# Manifesto from the Workshop Climate Change Impacts on Groundwater

## EU Working Group C workshop October 12th, Warsaw

A workshop on Climate Change Impacts on Groundwater" was held in Warsaw under the umbrella of the CIS Working Group C on Groundwater. The meeting was used to share information and exchange views between member states, stakeholders and scientists and aimed to establish the knowledge base on groundwater aspects of climate change as a basis for climate resilient river basin management plans (RBMPs) and to identify the needs for future work in climate change impacts on groundwater, both from policy and scientific perspectives. It was decided to move forward in two complementary ways:

1.) to support the policy process by making concrete recommendations for 2nd round of RBMPs on the basis of the established knowledge base, and
2.) to promote further research based on the inventory of knowledge gaps, which should establish an improved understanding of climate change impacts on groundwater, which may eventually be applied in the 3rd or 4th RBMPs.

Important outcomes of the workshop were that the impacts of climate change on groundwater are not limited to water scarcity in southern European countries, but also result in significantly changed seasonal regimes of snowmelt, in wetter winters, dryer summers and prolonged periods of droughts in other parts of Europe. It also appeared that secondary impacts of climate change, caused by human adaptations in energy and water policies have potentially large impacts on groundwater resources. However, there is a lack in understanding of how this will affect groundwater itself, as well as the receptors of groundwater such as ecosystems, surface waters and drinking water abstractions. The EU Working Group C on Groundwater *adopted the following manifesto,* advocating for action and a plea for further research to establish an improved understanding of climate change impacts on groundwater, because groundwater is a precious resource which is only slowly replenished and which is of great importance to the European society by providing drinking water, irrigation water and ecosystem services.

## Identified Knowledge Gaps

Since 2006, the combination of WFD and GWD involves a new paradigm in protection of groundwater, with increased emphasis on aquatic and terrestrial ecosystems and on the mutual influence between groundwater and surface waters. Up to now groundwater and surface water research was often performed in 'separate worlds' and really integrated research on soil-groundwater-surface water relations, including integrated modelling, monitoring and evaluation of measures is scarce. Moreover, pressures on groundwater systems tend to increase, partly as a result of the effects of climate change and associated human induced changes of surface and subsurface water management. Especially, secondary impacts of climate change, resulting from human intervention in water systems, are expected to have large short-term effects on groundwater resources. Examples of secondary impacts are:

- increasing groundwater abstractions especially for irrigation due to longer dry periods and higher water demand of crops leading to falling water tables and salt water intrusion, especially in periods of extreme hydrometeorological events;
- changing land use practices, including an increase in the production of energy crops, which already led to increasing nitrogen concentrations in groundwater due to increased use of fertilizers in some areas in Europe. Negative effects on pesticide concentrations and increased water demands affecting water quality and quantity;
- more intensive use of the groundwater bodies in relation to *energy policy*, for example by a sharp increase of aquifer thermal energy storage facilities in Europe and the search for unconventional fossil fuels which has potentially large adverse effects of groundwater quality;
- storage of $CO_2$ in deep aquifers or gas fields for $CO_2$ mitigation, which may affect the quality of groundwater resources and groundwater receptors, depending on the local hydrogeological situation.

Although climate change impacts on surface water systems are relatively well studied in relation to flooding risks and prolonged droughts, the primary and secondary impacts of climate change on groundwater systems are relatively unknown. Only a number of very recent studies give some information of the changes in groundwater recharge rates and renewal, the fluxes towards ecosystems and surface water receptors and related changes in groundwater and surface water quality. Very few of them include an evaluation of societal changes in reaction to climate change prognoses and consequences for biodiversity.

There is a clear need for further research in order to better understand how climate change impacts affect groundwater, in order to eventually scientifically support the implementation of the Water Framework Directive, the Groundwater Directive and EU policy initiatives on ´Water Scarcity and Droughts' and 'Climate Change Adaptation and Mitigation with respect to groundwater. A key research theme that we identified is the need to: "Develop methodologies to understand, evaluate and predict climate change impacts on groundwater resources and interlinked surface waters and ecosystems in order to eventually define climate-robust set of measures" The focus should be on both monitoring systems, which support signalling the effects of primary and secondary climate change impacts on groundwater resources and on developing methodologies and modelling tools to understand and predict the effects of both types of impacts. The methodologies should be able to assess the effects of local and regional measures and to produce scenario analyses, which help to select effective sets of counter effective measures, including scenarios for the conjunctive use of groundwater and surface waters and the assessment of favourable locations for artificial recharge of groundwater. A concrete proposal for EU funded research under the FPVII or FPVIII umbrella is attached in the Appendix.

# Appendix: A concrete proposal for research under FPVII/FPVIII

## Understanding the Impacts of Climate Change on Quantity and Quality of Groundwater Resources

### Introduction

The potential impacts of climate change on water resources have long been recognised, but still there has been comparatively little research related to groundwater, although it represents the major part of the exploited water resources in many EU member states. Moreover, the main focus of climate change research regarding groundwater has been on quantifying the likely primary impacts of changing precipitation and temperature patterns on water quantity in small localised catchments. However, other *secondary impacts* including an increase in water demands and changes in agricultural practices may have even stronger effects on the sustainable management of groundwater systems.

Global warming is likely to have substantial direct and indirect impacts on both groundwater quantity and quality across Europe. In Denmark and in many other EU member states increasing winter precipitation may result in increasing nutrient leakage, and hence work against measures planned in order to assure compliance with the Water Framework and Groundwater Directives and decrease the nutrient loads to associated aquatic ecosystems (Andersen et al., 2006). In southern Europe, where water resources are predominantly groundwater based, global warming is likely to reduce overall water availability with warmer and drier summers and more extreme rainfall events year round. The EU workshop revealed that climate change is expected to impact groundwater significantly in the rest of Europe too. Even for moderate climates relevant shifts in the length of the recharge season, the snowmelt period and the occurrence of prolonged droughts are predicted to occur, which may well lead to an overall reduction of groundwater recharge (Goderniaux et al. 2009) and water scarcity at the end of the summer period (Huss et al. 2010) or to increased transfer of nutrients from groundwater towards lakes and estuaries (Roosmalen et al. 2011).

Regarding the *primary impacts* of climate change on groundwater, much is still unknown about:

- the effects of extreme hydrometeorological events, including the propagation of floods and meteorological droughts towards groundwater
- changes in temporal patterns of groundwater recharge;
- the impacts of the quality of groundwater renewal;
- possible increased or altered risk for leaching and transport of contaminants and nutrients and its effects on groundwater ecology;;
- the impact on groundwater and stream water and contaminant fluxes towards aquatic and terrestrial ecosystems;
- changes in patterns of groundwater-surface water interactions which also affect the WFD and GWD risk assessments related to the chemical and quantitative status of surface water and groundwater bodies.

However, the largest short term effects of climate change might be due to human actions that react on the actual and predicted changes in precipitation and temperature patterns. Examples of such *secondary impacts* are the increase of water demands and abstractions of groundwater for irrigation due to higher evaporation which may lead to falling water tables and salt water intrusion (Oude Essink, 2010). Worldwide there is a large increasing trend in groundwater abstractions and groundwater depletion (Wada et al. 2011) which may amplify as a result of climate change. Other secondary impacts are related to adaptations of Europe's *energy policies*, including the increased production of energy crops which may change groundwater quality by increasing use of fertilizers and pesticides and increased water needs, the storage of heat and $CO_2$ and nuclear waste and the search for unconventional fossil fuels. Studies which try to understand the effects of these adaptations are few.

Moreover, little is yet done on monitoring of the long term effects of climate change in groundwater, which makes it difficult to distinguish between natural and manmade changes to groundwater systems. For example, long term monitoring of water tables, spring discharge and runoff is very scarce. There is a need to systematically assess historical monitoring data in order to understand the response of the groundwater to climatological changes in the past by developing techniques such as hindcasting, but also to develop methods to design improved and integrated monitoring and modelling of groundwater and surface water. Eventually, properly designed monitoring systems should enable us to record future changes related to primary and secondary effects of climate change, for example by the monitoring of spring discharges and groundwater recharge rates and quality, by systematically applying groundwater age tracers and dating techniques.

## Research topic

### Develop methodologies to understand, evaluate and predict the impacts of climate change on groundwater resources and interlinked surface waters and ecosystems

The focus of the proposed research should be on Europe wide assessment of the primary and secondary impacts of climate change on groundwater resources and groundwater receptors. This includes both the quantitative aspects (e.g. changes in temporal and spatial recharge patterns and increased water use), the chemical aspects (e.g. changes in transformation and degradation of chemicals, changing pathways of pollutants and groundwater-surface water interaction) and the ecological aspects (e.g. changes in groundwater ecology and derivation of threshold values to protect ecosystems). By assessing the potential impacts, the research should also clarify what consequences are expected for reference conditions, such as baseline shifts which may impact on groundwater.

The research should include an evaluation of societal changes in reaction to climate change prognoses, both related to water and energy policies. It should develop methods to understand the possible adverse effects of CCS practices, thermal heat storage and the search for unconventional fossil fuels on future groundwater uses and ecosystem services. It should also highlight the opportunities for using bio-indicators in

groundwater as an early warning and evaluation technique to deduce the effects of extreme hydrometeorological events on groundwater and associated ecosystems.

The research should improve the predictive assessments of climate change impacts. This includes the development of fully coupled soil-unsaturated zone-saturated zone-surface water models capable of simulating long term behaviour of hydrological systems, but with a very high temporal resolution which enables us to see the changes in seasonal patterns on water table depths, water quality and fluxes towards surface water and groundwater dependent ecosystems.. There is need to assess the uncertainty of the predictions by integrating the newest research results on contaminant fate and progress made in climate research, using the results of project like ENSEMBLES and PRUDENCE. The predictive methodologies should be able to produce scenario analyses, which help to select effective sets of counter effective measures, including scenarios for the conjunctive use of groundwater and surface waters and the assessment of favourable locations for artificial recharge of groundwater.

However, we should also invest in underpinning research based on collection of field data, because spatial heterogeneity in climatic, hydrogeological and hydrogeochemical conditions leads to uncertainties, which should be understood before proper modelling can reveal realistic scenarios of changes. The opportunities of Earth observation methods, such as GRACE and HOBE, should also be investigated in order to reduce uncertainty and may help to extrapolate monitoring and modelling results (link with GEO), and downscale from global to local models. The research should set the basis for a Europe wide system of groundwater monitoring focused on long term records of recharge rates, water table depths, spring discharges and water quality, which will enable future signalling of unexpected changes and the evaluation of measures that aim to reduce the effects of global and manmade changes.

## Expected Impact

The understanding obtained through the proposed research will help EU member states to properly identify probable climate change impacts on groundwater systems and help to focus measures in the third and fourth River Basin Management Plans. The research will help to identify primary and secondary climate change impacts on water demands and water supply over Europe, to develop smart and integrated monitoring and modelling programmes and to design tailor-made programmes of adaptation measures to avoid or counteract these impacts. The predictive models that will be developed will enable to understand the effects of local and regional measures and to run robust scenario analyses, which will help to select effective sets of adaptation measures. Eventually the research will help to make the RBMP climate proof and groundwater and surface water management climate resilient.

## References

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