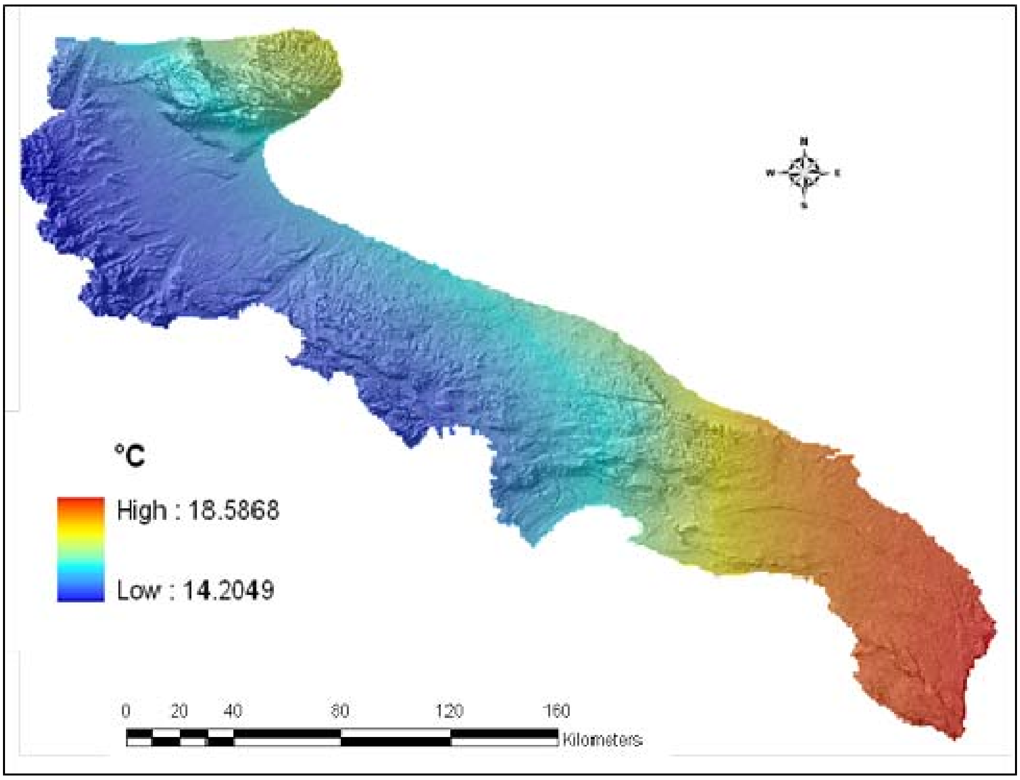


Figure 77: Projections of annual mean temperature (°C)

Future precipitation and temperature were used as climatic input in the hydrologic model.

Sensitivity analysis

Uncertainty may manifest itself in different ways in integrated hydro-economic modelling and differ fundamentally between different disciplinary realms (economics, hydrology, ecology), in terms of their underlying sources, characteristics and size. In order to face in a consistent way with different types of uncertainty in input data, model structure, parameter values, and model results, scenario and sensitivity analysis approaches can be used (Katz, 2002).

Therefore, in order to capture some of the uncertainty in the combinations of the economic and hydrologic variables in the proposed integrated tool, four different climate change scenarios (Table 4) were used. They derive from the combination of two global high-resolution models used to perform the climate change projections with the data of anthropogenic aerosols concentration and distribution, according to two different emission scenarios.

Table 4: Climate change scenarios

Global high-resolution model	**Emission scenario**	
	A2	B1
CNRM-CM3	CNRM-CM3 -A2	CNRM-CM3 -B1
IPSL	IPSL-A2	IPSL-B1

The Centre National de Recherches Météorologiques Coupled global climate Model version 3 (CNRM-CM3, Center National Weather Research, METEO-FRANCE, Toulouse) is based on the coupling of ARPEGE-Climat version 3 AGCM, OPA 8.1 ocean model, GELATO2 sea ice model and TRIP river routing scheme.

The global IPSL coupled model (Institut Pierre Simon Laplace des Sciences de l'Environnement Global) is based on the integration among the atmosphere model LMDZ-4, the land-vegetation model ORCHIDEE, the oceanic model ORCA and the sea ice model LIM.

The A2 and B1 are the emission scenarios of the IPCC-SRES for greenhouse gases and anthropogenic aerosol concentrations.

The A2 scenario is characterized by a world of independently operating, self-reliant nations; continuously increasing population and a regionally oriented economic development. The B1 scenario is characterized by a rapid economic growth with rapid changes towards a service and information economy; population rising to 9 billion in 2050 and then declining; reductions in material intensity and the introduction of clean and resource efficient technologies and an emphasis on global solutions to economic, social and environmental stability.

The four scenarios have been used as input to assess the hydrological sensitivity of proposed integrated tool to climate change within a reasonable interval where hydrological sensitivity is defined as the response of the model to a known quantum of climate change expressed in terms of changes to precipitation and potential evapotranspiration and resulting in changes to crop evapotranspiration, runoff and groundwater recharge (Jones et al. 2006).

In the following tables, Table 5 and Table 6, monthly percentage variation of temperature and precipitation for the considered scenarios are presented.

Table 5: Monthly variation of precipitation in the different scenarios (%)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CNCM3 A2	-38.9	-48.9	-17.4	-55.2	-59.9	-2.4	-2.2	51.1	-15.9	1.9	-31.7	-30.1
CNCM3 B1	-23.7	-16.7	-7.7	-26.8	-54.3	-13.3	-17.2	-12.9	-5.6	-3.5	-29.3	7.8
IPSL A2	9.0	-9.5	15.2	-33.3	-44.3	-18.0	13.0	-54.2	-46.6	-32.3	-27.3	19.4
IPSL B1	9.8	-7.5	-22.4	-32.3	-18.2	18.7	-37.1	-47.6	-20.7	-7.4	-6.8	1.9

Table 6: Monthly variation of temperature in the different scenarios (%)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CNCM3 A2	19.5	28.8	25.9	24.0	15.0	12.7	12.1	11.8	12.9	12.5	16.5	18.6
CNCM3 B1	16.6	20.4	16.0	16.2	10.7	10.1	8.9	11.5	10.4	8.4	11.1	18.1
IPSL A2	25.4	21.0	20.6	18.0	13.2	12.9	13.7	12.9	12.0	13.6	20.1	23.0
IPSL B1	18.2	18.4	18.0	15.0	9.0	9.3	11.6	13.1	10.7	12.6	21.2	20.1

Results

Simulation results for the NIR of the main crops cultivated in the case study area have been estimated for both baseline and cc scenario (Table 7).

Table 7: Results of NIR for the coupled model

Crop	Scenarios	Province				
		BA	BR	FG	LE	TA
Durum wheat	NIR t3_base	2,655	2,718	2,275	2,719	2,625
	NIR t3_cc	2,820	3,994	2,672	3,875	2,785
Potato	NIR t3_base	5,075	5,076	4,567	5,085	5,198
	NIR t3_cc	5,480	6,793	5,039	6,703	5,295
Tomato	NIR t3_base	5,400	4,996	4,987	5,323	5,297
	NIR t3_cc	5,516	6,855	5,082	6,764	5,339
Olive tree	NIR t3_base	3,184	3,973	3,165	3,980	4,003
	NIR t3_cc	5,124	6,446	4,785	6,266	4,947
Citrus tree	NIR t3_bas	3,391	4,450	4,083	4,448	4,818
	NIR t3_cc	5,454	6,882	5,123	6,738	5,294
Table grape	NIR t3_base	3,368	3,842	3,472	–	3,713
	NIR t3_cc	4,858	5,916	4,432	–	4,630

The highest water consuming crops in the region are orchards, tablegrape and vegetables.

The comparison of NIR between baseline and cc scenario shows a significant increase in the amount of water required for full irrigation technique for almost all crops in all the region as effect of the increased crop evapotranspiration, due to the increase of temperature, and the decrease in the precipitation that affects the water content in the soil available for crops.

The following figures (Figure 78 and Figure 79) show the olive and the citrus change in response to water in the two simulated scenarios: for the optimal production in the climate change scenario higher amounts of water are required, while maintaining the same amount of water given in the baseline scenario, reduced levels of production are obtained.

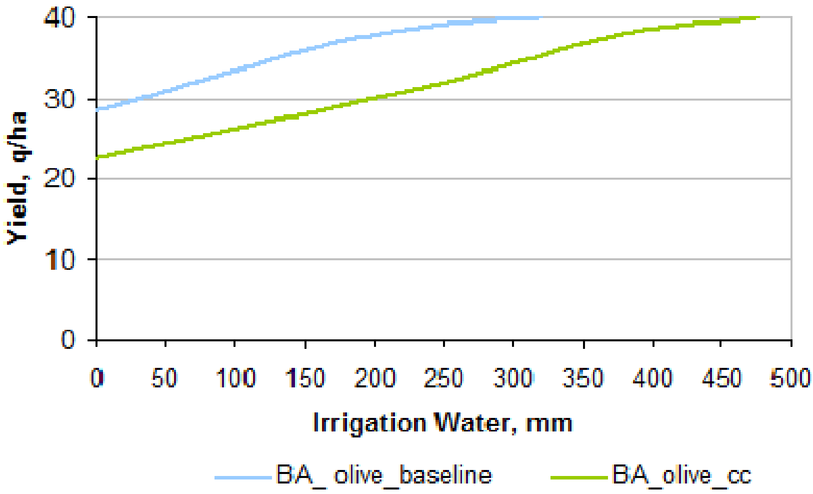


Figure 78: Future change in water response of Olive Tree

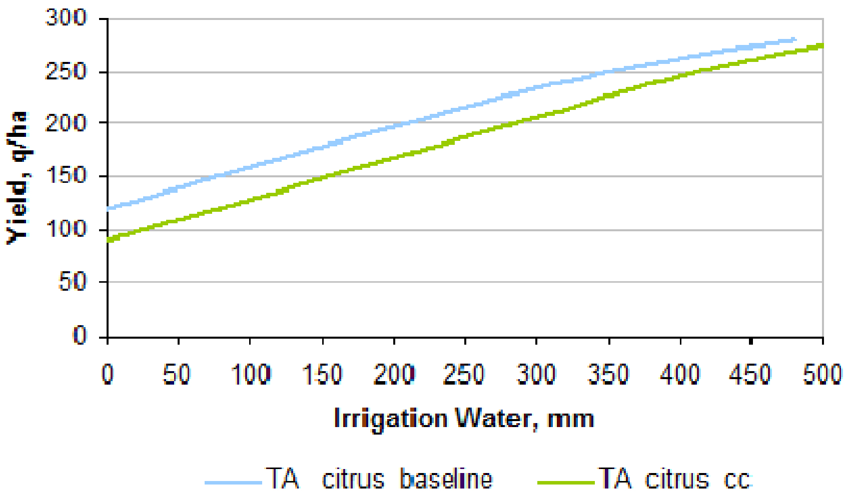


Figure 79: Future change in water response of Citrus

The results obtained for the baseline and climate change scenario in the region show that the total cultivated land is reduced by 8.5 % in the cc scenario and the percentage of irrigated land decreases from 31 to 22 % of the total agricultural land. Comparing land uses in the baseline and cc scenario, results reveal that the total area planted with field crops declines by 15 %, vineyard and vegetables by 54 % and 22 % respectively. This change is coupled with a rise of pastures by

31 % and orchard by 12 %. Olive trees remain constant given the specific surface constrain included in the model (Figure 80).

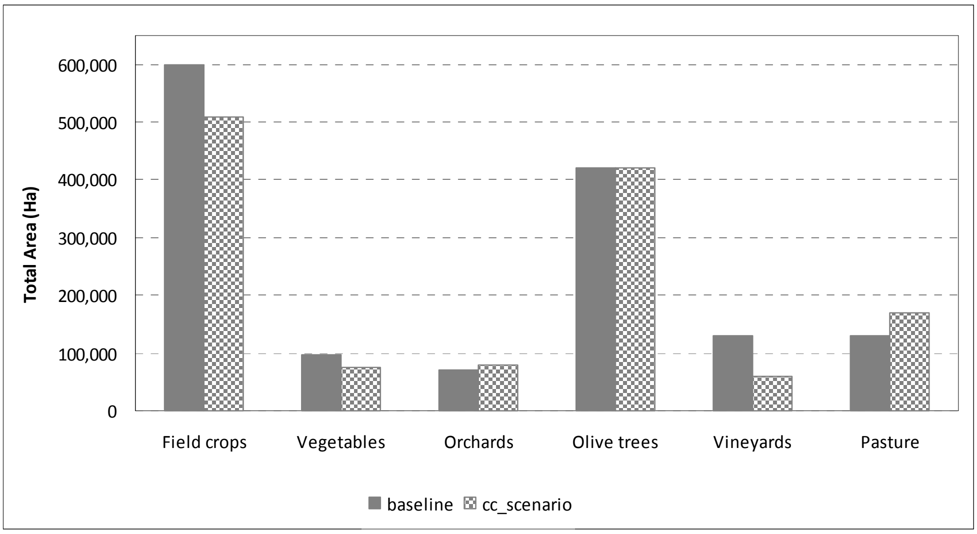


Figure 80: Land use change in the future with respect to the baseline scenario

In terms of irrigation techniques in the cc scenario complementary and partial irrigation are applied on the 50 % of the total irrigated surface in comparison with 42 % registered in the baseline.

Considering an unchanged number of farms, the average net income per farm over the year calculated at around 29,300 € in the baseline scenario, is reduced to 18,500 € in the new climatic scenario: in both scenarios farms specialized in table grapes, horticulture and fruit show better performances while the occurring changes in climate weight on farms specialized in olive, wine grapes and fruit more than other farm types (Figure 81).

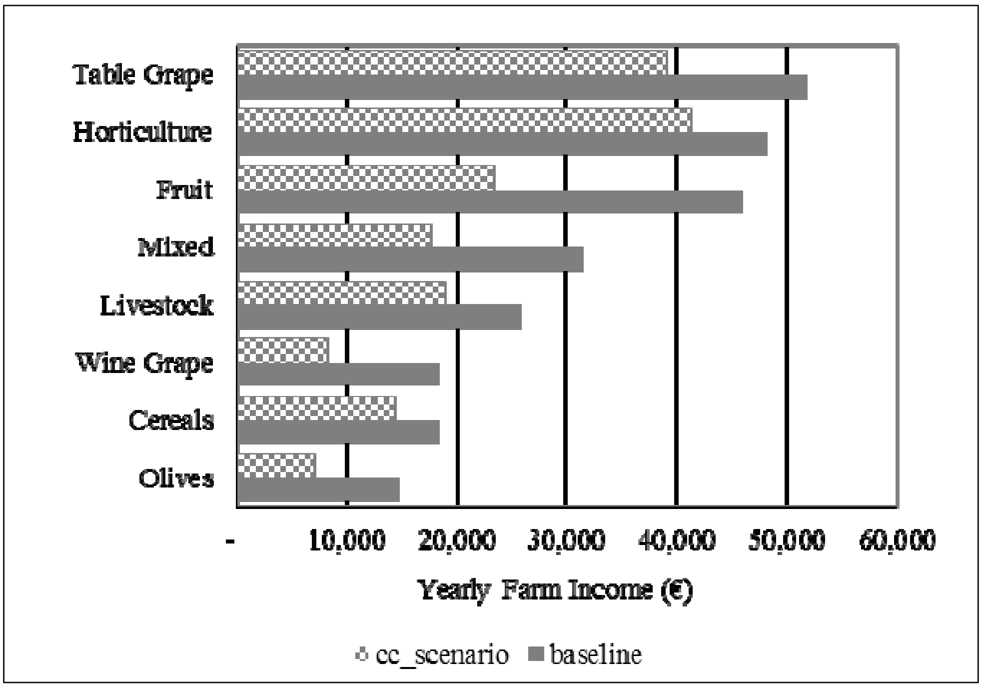


Figure 81: Change in net farm income due to climate change scenario

The reduction in the net farm income is mainly due to a decrease of total revenue not compensated by decrease of variable costs. Total revenue declines as effect of a drop in crop sales while payment of Common Agricultural Policy remains quite stable since they are quite completely decoupled from production.

The land use generated by the economic model has been used as input for the hydrologic model to estimate the water balance components under current conditions and future scenario. Irrigated areas decline from 480,712, as resulted from the updated map of land use, to 362,055 ha. The reduction of irrigated areas together with the variation in the cropping pattern and the adoption of the different irrigation techniques lead to a decrease of water demand for irrigation distributed all over the region.

Results of the hydrologic model in terms of potential irrigation requirements for the current conditions and for the future scenario of climate change have been spatially represented in Figure 82 and Figure 83.

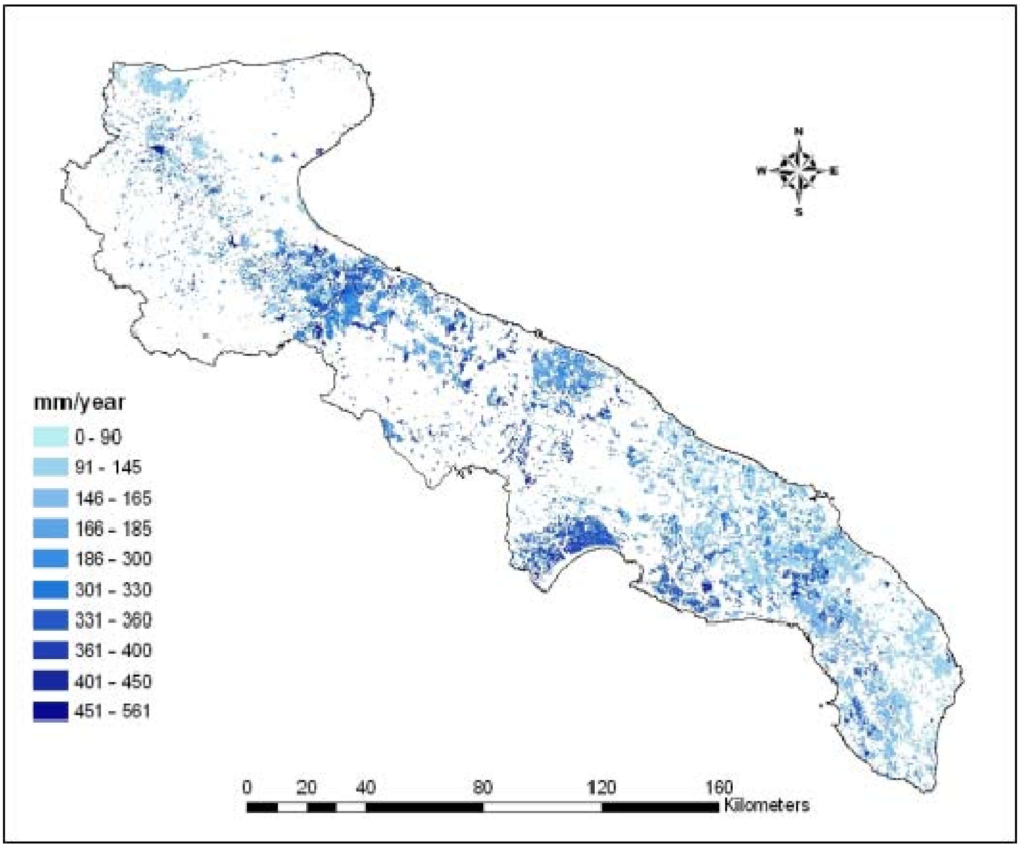


Figure 82: Current potential irrigation requirements (mm/year)

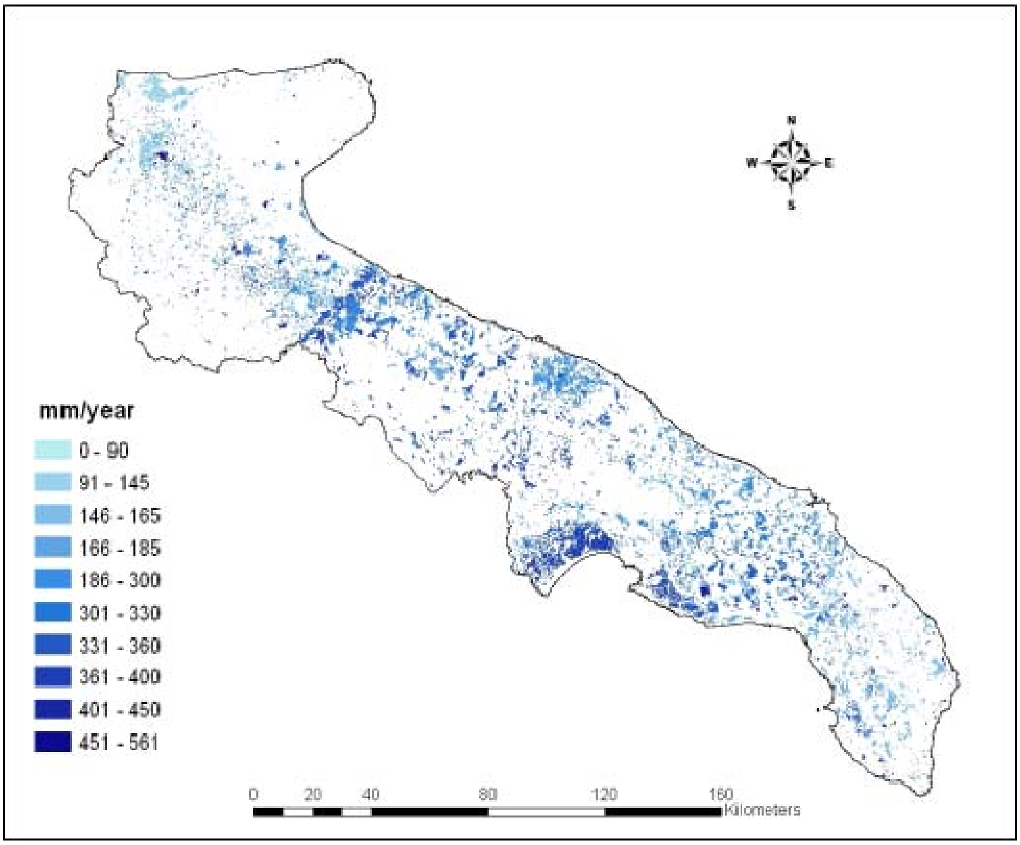


Figure 83: Future potential irrigation requirements (mm/year)

The following table (Table 8) shows the results of the irrigation requirements per each province of the region for the current conditions and the future scenario:

Table 8: Provincial irrigation water requirements (IWRs)

Provinces	Irrigated Area (1000 ha)		IWR – Present		IWR – Future	
	Present	Future	Mm^3	$m^3\ ha^{-1}$	Mm^3	$m^3\ ha^{-1}$
Bari	120.92	118.20	307	2541	271	2292
Brindisi	76.06	50.57	144	1894	122	2418
Foggia	117.51	88.27	240	2050	174	1974
Lecce	100.03	45.82	183	1839	90	1976
Taranto	66.20	59.19	191	2889	176	2973

The reduction is more evident in the province of Lecce that shows a radical change from high value crops, such as vegetables and vineyards, to less water demanding crops.

Groundwater recharge and surface runoff estimation, under current conditions and future scenario of climate change are listed in the following table (Table 9).

Table 9: Groundwater recharge and surface runoff

Provinces	Current conditions		Future scenario	
	Runoff	GW	Runoff	GW
	Mm^3	Mm^3	Mm^3	Mm^3
Bari	552	711	441	603
Brindisi	309	325	273	266
Foggia	1200	377	994	320
Lecce	452	590	441	430
Taranto	299	316	242	267

Groundwater recharge is referred to the amounts of water filling the groundwater reservoir and is a useful tool for groundwater resource planning and management (groundwater protection area delineation, pumping network design, etc.). The main recharge areas correspond to the geological units more permeable with soil cover quite thin and vegetation cover shallow rooted (thus reducing the field capacity and augmenting the amount of water available for deep infiltration). In the provinces of Bari and Lecce, where overlying deposits are very thin, the groundwater recharge is maximised in the region.

Table 9 shows that water availability expressed in terms of groundwater recharge and surface runoff appears to be reduced all over the region in the future scenario of climate change compared to the current situation and this is due to the reduced precipitation. In order to adapt to the future minor availability of water, farmers change the cropping pattern and reduce the irrigated areas.

For the sensitivity analysis, regression index was used in order to understand the dependence of the output parameters of the hydrological model, that are irrigation requirements, surface runoff and groundwater recharge, on the climatic input parameters, that are precipitation and temperature.

The variation of the input parameters was obtained running the model under the 4 different climatic scenarios previously described, that allowed to assess the range of possible values that each output parameter could assume, depending on the precipitation and temperature in input.

In the following table (Table 10) are reported the ranges of variation between the minimum and the maximum value of each output parameter for each province.

Table 10: Range of variation of each output parameter, expressed in Mm^3, for each province

Provinces	Irrigation Requirement		Surface runoff		GW recharge	
	Min	*Max*	*Min*	*Max*	*Min*	*Max*
Bari	271	399	285	453	401	603
Brindisi	122	175	182	284	181	266
Foggia	174	266	680	994	228	320
Lecce	90	183	437	657	280	430
Taranto	176	245	164	251	179	267

The variation reported in Table 10 can be explained observing the coefficient of determination (R^2) of the regression, which describes the percentage of the dependence of the output on the inputs, i.e. precipitation and temperature. The values of R^2 for each output parameter and for each province are reported in Table 11.

Table 11: Values of R2 for each output parameter and each province

Provinces	R^2		
	Irrigation Requirement	**Surface runoff**	**GW recharge**
Bari	0.90	0.81	0.66
Brindisi	0.88	0.91	0.82
Foggia	0.87	0.70	0.53
Lecce	0.86	0.92	0.79
Taranto	0.93	0.84	0.69

As showed in Table 12, the lowest values of R^2 are referred to the parameter groundwater recharge, meaning that the variation of such component is not only directly dependent on the precipitation and temperature. In fact, an important input variable influencing the rate of groundwater recharge is the permeability of the soil geologic layers.

To assess the role of the adaptation measures that farmers adopt to mitigate adverse effects of climate change, the effects of changing climate scenarios were simulated under fixed conditions of farm management. Results showed that the quantity of water required for irrigation strongly depends on the land use. In fact, in the scenarios characterized only by changes in climate, the irrigation demand is higher respect to the case of combined changes in climate, crop selection and farm management (Figure 84).

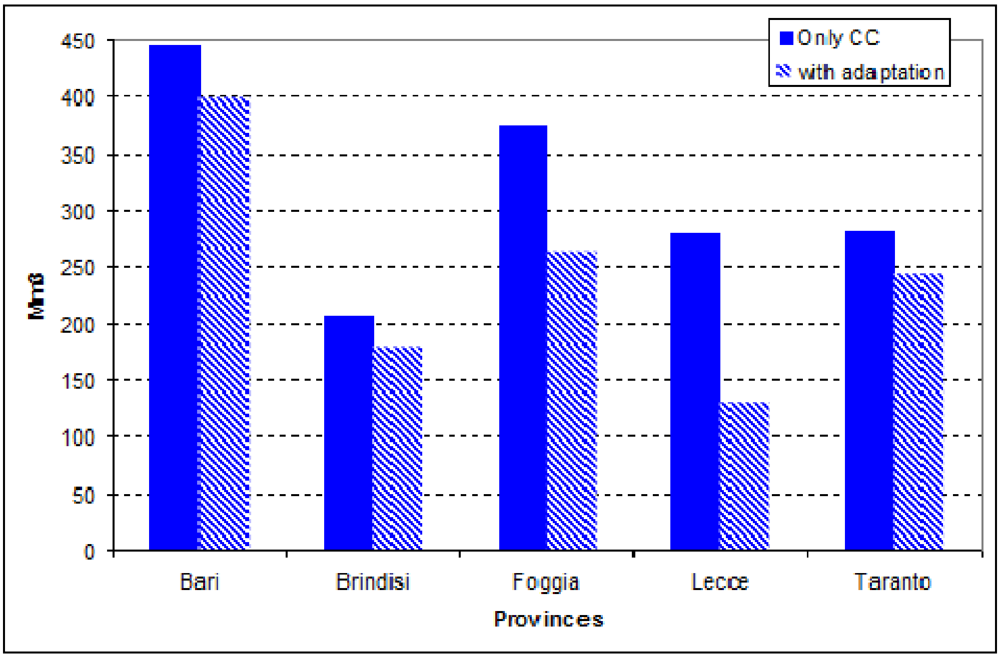


Figure 84: Crop irrigation requirements in climate change scenarios with and without adaptation, for each province

Impact and adaption

In a changing climate scenario, changes in the farm management confirm to be a key component in adapting agriculture and farmers to local conditions to meet their needs of food (Howden et al., 2007; FAO, 2010). Apulian farmers adopt different strategies in their farm management in order to adapt and/or mitigate adverse effects of climate change. First of all, they reduce the irrigated surfaces. Secondly, they shift toward less water intensive techniques: in the cc scenario complementary irrigation is applied on the 31 % of the total irrigated surface in comparison with 16 % registered in the baseline. Further, there is an effect of crop substitution and dangerously there is a serious phenomenon of land abandonment since a substantial area of the region traditionally or recently used by agriculture will not be cultivated anymore. Results also show that, notwithstanding the complex farm strategies adopted, farm income is seriously affected by future climate conditions.

These results put in question the overall sustainability of the agricultural systems that is supposed to increase productivity to meet food security. Accordingly, the socio-economic sustainability is also vulnerable with an income reduction for farmers of about 37 %.

The obtained results were discussed with local experts in water management in order to identify other potential adaptation measures to climate changes. The discussion highlighted the need for enhancing some of the consortia management tasks, namely the survey of the irrigation demand, to optimize the water allocation, above all in view of the future reduced availability. In addition, the development of a drought early warning system, capable to provide the consortia with reliable and timely forecast of water volume in the reservoirs would support water management activities as well. Moreover, the experts proposed some infrastructural interventions aiming to increase water availability. The reduction of the irrigation system vulnerability to drought could be achieved by enhancing the interconnection with other sources of water, both conventional and non-conventional. The former requires the development of new storage and delivering infrastructures. The latter needs reliable water treatment plants. Besides, the re-use of reclaimed water needs to deal with cultural barriers related to the willingness of farmers to use this water for irrigation. Technical assistance and knowledge transfer processes could facilitate the achievement of this goal.

2.3 CROSS SCALE AND CROSS CASE ANALYSES

The main objective of this Chapter is to provide an integrative view of current and future water resources by combining and analysing modelling outcomes from the European and the case study scales. The impact of climate change and future socio-economic developments as described by a range of plausible and comprehensive scenarios from the SCENES project on the hydrological situation as well as water demand are analysed through cross-case (Eder-Seine-Apulia) and cross-scale (European-case study) comparisons. While the cross-scale analysis focuses on the comparison of the European perspective (represented by large-scale modelling results) with the case study outcomes, the cross-case comparison envisaged a knowledge transfer regarding adaptation strategies across the different cases.

2.3.1 CROSS-SCALE ANALYSIS

Introduction

In the cross-scale analysis, the large-scale modelling provides an overview of the status of water resources in terms of water quantity for the European continent. It allows to identify patterns of change and to look beyond regional borders to compare the situation across countries and (transboundary) river basins. More detailed analyses were carried-out in the case studies based on regional-specific information and local knowledge. Finally, case study outcomes are used to improve the European modelling. This process stimulates the interchange of experiences and the knowledge transfer between project partners as well as the dissemination to stakeholders and decision makers (see also Chapter 4).

The cross-scale assessment takes a systems approach and analyses the continental and regional freshwater system with its connections between “drivers”, “pressures”, “state variables”, “impacts” and “responses” according to the DPSIR framework (see example in Figure 85).

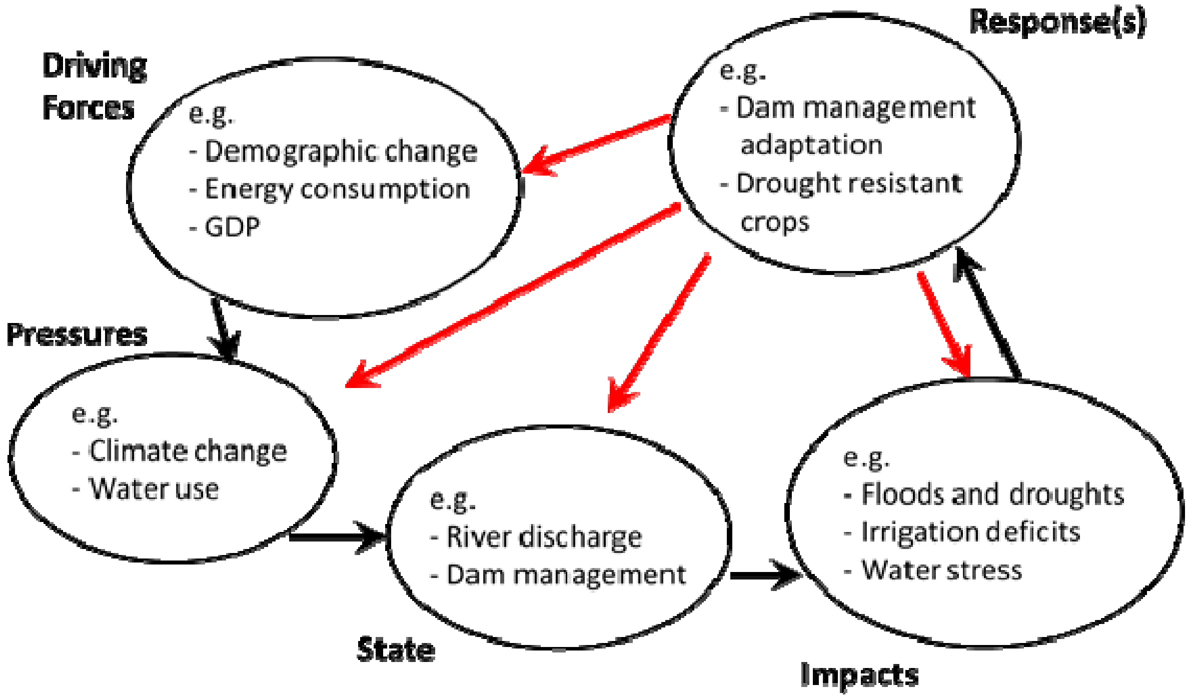


Figure 85: Example for the DPSIR framework applied in ClimAware

In the following, future results are presented as ensemble means of the selected GCM projections (i.e. CNCM3, ECHAM5, and IPSL) for both the SRES A2 and B1 emission scenarios. Next to climate change impacts, water use scenarios were considered, and hence, the SRES A2 and B1 scenarios were combined with the SCENES scenarios Economy First (A2-EcF) and Sustainability Eventually (B1-SuE), respectively. This allows (i) showing different pathways into the future and the potential effects of adaptation measures and (ii) addressing climate uncertainty with the use of a range of GCM projections. All scenarios and climate change inputs are described in Chapter 2.1, however, the same datasets were used for the case studies in the cross-scale analysis. Model runs for the baseline (1971-2000) and for the 2050s (2041-2070) were carried-out with WaterGAP3 to calculate water availability and water use of five water use sectors (domestic, manufacturing, thermal electricity production, irrigation, and livestock).

CS 1 – Eder River, Germany

Drivers

Population

The Eder River can be described as rural area with no major industries. In comparison to the other two case studies, the Eder basin has the lowest population density (~120 people / km^2). According to the assumptions made in the SCENES project for urban and rural population in Germany in the 2050s, future population is declining in the Eder basin by 10.7 % under the EcF scenario and 3.3 % under the SuE scenario with less urbanisation.

Gross Domestic Product (GDP)

According to the EcF scenario, GDP is expected to increase in Germany over the whole time period from about 1974 billion const. 2000 US$ in 2005 to 3194 billion const. 2000 US$ in 2050. The SuE scenario draws a different picture of the future where GDP decreases to 1054 billion const. 2000 US$ in 2050. Although population is expected to decline in the SuE scenario, income steadily decreases over the next fifty years.

Pressures

Climate change

In the Eder River basin, changes in mean annual precipitation seem to be minor in the 2050s (Table 12). While the ensemble mean out of the three different climate projections shows an increase by 2.4 % under the SRES A2 scenario compared to the baseline, mean annual precipitation decreases by 3.4 % under the SRES B1 scenario. Even when analysing each projection solely, the uncertainty range due to the chosen climate scenario realisation is between -9.4 and +9.9 %. Nevertheless, mean annual temperature could be increasing by 2.2°C on average under the SRES A2 scenario. Under the lower emission scenario SRES B1, the increase could be lowered at the Eder River by 0.5°C in the 2050s.

Table 12: Change in climate variables at the Eder River in the 2050s provided as ensemble mean for the SRES scenarios A2 and B1 including uncertainty range due to the GCMs

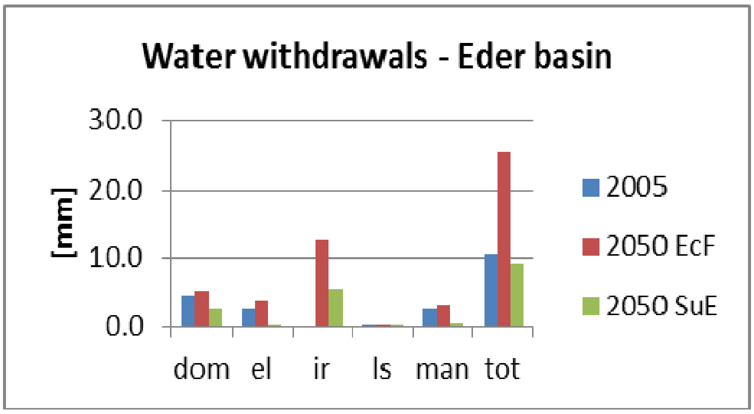
Eder	2000s	2050s (ens. mean)	uncertainty GCM
Precipitation (A2)	901mm	+2.4%	(-9.2 to 9.9%)
Precipitation (B1)	901mm	-3.4%	(-9.4 to +3.0%)
Temperature (A2)	8.0°C	+2.2°C	(+1.6 to +2.5°C)
Temperature (B1)	8.0°C	+1.7°C	(+1.3 to +2.2°C)

Water use

The Eder basin is characterized by low population density and less industrial activities resulting in low water withdrawals for the domestic and industry sectors. In the year 2005, total water withdrawals amount to 10.5 mm of which 44.5 % were abstracted by households and small businesses (Table 13). In comparison to the other two case studies, the lowest value for water withdrawals was found. According to land use change simulations, irrigated agriculture will become an option in the future to increase agricultural output, i.e. increasing yields due to warmer climate and optimal water supply. As a result, water withdrawals will increase up to 25.5 mm in EcF despite a decrease in population. Total water withdrawals are expected to decrease under SuE, however, most of the water is abstracted for irrigation purposes.

Table 13: Water withdrawals at the Eder River for the years 2005 and 2050 considering an Economy First and a Sustainability Eventually scenario

Eder	2005 [mm]	2005 [% share]	2050 EcF [mm]	2050 SuE [mm]	2050 EcF [% change]	2050 SuE [% change]
dom	4.7	44.5	5.4	2.8	+15.7	-39.9
el	2.8	26.3	4.0	0.2	+43.6	-93.6
ir	0.0	0.0	12.6	5.5	>100.0	>100.0
ls	0.3	2.7	0.3	0.2	-7.2	-19.9
man	2.8	26.5	3.3	0.5	+17.4	-81.1
tot	10.5	100.0	25.5	9.2	+143.4	-12.4



State variables

River discharge

The European maps in Chapter 2 show a north-south divide for change in mean annual water availability for the 2050s. The Eder River is located in the transitional zone where the different climate change projections show no clear trend in the direction of change. While ECHAM5-A2-driven WaterGAP simulations indicate a small increase (+8.3 %) in mean annual water availability, CNCM3-A2 and IPSL-A2 projections result in a small (-5.4 %) and even stronger decrease (-39.2 %), respectively (Figure 86). However, regarding seasonal changes of water availability, the model simulations agree in direction of change for the summer period (JJA), the time when often low flows prevail in Europe. On average, future ensemble mean water availability is expected to decrease by 37.5 % in summer and 21.8 % in autumn (SON) compared to the baseline conditions.

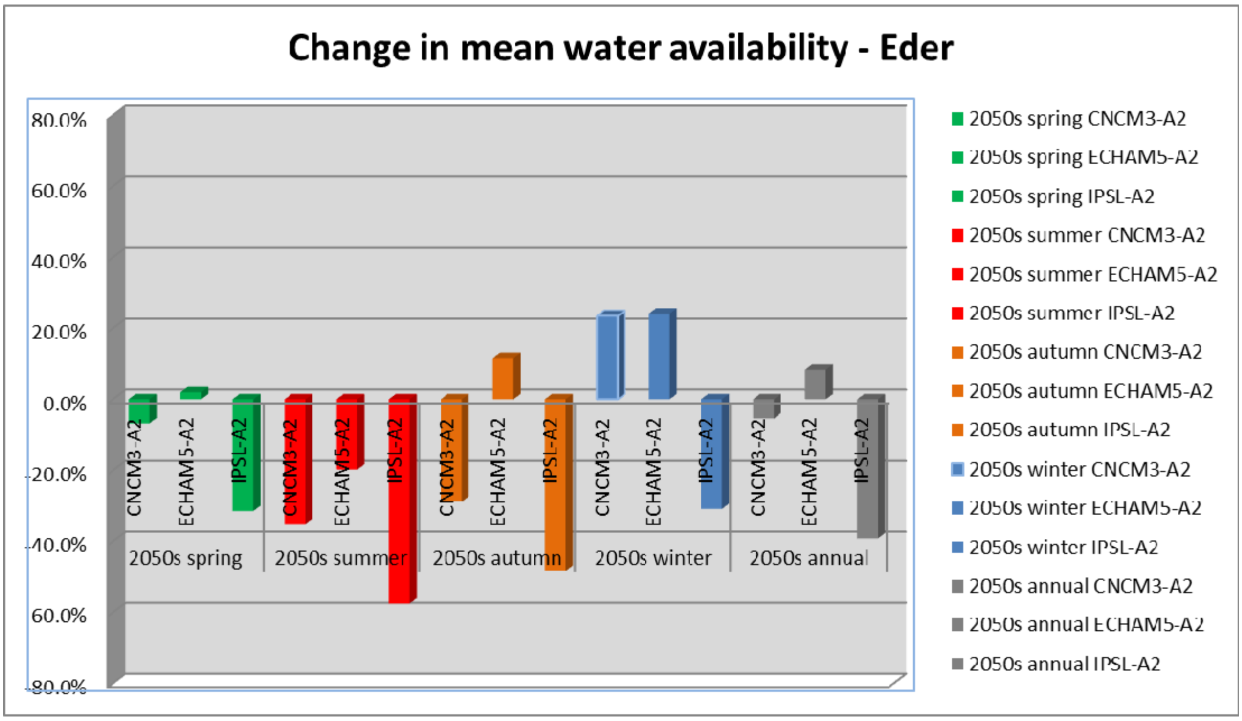


Figure 86: Change in mean seasonal water availability in the 2050s driven by three different GCMs (CNCM3, ECHAM5, and IPSL) under the SRES A2 emission scenario.

Assuming the SRES B1 emission scenario, results for change in mean water availability are less contradictory (in comparison to SRES A2) indicating a reduction in river flows throughout the year (Figure 87). Here, the decline in summer flows is slightly lower (-33 %) for the ensemble mean.

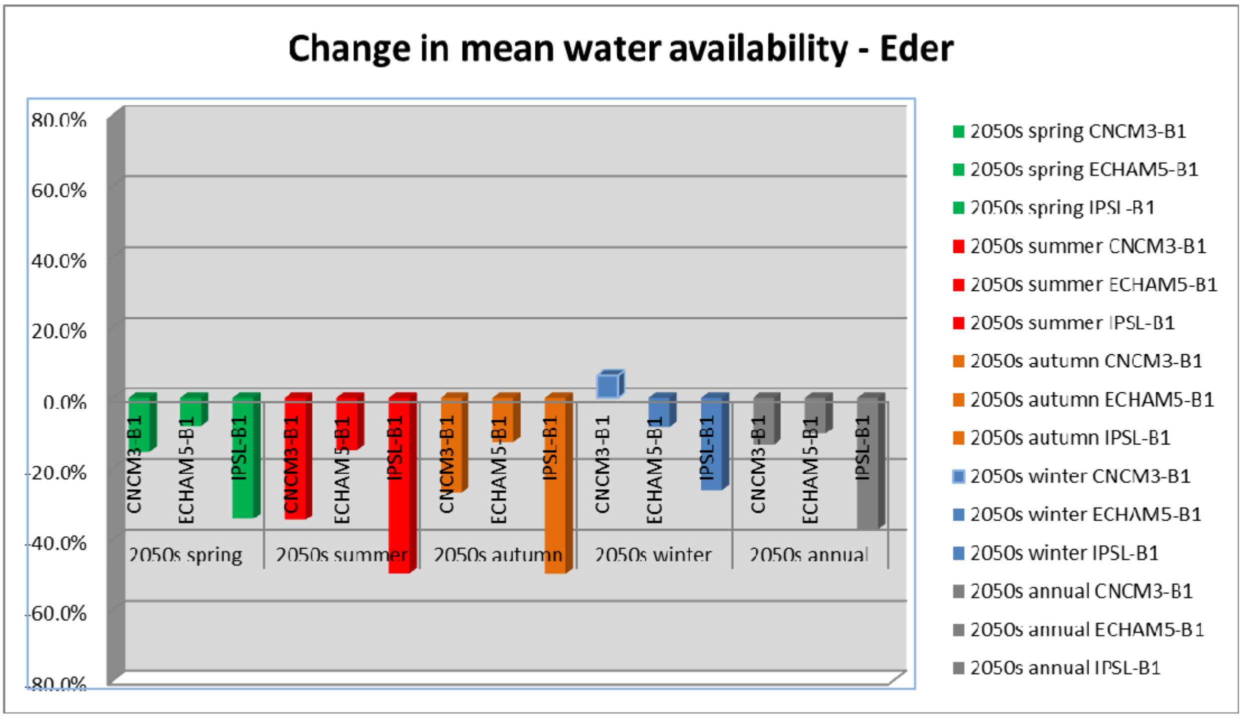


Figure 87: Change in mean seasonal water availability in the 2050s driven by three different GCMs (CNCM3, ECHAM5, and IPSL) under the SRES B1 emission scenario.

Current reservoir management

Of importance at the Eder River is the Ederdam, which constitutes the third biggest dam in Germany regarding the storage capacity. According to CS1 information (Cemus & Richter 2008), the main purpose of the Ederdam is to support and maintain navigation downstream on the Weser River during summer months. Therefore, a minimum water level of 120 cm needs to be maintained at the gauging station in Hann. Münden. In addition, for the transportation of cargo (heavy load and crop transports), the water level is sometimes temporarily elevated by 5 to 40 cm at the Weser River through water releases from the Ederdam (i.e. by so-called “artificial waves”). Besides navigation, the Ederdam is also used for flood control and hydropower generation. Especially during the summer month, the reservoir is advertised as tourist attraction and is used by tourists for swimming, diving, fishing, surfing, sailing and water skiing.

Impacts

Reservoir storage (inflow)

The Ederdam has a storage capacity of 202.4 million m^3 of water. In general, discharge of the Eder River is stored during high flows, while it is released during low flow conditions for the different purposes. Within the baseline period (1971-2000), the mean annual reservoir inflow accounts for 674.5 million m^3. Future reservoir inflow is expected to be lower as a result of climate change. Considering the ensemble mean, inflow is reduced in the 2050s by 9.1 % (613.4 million m^3) under the A2-EcF scenario and by 18.8 % (547.5 million m^3) under the SRES B1-SuE scenario. Reservoir inflow under each single GCM-scenario combination is provided in Table 14. The range of uncertainty is between -34.6 % and +9.3 % for A2-EcF and -34.8 % and -10.2 % for B1-SuE indicating a decreasing trend of the long-term average annual reservoir inflow (except the A2-EcF model simulation driven by ECHAM5).

Table 14: Long-term average annual inflow for the Ederdam for the baseline and the 2050s under the different GCM-scenario combinations

	2000s	2050s EcF			2050s SuE		
	baseline	CNCM3-A2	ECHAM5-A2	IPSL-A2	CNCM3-A2	ECHAM5-A2	IPSL-A2
inflow [mil m3]	674.5	661.5 (-1.9%)	737.2 (+9.3%)	441.4 (-34.6%)	596.9 (-11.5%)	605.6 (-10.2%)	440.1 (-34.8%)

Low flows

The results for the Eder River show that climate change is expected to have a moderate impact on annual water availability in the 2050s, however, flows during summer are likely to decrease. Consequently, highest impacts can be expected in summer during times of low flows. This may affect the current dam management which needs to balance different interests such as navigation, flood protection, and tourism. In addition, the implementation of the EU Water Framework Directive (200/60/EEC) needs to be considered, which requires all Member States to protect and restore water bodies in Europe, aiming for a “Good Ecological Status”. In cooperation with the CS1 partner, it was agreed to analyse river discharge in up- and downstream direction of the Ederdam at the gauging stations Schmittlotheim and Fritzlar (both located at the Eder River), Grebenau, Guntershausen, and Bonaforth (at the Fulda River), and Hann. Münden (at the Weser River). An overview on the locations of these gauging stations is provided in Figure 88, while the Ederdam can be found between the gauging stations Schmittlotheim and Fritzlar. Consequently, river flows in Fritzlar, Guntershausen, Bonaforth and Hann. Münden are impaired by the Ederdam management, in Schmittlotheim and Grebenau they are not.

The change in river low flows in the 2050s in comparison to the baseline period are shown in Figure 88 for the A2-EcF scenario, while related values for the selected gauging stations are provided in Table 16.

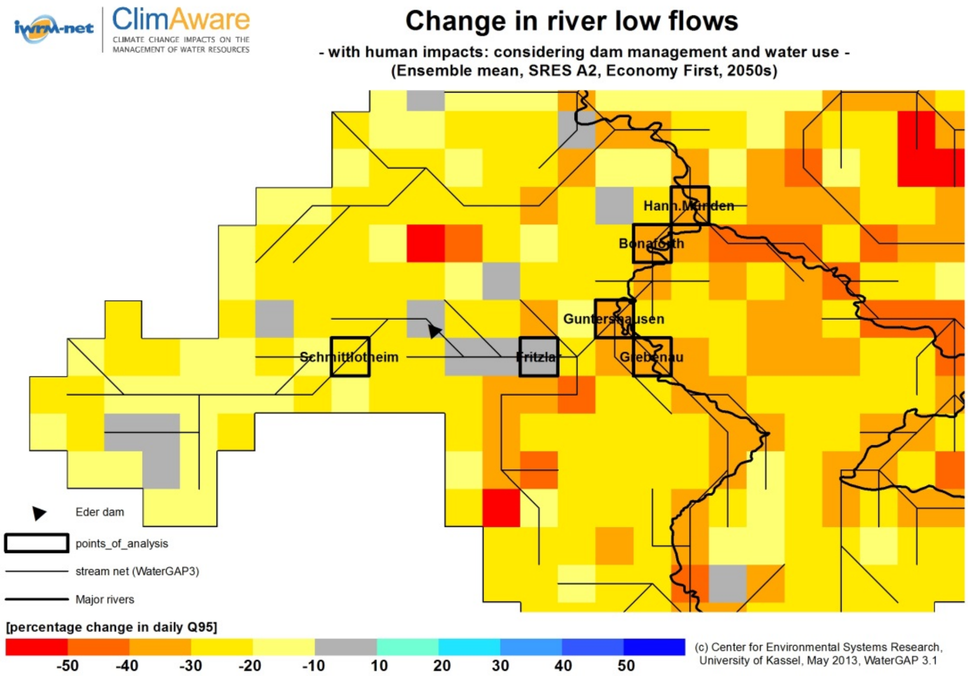


Figure 88: Change in Q95 at the Eder River in the 2050s as represented by the ensemble mean for the A2-EcF scenario.

In the 2050s, the Ederdam is still able to counteract the impact of climate change plus changes in water use for a small downstream river reach until Fritzlar. In downstream direction of the dam, low flows can still be elevated so that the change in Q95 can be maintained within the range of ±10 % due to the dam management with a decrease of only 8 % in Fritzlar. However, at the downstream gauging stations of Fulda and Weser, Q95 is reduced by 31 to 35 % in the 2050s due to climate change and despite Ederdam management. Under the B1-SuE scenario, low flows will be reduced by only 16 to 20 % at Fulda and Weser. These results are in accordance with the Integrated Climate Protection Programme Hesse 2012 (Integriertes Klimaschutzprogramm Hessen, INKLIM 2012), which analysed the impacts of different GCM-scenario combinations on hydrological parameters at selected gauging stations of the Hessian river basins Lahn and Main. Here, river flow simulations were performed by the water balance model LARSIM (Large Area Runoff Simulation Model, Ludwig & Bremicker 2006), which was driven with regional climate data from ECHAM5-WETTREG for the SRES emission scenarios A2, A1B and B1. WETTREG (UBA 2007) is a statistical model which was used to downscale global ECHAM5 results by means of data from 60 climate stations and 300 precipitation stations. Else the model CCLM (version 4.8) was used, which is dynamic regional climate model with a 7 km grid, to downscale global ECHAM5 results (Brahmer 2013). Results of INKLIM 2012 show that summer flows and low flows are likely to decrease in the future (HLUG 2008, Brahmer 2013). Depending on the applied scenario, mean monthly low flows decline by 5 to 25 % in the “near future” (2021-2050) in comparison to 1961-

1990. In the “far future” (2071-2100), the low flow situation is further intensifying. Here, mean monthly low flow decrease by 15 to 40 % on Hessian rivers.

Table 15: Change in Q95 river low flows in the 2050s presented as ensemble mean for selected gauging stations at Eder, Fulda and Weser rivers in comparison to the baseline 2000s all including dam management

River	Station	Change 2050s Ens.mean A2-EcF (Q95,2050s,with dam / Q95,2000s,with dam)	Change 2050s Ens.mean B1-SuE (Q95,2050s,with dam / Q95,2000s,with dam)
Eder	Schmittlotheim*	-22%	-28%
Eder	Fritzlar	-8%	-6%
Fulda	Grebenau*	-36%	-30%
Fulda	Guntershausen	-31%	-17%
Fulda	Bonaforth	-35%	-16%
Weser	Hann. Münden	-34%	-20%

*) Stations Schmittlotheim & Grebenau: upstream of dam-influenced basin, other stations downstream

In general, dams usually generate a less variable flow regime with elevated low flows and dampened flood peaks (Nilsson et al., 2005). In the following, the effect of the Ederdam on river low flows downstream shall be demonstrated. Hence, we compared the river low flow (represented by Q95) to the natural flow regime (i.e. to a hypothetic situation without dam management). According to the large-scale modelling results, the releases from the Ederdam elevate Q95 by 20 % in Fritzlar in the baseline period compared to the natural flow regime without dam management (Table 16). In downstream direction of the river network the effect is decreasing. The dam releases lead to an increase of Q95 by 17 % in Guntershausen and Bonaforth, and by 12 % in Hann. Münden. Schmittlotheim is not influenced by the Ederdam, since it is located at the Eder upstream the Ederdam and Grebenau is not influenced, since is located at the Fulda, but upstream the confluence of Fulda and Eder. In the 2050s under climate change conditions, these values are likely to be reduced and even become negative. While in Fritzlar Q95 low flows can still be elevated by 9 % under the A2-EcF scenario, low flows are decreasing by more than 20 % at the gauging stations downstream. This means, except in Fritzlar, low flows in the 2050s are even lower than the natural flow regime of the baseline period in our simulations. Under the B1-SuE scenario, the impact of climate change on river low flows is diminished. In Fritzlar, low flows can be elevated by 13 %, and in Hann. Münden they are decreasing by only 10 % in comparison to the naturalised flow regime of the baseline period.

Table 16: Change in Q95 (low flow) at different gauging stations for the baseline (2000s) and the future (2050s) in comparison to a hypothetic situation without Ederdam in the baseline (i.e. in comparison to a naturalised flow regime).

River	Station	Change 2000s (Q95,2000s,with dam / Q95,2000s,without dam)	Change 2050s Ens.mean A2-EcF (Q95,2050s,with dam / Q95,2000s,without dam)	Change 2050s Ens.mean B1-SuE (Q95,2050s,with dam / Q95,2000s,without dam)
Eder	Schmittlotheim*	0%	-22%	-28%
Eder	Fritzlar	20%	9%	13%
Fulda	Grebenau*	0%	-36%	-30%
Fulda	Guntershausen	17%	-20%	-3%
Fulda	Bonaforth	17%	-23%	-2%
Weser	Hann.Münden	12%	-26%	-10%

*) Stations Schmittlotheim & Grebenau: upstream of dam-influenced basin, other stations downstream

<u>High flows</u>

High flows can be damaging, but also beneficial. On the one hand, high flows can devastate urbanised and cultivated areas with damages to human lives and property (Fitzhugh and Vogel 2010). On the other hand, high flows lead to inundation of natural floodplains and riparian wetlands, and the health of riverine ecosystems often depends on natural patterns of these events (Junk et al. 1989). According to the results, no major changes are evident for Q10 (representing high flows) in the 2050s (Figure 89).

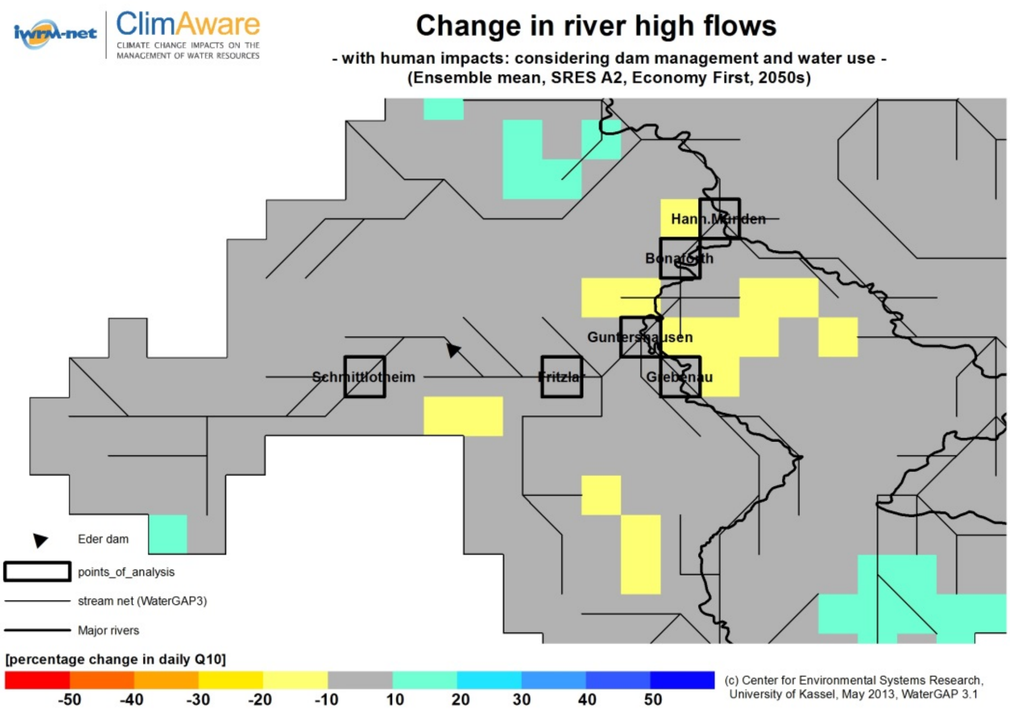


Figure 89: Change in Q10 (high flows) at the Eder River in the 2050s as represented by the ensemble mean for the A2-EcF scenario.

Under the A2-EcF scenario, the change in Q10 ranges between -1 and +4 % at the selected gauging stations in the Eder catchment indicating no remarkable change in the 2050s (Table 17). Taking into account the B1-SuE scenario, high flows do not deviate much from the baseline situation as well, but they tend to be slightly lower in the 2050s. Within INKLIM 2012, increases in winter flows as well as in small and medium floods were found for distinct Hessian rivers (HLUG 2008, Brahmer 2013). Here, mean monthly high flows increase by 2 to 12 % in the "near future" (2021-2050) under the different GCM-scenario combinations in comparison to 1961-1990. No clear signal was found for large floods.

Table 17: Change in Q10 river high flows in the 2050s represented by the ensemble mean for selected gauging stations at the rivers Eder, Fulda, and Weser in comparison to the baseline (2000s) all including dam management

River	Station	Change 2050s Ens.mean A2-EcF (Q10,2050s,with dam / Q10,2000s,with dam)	Change 2050s Ens.mean B1-SuE (Q10,2050s,with dam / Q10,2000s,with dam)
Eder	Schmittlotheim*	4%	-5%
Eder	Fritzlar	3%	-10%
Fulda	Grebenau*	1%	-9%
Fulda	Guntershausen	0%	-8%
Fulda	Bonaforth	-1%	-8%
Weser	Hann. Münden	1%	-7%

*) Stations Schmittlotheim & Grebenau: upstream of dam-influenced basin, other stations downstream

Dams usually dampen flood peaks. Hence, just as described for the low flows, the effect of the Ederdam on high flows shall be demonstrated by a comparison to a naturalised baseline period. Accordingly, dam operation at the Eder River lowers Q10 by 10 % at the gauging station in Fritzlar, 6 % at the downstream Fulda gauging stations, and 4 % in Hann. Münden in the baseline period (Table 18). Nearly similar values were found for the 2050s taking into account the ensemble mean of the A2-EcF scenario. Considering the ensemble mean of the B1-EcF model runs, dam management leads to a reduction of Q10 by 19 % in Fritzlar, 13 to 14 % at the downstream stream Fulda gauging stations, and 11 % in Hann Münden in comparison to the naturalised baseline without dam. This means, under the B1-SuE scenario, the Ederdam can dampen high flows even more effectively in our results due to reduced discharge in the future under climate change.

Table 18: Dampening of Q10 (high flows) due to the Ederdam management at different gauging stations for the baseline (2000s) and the future (2050s) in comparison to naturalised baseline period, i.e. a hypothetic situation without Ederdam management

River	Station	Change 2000s (Q10,2000s,with dam / Q10,2000s,without dam)	Change 2050s Ens.mean A2-EcF (Q10,2050s,with dam / Q10,2000s,without dam)	Change 2050s Ens.mean B1-SuE (Q10,2050s,with dam / Q10,2000s,without dam)
Eder	Schmittlotheim*	0%	4%	-5%
Eder	Fritzlar	-10%	-8%	-19%
Fulda	Grebenau*	0%	1%	-9%
Fulda	Guntershausen	-6%	-6%	-14%
Fulda	Bonaforth	-6%	-6%	-13%
Weser	Hann.Münden	-4%	-3%	-11%

*) Stations Schmittlotheim & Grebenau: upstream of dam-influenced basin, other stations downstream

<u>Water level (Weser) vs. tourism Eder</u>

Climate change is expected to have an impact on the inflow to the Ederdam, which in turn will require an appropriate future management. The model results show that due to a lower inflow into the dam, low flows (Q95) may no longer be elevated in the future compared to naturalized flow conditions. This will have consequences for the navigation on the Weser River as well as for recreation and leisure purposes (tourism). Nevertheless, the dam still covers high flow discharges leading to a reduction in Q10 downstream.

<u>Response</u>

Adaptation strategies need to be considered with regards to future reservoir management. In order to think about adaptation options, the following statements should be considered:

1. It is supposable that the current reservoir management is sufficient to fulfil future challenges.
    a. The operation of the Ederdam is in a testing mode since the year 2012 to consider increasing low flow variability to maintain future navigation on the Weser River (Theobald et al. 2013).
    b. Detailed investigations on future flood situations available by now are not assessed to be reliable to change flood of design criteria in Hessen (Brahmer 2013). So flood protection does not need to be improved yet. Nevertheless it is recommended for future flood risk management to investigate the effect moderate increased floods on schemes of flood mitigation measures and land use (Theobald et al. 2013).
    c. In future the generation of hydropower may suffer in average a slight decline of produced electricity by a few percent of the present yield in the investigated reaches. This occurs due to small shifts of the mean annual discharge and increased discharge variability (Theobald et al. 2013).

2. The impact on nature in accordance to the Water Framework Directive depends very much on the climate change as an exogenic fluvial factor. According to the presented results for case study 1 on the investigated human impact and possible measures it is likely that for surface waters in Northern Hesse the attainment of the good ecological status considering hydromorphological constraints is not hindered specifically by climate change.

CS 2 – Seine River Basin, France

Drivers

Population

Today, about 16 million people live within the Seine River basin, which possesses the highest population density among the three ClimAware case studies with approximately 214 people/km^2. Of special importance is Paris, a large metropolitan area with nearly 10 million inhabitants in the urban unit ("unité urbaine"), which need to be supplied with freshwater throughout the year. According to the assumptions made in the SCENES project for urban and rural population in France in the 2050s, future population is expected to increase in the Seine River basin by 27.8 % under the EcF scenario and declining by 3.6 % under the SuE scenario. The increase in the EcF scenario is quite strong as further urban sprawl is expected.

Gross Domestic Product (GDP)

GDP is derived from the national value which is expected to double between the base year (2005) and 2050 under the EcF scenario. Contrary to this development is the decline in GDP by 30 % as assumed under the SuE scenario. The negative growth is also obvious for future development in income which is expected to decrease until 2050 despite population declines.

Irrigated area

According to the SCENES scenarios, large increases in irrigated area are expected for the Seine River basin. While an irrigated area of 169,090 ha is assumed for the base year, the extent will increase by 247 % under the EcF scenario and 22 % under the SuE scenario in the year 2050. This intensification is partially the result of agricultural production moving from Southern to Western and Northern Europe because of changing weather conditions and agricultural intensification on high productive land.

Pressures

Climate change

For the Seine River basin, all six GCM-scenario realisations agree in direction of change with lower mean annual precipitation values in the future (Table 19). In the 2050s, the basin may face 7.3 % less precipitation under the SRES A2 scenario and 11.3 % less under the SRES B1 scenario. The mean annual temperature will increase by 2.1°C under the SRES A2 scenario till 2050, while an increase of 1.6°C can be expected under the SRES B1.

Table 19: Change in climate variables of the Seine River basin in the 2050s as represented by the ensemble mean for the SRES scenarios A2 and B1 including uncertainty range

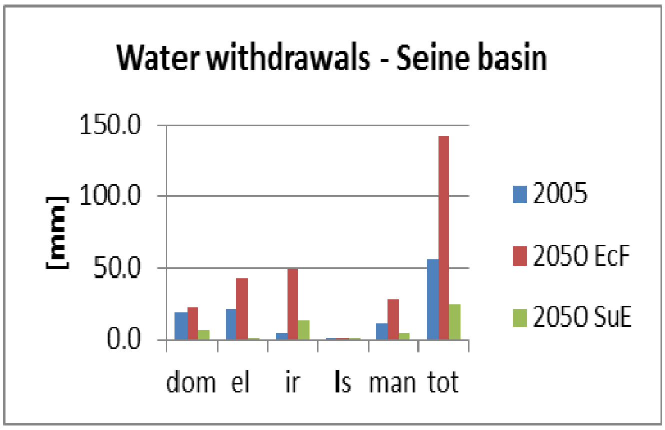
Seine	2000s	ensemble mean	uncertainty GCM
Precipitation (A2)	839mm	-7.3%	(-12.0 to -3.5%)
Precipitation (B1)	839mm	-11.3%	(-13.0 to -9.6%)
Temperature (A2)	10.6°C	+2.1°C	(+1.7 to +2.3°C)
Temperature (B1)	10.6°C	+1.6°C	(+1.3 to +1.9°C)

Water use

In the Seine River basin, total water withdrawals account for 55.7 mm during year 2005. Most of the water is abstracted for industrial purposes (38 % thermal cooling and 19.7 % manufacturing) and households (34.7 %). Water withdrawals for agricultural purposes are minor in this region compared to the other sectors (Table 20). In the year 2050, water withdrawals are expected to increase by 156.2 % in the A2-EcF scenario while decreasing in the B1-SuE scenario (-55.7 %). Under A2-EcF assumptions water withdrawals increase across all sectors but particularly in the irrigation sector (due to the large increase in irrigated area and reduced precipitation) followed by the industry and domestic sectors. A different future development is drawn by the B1-SuE scenario where technological improvements reduce water withdrawals in all sectors. However, water savings due to an increased efficiency cannot prevent the irrigation sector from an increase in water withdrawals in 2050.

Table 20: Water withdrawals at the Seine River basin for the years 2005 and 2050 considering an Economy First and a Sustainability Eventually scenario

Seine	**2005 [mm]**	**2005 [% share]**	**2050 EcF [mm]**	**2050 SuE [mm]**	**2050 EcF [% change]**	**2050 SuE [% change]**
dom	19.3	34.7	22.6	6.0	+16.7	-69.2
el	21.2	38.0	42.8	1.1	+102	-94.6
ir	3.9	6.9	49.0	13.0	+1156.4	+233.3
ls	0.4	0.7	0.4	0.4	+9.4	-8.9
man	11.0	19.7	28.0	4.3	+155.5	-61.0
tot	55.7	100.0	142.8	24.7	+156.2	-55.7



State variables

River discharge

In consequence of lower precipitation values and higher temperatures, water availability is likely to be reduced in the Seine River basin in the 2050s compared to the baseline (Figure 90, Figure 91), especially during low flow conditions. In autumn (SON), water availability decreases by 34.4 % and in summer (JJA) by even 68.8 % considering the ensemble mean. Among the three case studies, this accounts for the strongest reduction in summer water availability. All model simulations result in an agreement in the direction of change for the different seasons in this river basin, except the ECHAM5-A2 driven model run predicts an increase in water availability in winter (DJF). In general, the least impacts are expected for the winter month. Model simulations driven by the SRES B1 scenario result similar but less pronounced reductions in seasonal water availability (Figure 91). For example, water availability in summer is reduced by 33.4 % and in autumn by 31.4 %.

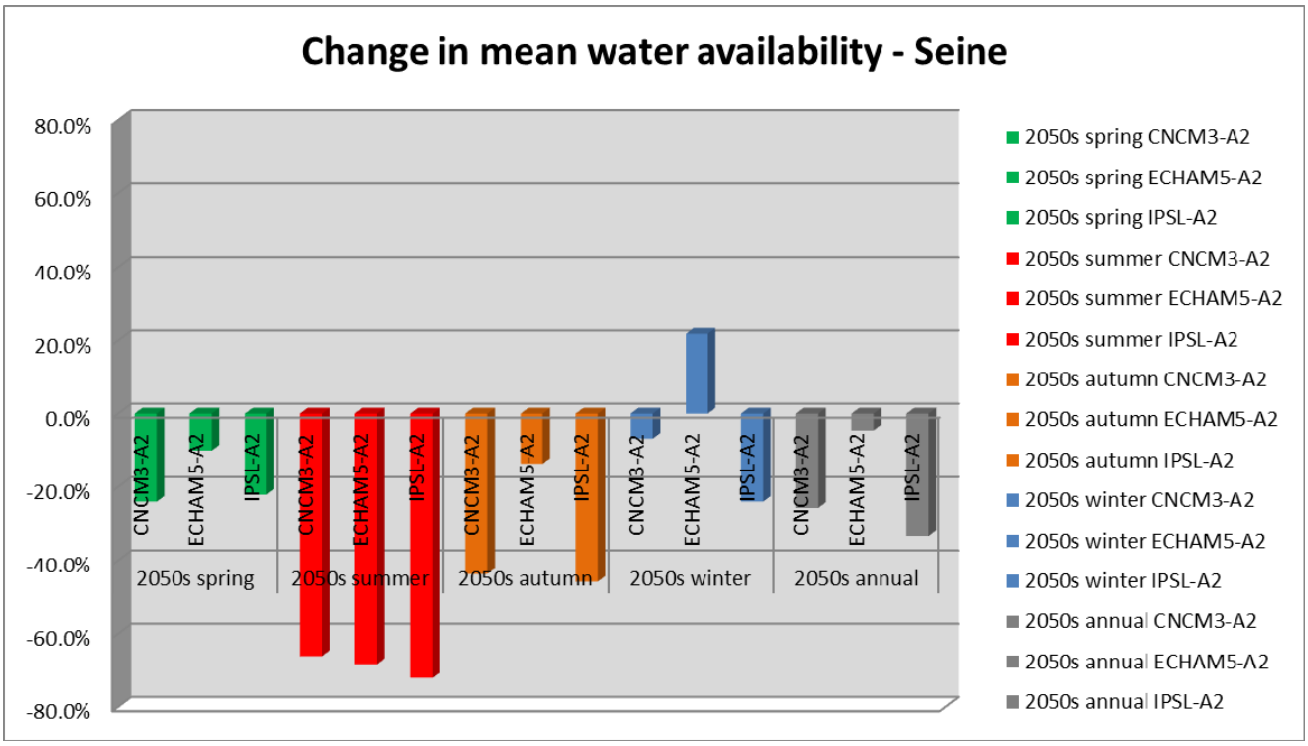


Figure 90: Change in mean seasonal water availability for the Seine River basin in the 2050s driven by three different GCMs (CNCM3, ECHAM5, and IPSL) under the SRES A2 emission scenario.

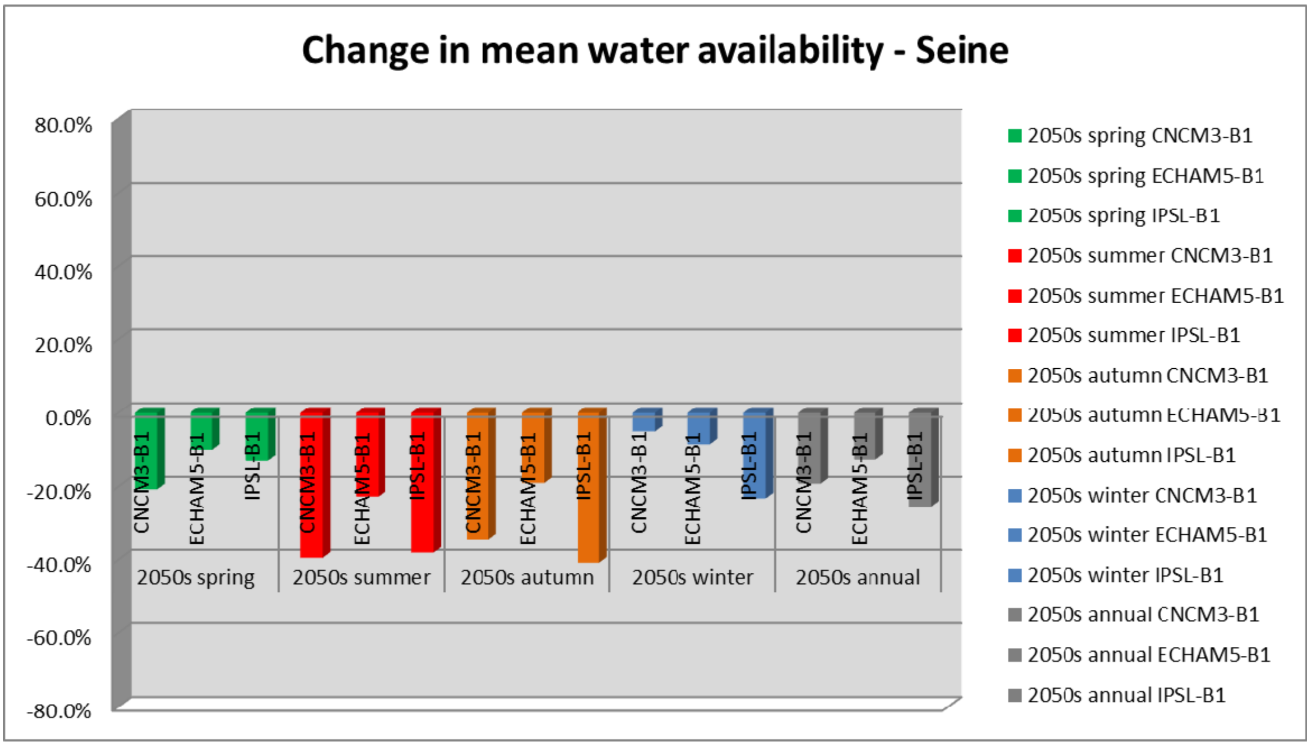


Figure 91: Change in mean seasonal water availability for the Seine River basin in the 2050s driven by three different GCMs (CNCM3, ECHAM5, and IPSL) under the SRES B1 emission scenario.

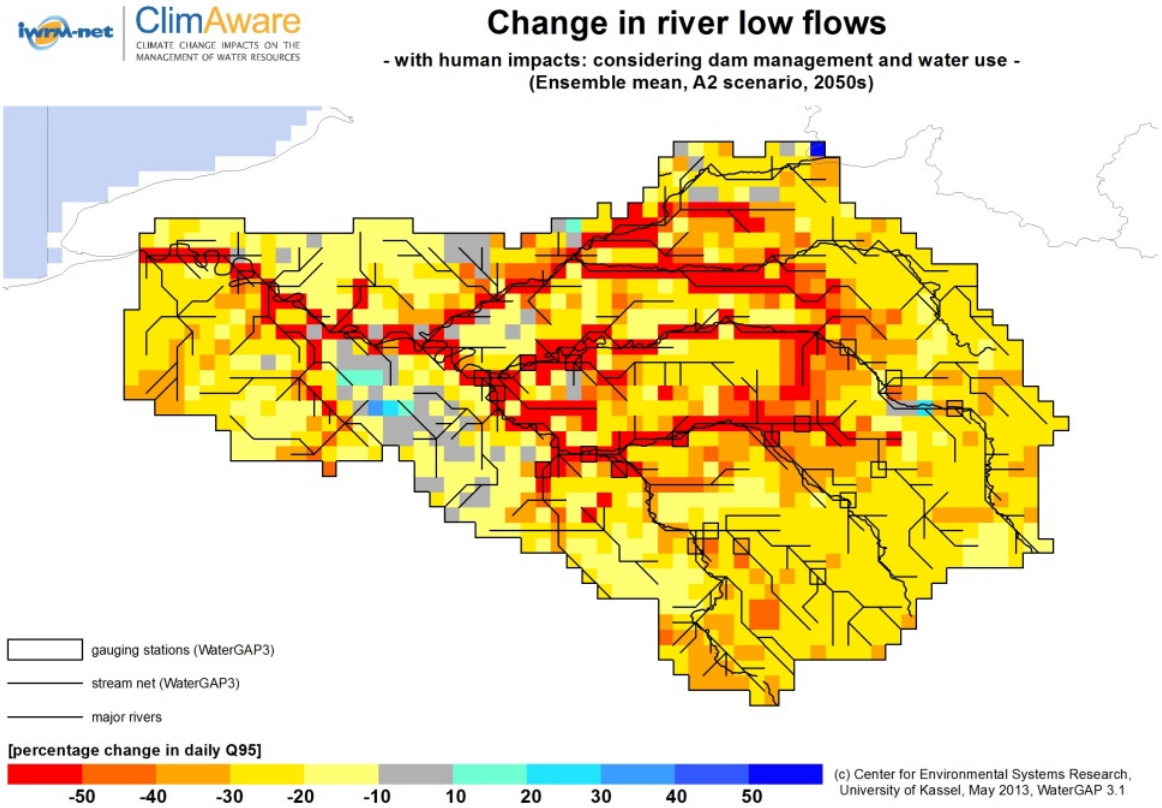
Reservoir management

Dam management is of special importance in the Seine River basin because the main rivers Aube, Marne, Seine and Yonne are regulated by large artificial reservoirs with a total storage capacity of 804 million m^3. The main purpose of these dams is water supply and flood protection by preventing extreme low and high flows. Especially the large metropolitan area of Paris with approximately 10 million inhabitants needs to be supplied with freshwater. Hence, human water supply needs to be ensured during the low flow period from June to November. The Seine River basin will be affected by climate change impacts with a likely decrease in water availability across all seasons, especially during the release period July to October. For example at the gauging station Paris-Austerlitz, the ensemble mean indicates a loss in river discharge by -63.7 % under A2-EcF and -47.6 % under B1-SuE. At the same time water withdrawals may increase as assumed under the A2-EcF scenario.

Impacts

Low flows

In the 2050s, Q95 is likely to decrease in the Seine River basin under both A2-EcF and B1-SuE scenarios (Figure 92). Single values for selected gauging stations are presented in Table 21.



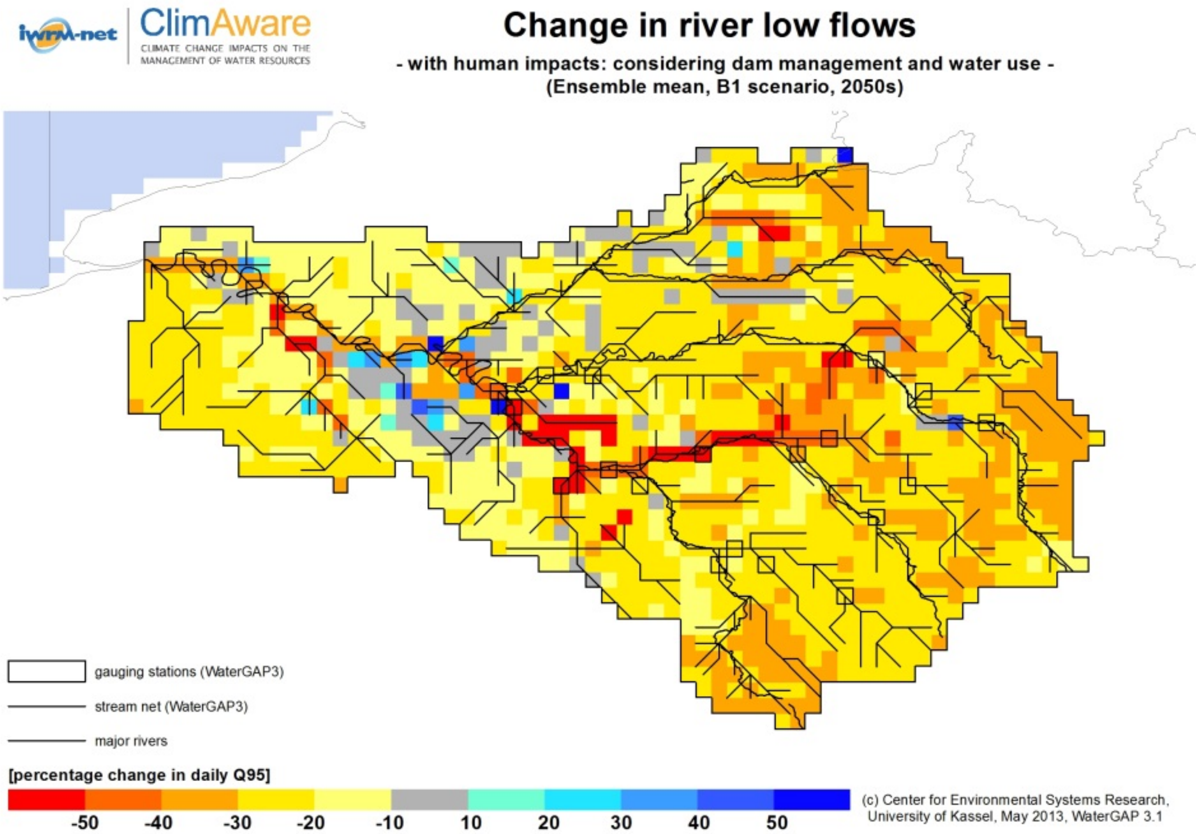


Figure 92: Change in low flows (Q95) in the Seine River basin in the 2050s compared to the baseline as represented by the ensemble mean for the A2-EcF (upper map) and B1-SuE (lower map) scenarios.

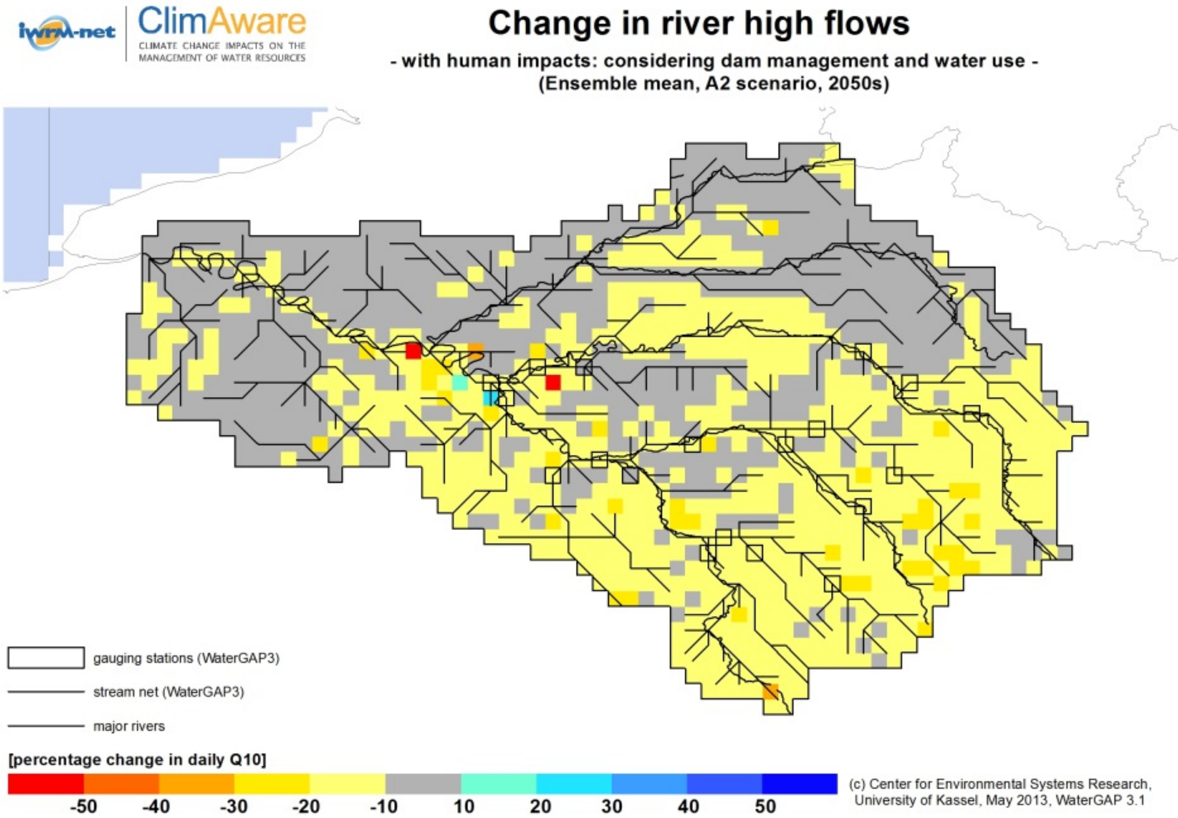
At all gauging stations listed in Table 21, Q95 is expected to decrease taking into account all GCM-scenario combinations. The ensemble mean at the different gauging stations changes on average by -55 % (with a range from -98 to -24 %) under A2-EcF and by -36 % (with a range from -69 to -18 %) under B1-SuE. Thereby, impacts on low flows often increase in downstream direction with higher changes on the Seine River (close to Paris) than on the smaller tributaries. Due to less reduction in water availability and more efficient use of freshwater resources under the B1-SuE scenario, changes are lower (-19.4 %) in comparison to the A2-EcF scenario.

Table 21: Change in low flows (Q95) at selected gauging stations of the Seine River basin in the 2050s compared to the baseline. Results are presented by the ensemble mean including uncertainty range for the A2-EcF and B1-SuE scenario

River	Station	Change 2050s A2-EcF	Uncertainty A2-EcF	Change 2050s B1-SuE	Uncertainty B1-SuE
Armancon	Brienon-sur-Armancon	-26.6%	(-38.5 to -5.9%)	-26.8%	(-36.8 to -9.2%)
Armancon	Aisy-sur-Armancon	-26.5%	(-39 to -4.5%)	-27.7%	(-38 to -8.3%)
Aube	Trannes	-24.7%	(-39.5 to -0.5%)	-29.4%	(-38.6 to -11.9%)
Aube	Arcis-sur-Aube	-65.9%	(-77.1 to -57%)	-44.7%	(-56.1 to -32.6%)
Grand Morin	Montry	-81.7%	(-86.3 to -74.6%)	-25.5%	(-32.4 to -16.1%)
Loing	Episy	-71.2%	(-79.7 to -54.7%)	-60.6%	(-68.7 to -45.1%)
Marne	Saint-Dizier	-31%	(-46 to -7.7%)	-26.7%	(-36.1 to -9.5%)
Marne	Noisiel	-96.9%	(-99.1 to -93.6%)	-25.6%	(-37.5 to -15.2%)
Marne	Chalons-en-Champagne	-32.4%	(-52 to -9%)	-18.4%	(-28.6 to -12.9%)
Saulx	Vitry-en-Perthois	-26.6%	(-40.4 to -5.7%)	-29.7%	(-37.7 to -16.1%)
Seine	Paris	-96.7%	(-97.9 to -94.6%)	-48.2%	(-66 to -30.3%)
Seine	Bar-sur-Seine	-24.1%	(-37.2 to -1.7%)	-26.7%	(-36 to -8.3%)
Seine	Nogent-sur-Seine	-94.4%	(-96.8 to -91.1%)	-64.1%	(-87.2 to -43%)
Seine	Montereau	-86%	(-92.1 to -77%)	-45.6%	(-63.3 to -26%)
Seine	Alfortville	-97.5%	(-97.7 to -97.3%)	-68.7%	(-92.4 to -42.5%)
Seine	Mery-sur-Seine	-55%	(-74.1 to -30.2%)	-30.1%	(-41.2 to -14.6%)
Serein	Chablis	-30%	(-41.2 to -8.7%)	-29.3%	(-39.8 to -10.9%)
Yonne	Gurgy	-32.1%	(-45.3 to -13.1%)	-27.8%	(-36.7 to -11.5%)
Yonne	Courlon-sur-Yonne	-52.6%	(-62.3 to -33.3%)	-27.1%	(-36.6 to -10.4%)

<u>High flows</u>

In the 2050s, Q10 is likely to decrease slightly under A2-EcF and B1-SuE scenarios (Figure 93). Single values for selected gauging stations located at the main tributaries and the Seine River are presented in Table 22.



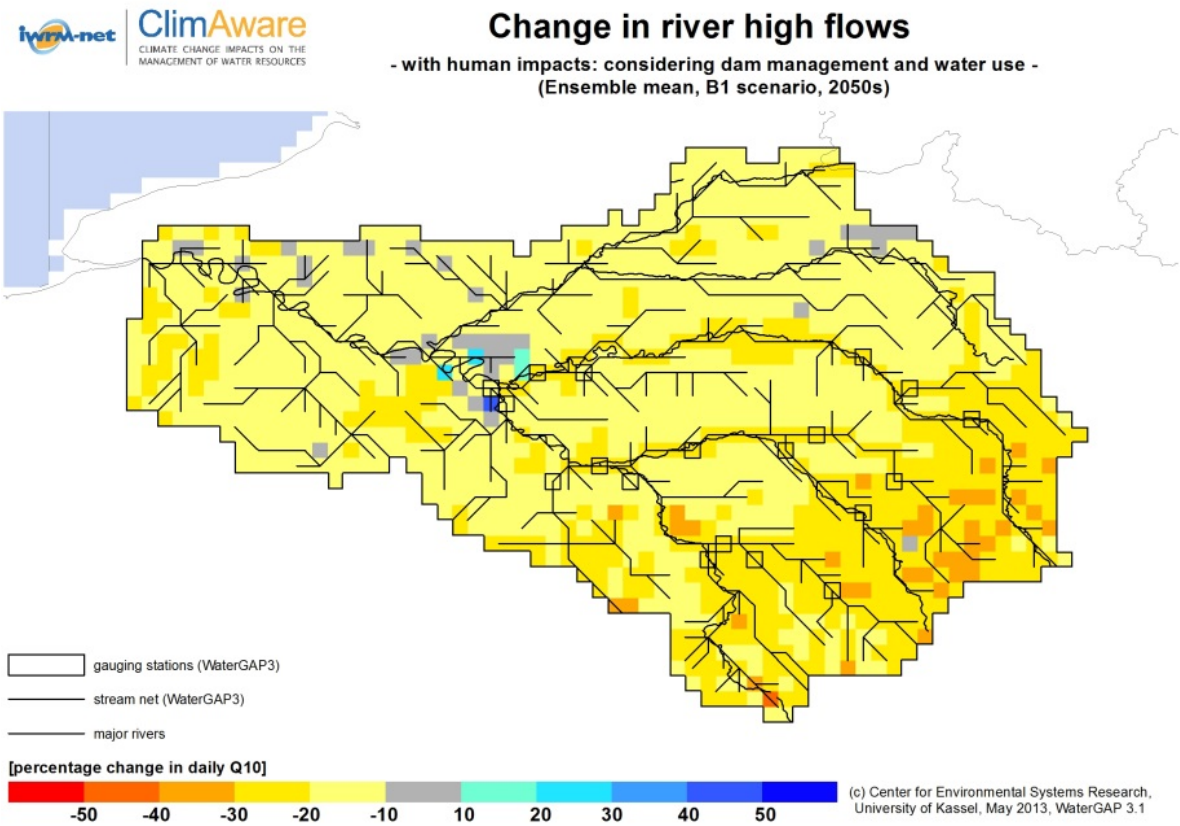


Figure 93: Change in high flows (Q10) in the Seine River basin in the 2050s compared to the baseline as represented by the ensemble mean for the A2-EcF (upper map) and B1-SuE (lower map) scenarios.

Table 22: Change in high flows (Q10) at selected gauging stations in the Seine River basin in the 2050s compared to the baseline. Results are presented by the ensemble mean including uncertainty range for the A2-EcF and B1-SuE scenarios.

River	Station	Change 2050s A2-EcF	Uncertainty A2-EcF	Change 2050s B1-SuE	Uncertainty B1-SuE
Armancon	Brienon-sur-Armancon	-11.3%	(-23.3 to 6.8%)	-21.3%	(-29 to -14.8%)
Armancon	Aisy-sur-Armancon	-12%	(-23.1 to 5.8%)	-21.4%	(-29.6 to -14.2%)
Aube	Trannes	-16.1%	(-31.4 to 7.1%)	-28.3%	(-37.2 to -19.2%)
Aube	Arcis-sur-Aube	-14.1%	(-29 to 5.7%)	-24.3%	(-31.8 to -17.6%)
Grand Morin	Montry	-9.5%	(-22.1 to 10.9%)	-18.8%	(-23.2 to -14.9%)
Loing	Episy	-11.3%	(-23.4 to 10.7%)	-18.9%	(-26.3 to -12.4%)
Marne	Saint-Dizier	-11.6%	(-26.6 to 11.3%)	-23.8%	(-31.7 to -16.5%)
Marne	Noisiel	-14%	(-25.5 to 4.4%)	-21.2%	(-27.6 to -14.5%)
Marne	Chalons-en-Champagne	-15.2%	(-27 to 2.5%)	-24.6%	(-31.4 to -16.8%)
Saulx	Vitry-en-Perthois	-10%	(-23.7 to 10.6%)	-20.2%	(-24.4 to -16.3%)
Seine	Paris	-13.3%	(-25.6 to 5.8%)	-19.5%	(-26.7 to -13.3%)
Seine	Bar-sur-Seine	-14.2%	(-27.5 to 7.2%)	-25.3%	(-33.8 to -17.2%)
Seine	Nogent-sur-Seine	-14.5%	(-27.5 to 4.1%)	-21.4%	(-28.9 to -14.7%)
Seine	Montereau	-12.6%	(-24.6 to 6%)	-20%	(-28.4 to -13.6%)
Seine	Alfortville	-12.6%	(-24.7 to 6.8%)	-19.8%	(-27.4 to -13.6%)
Seine	Mery-sur-Seine	-15.2%	(-28.1 to 2.2%)	-22.5%	(-29.2 to -16.3%)
Serein	Chablis	-12%	(-23.3 to 6%)	-21.2%	(-29.2 to -13.9%)
Yonne	Gurgy	-12.4%	(-24.8 to 6.7%)	-20.8%	(-30 to -13.3%)
Yonne	Courlon-sur-Yonne	-9.4%	(-21.2 to 11.5%)	-18.2%	(-24.5 to -12.7%)

The ensemble mean at the different gauging stations changes on average by -13 % (with a range from -16 to -9 %) under A2-EcF and by -22 % (with a range from -28 to -18 %) under B1-SuE, indicating that high flows are lower and better compensated by the dam management. On average, Q10 can be dampened by 9 % more under the B1-SuE scenario compared to A2-EcF at the different gauging stations. Regarding the uncertainty range, Q95 decreases at all gauging stations under the B1-SuE scenario. Under the A2-EcF scenario, model runs driven with CNCM3 and IPSL provide reductions in high flows, while the model results driven with ECHAM5 climate input show a small increase of 7 % (with a range from +2 to +12 %) on average for the different gauging stations.

Response

According to the impact study, the Seine River basin is expected to be mainly influenced by climate change leading to large reductions in water availability in particular during summer and autumn seasons. In order to avoid competition for the water resources available, a coordinated development and management of water in terms of an Integrated Water Resources Management (IWRM) should carefully be evaluated as an adaptation option. As shown by the B1-SuE scenario, water savings due to technological improvements lower water withdrawals and thus reduce the pressure put on the water resources. In addition, a more flexible management of the dams might be considered in particular to elevate low flows during summer and autumn seasons to fulfil water demand for human activities as well as to ensure environmental flow provisions. With regards to adaptation strategies, the following statements should be respected:

1. What is the impact of climate change on seasonal water stress?

   The results of the simulations with naturalized flow show a substantial increase of the severity and length of low-flow events due to climate change. This phenomenon is observed for all simulations and on all the gauging stations of the river basin. When use restriction of water is currently expected to happened once every 20 years, in future conditions this frequency will be once every 10 years.

2. What is the impact of future water demands?

   Since the results of a socio-economic study from the project Explore 2070 were used, the only impacts taken into account are restrictions applied on water demand when low-flow thresholds are reached. As said above, this impact will be twice more important in the future.

3. Does current reservoir management need to be adapted to future conditions?

   As the major impact of climate change concerns the severity and the length of low-flow period, the adaption should concern the tactical management of low-flows. The most evident conclusion is that it's not necessary to completely empty the reservoirs at the end of the low-flow season to be able to fill the reservoir the next year. This has been shown with the new filling curve drawn for the adaptation of the tactical management.

CS 3 – Apulia Region, Italy

Drivers

Population

The Apulia region comprises urban and rural areas with the biggest agglomeration in Bali. Currently, about 4 million people live in the Apulia region and the population density is slightly above the national average (209 people per km^2). According to the SCENES scenarios, population is expected to increase in the Apulia region by 5.5 % under EcF and 6.3 % under SuE.

Gross Domestic Product (GDP)

GDP values are derived from the national trend, which increases in both scenarios by more than 50 %. Since population numbers are lower under SuE, income will be higher compared to EcF. This development differs from the other case studies where the economic growth is highest in the EcF scenario.

Irrigated area

Rather than SCENES results, CS3 information on future land-use and crop distribution are applied for the Apulia region. The changes were modelled within the ClimAware project by the newly developed economic model of the CS3 partner. Accordingly, the extent of irrigated area decreases from 394,224 to 372,853 ha (-5.4 %) in the 2050s. Furthermore, the total area planted with vineyards, vegetables, and field crops is downsized, while the extent in area for pasture and orchards is augmented (for more information, see Chapter 2.2.3). For the Apulia region, the same land-use changes are assumed for the EcF and SuE scenarios.

Pressures

Climate change

In the Apulia region, climate change is likely to have a very strong impact. Compared to the other two case studies, the Apulia region has the lowest annual precipitation (594 mm) in the baseline and the highest decreases in the 2050s which amount to -20.6 % under SRES A2 and -14.4 % under SRES B1 (Table 23). Regarding the uncertainty range, all GCM-scenario combinations agree in the direction of change (-12.8 to -25.2 %). In addition, the strongest temperature rise is simulated for the Apulia region with +2.3°C (SRES A2) and +1.8°C (SRES B1). Overall, the changes in annual precipitation and air temperature do not differ much between the GCMs and emission scenarios in the Apulia region.

Table 23: Change in climate variables in the Apulia region in the 2050s compared to the baseline provided as ensemble mean and uncertainty range for the SRES A2 and B1 scenarios

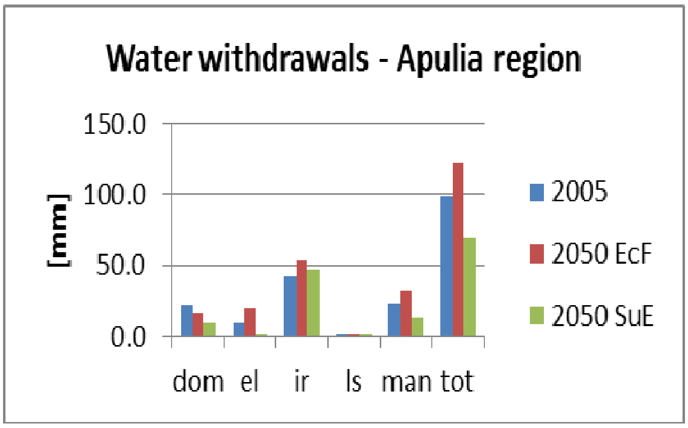
Apulia	2000s	ensemble mean	uncertainty GCM
Precipitation (A2)	594mm	-20.6%	(-25.2 to -17.1%)
Precipitation (B1)	594mm	-14.4%	(-16.8 to -12.8%)
Temperature (A2)	15.4°C	+2.3°C	(+2.0 to +2.4°C)
Temperature (B1)	15.4°C	+1.8°C	(+1.5 to +2.1°C)

Water use

According to large-scale simulations, irrigation is the dominant water use sector in the Apulia region in the base year 2005 with a share of 43.0 % of total water use followed by the industrial (34.1 %) and domestic (22.9 %) sectors (Table 24). These shares differ from values provided by the case study partner so that water uses of the agricultural (54.1 %) and domestic sectors (36.4) are underestimated, while the industrial sector (9.4 %) is overestimated in this study. The deviations of the industrial and domestic sector derive from the fact of downscaling national numbers. In the future, water abstraction for irrigation purposes are very likely to increase even under the SuE scenario conditions. Irrigation efficiency is relatively high with 60-80 % for sprinkler irrigation and 75-90 % for dripping irrigation leaving only some space for further improvements. Industrial water withdrawals are expected to increase under EcF, in particular as a result of an increasing thermal electricity production and a higher demand for cooling water. Future water withdrawals as calculated for the SuE scenario show a clear reduction in industrial and domestic water abstractions as a result of water savings due to new technologies.

Table 24: Water withdrawals in the Apulia region for EcF and SuE scenarios for the years 2005 and 2050

Apulia	2005 [mm]	2005 [% share]	2050 EcF [mm]	2050 SuE [mm]	2050 EcF [% change]	2050 SuE [% change]
dom	22.6	22.9	16.4	9.3	-27.7	-58.9
el	9.6	9.7	19.7	0.6	+104.9	-94.1
ir	42.5	43.0	53.4	46.8	+25.6	+10.1
ls	0.1	0.1	0.1	0.1	-2.8	-5.7
man	24.1	24.4	32.9	12.9	+36.8	-46.5
tot	98.9	100.0	122.5	69.7	+23.7	-31.8



State variables

Water availability

Due to the strong decline in precipitation and the high temperature increase, the Apulia region shows substantial decreases in water availability in the 2050s (Figure 94). Water availability is likely to decrease in all seasons of the year, especially in spring (MAM), summer (JJA) and autumn (SON). By far the strongest impacts are calculated with the CNCM3 climate datasets. The European maps in Chapter 2.1 showed that CNCM3 has its highest impact on water availability in the Mediterranean, while IPSL shows larger influence in Eastern Europe.

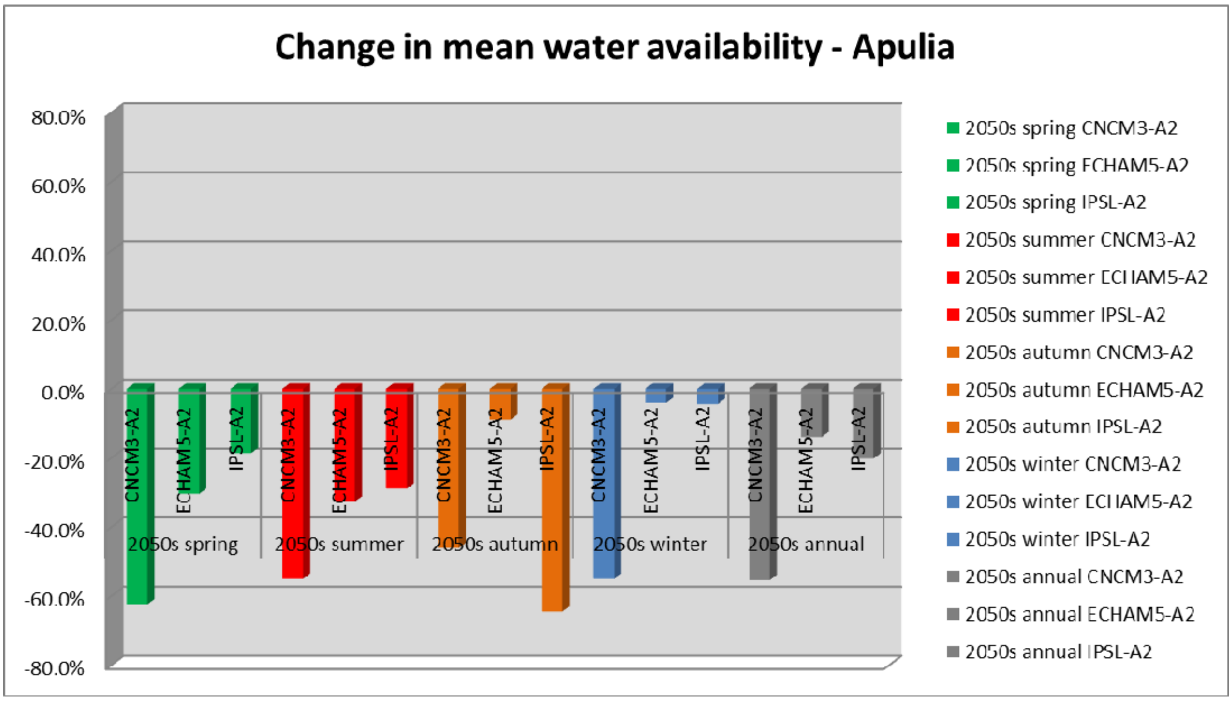


Figure 94: Change in mean seasonal water availability for the Apulia region in the 2050s compared to the baseline. Model results are presented for three different GCMs (CNCM3, ECHAM5, and IPSL) and the SRES A2 emission scenario.

In the Apulia region, the SRES B1 emission scenario has its strongest effects (i.e. in regard to the SRES A2 scenario) compared to the other case studies (Figure 95). Water availability decreases across all seasons, but the decline is substantially lower than in the SRES A2 scenario due to limited greenhouse gas emission of the SRES B1 scenario. While annual water availability is reduced by 29.8 % under SRES A2, the decline in freshwater resources is less pronounced under SRES B1 (-18.7 %) in the ensemble mean.

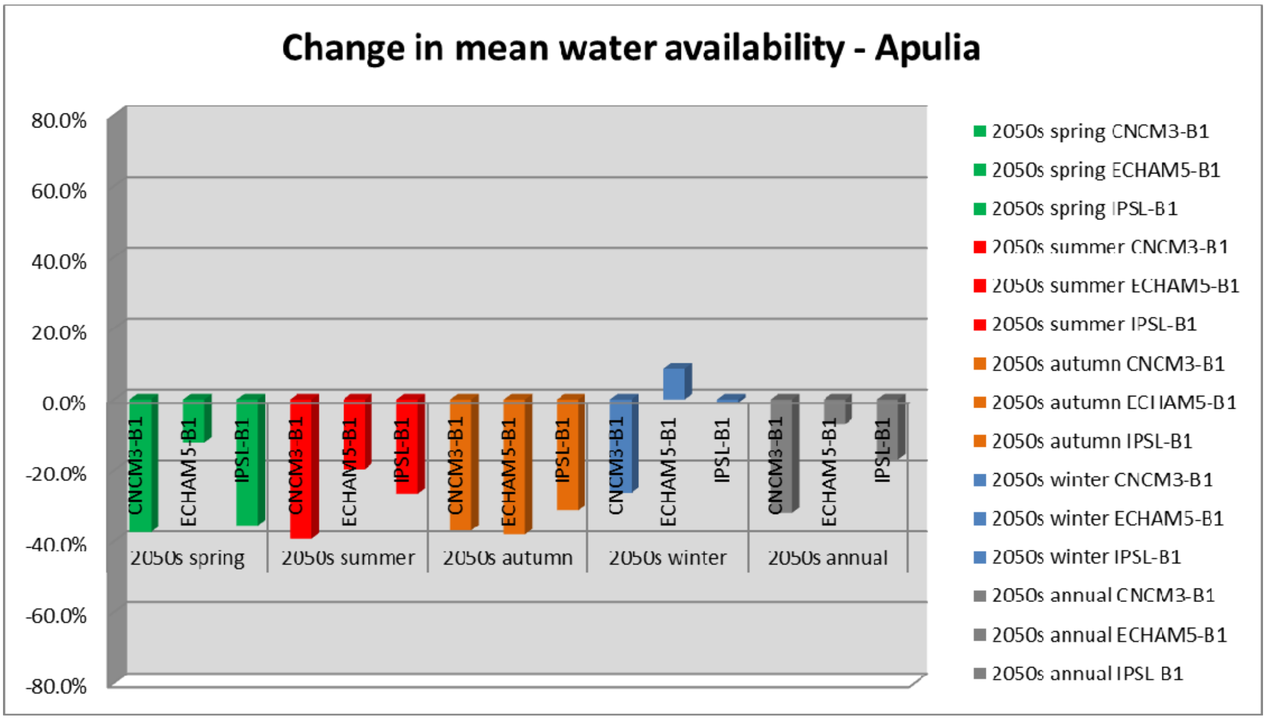


Figure 95: Change in mean seasonal water availability for the Apulia region in the 2050s compared to the baseline. Model results are presented for three different GCMs (CNCM3, ECHAM5, and IPSL) and the SRES B1 emission scenario.

Impacts

Agricultural water stress (monthly)

Agricultural water stress has been defined as the ratio of irrigation water withdrawals-to-water availability (i.t.a.) on a monthly basis. By using this indicator, it is assumed that a region or basin area suffers from severe water stress if i.t.a. > 0.4 (red colour) or, in other words, if monthly irrigation water requirements exceed 40 % of reliable monthly discharge. For 0.2 < i.t.a. ≤ 0.4 the basin is under medium stress (orange colour) and for values below 0.2 (white), the region has low stress (Table 25). The classification is following the same categories as w.t.a. (cf. Table 26)

In the baseline, severe agricultural water stress occurs from May to September and is highest in July and August. The period of severe water stress will already start in April under the A2-EcF scenario (for two GCM-realizations) and lasting 6 months instead of 5. A similar picture is drawn for the B1-SuE scenario but not as severe as under A2-EcF (Table 25).

Table 25: Monthly agricultural water stress in the Apulia region in the base year and future scenarios (2050s). Red is severe, orange is medium, and white is low water stress.

irrigation wta	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000s												
2050s A2 EcF												
CNCM3												
ECHAM5												
IPSL												
2050s B1 SuE												
CNCM3												
ECHAM5												
IPSL												

Water stress (monthly)

Here water stress is a measure of the amount of pressure put on water resources and aquatic ecosystems by all users of these resources, including municipalities, industries, thermal power plants and agricultural users. For calculating today's and future water stress the withdrawals-to-availability ratio is used (w.t.a.) on a monthly basis. A region is assumed to be under low water stress if w.t.a. ≤ 0.2; under medium water stress if 0.2 < w.t.a. ≤ 0.4 (orange colour) and under severe water stress if w.t.a. > 0.4 (red colour) (see agricultural water stress).

According to the definition of water stress, the Apulia region is six consecutive months, from May to October, under severe water stress, i.e. more than 40 % of the water resources are withdrawn for human activities. This situation becomes more severe under the A2-EcF scenario when, depending on the GCM realization, up to 9 months of the year fall into the severe water stress class. The results obtained with CNCM3-A2 climate lead to the most critical situation in the Apulia region, which is then expected to be 9 months under severe water stress while the remaining months are classified as medium. In this case the very dry climate conditions exacerbate the water stress situation in the 2050s. Compared to the results provided in Table 25, water stress in March or October is driven by non-agricultural water uses.

Water stress under the B1-SuE scenario realizations is less severe compared to A2-EcF, however, 5 to 7 months of the year could be affected by water stress. Although the CNCM3-A2 realization leads to the most critical situation in the 2050s, the CNCM3-B1 realization results even in a reduction of monthly water stress by one month (5 months in total).

Table 26: Monthly water stress in the Apulia region in the base year and future scenarios (2050s). Red is severe, orange is medium, and white is low water stress.

wta	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000s												
2050s A2 EcF												
CNCM3												
ECHAM5												
IPSL												
2050s B1 SuE												
CNCM3												
ECHAM5												
IPSL												

<u>Income</u>

Agriculture is the main economic sector of the Apulia region with its fertile coastal plains, where different vegetables, fruits and crops are cultivated. Furthermore, Apulia is an important wine growing region. The agricultural productivity, however, depends on available freshwater resources for irrigation requirements. Climate change is likely to have a strong impact in the Apulia region. Higher temperature and less precipitation cause that crop water requirements are enhanced and water availability is strongly reduced throughout the year in the 2050s. Consequently, agricultural productivity is likely to be debased under climate change leading to lower incomes for local farmers and the region itself as well as lower food security levels.

<u>Response</u>

According to the simulated trends (less water availability and increasing irrigation water withdrawals) in the Apulia region, adaptation strategies should take into account that:

1. land use and cropping patterns changes confirm to be a key component in adapting agriculture to climate change reducing the pressure on water resources. Farmers can reduce the irrigated surfaces and/or shift toward less water intensive techniques. In addition, a phenomenon of land abandonment emerged.
2. The increase of water use efficiency, at district and farm level, can partially counteract the impacts of climate change above all in some areas of the region where higher are the inefficiencies.

In order to analyse segregated from each other the impact of crop selection and climate change on water withdrawals, a sensitivity analysis was conducted for the Apulia region. Considering only climate change, water withdrawals are increasing from 42.5 to 57.1 mm/year (+34 %) under the A2-EcF scenario and 50.7 mm/year (+19 %) under the B1-SuE scenario (Figure 96). Taking into account land-use changes of the 2050s as well (as provided by the CS3 partner), the rise in water withdrawals can be diminished to +26 % under the A21-EcF scenario and +10 % under the B1-SuE scenario (Table 27). This means, water can be saved by a different crop selection. The future crop selection (as simulated by the CS3 partner) causes lower water withdrawals by 3-4 mm/year in comparison to the crop selection in the baseline period. However, the impact of climate change is not counteracted.

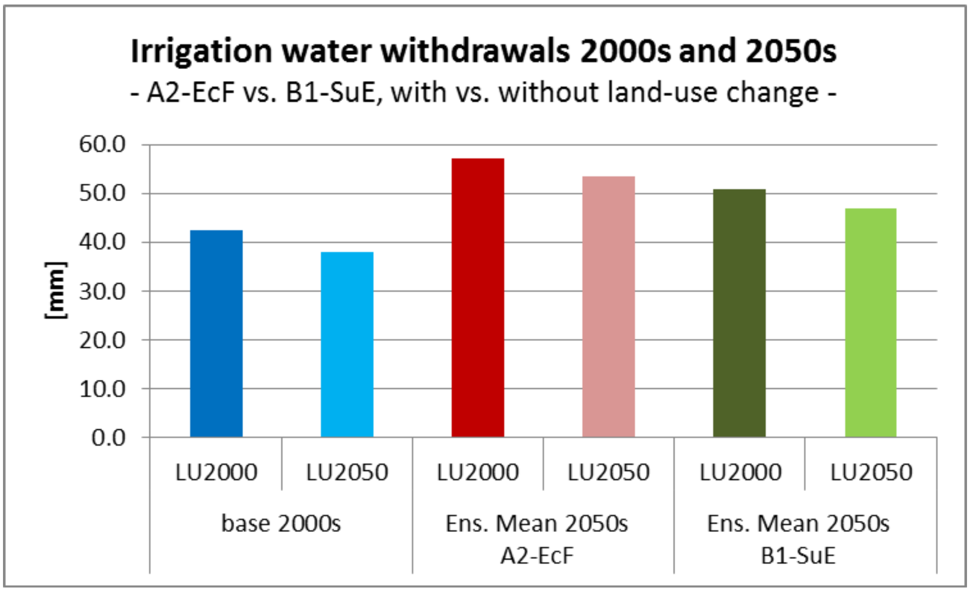


Figure 96: Mean annual irrigation water withdrawals in the Apulia region in the 2050s compared to the baseline (2000s) as represented by the ensemble mean for the A2-EcF and B1-SuE scenarios. For each time slice, land-use (LU) of the years 2000 and 2050 has been taken into account.

Table 27: Corresponding mean annual water withdrawal values for the Apulia region as depicted in Figure 96

Climate	Land-use	withdrawals [mm]
base 2000s	LU2000	42.5
	LU2050	37.9
Ens. Mean 2050s A2-EcF	LU2000	57.1 (+34%)
	LU2050	53.4 (+26%)
Ens. Mean 2050s B1-SuE	LU2000	50.7 (+19%)
	LU2050	46.8 (+10%)

2.3.2 CROSS-CASE COMPARISON

Introduction

The emphasis of this comparison of the different case studies is to distinguish approaches, management and adaptation strategies which are relevant not only for one case study but in general. Due to this the exploration of the concept for strategic, tactical and operational management depending on the water issue is of interest. Overlappings and differences regarding the different case studies are summed up for aspects like the main impacts, pressures and driving forces, the main adaption strategies, how to handle the results, how to organize and how to distribute the developed results. By highlighting why there are overlappings and differences between the case studies references to the different approaches of the case studies are developed.

Impacts, Pressures, Driving forces

All case studies deal with the impact of climate change. Due to this all case studies are confronted with the aspects of climate and model uncertainties, especially with the fact, that results on future trends for flooding are less reliable than for droughts. This is caused by the different modelling time scales of the evolution of droughts compared to floods since the former last longer. The effects of this impact on water resources management are examined, but focusing on different emphases depending on the case study. While case study 1 concentrates on hydromorphological characteristics according to the WFD, case study 2 focuses on low-flow replenishment and flood alleviation. Common to both case studies is the consideration of flowing waters which are influences by dam management and human use of the streams as well as the floodplains. In contrast case study 3 deals with agricultural water use and irrigation aspects of water resources management, aspects which are also clearly influenced by climate change.

Besides the impact of climate change, other impacts are relevant for the current and future water resources management, including the water demand and water supply. The relations between these mainly socio-economic and climatic impacts deviate depending on the case study. Regarding only the impact of climate change on the different case studies this impact is the lowest for Northern Hesse (case study 1) and the strongest for the Apulia region (case study 3). Besides this impact for case study 1 especially morphodynamic processes during the course of time is relevant for the sustainable effectiveness of the considered restoration measure according to the WFD. In case study 2, the expected use and management of the investigated reservoir system is a second important impact on flood and low-flow events in the river basin. For low flows, unlike in case study 3, the main issue is not the water supply for industrial, agricultural or domestic use, but the water quality considering the goal of good ecological status in the context of the WFD. In case study 3 decisive impacts on the water scarceness in the viewed region are economic and demographic changes as well as changes in the agricultural practices beneath the impacts of climate change.

Approaches, management and adaptation strategies of the different case studies

As already mentioned above all case studies deal with climate and model uncertainties. This is handled by all case studies as common scientific practice by a range of scenarios. In general the results by modelling are less reliable on future trends for flooding than for droughts.

Due to this, the case study the most affected by this problem is case study 2, which mainly focuses on flood alleviation among other emphases. The approach of case study 2 to handle this is a dam management strategy called Centralized Tree-based Model Predictive Control which uses the information available in real time, including weather forecasting to obtain an adaptive control for the reservoirs management.

With regard to the scientific content, there is especially a link concerning the aspect of low flows between the case studies 1 and 2. In both case studies there is the opportunity to compensate low flows at least to a certain extent by adjusted dam management. In case study 2 this is the main strategy of adjustment while in case study 1 there are also other opportunities discussed, like adjusting the implementation of the restoration measure or adjusting the reference conditions which define the good ecological status according to WFD.

All case studies work with scenarios which cover different possible developments of the future to investigate the influence of climate change in dependence of these developments. Case study 1 works with scenarios, which illustrate different states during the lifetime of a restoration measure depending on morphodynamic processes. Case study 2 works with 7 GCMs scenarios in present

(1961-1991) and future time (2046-2065) and one scenario of withdrawal evolution for assessing the evolution of the dam management performance. Case study 3 works with different scenarios of land use changes influencing farmer’s income, water demand and irrigation practices.

All case studies investigate future states, where only the impact of climate change is developed without any further adaption. In addition to the impact of climate change, case study 1 considers morphodynamic processes in their future scenarios, case study 2 takes also into account the withdrawals evolution in the river and case study 3 includes changes in farmers’ behaviour since it is expected, that there will be no realistic future scenario without these additional changes.

Acting on the challenge of climate-change induced modifications of the Water resources management may be oriented on thresholds for adaption in management and operation. For case study 1 no direct thresholds in discharge could be investigated since the major influence on the hydromorphological effectiveness of measures is the limitation for morphodynamic self-adjustment of the stream. For the investigated Lower Eder River the management of the Ederdam may be oriented towards the threshold concept as it is applied for case study 2. Nevertheless a direct influence of the dam management on hydromorphological measures effectiveness under the consideration of the present socio-economic framework of navigation, flood-protection and hydropower is even for slightly climate-change induced discharge modifications not expected to be substantial. In addition to this for the discharge operation of the Ederdam according to its aims of improving low flow situations a testing mode is implemented since 2012. In case study 2, flow thresholds already exist and are currently used by the stakeholders for defining the seriousness of a flood or a low-flow event at some gauging stations downstream the reservoirs. The adaptation strategy mainly consists here in explicitly taking into account these thresholds in the management strategy. This management strategy also induces the need of reservoir control centralization for the gauging stations concerned by several reservoirs. In CS3 a threshold was imposed to water withdrawals, both for surface and groundwater resources in order to complain with WFD objectives.

Inevitably, the future climate change still underlies uncertainties in the exact extend of occurrence. Accordingly, it may be difficult to find appropriate adaption measures which are reliable under all possible future developments. Considering these uncertainties, it is reasonable to execute those measures with the smallest risk of failure under possible diverging climate development (no-regret measures). Usually such no-regret measures are multi-purpose, cheap and quick to establish and in case of misjudged single-purpose easy reversible (as far as possible).

In case study 1 this kind of hydromorphological effective measures for the implementation of the WFD are those which are realized at minor limitations of morphodynamic self-adjustment. Changes in the existing construction of dykes or other technical flood protection devices are usually expensive and single-purpose measures. These are measures which fulfil the no-regret-strategy only limited.

In case study 2 only no-regret measures are considered. The project focuses on adapting management rules and not on investigating in new structures investment or modification of existing structures. The proposed adaption measures take only into account the reservoir manager point of view. This is why alternative solutions such as withdrawals reduction policy were not explored.

In case study 3 the main institutional adaptation measures identified, such as flexibility of the system and integration of stakeholders visions, fully represent no-regret measures.

All case studies were implemented in in close collaboration with different groups of stakeholders. In the first phase of the project as well as during the project runtime, these were especially practice partners, who provided access to the available data about the actual state as well as about their planning and intentions regarding the themes of the different case studies. Else it was valuable for all case studies to exchange also interim assumptions and results with these groups of stakeholders. The practice partners were strongly interested in the results and intend to incorporate and establish them in the implementation of restoration measures according to WFD (case study 1), the dam management and operation (case study 2), or the future land use and irrigation practices (case study 3).

Beneath these local practice partners on river basin level the second important target group are policy makers on EU-level and on national level (financial, funding institutions, WFD). These are more involved or informed in the end of the project, especially by this joint final ClimAware project report provided by all project partners to SCP and by the national reports provided by each project partner to its national funding institution.

3 Partners' Involvement

3.1 PROJECT MANAGEMENT AND COORDINATION

The project started in September 2010 (officially in January 2011 for the French partners) for a duration of three years.

3.1.1 PROJECT COORDINATION

The overall coordination is done by the Department for Hydraulic Engineering and Water Resources Management under the lead of Prof. Dr.-Ing. Stephan Theobald, head of this Department at the University of Kassel (Germany). The Projects management is splitted into scientific and administrative coordination. Prof. Dr.-Ing. Theobald is responsible for the scientific coordination, which includes structuring the project, research control, monitoring the time schedule, and reporting to IWRM-Net. The scientific coordination takes place at the annual project meetings where all partner present their progress and intermediate results, where the link between the work packages is discussed and the time table for the next year determined.

The administrative coordination was conducted by the environmental coordination of the University of Kassel, until end of August 2012 and was continued by the Department of Hydraulic Engineering and Water Resources Management, from September 2012 on. The administrative coordination supports the project coordinator in his tasks and is especially responsible for administrative issues. She coordinates the communication within the consortium and organizes the annual project meetings in cooperation with the respective partner at whose institution the meetings take place. She also communicates with the Office International de l'Eau functioning as the IWRM-Net Scientific Coordination Project (IWRM-Net SCP) in questions regarding the obligations within the IWRM-NET. This includes the coordination of the reporting to the SCP. Moreover, the administrative coordinator prepares presentations for meetings and represents the consortium at such meetings when the scientific coordinator may not participate. She also prepares the articles for the SCP newsletter in consultation with the partners. Another task is the coordination of the dissemination activities, which includes the update of the website and the preparation of the flyer. For the German partners, the reporting and financial issues are also organized by the administrative coordinator.

All partners support the project coordinator in achieving the objectives of the overall project by contributing to the dissemination activities.

3.1.2 PROJECT WORKSHOPS AND MEETINGS

Workshops and project meetings help to coordinate the research partners to exchange ideas and results and monitor the research process. The Project meetings are alternating at each partner´s home institution.

In autumn 2010 the ClimAware project started with a kick-off meeting in Kassel/Germany. The meeting took place 11 to 12 October 2010 and was organised by the University of Kassel. The major aim of the meeting was to get to know each other and the work of each institution. Moreover, every partner presented his or her work package and case study and it was tried to bring the different perspectives together. A table was prepared that was filled in by all partners in the months following the meeting to compare their approaches regarding the use of scenarios.

A second meeting took place 19 to 21 September 2011 in Bari/Italy at the IAMB's office (Instituto Agronomico Mediterraneo di Bari). It was organised by the project coordinator in cooperation with IAMB. All partners presented their research progress and discussed the intermediate results. The link between the case studies and the European modelling respectively was further discussed and parameter for the comparison developed. Regarding the cross-scale comparison it was recorded that the European modelling is used for policy advisory to policy makers and stakeholders. Adaptation measures are designed following the results of the case studies and in cooperation with stakeholders and implemented locally.

Moreover, IAMB had organised a field trip to their investigation area, which gave all partners a better picture of the problems of agriculture in South of Italy where farmers face droughts and water shortages.

The third meeting took place 12 to 14 September 2012 in Paris at the Seine Grands Lacs office in combination with a field trip to Troyes/France to the Aube reservoir. It was organised by Seine Grands Lacs and the project coordinator. All partners presented their research progress and discussed intermediate results especially with regard to the cross scale analysis. Details and deadlines for data exchanges were fixed, as well as organisational issues e.g. reporting, further meetings and dissemination activities.

The field trip to the Aube reservoir as part of the Seine River Basin reservoir gave all partners a very informative impression of the investigation area of the French partners.

A forth meeting took place 11 to 13 June 2013 in Kassel at the Klimzug-building in combination with a field trip to different stations at the Lower Eder River. It was organised by the project partners from Kassel. The research progress was presented by all partners, results were discussed, especially regarding the cross case and cross scale analysis and a time schedule for final collaboration was developed.

The field trip to different stations of the Lower Eder River and the Ederdam informed the project partners about the investigation area of the German partners and about the in Germany typical kind of implementation of restoration measures according to the WFD.

A last project meeting took place at 20th of November in Rome for a common editorial reversion of the first draft of the Final report and coordination of final collaboration and dissemination activities for the ClimAware project.

The consortium ClimAware was present at all IWRM-NET meetings organised by the IWRM-NET SCP.

For the participation at the kick-off meeting of the IWRM-NET 2nd call consortium in Brussels in November/December 2010 a poster and presentation was prepared by all partners. At this meeting Prof. Stephan Theobald from the University of Kassel, Dr. Ilona Bärlund from CESR and Dr. Nicola Lamaddalena from IAMB were present.

The second IWRM-NET SCP meeting took place in Paris in October 2011. Vanessa Aufenanger from the University of Kassel took part at the meeting and presented the intermediate results of

ClimAware. Dr. Charles Perrin from Irstea and Regis Thépot from Seine Grands Lacs were also there to support the presentation and discuss with the other consortia the collaboration between the IWRM-NET projects.

At the latest IWRM-NET SCP meeting in Lyon in June 2012, the consortium ClimAware was represented by Dr. Charles Perrin from Irstea, who presented the intermediate results of the ClimAware partners, and Katrin Kehr and Vanessa Aufenanger from the University of Kassel.

The ClimAware website was launched in autumn 2010 and is the main mean of disseminating information on the project and its results as soon as they are available. The website includes an internal web space where all relevant material is available for the partners (protocols, poster, flyer, logo, etc.)

The website can be accessed here: www.uni-kassel.de/go/climaware

Additionally, a flyer was designed that informs about the background and aims of the project. It is used to distribute at conferences. A poster and the flyer were presented at the Innovation Festival of the Climate-KIC of the European Institute for Innovation and Technology (EIT) in September 2011.

The ClimAware partner also contributed to the IWRM-NET SCP newsletters.

On the 28th of November 2013 the ClimAware project was presented in a SCP-Webinar entitled "Impacts of climate change on water resources management – regional strategies and European view." by Christof Schneider.

3.2 DISSEMINATION OF RESULTS, KNOWLEDGE TRANSFER

This project addresses two target groups:

- **Policy makers on EU-level:** An overview of the most vulnerable regions in Europe, including information on why these regions are vulnerable to climate change is given. In addition, adaptation measures are developed and analysed along several factors including an assessment of which measures should be promoted, and which could be prevented.

The review process of the Water Framework Directive and the Water Scarcity and Drought policy can take advantage of synergy effects according to the analyses conducted. By providing results for medium- and long-term impacts of climate change on freshwater resources in terms of quantity and quality, the Commission is able to identify measures to be considered by Member States in the future WFD planning cycles.

- **Water managers on river basin level:** These mangers get a set of tools containing vulnerability indicators related to climate change, adaptation measures, and evaluation instruments which they can use to develop specific adaptation actions or the next programme of measures required by the Water Framework Directive. In many cases, water managers will have to complement the available information and tools with specific local data and knowledge. Using a scenario approach helps to evolve different pathways into the future and to be prepared for various developments. The scenarios may overstate the development of future water resources but they span a variety of possibilities that can be used as a basis for flexible management.

Case study 1, Hydromorphology (Germany)

The dissemination of knowledge and results concerning the implementation of the WFD and the floods-directive to practitioners and policy were warranted by the participation of the following practice partners:

- Wasser- und Schifffahrtsamt (WSA) Hann. Münden
- Flussgebietsgemeinschaft Weser (FGG Weser)
- Hessischen Ministerium für Umwelt, Energie, Landwirtschaft und Verbraucherschutz (HMUELV)
- Hessisches Landesamt für Umwelt und Geologie (HLUG)
- Regierungspräsidium Kassel (RPK)

The practice partners provide access to the available data (e.g. land use, topography, management of reservoirs). They are strongly interested in the results and will incorporate them in the establishment and updating of the programmes of measures and river basin management plans according to the WFD.

Several work meetings took place where the results of the project were presented and discussed with the practice partners listed up above.

In the context of the project Flood risk management plan for the river Fulda (HWRMP Fulda) there were several meeting consulting the data base for the catchment area of the Lower Eder River.

08 September 2011: Workshop about climate change in Northern Hesse, consequences and adaption strategies for water resources management with practice partners from HLUG, WSA and the University of Brunswick – Institute of Technology.

13 November 2011: Consulting in the context of the Project Flinkman with the practice partners from HMUELV, RPK, Wasserverband Schwalm and consultants.

28 October 2012: Dialogue with consultants involved in the design of local schemes for the floodplain restoration measure near Bergheim

10/11 April 2013: Consulting in the context of the Project KLIMZUG (Northern Hesse) among others with the practice partners from WSA, HLUG, RPK and the University of Brunswick – Institute of Technology.

Figure 97: The practice partner Dr. Brahmer (HLUG) presents climate change data for Hesse at the work meeting on 10/11 April 2013

30/31 October 2013: Meeting with the WSA about the optimisation of the control of the Ederdam.

26/27 November 2013: Consulting in the context of the Project KLIMZUG, among others with the practice partners from WSA, oral presentation about climate change in Northern Hesse, consequences and adaption strategies on the example of Eder and Fulda River (Final conference).

Case study 2, Dam management (France)

In addition to the dissemination activities of the whole ClimAware project, Irstea is also involved in the Explore2070 project and developed links between the two projects.

Irstea and Seine Grands Lacs took part to the two last SCP meetings (Paris and Lyon) to present the results of the project.

A number of work meetings were also organised between the two French partners to coordinate the work within the French case study. At some meetings stakeholders of the River Seine basin (public administrations, drinking water producers, waste water managers…) were present for discussions on project results and feedback.

The results of the CS2 were presented at several international conferences:

- IS.Rivers conference in June 2012 (oral presentation)
- EGU 2013 (Vienna) in April 2013 (2 oral presentations)

- IAHS 2013 (Goteborg) in July 2013 (oral presentation)

An article is in press in the peer-reviewed International Journal of River Basin Management (Dorchies et al., 2013) concerning the impact of climate change keeping current reservoir management. At least one more article is planned on the adaptation strategies developed in the project (TB-MPC and new filling curves).

A presentation proposal has been accepted at HIC2014 (New York) in August 2014 on TB-MPC issues and another one concerning the overall case study will be presented to “Adaptation frontiers conference” (Lisbon, Portugal, 10th – 12th of March 2014) organised by the EU FP7 ERA-NET project “CIRCLE-2”.

A conference about climate change issues on the River Seine and involving different projects and stakeholders is organized by Irstea and Seine Grands Lacs and will occur during the second trimester of 2014.

The tools elaborated for generating the new multi-objective filling curve on the reservoir will be delivered to the EPTB Seine Grands Lacs. These tools would be used for assessing the risk considering the state of the reservoirs on one particular day and they also would be used in negotiations with other stakeholders of the catchment (State and local administrations…) for the updating of the reservoirs management rules.

Case study 3, Agricultural water use (Italy)

Knowledge and results concerning the impact of climate changes on agriculture water management were disseminated to the following groups of stakeholders:

- Water Management Boards
- Farmers’ Associations
- Researchers in water field
- Water Basin Authority

through several meetings:

- May - June 2012: bilateral meetings with farmers and water managers at provincial level;
- May 2013: meeting with stakeholders on the implementation of the WFD as a tool to reduce the pressure on groundwater resources.
- January 2014: A final workshop with all relevant stakeholders was organized by the IAMB team. The main objective of the meeting was to validate the identified adaptation measures to climate change, in order to:
    - define the effective possibility to realize them, in particular specifying the elements that can facilitate or hamper their implementation;
    - assess their effectiveness in limiting the impact of climate change;
    - integrate them with new proposals.

  The attendance to the meeting was enough satisfactory since 17 stakeholders (90% of the invited), participated to the workshop. Research institutions, Apulia basin authority, local irrigation water users associations and regional government were well represented.

The workshop was divided in two main sessions. A quali-quantitative approach was used in order to draft a Cognitive Map (CM) about adaptation to climate change in Apulian Agricultural Sector. CM is an Information and Communication tool significantly able to support public participation. It is a representation of a belief system in a given domain, it comprises of concepts representing key drivers of the system, joined by directional edges or connections representing causal relationships between concepts. Key to the tool is its potential to allow feedback among its nodes, enabling its application in domains that evolve over time. The tool is said to be semi quantitative, because the quantification of drivers and links can be interpreted in relative terms only (Kok, 2009).

After a brief presentation of Climaware project's results, during the first consultation round, the ideas and opinions of stakeholders on the main objectives that need to be pursued in order to reach a state of adaptation to climate change in the Apulia region were collected. Once collected, the stakeholders' perceptions/ideas/knowledge were elaborated in order to group the similar concepts into common clusters, as indicated in the following table (Table 28).

Table 28: Objectives identified by stakeholders and corresponding clusters

POLICY	➢ Effective integration of the resources in the Programming 2014-2020 ➢ Redefining local policies in accordance with regulatory/administrative and European/national scenarios, in the field of water and enterprise ➢ Sustainability of the aquifer ➢ Crop orientation for planning the irrigation resource consumption
MANAGEMENT OF WATER DEMAND	➢ Optimization of water use ➢ Determination of the irrigation variables and choice of the appropriate irrigation method ➢ Management of water demand for irrigation: tools and measures to respond to the increase of the uncertainty of the availability ➢ Flexibility of irrigation systems and water supply ➢ Reduction of irrigated areas ➢ Estimation of irrigation demand for optimizing the allocation of water resources ➢ Environmental sustainability and management flexibility with economic criteria
TRAINING AND CONSULTATION (TECHNICAL ASSISTANCE)	➢ Training the farmers to a sustainable use of water ➢ Increase the decision capacity of farmers towards more appropriate management solutions
USE OF NON CONVENTIONAL	➢ Use of non-conventional water ➢ Reduction of groundwater use by fostering the use of waste water

RESOURCES	
GOVERNANCE	➢ Effective model to govern the aquifer ➢ Balance between water availability and demand (on pluriannual basis) ➢ Infrastructure interventions to increase water availability through actions and activities aimed to save water ➢ Management of criticalities (protocol for drought management) ➢ Decision chain ➢ Shared and participated model of governance ➢ Improve services of technical assistance ➢ Balance between public and private water use with careful control on groundwater and reservoirs
INFRASTRUCTURES	➢ Modernization of delivery irrigation systems
MONITORING AND CONTROL	➢ Survey of the groundwater withdrawals to obtain the water balance and the environment availability

With the collaboration of all stakeholders, the identified objectives were coded into the CM shown in Figure 98, which is a graphical representation of their mental models. In particular, the CM represents the relations of cause-effect (arrows) existing between the adaptation measures identified by IAMB team and integrated by stakeholders (boxes in green) and the objectives proposed by stakeholders (boxes in blue).

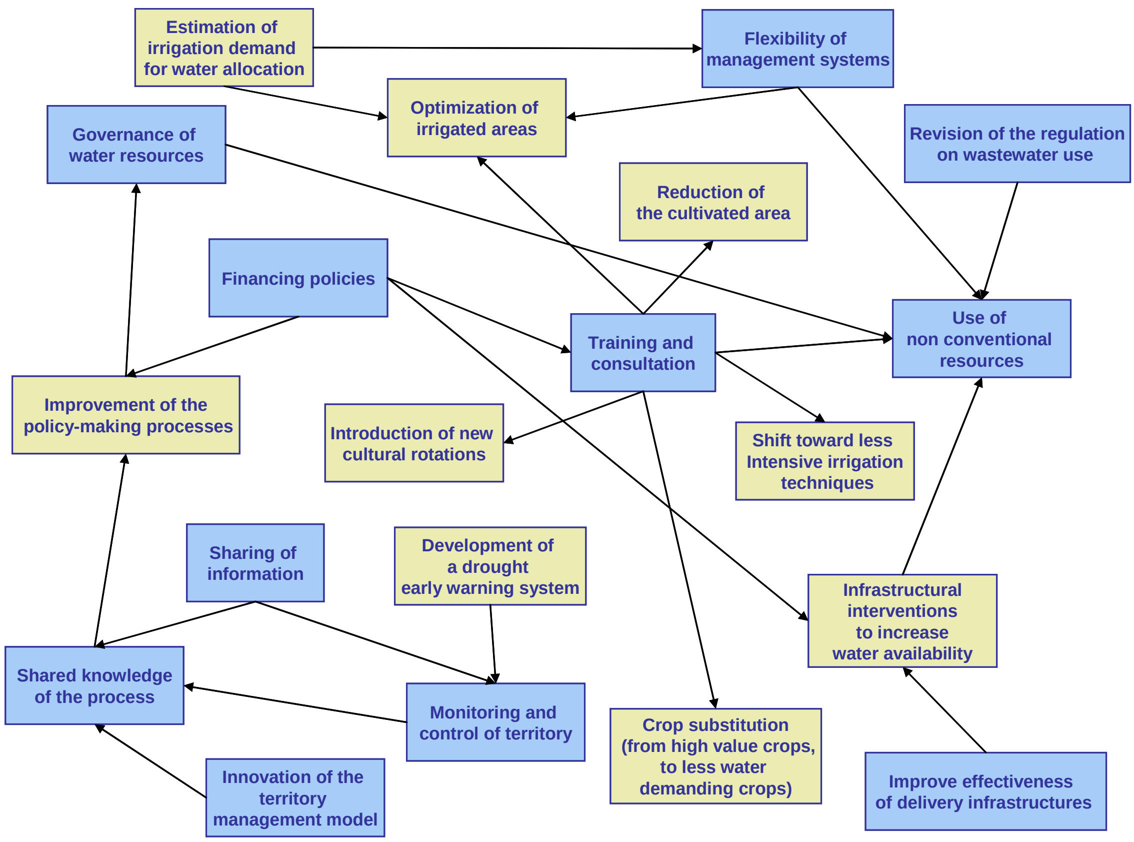


Figure 98: CM representing the relations between the adaptation measures identified by IAMB team and integrated by stakeholders (boxes in green) and the objectives proposed by stakeholders (boxes in blue)

As shown in Figure 98, the central issue identified by stakeholders is “Training and consultation”, that proved to be a crucial and key element for the realization of important adaptation measures, as for example the optimization of irrigated areas or the crop substitution. An important role is also played by the financing policies, needed to fund the training itself, together with the infrastructural interventions and the policy-making processes improvement.

During the construction of the CM an interesting debate involving all stakeholders took place, and the main theme highlighted by all of them was the **lack of a shared strategy in the field of water management at regional scale**. In conclusion, they all agreed that the model and the knowledge of the territory are the base of an effective process of adaptation to climate change.

The second session of the workshop aimed at collecting the key elements that in the opinion of stakeholders are the real obstacles to the realization of the identified adaptation measures. They are listed below:

- Fragmentation and opacity of knowledge and information;
- Reduced foresight by many stakeholders of the conversion/modification of the cultural and/or management choices, towards a more sustainable system;
- Bureaucratic/administrative difficulties to access to funding and the realization of interventions;

- Everything that obstacles the flexibility;
- Lack of integration and coordination in the competences;
- Scarce knowledge of the agronomic techniques by technicians;
- Limited financial resources;
- Limited knowledge of the problems;
- Transparency of the decisional processes;
- Long term revenue

In conclusion, during the meeting feasible adaptation measures to climate change of Apulian agricultural sector were identified, their effectiveness in limiting the impact of climate change was estimated and the main elements that can facilitate (objectives) or hamper (obstacles) their implementation were recognised.

In the following are reported some photos of the workshop (Figure 99 and Figure 100).

Figure 99: Welcome and opening presentation

Figure 100: Stakeholders during the working sessions

In addition, the contribution of IAM-B to the project dissemination has been carried out through the following activities:

- The results of the Italian case study have been presented:

  1) in the international conference on Environmental Science and Technology that has been hold in Athens (Greece) on September 5-7 2013, with the paper titled: "Integrated

hydrological-economic model to quantify impacts of climate change on agricultural water management in the Mediterranean";

2) in the 1st CIGR Inter-Regional conference on Land and Water Challenges that has been hold in Bari (Italy) on September 10-14, 2013, with the paper titled: "Hydro-economic modelling to assess climate changes impact on agriculture water management in a semi-arid region".

- A paper will be prepared and submitted to a peer-review journal.

Common dissemination activities

A presentation of the complete ClimAware project has been submitted to the European Geosciences Union (EGU) 2014 General Assembly.

4 Discussion of results

Within the ClimAware project five different partner institutes collaborated on continental and regional scales in order to assess current and future water management issues from different perspectives. In particular, the objective of WP1 was to select appropriate climate change projections and socio-economic scenarios as well as to perform European modelling (EM) for water availability and water use (water withdrawals and consumption) of the main water related sectors to analyse the alterations of the hydrologic regimes in Europe in the 2050s.

In order to address socio-economic changes, two different and opposed water-related scenarios were chosen from the SCENES project, named Economy First (EcF) and Sustainability Eventually (SuE). Large volumes of water are withdrawn from European river basins, mainly in the UK, Benelux countries, Germany, and Northern Italy and used for domestic, industrial, and agricultural purposes. If following the pathway of an EcF scenario total water withdrawals are expected to increase by 46 % in Europe in 2050, but may decrease by 66 % assuming SuE scenario conditions. Due to a future vision dominated by market orientation with less investment in new technologies and education, the industrial sector continues to grow and thus its demand for water. On the other side, technological innovations and an increasing commitment to save water in all sectors, as assumed for SuE, results in a decrease of total water withdrawals across Europe. By applying these two different socio-economic scenarios, a broad range of possible futures in regard to water resources could be considered within the ClimAware project.

Regarding climate change, different projections from three GCMs (CNCM3, ECHAM5 and IPSL) were applied, which were recently established in the WATCH project. The GCM projections were based on the two different SRES emission scenarios A2 and B1. WaterGAP3 results show that climate change is very likely to have a strong impact on water resources, especially in the Mediterranean region but the direction and intensity of suggested change often depends on the chosen GCM. Consequently, results in this report were presented as an ensemble mean for each emission scenario including the uncertainty range derived from the three GCMs. It is well known that the choice of the emission scenario is of less importance for the early decades of the 21st century than for the later ones since they start to diverge in the second half of the century. In general, changes in climate-sensitive WaterGAP3 results are slightly lower under the SRES B1 scenario in Europe than under the SRES A2 scenario. In the second half of the century, this effect could be stronger.

In Europe, a north south divide was found for future mean annual water availability, where water resources are decreasing in Southern Europe while increasing in Northern Europe. However, depending on the GCM applied, the intensity of change was especially strong in Southern Europe with CNCM3 climate input, and in Eastern Europe up to Scandinavia (IPSL input), or more moderately all over Europe with only minor changes in central Europe considering ECHAM5 climate input. Besides mean annual values, it is also important to look at changes of seasonal river flows, which can be stronger (i.e. variability can be higher within a year than between years). In Europe, low flows usually occur in late-summer and early-autumn. WaterGAP3 results suggest a decrease in low flows over large parts in Europe. Besides the Mediterranean rim countries and the Black Sea region with a reduction in low flows of more than 50 %, low flows are likely to decrease in Southern UK, central Europe, and also in Southern Sweden and the Baltic States. Regarding the three selected case studies analysed in the project, strongest impacts of climate change can be expected in the Apulia region (CS3) in the 2050s. Here, an agreement of all model runs in both the direction of change and in all seasons of the year became obvious indicating substantially reduced river flows throughout the year. Additionally, a strong impact of climate change can be expected in the Seine River basin (CS2), too. While impacts in spring and winter are more moderate, the strongest reduction in summer flows was found in this case study. The Eder River (CS1) is located in the transition zone between increasing (Northern Europe) and decreasing water availability (Southern Europe) associated with a higher uncertainty in the direction and intensity of change. Nevertheless, while changes in spring and winter flows are more moderately or contradictory between the different climate projections, low flows in summer and autumn are likely to be reduced in this case study as well. The presented three case studies show clearly the distinct regional differences in the impact of climate change in terms of direction, intensity and uncertainty.

River discharge of the Lower Eder River (CS1) and Seine Rivers (CS2) are highly influenced by dam management. Due to the importance of dam operation in these two case studies, a new dam operation scheme using dynamic optimisation and new dam types (navigation, hydropower and flood control) were implemented in WaterGAP3. According to the WaterGAP3 results, both case studies may have to manage reduced river discharges during the low flow period accompanied by reduced annual reservoir inflows in the future. These changes resulting from climate change should be considered in future planning and adaptation strategies. Realizing future adaption strategies for the Ederdam such a test operation mode is already implemented since 2012 (Theobald et al., 2013, p. 199).

In order to determine water stress, the withdrawal-to-availability ratio (w.t.a.) was determined for the three summer month (JJA). According to this indicator, basins under severe water stress were found in particular in countries of the Mediterranean but also in UK, Belgium and Ukraine in the baseline period (1971-2000). For the selected case studies, the w.t.a. indicated severe water stress in the Apulia region (CS3), medium water stress in the Seine River basin (CS2), and no/low water stress in the Weser river basin (the superior basin of the Eder River).

Under the A2-EcF scenario, the area under severe water stress in summer is likely to increase in Southern and Western Europe and a large area of medium water stress occurs in Eastern Europe. Under the B1-SuE scenario, the impact of climate change (i.e. reduced summer flows) can be partly compensated by lower water withdrawals as expected in this scenario. However, increasing water stress was still found in Western European basins. The situation is similar for the Seine River basin (CS2), where severe summer water stress is likely to occur in the 2050s under both the A2-EcF and the B1-SuE scenarios due to strong reductions in low flows. Total water withdrawals were simulated to increase in the Seine River basin under the A2-EcF scenario assumptions, especially because of higher abstractions in the industrial and agricultural water use sectors. In the B1-SuE scenario, total water withdrawals could be decreased in the 2050s but still severe water stress is likely in the Seine basin. In the Apulia region (CS3), severe water stress occurs on average in six consecutive months of the year (May to October) in the baseline period. Here, decreasing water availability is again the dominant factor causing increased water stress in the 2050s in both scenario combinations despite decreasing water withdrawals in the B1-SuE scenario. Depending on the GCM-scenario combination, 1-3 more months fall into the severe water stress class in the 2050s. In the Weser basin (CS1), the no/low water stress situation changes to medium (B1-SuE) and even severe water stress (A2-EcF) in the 2050s. Under the given scenario assumptions, the conditions for irrigation water requirements move further north in Europe leading to rising agricultural water uses. Hence, even in the Weser basin, irrigated agriculture may become an option to increase agricultural output under optimal crop growing conditions. While this leads to increasing yields due to warmer climate and optimal water supply, water stress is likely to increase in combination with reduced summer flows. To put this assessment of the Weser basin into perspective it must be mentioned that the withdrawals used for the w.t.a. includes water consumption and as well as return.

In challenging situations when water quality is deteriorated by withdrawals this may cause serious threats to the water resources management in a climate-change scenario. For the Weser basin especially the Werra River and Oberweser (Upper Weser River) the influence of saline discharges are the major impact on water quality (Geschäftsstelle Weser, 2009, p. 68). Since withdrawals are not mentioned in the context of significant surface water impact (Geschäftsstelle Weser, 2009, p. 23) it might be valid for future studies on the Weser basin to include the focus on water consumption supplementary to water withdrawal.

Results of case study 1 show the importance of human impact in comparison to the effects due to climate change. Hydrodynamic-numerical models were applied to investigate the effects of human impact and climate change on the surface waters by the example of the Lower Eder River. The approach of full-reach-investigations using 1D-parameters and a measure-specific investigation using 2D-parameters is very useful and gives reliable results. Obviously in the region of investigation of case study 1 (Lower Eder River in the Weser basin) the human impact caused by stream training, weir-induced backwater situations and flood plain use is expected to remain more severe than the expected effects of discharge modifications induced by climate change. This assessment is supported by the consideration of climate change as a framework condition which cannot be influenced by water resources management. Since the measures concerning the aims of the WFD (Annex V, Table 1.2) are generally oriented on anthropogenic-non-altered streams (European Parliament of the Council, 2000), these kinds of measures supporting morphodynamic fluvial processes always remain the best choice for stream restoration. Consultations with various stakeholders throughout this project as well as in synergetic work on other projects show a wide agreement on these kinds of restoration measures. Although the finally developing stream morphology may change due to climate change these measures are not expected to need adaption. In this sense the objectives set at the beginning of the project and the finally achieved results and conclusions do not diverge.

Usually special attention is given to topics like instream flow requirements or acceptable discharges of wastewater related to water temperature. In these aspects climate change induced rises of the water temperature may shift the general orientation (benchmark of reference) of today's summer cold streams to future summer warm streams. This would give reason to the assumption that fauna and flora will also have to adapt to this shift in water temperature. Nevertheless the actually available knowledge on possible deterioration of the ecological state is too limited to justify reliable recommendations yet. So further observations, to compare non- or minor-altered streams with anthropogenic-disturbed streams are an appropriate concept. For the investigated region of the Lower Eder River water temperature related topics are not expected to be of major future importance since the discharge from the Ederdam usually is cold deepwater (Theobald et al., 2013, p. 188).

Objectives of case study 2 were to assess and propose adaptation strategies on the reservoir management considering climate change. A model was drawn to simulate river and reservoir systems and the results of the assessment show that drought will be a major issue for the River Seine basin in the future. In order to assess the reservoir management, performance indicators based on the low-flow and high-flow thresholds used by stakeholders on the catchment were calculated.

Two adaptation measures were proposed at two different levels of management. The first one intends to redesign the objective filling curves minimising the risk probability not to be able to achieve multiple objectives at some downstream gauging stations of the reservoirs in the future. This calculation is based on naturalized flows series that come from historical or generated data.

The second adaptation measure consists in using a real-time controller that intends to take into account all available data in real-time. To the best of our knowledge, the Tree-Based Model Predictive Control (TB-MPC) is the most advanced and flexible kind of real-time controller in this domain. This project is the first application of Model Predictive Control and moreover of TB-MPC to a multiple reservoir system, for both flood and drought objectives applied on very long time series. Important difficulties were met during the development of this real-time controller. One of them, which is not yet solved, is the weakness of the performance of the optimiser. For this reason the results obtained with TB-MPC are not yet optimal, especially for flood management.

The best results regarding the performance indicators in both present and future conditions are obtained with the management combining the new multi-objective filling curve and the current real-time rules using thresholds at stations close to the reservoirs. However, even with this management adaptation, the indicators show that climate change will impact low-flow periods. As an example, it can be expected that the alert threshold (which is the first threshold that causes restrictions in water uses) will be reached 5 % of the time in the future instead of 1 or 2 % in present time.

Case study 3 had the objective to assess the quantitative effects of climate change on water balance components and water use in the agricultural sector of the Italian Apulia region and to identify appropriate and feasible adaptation measures. A coupled hydro-economic model was implemented. The simulations carried out allowed to investigate hydrological processes and possible impact of climate changes on water resources particularly relevant for water planning strategies as well as to highlight the trade-offs existing in the agricultural ecosystem of Apulia region between agricultural sector performance and pressures on water resources.

Obtained results proved that climate change is likely to reduce agricultural productivity, production stability and incomes, which would increase food insecurity levels. From another side, the applied climate change scenario affects the water availability of the region, expressed in terms of surface runoff and groundwater recharge, drastically reducing it as an effect of the reduced precipitation.

5 Conclusion and Recommendations for Future work

This report has been prepared within the ClimAware project as a contribution to the 2nd IWRM-NET Funding Initiative for Research in Integrated Water Resources Management. The main goal of this project was to assess the impacts of climate and socio-economic changes on freshwater resources in Europe across the European and regional scales. Of particular importance in the project was the development of an integrated approach to perform an analysis across Europe and different case studies by knowledge transfer and data exchange between the project partners in terms of cross-scale and cross-case comparison.

In the first case study the influence of climate change on the hydromorphological conditions according to the WFD were evaluated for a section of the Eder River (Germany). The objective of this case study was to examine on a typical river section, how the WFD objectives can be implemented sustainably in consideration of climate change. Discussions with stakeholders from water authorities, water boards, municipalities and engineering consultants throughout this project as well as in synergetic work on other projects show a wide agreement on the sustainability of morphodynamically self-adjusting restoration measures. The Lower Eder River is an example which shows the influence of human impacts on the streams ecological state as well as appropriate stream development measures and possible advantages of managed water systems.

In that context it is important to distinct strictly between dams with the release of cold deep-water, small weirs without and large weirs with significant rise of water temperature. Large weirs are assessed to be of higher impact on water temperature than small weirs. The same effects like at small weirs are expected for dams with cold deepwater release from stratified water bodies. Since dams are usually assessed as heavily modified waterbodies it is very plausible to assume that some climate change induced shifts in stream ecological alteration like water temperature may be dominated or even minimized by appropriate dam operation.

In addition to stream ecological purposes future dam management will have to be balanced in an appropriate way to consider all aspects of social and economic aims of a sustainable water resources management. This includes especially effects of climate change on shifted stream ecology as well as flood protection, navigation, energy supply or recreation. The future work on necessary adaptions will have to reflect constraints and uncertainties like those resulting from climate change or demographic shifts.

The study on the River Seine basin highlighted several aspects that should be considered when assessing a regulated water system. First of all, all the situations that stakeholders want to avoid (here water scarcities and floods) deeply depend on the chosen flow thresholds. As a consequence, simulations driven by climate models should provide results that could be comparable in absolute values. This is why it was decided to correct the bias on climate inputs in order to get a hydrological regime similar to the historical one in present time (1961-1991). Then the study makes the strong assumption that this bias observed in present time should be the same in future time by applying the same bias correction on climate inputs in future time (2046-2065). Despite this effort, climate inputs used in simulation remain the first source of uncertainty in the results. An original integrated model was built for this study taking into account hydrology, hydraulic propagation, withdrawals and reservoir management. The lumped hydrological model does not allow taking into account potential changes in runoff phenomena due to a change of the land use. An assumption was also taken that rainfall-runoff dynamics will not change in the future, which could also result in a strong source of uncertainty. One goal of this study was to propose adaptation measures to the regulated system. It was decided after discussing with the EPTB Seine Grands Lacs to only explore non-regret adaptations because it would be difficult to imagine the construction of new reservoirs considering that main tributaries are already equipped with a reservoir and because of more important environmental constraints than in the past. Regarding the WFD, the results of the case study show that the increasing of water scarcities would deeply affect the objective of keeping water bodies in a “good state”. Indeed, waste water treatment plants for domestic water and industries are currently dimensioned for a pollution dilution taking into account current drought events based on past statistics. Whatever the reservoir management, with the expected reduction of flow during drought period, the dimension of these installations could be questioned in the future.

The third case study considers agricultural water use in the Apulia region (Italy), where economic and demographic changes cause an increase in the demand for good-quality municipal and industrial water. Besides, changes in the agricultural practices increase the demand for water in the agricultural sector. Since water is scarce in this region, the study focused on the agricultural sector, which has the largest water saving potential. The results of the research carried out in the Italian Apulia region should be addressed to different level of stakeholders to act in an efficient and equitable way to mitigate climate impacts threatening the future of agriculture. In the meanwhile, future research should address the evaluation of present and future water balance of the region taking into consideration the variation of non-agricultural water demand and an increased uncertainty in water availability. Further, in situ adaptive plant response to variation of climatic parameter could be investigated (Lovelli et al., 2012) to achieve a more accurate determination of crop coefficient and, accordingly, of water use and irrigation requirements.

The cross-scale comparison was performed to provide an integrative view of current and future water resources by combining and analysing modelling outcomes from the European and case study scales. In all three case studies, climate change and future socio-economic developments are likely to have an impact on river flow regimes and water scarcity, especially on low flows, but with different consequences.

The European water sector will be affected by a changing climate. As already emphasized the impact on different European regions due to climate change occurs obviously in very different terms of direction, intensity and uncertainty. The majority of the EU needs to prepare for more droughts. Water scarcity is especially a problem in Southern and South-Eastern Europe. Therefore, climate change adaptation will be necessary throughout the entire EU in distinct regional patterns and can in many circumstances significantly reduce vulnerability. In the Mediterranean region, river flows are likely to be reduced throughout the year under climate change in the 2050s and irrigation water withdrawals may increase due to higher temperatures and lower precipitation values. Results for the Apulia region show a growth in water stress with about 1-3 more months per year under severe water stress in the future. This tendency can be slightly dampened by a different crop selection and further improvements in irrigation water use efficiency if possible. Nevertheless, the impacts of climate change could not entirely be counteracted in the Apulia region under the applied scenarios. A similar situation could arise in other regions in the Mediterranean where agriculture is the dominant water use sector and a major source of income.

For the Apulia region, further analysis and management strategies have been provided in the project by the regional perspective in case study 3. At farm level, farmers adopt different strategies in their farm management: they reduce the irrigated surfaces and shift towards less water intensive techniques. In addition there is an effect of crop substitution and a serious phenomenon of land abandonment since a substantial area of the region will not be cultivated anymore. At system level, discussions with local experts in water management highlighted the need for enhancing some of the consortia management tasks, namely the survey of the irrigation demand, the optimization of the water allocation in view of the future reduced availability, the development of a drought early warning system and infrastructural interventions aiming to increase water availability. The reduction of the irrigation system vulnerability to drought could be achieved by enhancing the interconnection with other sources of water, both conventional and non-conventional. The former requires the development of new storage and delivering infrastructures. The latter needs reliable water treatment plants. Besides, the re-use of reclaimed water needs to deal with cultural barriers related to the willingness of farmers to use this water for irrigation.

For large parts of Europe reaching from Southern Europe up to the south of Scandinavia, low flows, usually occurring in late-summer and early-autumn, are likely to be reduced by climate and socio-economic changes in the 2050s. Results for the Seine River basin indicate that low flows are likely to be considerably lower in the summer season of the 2050s. This water shortage during summer could intensify the competition between the different water use sectors as several demands need to be fulfilled: the provision of freshwater for the large metropolitan area of Paris, for hydropower generation, and process water for manufacturing industries. Even irrigated agriculture may get a larger role in the Seine basin in the future than under today's conditions. Hence, a coordinated development and management of water in terms of an Integrated Water Resources Management (IWRM) should carefully be evaluated as an adaptation option. As shown by the B1-SuE scenario, water savings due to technological improvements can lower water withdrawals in the different water use sectors and thus reduce the pressure on future water resources. A crucial factor at the Seine river basin is the management of different reservoirs. A more flexible management of the dams might be considered in particular to elevate low flows during summer and autumn seasons to fulfil water demand for human activities as well as to ensure environmental flow provisions. The dam operation as well as management strategies were further evaluated in case study 2 by the regional view at tactical (adaption of target reservoir filling curves) and at operational (real-time reservoir management) levels. The result is a centralized real-time controller called Tree-Based Model Predictive Control (TB-MPC) developed in collaboration with TU Delft (Netherlands) and Politecnico di Milano (Italy). For the reservoirs' management on the Seine River, this tool uses all the information available in real time, including ensemble weather forecasting, and hence, shows a real improvement for drought and flood management.

No/low water stress occurs at the Eder River and its superior basin (Weser river basin), in the baseline period. However, current climate change projections indicate that low flows are likely to be reduced as a result of climate and socio-economic changes in the 2050s. In this case study, the management of the Ederdam is of special importance, which supports navigation on the Weser River particularly during times of low flows. As mean annual reservoir inflow is expected to decrease as well in 5 out of 6 scenarios, an adapted future dam management is required. The large-scale results of some scenarios suggest that the Ederdam may not be sufficient anymore to maintain navigation on the Weser River during times of low flows in the 2050s. Here, further analyses with a more detailed dam operation scheme and regional climate data would be advisable to evaluate the consequences especially with regard to tourism because the Eder reservoir is also used for recreation and leisure purposes during summer. This may be done on the base of existing regional investigations (Brahmer, 2013; HLUG 2005; HLUG 2008) and in addition to the test operation mode as it is implemented since 2012 (Theobald et al., 2013).

Regarding the improvement of the hydromorphological conditions of rivers according to the objectives of the WFD (Case Study 1), restoration measures, like they are implemented at the Lower Eder River, supporting morphodynamic fluvial processes, remain to be the best choice for stream restoration. Though the finally developing stream morphology may change due to climate change these morphodynamic self-adjustable measures are not expected to need adaption.

According to the results of the ClimAware project, climate change and water use is likely to modify river flow regimes in many European regions. Further studies are required to address the impact on water quality and river ecosystems. Water quality is fundamentally linked to the river flow regimes as the flow influences concentration and transport of chemicals, oxygen, nutrients and organic matter. This is especially the case, when rivers are impaired by sewage or non-point source pollution. In addition, rising water temperature can be crucial for aquatic ecosystems but also for the cooling of thermal power plants. Due to the expected decreases in river low flows over large parts in Europe, water quality is likely to be negatively affected as a result of reduced dilution capacity. Furthermore, river ecosystems will be at risk due to altered flow regimes. In a river ecosystem, different flows have different ecological functions and provide specific habitats. Consequently, intelligent operation schemes for reservoirs and integrated management of freshwater resources will be required.

Looking ahead to 2050 it is evident that adaptation and mitigation solutions are required to reduce vulnerability to climate change and further resource use. Wherever shortage of water availability in relation to water demand exceeds acceptable limits both water supply and water demand management as well as more efficient use of freshwater resources need to be addressed. Historically, water shortages have been solved by increased supply. This was a very successful way in some European regions like the German southwest supplied with water from the lake Constance or some Northern and Central German regions supplied from the Harz Region. Similar concepts, i.e. building storage capacities, inter-basin transfers, and desalination are widely favoured ways to deal with water scarcity and droughts in many parts of Europe. There is a growing understanding though for some European regions those demand-led approaches are indispensable for a long-term strategy to reduce water stress. Because increased water supply may lead to a higher demand, as the incentive to use water more efficiently loose on appeal. So in the threatened regions priority to regulate the demand side might be more reasonable. There are many ways that can be used to manage water demand, both directly, e.g., water restrictions and consumption cuts, leakage control in water distribution system, water sensitive urban design; or indirectly, via increasing the efficiency of water use, e.g., water saving in building codes, improved agricultural water management, reducing freshwater demand for industrial cooling, and water pricing, use of engineered crop varieties, incentive schemes to promote water efficient products, develop programmes to promote efficient use of water, share best practices to reduce water consumption of companies. Nevertheless it is crucial to verify regional needs and to consider constraints like demographic changes, the risk of microbial contamination of underused existing water supply systems or the threat of undesired deposits in poorly discharged existing sewer systems.

Another focus behind all climate change adaptation activities should be to include adaptation needs in current land use management and practice and to strengthen the role of ecosystems. Land use change is one of the main drivers degrading water resources in quantitative and qualitative terms and vulnerability to extreme events. Because of the close link between human activities and land cover, land use and river basin hydrology, there is a need to consider the long-term impacts of climate change.

Although all actions that are implemented for adaptation to current climate variability can be used for climate change adaptation, there are some peculiarities that should be addressed. The uncertainty of the projections and changes in human pressures (i.e. water abstractions) as well as the addition of the time dimension play a major role. Therefore, all climate change adaptation policies should require actions that are chosen not only on the basis of their effectiveness to current climate variability and human pressures, but also on the basis of their ability to address future climate change and changing human pressures. However, applying different scenarios and climate projections should be considered to construct several possible future pathways and hence, to address the uncertainty in future developments.

By comparing different scenarios, it can be concluded that socio-economic scenarios dominate the dynamics of water scarcity. Even a substantial decrease in water withdrawals does not prevent some European regions from water scarcity. This is apparent during the summer season. Therefore, region-specific adaptation should not be discussed in isolation and the focus of any policy intervention should be on the socio-economic drivers, such as land use, demographic change and production patterns. Technical measures that mainly aim to maintain the current state or are trying to reduce the impacts are not sufficient to save water and to reduce vulnerability to water scarcity in the future.

Adaptation strategies are needed at all levels of governance, from international to local. Due to varying climate impacts and sectors affected, most actions will take place at the regional and local levels. Therefore it is crucial to verify the different regional and local needs as well as accordant adaptions. Nevertheless, adaptation cannot be viewed independently and must be regarded as the basis of all policies ensuring the relevance of changes related to global warming. The main role of the EU in this context is to stimulate that process and to promote solidarity among EU Member States for regionally different adaption strategies. In general, it is important to accept that temporary lack of knowledge on climate impacts and societal change does not have to be a reason for delaying investments in response measures. Short-term actions may be possible as long as they do not hinder more strategic measures in the future and give special preference to no-regret measures.

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Appendix

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GLOSSARY OF ACRONYMS AND ABBREVIATIONS

BVI	◄	Intermediary sub-basin (between an upstream and a downstream station)
CESR	◄	Center for Environmental Systems Research
CIHEAM-IAMB	◄	Mediterranean Agronomic Institute of Bari, Land and Water Resources Management Department
CLC 2000	◄	CORINE Land Cover dataset of the year 2000
CNCM3	◄	Global Climate Model from Météo-France, France
CROPWAT	◄	A computer program for irrigation planning and management, Food and Agricultural Organization of the United Nations
CRU21	◄	Climate dataset CRU TS 2.1 of the Climate Research Unit http://www.cru.uea.ac.uk/~timm/grid/CRU_TS_2_1.html
CRU31	◄	Climate dataset CRU TS 3.1 of the Climate Research Unit http://iridl.ldeo.columbia.edu/SOURCES/.UEA/.CRU/.TS3p1/.dataset_documentation.html
CS	◄	Case study
DPSIR	◄	Driving forces, Pressures, States, Impacts and Responses; causal framework for describing the interactions between society and the environment
DTM	◄	Digital terrain model
EcF	◄	SCENES scenario Economy First
ECHAM5	◄	IPCC Climate Model: Atmospheric General Circulation Model http://www.mpimet.mpg.de/en/wissenschaft/modelle/echam.html
EIT	◄	European Institute for Innovation and Technology
ELDRED2	◄	European Lakes and Reservoir Database as developed and provided by the European Environmental Agency (EEA)
EPTB	◄	Public river basin authority
et al	◄	et alia (and others)

ET_o	◄	reference evapotranspiration
ET_c	◄	crop evapotranspiration
EU-FP6	◄	EU's Sixth Framework Programme for Research and Technological Development http://ec.europa.eu/research/fp6/index_en.cfm
Explore2070	◄	National project on climate change impacts on waters in France by 2070
FGG Weser	◄	Flussgebietsgemeinschaft Weser (River Basin Community)
FP6	◄	EU's Sixth Framework Programme http://ec.europa.eu/research/fp6/index_en.cfm
FUT	◄	In case study 2, it represents the studied future time period (2046-2065)
GCM	◄	General Circulation Model *or* Global Climate Model
GHG	◄	Greenhouse gases
GIS	◄	Geographic information system
GLCC	◄	Global Land Cover Characterization map
GPCCv5	◄	Precipitation data of the Global Precipitation Climatology Centre, version 5
GR4J	◄	Daily lumped rainfall-runoff model with 4 parameters http://webgr.irstea.fr/modeles/journalier-gr4j-2/?lang=en
GRanD	◄	Global Reservoir and Dam database
HLUG	◄	Hessisches Landesamt für Umwelt und Geologie (german authority)
HMUELV	◄	Hessischen Ministerium für Umwelt, Energie, Landwirtschaft und Verbraucherschutz (HMUELV) (german authority)
HWRMP-Fulda	◄	flood risk management plan for the river Fulda
HN-Model	◄	Hydrodynamic numerical model
IPCC	◄	Intergovernmental Panel on Climate Change
IPCC SRES scenario A2	◄	SRES scenario http://www.ipcc.ch/ipccreports/tar/wg1/029.htm#storya2

IPCC SRES A1B	◄	see *A1B IPCC*
IPCC-IS92a	◄	Emission scenario IS92a, IPCC 1992 http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml
IPSL	◄	Global Climate Model from the Institute Pierre Simon Laplace, France (IPSL-CM4) http://icmc.ipsl.fr/model-and-data/ipsl-climate-models/ipsl-cm4
IRD	◄	Institut de Recherche pour le Développement
IWRM	◄	Integrated water resource management
KLIMZUG NORDHESSEN	◄	trans-disciplinary collaborative project for Nordhessen as a model region for climate change adaption
LandSHIFT	◄	Global land-use model LandSHIFT (Land Simulation to Harmonize and Integrate Freshwater availability and the Terrestrial environment) http://www.usf.uni-kassel.de/cesr/index.php?option=com_project&task=view_detail&agid=27&lang=en
LUC	◄	Land-use change
MICRO3.2	◄	Global Climate Model from the Center for Climate System Research, University of Tokyo, Japan (MIMR) http://www.ccsr.u-tokyo.ac.jp/ehtml/etopindex.shtml
MIMR	◄	s. MICRO3.2
MIMR-A2	◄	s. MICRO3.2, output for IPCC SRES A2 scenario SCENES EU/FP6 project: Water Scenarios for Europe and for Neighbouring States http://www.environment.fi/default.asp?contentid=379147&lan=EN
MNQ	◄	mean annual low-flow discharge
MPC	◄	Model Predictive Control
NIR	◄	Net irrigation requirements
PST	◄	In case study 2, it represents the studied present time period (1961-1991)
Q10	◄	10 percentile of the flow duration curve
Q95	◄	95 percentile of the flow duration curve
QMNA5	◄	5-year minimum monthly flow
Rio+20	◄	United Nations Conference on Sustainable

		Development
SAFRAN	◄	Climate reanalysis developed by Météo-France
SCP	◄	Scientific Coordination Project
SGL	◄	Seine Grand Lacs
SuE	◄	SCENES scenario Sustainability Eventually
TB-MPC	◄	Tree-Based Model Predictive Control
TGR	◄	Semi-distributed rainfall-runoff model based on GR4J and a linear lag and route propagation model
TMY	◄	typical meteorological year
WATCH	◄	EU/FP6 project: water and global change http://www.eu-watch.org/
WFD	◄	Water Framework Directive
WaterGAP	◄	Global water model WaterGAP (Water - Global Assessment and Prognosis) http://www.usf.uni-kassel.de/cesr/index.php?option=com_project&Itemid=143&task=view_detail&agid=47
WP	◄	Work package
WSA	◄	Wasserschifffahrtsamt (german agency for navigation)
WWF	◄	World Wide Fund For Nature