Final Report

Topsoil

Resilient soil and water resources

Understanding the water beneath your feet

The TOPSOIL project is part of the Interreg North Sea Region Programme with the objective to preserve and protect the environment against climate change impacts/effects by demonstrating new and/or improved methods for improving the climate resilience of target sites. The funding is provided by the European Regional Development Fund of the European Union.

Colophon

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Preface

Within the North Sea Region, the effects of climate change – more damaging storms, floods and drought – are hard to predict. Nevertheless, disruption is almost certain. Meanwhile, the effects of climate change can now be seen on the news almost daily. Take the drought in 2018, with low water level in rivers and crop damage, as well as flooding as a result of short and extreme thunderstorms. But what we don't see is the change below the surface. There's a slow, invisible process taking place beneath our feet but with a significant long-term impact on the quality of our environment and on human existence. TOPSOIL is all about what's happening underground.

"We believe that by making the interaction between soil, groundwater and surface water more visible, climate change adaptation should become more efficient."
With this document we aim to spread the message further, share our approach and our insights and highlight the urgent needs for adaptation.
We have learnt a lot about the challenges faced in groundwater management resulting from climate change, and about stakeholder involvement and transnational cooperation. As a result of the pilot studies, we gained tremendous knowledge, which in turn led to new management plans. For each of the pilots, tailored to the specific management questions and existing knowledge gaps (some still exist), steps have been identified to deal with the increasing need for adaptation, while recognizing - uncertainty and vulnerability. The pilots addressed current pressures (some already severe) - both on the upper subsurface levels, on groundwater and on surface water. TOPSOIL pilots have shown that climate change adaptation and sustainable groundwater management requires a stronger cohesion between land management and water management. The future climate changes will impact all.

In 2019 the TOPSOIL project has been extended till the end of 2021. In the extension support has been provided to local and regional groundwater managers to respond better to the need for balancing seasonal changes in groundwater availability and quality. The benefits of all TOPSOIL results have been capitalized further developed those relevant to local and regional groundwater management stakeholders. This report presents an updated version including results and messages from all of the project periods.

Following an introduction to the project itself (Chapter 1 & Chapter 2), Chapter 3 sums up the insights from a governance perspective. Chapter 4 specifies the efforts of transnational meetings while Chapter 7 builds the connection to the Sustainable Management Goals. Main insights linked to the technical challenges are presented in Chapter 5 (technical solutions). Chapter 6 provides an overview on how TOPSOIL partners have capitalized on the results of the project in many different ways. In Chapter 8 the outcomes are presented and the recommendations are in Chapter 9. More details, references and specific contacts can be found in Annex 4 "New Management Plans".
Enjoy the read and feel free to get back to us with any questions!

We hope you enjoy the read.

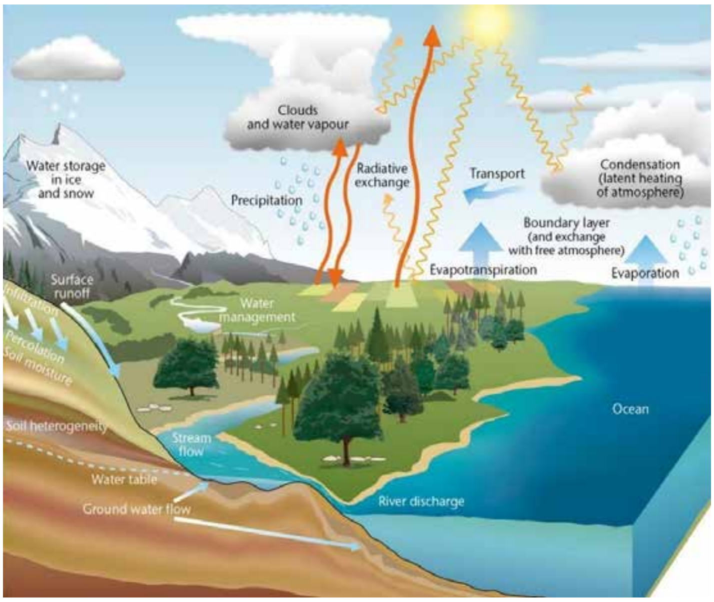
Sincerely
The Topsoil Partnership

Topsoil consortium, final conference Horsens (DK) October 2020

Content Table

1. TOPSOIL: an introduction

An important part of the water cycle takes part under our feet, within the uppermost 20-30 meters of the subsurface. Although not visible and not completely understood, the topsoil plays an important role in our adaptation to the impacts of climate change in the North Sea Region. Scientific studies of the subsurface, using new techniques and models, should lead to a better understanding of the processes and the hydrological system, improving adaptation to climate change. This will change our way of managing water systems.



(Reference: UK Metoffice)

The impact of climate change is manifold, e.g. rising sea levels, drought caused by less rainfall and increased evaporation in summer, less absorption of fertilizers and the effects on soil conditions, heavy rainfall leading to run off and rising groundwater levels in winter. During the course of the project, it also became clear that these challenges are already increasing. It is increasingly difficult to balance the demand and availability of groundwater with good quality. The impacts of climate change must be dealt with now and later.

TOPSOIL has addressed all these issues and provides a short overview of the main principles in a video.
https://www.youtube.com/watch?v=nk_mK4hduz0&t=2s

To tackle the impact of climate change on the subsurface, the TOPSOIL project started in 2015, with the Central Denmark Region as lead partner. Five countries are working together: Denmark, Germany, Belgium, The UK and the Netherlands. The project focusses on five shared challenges - building on the earlier Interreg IV project WaterCAP:

1. Groundwater flooding in towns and agricultural areas

Increase in precipitation will lead to a rise in groundwater level and flooding in both rural and urban areas. It can damage houses, infrastructure and crop yield.

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2. Saltwater intrusion into freshwater reserves.

Rising sea level with saline water intrusion into fresh ground-water and surface water. This can lead to loss of crop yield, contamination of fresh water resources and influence the surface water quality.

3. The need for a groundwater buffer to store excess rain water for later use. The challenge of balancing demand and availability will increase with climate change further!

Less precipitation and higher evaporation will lower the groundwater level but increase the demand for groundwater. This will lead to crop losses, lower river levels and less uptake of nutrients by crops.

4. Better management of soil conditions, to strengthen resilience to extreme rain events and improve water quality.

More extreme events will lead to more flooding and drought. Degradation of the soil will reduce the resilience for these events.

5. An unused capacity to break down nutrients and hazardous pollutants in the uppermost layers

A healthy soil can break down nutrients and pollutants. Understanding the system is important to know how to act when considering the impact of climate change.

These five challenges have been studied in 16 pilot areas (see figure 1) for developing and testing solutions for managing the uppermost 20-30 meters of the subsurface. This is where we cultivate crops, build our infrastructure and develop our modern society. This is also where we have infiltration into our drinking water resources and where pollution spreads from contaminated point sources. The main hydrological and chemical dynamics are represented in this uppermost part of the subsurface. The effects of climate change is, therefore, of great importance in this part of the soil and they have a direct impact on the uppermost layers and on the surface. Because of the direct interaction between land use, groundwater, surface water and soil, an integrated concept of land and water management is needed. The five TOPOIL challenges are therefore often interconnected and demand solutions and management plans that embrace mutual challenges.

Not all five challenges are present in every pilot, although the different countries all face the same problems more or less. This is also why exchange of knowledge on old and new challenges is so fruitful. The flooding of towns in particular was a key part of the Danish pilots, while salinization was part of pilots in Belgium and North Germany. Surface to groundwater connectivity and drought issues were mainly investigated in England, the Netherlands and the eastern part of Niedersachsen. Water quality issues were looked at by all the pilots.
More information of the pilots can be found in the pilot catalogue and the midterm catalogue (https://northsearegion.eu/topsoil/output-library/communication-tools/).

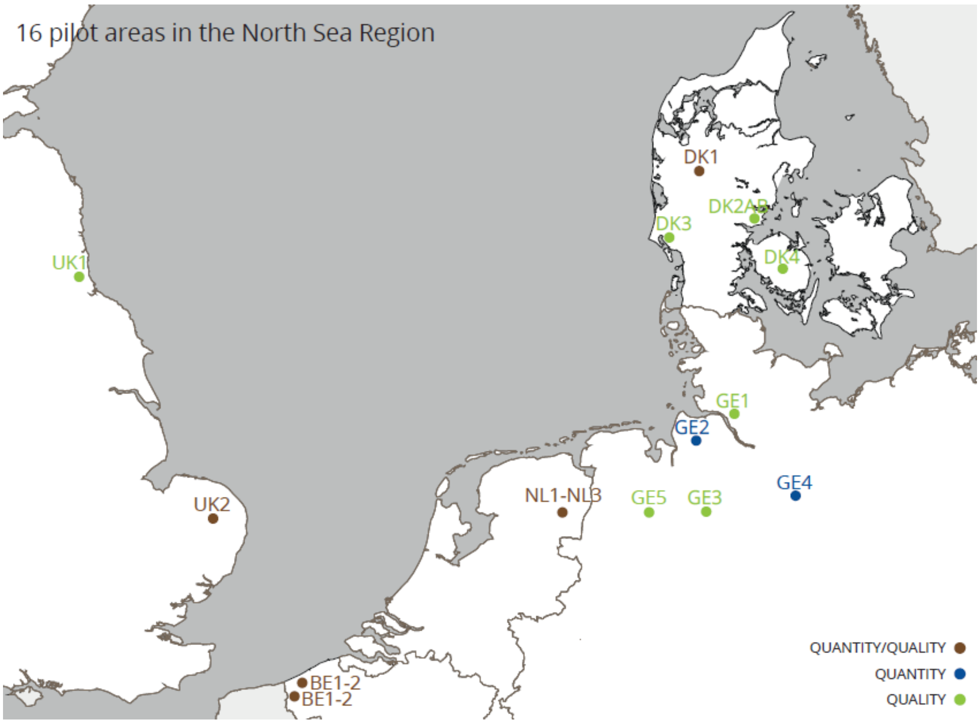


Figure 1 Some pilot are manly focusing on water quality issues (nitrate, pesticides), some on water quantity (drought, flooding) and some on both.

2. Work packages and approach

Figure 2 shows the project structure existing out of different work packages (WP). While communication about and within the project activities has been a central element, all pilots have used five identical steps in their approach to maximise the transferability/transnationality of the solutions. These steps are:

1. Consultation of stakeholders to improve the understanding of the challenge and need for new service;
2. Implementation of technical field investigations;
3. Interpretation of data and modelling of the existing and new data collected;
4. Exploration of best governance and practice from the five countries involved, in search of new best standards;
5. Development of a new management regime.

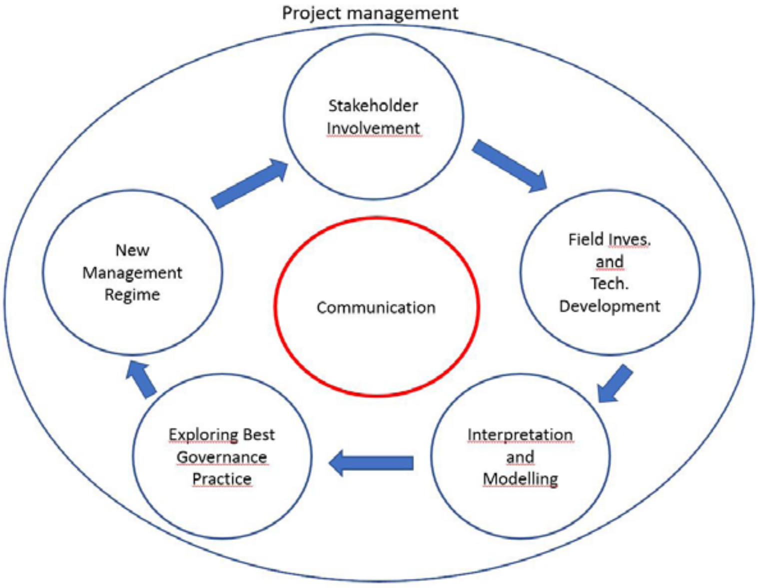


Figure 2 Project structure TOPSOIL

The setup of the different components is described below, while further chapters will contain the main messages.

2.1 Project management (WP1)

The TOPSOIL project is a large project, involving 16 pilot areas and 23 beneficiaries in 5 countries. Being the only Interreg North Sea VB project with such a strong focus on groundwater, TOPSOIL has been organized bottom-up to accommodate the rich diversity of partners and the issues being dealt with. This means that the project coordinator (Central Denmark Region), together with the Work Package lead partners, provided the frame and the partners identified those themes and issues they needed to solve in their pilots - and on which they could benefit from transnational exchange. The consortium met every six months, at meetings hosted by different partners, taking the opportunity to delve further into the local pilots. Further coordination took place in monthly (telcon or face to face) Steering Committee meetings. Between 2020 and 2021 two online and one hybrid partner meeting allowed enabled continued technical exchange. This resulted not only in a more effective delivery than promised in the proposal and also strengthened trustful working relationships which contributed to efficient reporting towards the funding bodies. More importantly, it has led to further cooperation - not only transnational - and an informal technical network on groundwater management throughout the North Sea Region (see also chapter 4 “Benefits of Transnational Exchange”). In figure 3 is an overview of some of the numbers achieved by the different activities.

5 countries	24 partners	16 pilots
Total budget € 7.342.220	More than 20 videos	44 solutions adopted
23 Transnational meetings	21 press releases	48 Geological and geophysical field work
		15 Hydrological models developed and tested
2 Policy days		20 Measures identified

Figure 3 TOPSOIL activities in numbers

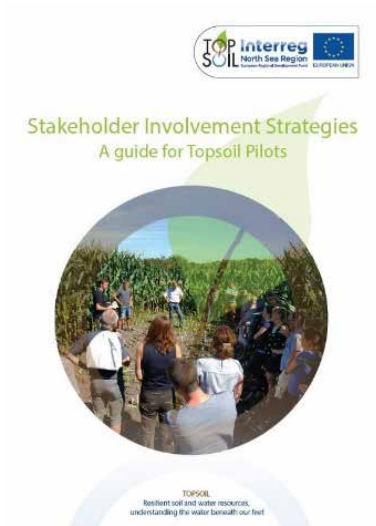
2.2 Communication (WP2)

Spreading the message and informing other water managers, regional public and other stakeholders on activities has been built into TOPSOIL from the very beginning- as communication is even more central if the subject is not visible as is the case with groundwater and the subsurface. The pilot projects have played an important role in providing the necessary evidence base and offer an additional opportunity to interact with the general public and other professionals. While the scientific results were communicated in technical contexts (see also 2.4) we have presented the objectives, results, benefits and demonstration projects that have been achieved and implemented to water managers across the North Sea Region, facilitating the uptake of measures and interaction with the public and stakeholders in the different pilot project areas- during events (see also 2.3) as well as in numerous publications (see annex 1).
The TOPSOIL-message is communicated through webpage, social media, videos, articles in professional papers and press releases. Addressing issues relevant to adapted groundwater management, several transnational workshops were organized to inform and involve stakeholders from local and regional to European level (see also chapter 4).

Figure 4 Danish stakeholders visit Drenthe

2.3 Stakeholder consultation (WP3)

Stakeholder involvement has been the second key aspect of the TOPSOIL project. At the pilot level, stakeholder involvement has been critical both to ensure that the pilots are delivered as planned and that the results are accepted in order to be adapted and have sufficient influence on the future management of the sites. The Stakeholder Involvement Strategies were based on the Topsoil Guide for Stakeholder Involvement (see figure 5), which in UK is centred around the well-established Catchment Based Approach. Each pilot has used this guide to engage stakeholders successfully to the pilots. The strategy has been part of the project from start to finish because trust is needed when adapting water management to the effects of climate. Especially when these effects to the soil are not directly visible.



https://northsearegion.eu/media/5658/topsoil-stakeholder-involvement-guide.pdf

Figure 5 Topsoil Guide for Stakeholder Involvement

By using the stakeholder strategy, we have developed:

- Better awareness of the importance of stakeholder participation within each pilot and familiarization with appropriate participatory methods and approaches;
- Identification of key stakeholders at pilot and project level and ensuring their involvement in project activities;
- A framework for planning stakeholder participation and a critical evaluation of the success of each pilot in involving stakeholders;
- A collated information and dissemination in relation to the approaches taken throughout the project and their possible impact on developing "new thinking" and management changes.

The stakeholder involvement process has been carried out throughout the whole project, to ensure the use of the results after the project has ended. Also, at project level, TOPSOIL has invited key stakeholders with specific expertise to take part and contribute to transnational partner meetings and pilot activities, thematic workshops on project challenges, governance challenges and field trips to discuss pilot implementations. This strong stakeholder approach has been new and challenging to some of the partners. However, it proved as very beneficial as it helped to build better tools and improved support for groundwater management. The partners agreed that the extra efforts have been well worth it (see also chapter 4).

2.4 Technical field investigations (WP4)

To learn more about the subsurface, (geophysical) techniques are needed to build robust models that simulate groundwater and the interaction with soil and surface water. These special techniques (newly developed in part) and field investigations have been applied in different pilot areas. The acquired data contributes to geological and hydrological 3D models.

Within TOPSOIL we have created, innovated and tested new technology with the aim to identify geological layers and soil characteristics, salinity, pathways for salinity or nutrients/pollution, small watercourses runoff and hydraulic properties. The investigations are partly done via staff exchange and close cooperation between the lead of the pilot area and the investigation team.

Structures and processes in the subsurface must be identified in order to do proper and sustainable management of soil and water. Overview measurements, as carried out by SkyTEM for example, were implemented in some pilots and show the distribution of freshwater and saltwater in the aquifers, for instance, while other pilots used results from airborne electromagnetic measurements by BGR (Federal Institute for Geosciences and Natural Resources) prior to the project's start, to interpret groundwater conditions.

Figure 6 tTem in action

Methods have been under development to relate the resistivity distribution in the aquifer covering layers to clay content and hydraulic conductivity to assess groundwater protection and recharge. In some pilots the structural layering is surveyed by seismic methods, with special emphasis on shear waves. A particularly promising approach has been the tTEM method. Before the extension the tTEM system – newly developed by HydroGeophysics Group Aarhus University within the TOPSOIL project – was applied in some pilots to provide resistivity information in the target depth range of 0–70 m, see figure below. The use of tTEM was so promising that in the extension the tTEM system was tested in all participating countries. For further information on the different test see Appendix 3.

Approach and results of have been published in several peer-reviewed and management oriented publications. An overview of the used methods in the different pilots can be found in figure 7.

Technical methods	Pilots
Seismic survey (S-wave, P-wave)	GE-1, NL-3, DK-3
Drillings/direct push	GE-1, GE-2, DK-2A, NL-3
Mapping with EM/radiometry	GE-5, BE-1
Ground Conductivity Meter (GCM)	GE-5, DK-2A, DK-2B
Towed ground-based transient electromagnetics (tTem)	DK-1, DK-2A, DK-2B, DK-3 , BE-1, BE-2, GE-2, GE-3, GE-5, UK-1, NL-1B, NL-3
FloaTEM	DK-1
Airborne EM (AEM/SkyTEM)	BE-1, NL-3
Georadar	GE-1
Surface Nuclear magnetic resonance (NMR)	GE-1
Electical resistivity (ER)	NL-1, GE-1, GE-2, GE-3, DK-1
acoustic doppler sensors	GE-4
Tracer experiment	NL-2
Dataloggers, turbidity meters	UK-2, BE-2
Borehole depth sampling	UK-1

Figure 7 Methods applied in TOPSOIL to better understand and manage groundwater and the top 30 meters of soil.

The work has been done in close cooperation with the other WPs, especially WP 3 and 5. The work builds on different knowledge and new perspectives from beneficiaries.

2.5 Interpretation of data and modelling (WP5)

Hydrological and geological tools have been newly developed and applied to model the geology in the shallow subsurface and to prepare the basis for new management. These methods are based on geophysical as well as geological and hydrogeological data that will be integrated and interpreted.

With the data and the modelling, we have been able to:

- Analyse the hydrogeological data from the North Sea region on geology, groundwater and surface waters;
- Set up models of varying complexity to analyse the data and hydrogeological systems in question (see also figure 8);
- Carry out predictions of the impact of future changes in land use, water management and climate change on water resources and groundwater quantitative and chemical status according to the Water Framework Directive.

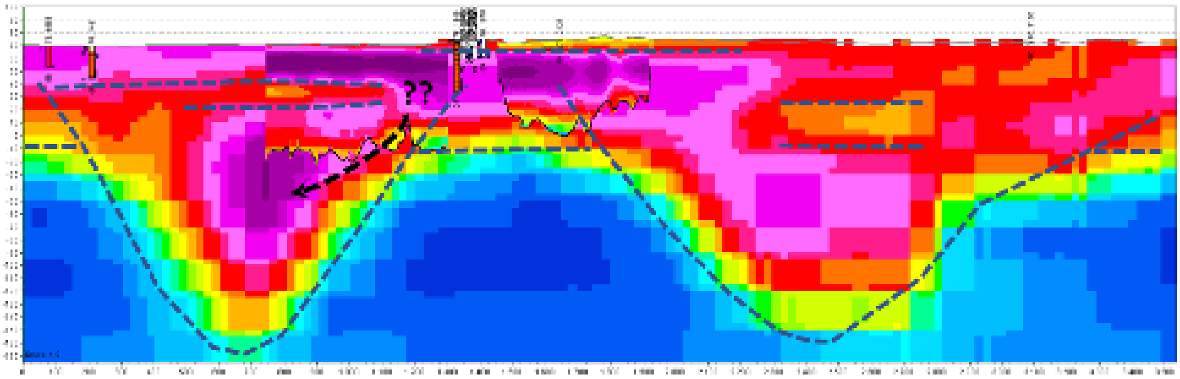


Figure 8 Example of r tTEM analysis with: a) Investigated fields; b)calculated resistivity maps at depth of 15-20 meter; c) detailed image of the permeable aquifers in a south-north profile (DK-2A).

Modelling has been used to investigate flooding in urban and rural areas (DK-4 in Odense and DK-1 in Sunds) and to investigate the ability to use groundwater reservoirs as buffers to store water in periods of excess rainfall. The expected increasing problems with saltwater intrusion into coastal freshwater reserves have been investigated through state-of-the-art advanced density-dependent modelling tools (e.g. GE-2 in Germany) in combination with a basic understanding of the geological structures required to make reliable predictions of the risk of saltwater intrusion. The modelling ap proach is used as a tool to make a robust risk-assessment of a threat from contaminated point sources in future climate changes (DK-4 in Odense).

Further, the capacity degradation of nutrients, as well as other hazardous pollutants, in the uppermost layers have been investigated

While we are proud to say that we fostered the knowledge base on the subsurface for the different pilot areas, it is also important to acknowlede that the collection and integration of data remains a central challenge. Models needed to investigate and explain the impact of climate change on ground- and surfacewater are as good as the available data. But it not always clear if data is available and what the quality of the data is. So, a better interface between data and models is needed.

Figure 9 Digging to understand the soil

2.6 Exploring best governance and practice (WP6)

Acknowledging the need to integrate technical results with the institutional and legal requirements, and with stakeholders needs, governance became a central issue in the modelling project. A Transnational Governance Team (TGT) was formed, with representatives from all TOPSOIL countries, to explore the best governance and practice from the five involved countries. One of the goals of the TOPSOIL project was to develop a European governance toolkit by collecting information on applied governance tools and their impact. To do so, common central governance issues were collected at the first partner meeting and discussions were organized on different governance topics. Then the TGT set up a toolkit in the form of dedicated workshops, providing the floor for the full consortium to discuss and reflect on management and governance throughout the NSR area and mirror management towards the five pilot challenges.

To structure these workshops, the case study approach was developed: One partner describes the local situation and defines governance questions which address the challenges of implementing sustainable groundwater management. The partners from the different countries prepare a response based on this case study "What, if I faced the same situation?". The objective of the workshops is to address each of the TOPSOIL challenges at least once in such case study approaches.

The results of these meetings, together with the workshop reports are than further developed into roadmaps for regional management. In the roadmaps, core questions on the main themes in the workshop (currently often the distribution of responsibilities, monitoring and stakeholder involvement) are illustrated with examples from the different countries. Workshop reports have been made for later use within the pilots. The synthesis of the different roadmaps for the discussed challenges are written in the next chapter.

2.7 New management plans (WP7)

A new management plan has been made for each pilot It is not a management plan in the sense that it describes the water management in a whole catchment area or in detailed actions / measures. The management plan reflects the experiences obtained from the pilots. It provides a short summary of the challenge(s), steps taken, measures identified and recommendations to change management in order to adapt climate change. During the extension of TOPSOIL, some of the management plans were already put into practice. Technical reports are available for more detailed information.
The references can be found within the management plans, together with the name of the organisation that can present more detailed information. An overview of the measures can be found in chapter 5.

3. How does the governance system contribute to climate change adaptation in GW management?

Groundwater experts know that good technical measures, such as small-scale buffering or abstraction measures, often fail to be implemented due to barriers in the governance context, and not for technical reasons. These can be regulatory, organisational, institutional (including access to data) or linked to barriers or stakeholder cooperation.

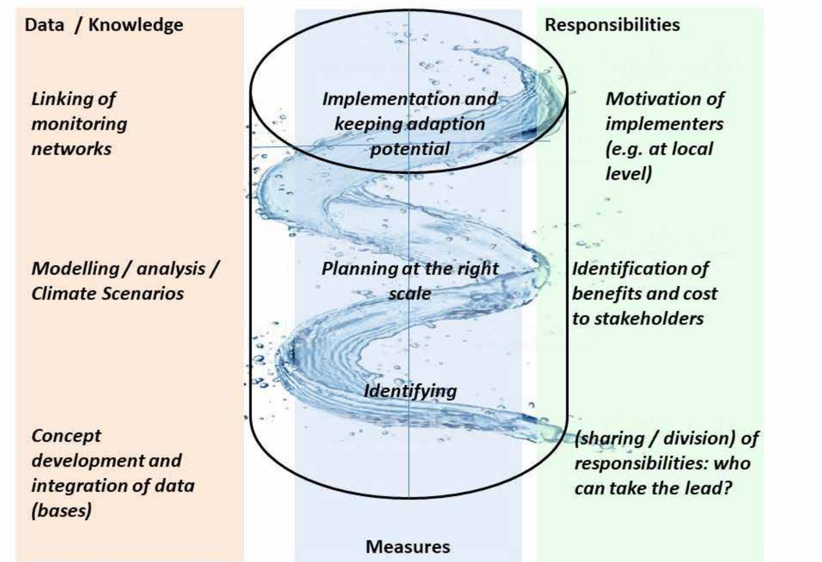


Figure 10 Water management is a iterative process which moves between generating data and knowledge, involving stakeholders and identification / implementation of measures. Source: Own development.

During these TOPSOIL discussions we identified typical governance issues. These issues need to be addressed during the management process – some repeatedly at different times, some at a specific point. Figure 10 (above) shows the issues as part of the management process (represented by the water spiral): during the process, they must be addressed in an iterative way, as part of different main themes, i.e.

- data / knowledge
- responsibilities
- technical and other measures.

This represents the toolkit which was very helpful by discussing governance issues.

In TOPSOIL each of the themes has acted as a red thread during discussions on saltwater intrusions, groundwater flooding, water scarcity, soil conditions and improving breakdown capacity. It became clear that the different issues need to be addressed so that GW management contributes to the adaptation to climate change.

In the following, we synthesize the results of our transnational governance discussions, workshop reports and roadmaps, illustrating the main points with examples from the different challenges. With this we would like to emphasize general needs, in the governance context, to help groundwater management to increase societal resilience.

More information can be found in the following documents:

- TOPSOIL Roadmap: How to improve regional governance on groundwater flooding
- TOPSOIL Roadmap Nutrient Management: "Improving local implementation of groundwater protection in the regulatory context of European Directives"
- Workshop Reports "Water Rights…" & Roadmap
- Workshop Report & Roadmaps: Small Scale measure in salinity

They are available at: https://northsearegion.eu/topsoil/work-packages/governance/

3.1. Responsibilities: Who supports adaptation to climate change in groundwater management?

In constitutional states, many of the tasks in groundwater management are in the hands of local and regional authorities. The authorities are restricted by the laws in place. For an effective management approach, legal responsibility must be clear, and in the best case comprehensive: the same institution (authority, NGO, water provider, other stakeholder) should be responsible and (financially) capable for identifying the risk and extent, the impact, the (potential) damage and planning and implementation of solutions.

However, in times of limited resources and new issues such as climate change adaptation, responsibilities cannot always be clearly divided. Water authorities need to involve land managers and other stakeholders to meet their objectives; land owners feel the need for cooperation in order to protect their property.

In the context of groundwater flooding, for example, the Danish partners found that the municipality has no responsibility for rising groundwater caused by sealing the sewer. Restoring a sewage pipe was expected to lead to rising groundwater levels, since the pipe would act as a drain and would not carry the groundwater away any more. However, within the current system, a Danish municipality was not mandated to take action for preventing flooded cellars. Faced with similar challenges in the Netherlands, authorities would invite stakeholders to engage in the discussion on how to solve the issue. Stakeholder involvement and sharing responsibility is more strongly established in the Dutch governance context.

Regarding improving soil conditions and enhancing the breakdown capacity in TOPSOIL, the discussions on nutrient management emphasized that local stakeholders such as land users and land owners must not only be involved but also feel motivated to take on the responsibility for protecting groundwater. For example, by growing maize with grass under sow (see figure 11). Offering financial compensation is only one tool for this. The knowledge that multiple benefits are linked to a good soil structure can also be a driver. In any case, monitoring data plays an important role in terms of communicating the status of the groundwater and the impact of management options. It also became clear that the legal framework at EU level is the strongest driver for change. For example, farmers identified in the most vulnerable abstraction areas are often more motivated as they are aware of the (potentially) increasing legal pressure on their work.

Figure 11 Maize with grass under sow

Also, in the different countries various approaches can be observed towards European requirements. In the Netherlands, the water authorities expect the farmers' union to take care of the nutrients problem. From the perspective of the Province of Drenthe, the union is / should be aware that solving nutrient management is linked to the farmers' "licence to produce". In Germany, the farmers' organization expects the water authorities to balance the pressure for water protection with the interest of economically viable agriculture. However, a particular challenge could be identified in all countries: farmers who are not participating in projects often own very large farms and are simply too busy to engage. From the perspective of the water authority, only the threat of new and stronger regulation might act as a driver for water protection.

Climate change adaptation may require either an adaptation of the legal basis or a good use of the inherent flexibility of some regulations. This may also require a strong role from stakeholders

3.2. Data / Knowledge

Developing models and using measured data is a well-established and necessary practice for their calibration or to monitor the status of groundwater. Still, there are several issues which need special attention from a governance perspective.
For example, in groundwater flooding and scarcity setting up monitoring networks to assess the impact of measures or observing development in the change of groundwater levels, often requires a combination of local and regional monitoring networks and close cooperation between the responsible authorities. Monitoring with soil conditions and the breakdown capacity of TOPSOIL may require many more monitoring points as local management practice or the heterogeneity of the underground may lead to unexpected transport paths from surface to groundwater. Monitoring the status of groundwater bodies may not be enough for the identification of potential land management approaches. Water providers, being directly impacted by groundwater quality, have often installed more detailed monitoring networks. Even these cannot point exactly towards sources of particular substances and need to be enhanced. Modelling can provide a first bridge to this gap.

Figure 12 Recharge and cleaning of abandoned mine-water to protect drinking water wells (UK).

However, modelling needs to build on databases. Databases that are accessible for modelling purposes are important. It has been observed that still, in times of data harmonization and high-level computational capacities, acquiring data and integrating it into the modelling concepts still takes up the major part of a project.
Also, the availability of data can be a problem. Soil information is not always freely available. It's owned by different companies, not always shared with the public and sometimes protected because of sensitive information (mining). This makes it hard to get a good up-to-date overview of all available information.

Data ownership on a field scale is also an issue in some countries. As real, locally measured data needs to be provided to actually proof the impact of land management on the groundwater, farmers in the Netherlands are often keen to get samples of their groundwater and are interested in samples on their farm. In Germany this is a very sensitive issue: generating farm or plot-specific data seems to be watched more carefully by farmers in Germany as they do not want to become too transparent. They are also concerned that the data might influence land value, for instance. However, farmers engaged in a project show a particularly strong interest in learning and are more open to new information.
As climate scenarios are a central tool in modelling assessments related to climate change adaptation, the transnational exchanges showed that there are different approaches to using climate scenarios. In a workshop, water managers and modelling scientists identified four main points for further discussion:

1. How are climate change scenarios to be chosen for regional approaches;
2. The importance of groundwater modelling to model the entire water cycle within an environmental unit;
3. How to convey the use of climate change scenarios and the implications for environmental management;
4. The implications of climate change scenarios and the management of water quality.

All countries start with IPCC scenarios. Then the local authorities calculate the local scenarios modified for the region. It became apparent that choosing different scenarios depends strongly on the purposes for use and are difficult to compare.

3.3. Technical and other measures

Regarding salinity prone groundwater bodies, the extreme droughts and floods over the past years have shown the weakness of a governance system, i.e. small-scale measures are not seen as a short-term action in groundwater management. There are no regulations or procedures to approve or monitor the impact of such measures, or to allow for the fact that many small-scale abstractions could negatively impact the sustainability of groundwater bodies. Similarly, infiltration measures that might support the short-term stabilization of groundwater bodies cannot be approved or implemented.

Concerning the shortage of groundwater, abstractions rights played a major role. During transnational exchanges it became clear that rights for large scale abstractions (> 150.000m³/year) are assigned based on impact assessments models in all countries. When assessing the impacts of abstractions, both Nature2000 and the WFD water bodies need to be considered, combined with the effects of climate change.

Figure 13 Nature2000 and WFD-goals are influenced by abstractions and climate change (NL)

Soil and groundwater characteristics are often considered, or a particular form of agricultural management. In the GE-4 pilot, an additional effort for assessing the sum-impact of all small abstractions was also modelled. Climate change impacts are not always systematically considered. However, it is very important not to overexploit the aquifers, because of the expected decreasing available volumes of groundwater in summer. Examples from Belgium and UK showed that it can be very difficult to phase out licenses for groundwater abstractions.
Controlling abstractions by licensing can include the following approaches: limit the duration of permits; maximise the total volume of the extraction for a region (catchment-based approach); maximise the amount per license.

Planning climate change adaptation includes the identification of measures and choosing the right scale while keeping the adaptive potential. Up till now the effects of climate change have not been included in the articulation of environment goals, as in Nature2000 directives or WFD. In water management, groundwater bodies have been considered as slow in responding to measures and weather impacts. At the same time, the current regularity of extreme weather phases points to long term changes due to climate change. A new flexibility in measures and monitoring is required. The greater the shortage of groundwater the more important the use of hydrological models, in combination with monitoring the effects and the extracted amount of groundwater. The groundwater body appears to be more affected by the climate changes than we had expected earlier. The modelling performed in DK-4 pilot shows the possibility of integrating individual components: geology, hydrology, abstractions data, urban and climate data into one modelling tool to achieve a robust risk-assessment from the contaminant point sources. Besides the contamination transport paths in the future climate, this modelling shows the strong connection between water-cycle factors and can be used to predict the impact of climate changes on the system.

4. Benefits of transnational exchange

While all partners searched for solutions in different fields of groundwater and soil water related problems, the approaches, organisational or financial structures and the patterns of prioritisation are different. The intense transnational exchange in TOPSOIL gave opportunity to inspect the own approaches and structures and open minds to different ways. By having a look in other countries and discussing each problem you discover new ideas. For instance, Denmark quickly has decided to create dykes needs to create dykes in some areas to prevent flooding during heavy rainfall events in the winter. This is new to Denmark, but Belgium and the Netherlands have several decades of experience with this issue, so they could share a whole catalogue of solutions.

Some problems are very similar, some differ between countries. But we all have the same language to deal with problems. Techniques and strategies that were developed in one country could be used in other pilots (e.g. SkyTEM and tTEM) and gave more insight in solving the problems. For example the approach of stakeholder involvement in the UK was very helpful for other pilots to organise this in a professional way.

This led to a considerable number of meetings in the TOPSOIL partnership. Nine partnership meetings at partner locations, two online partner meetings, 14 transnational governance workshops. At least three pilots involving active partners from two countries were implemented following review and consultation.

The knowledge exchange included issues on, for example, the different investigation methods for the TOPSOIL survey, the TOPSOIL mapping, the use of models to calculate the effect of climate change and adaptation measures, and the availability of data, or institutional and governance challenges. Not only partners were invited for these subjects but also stakeholders from outside the project: farmers (organisations), municipalities, water companies and consultancies. Last but not least during the Topsoil extension we got the great privilege of carrying out a tTEM EuroTour were Aarhus University did tTEM mappings in England, Belgium, Netherlands and Germany. The mappings provided an insight into water related issues from abroad, and how to tackle them, i.e. flooding, dyke management, saltwater intrusion, mapping water filled fractures

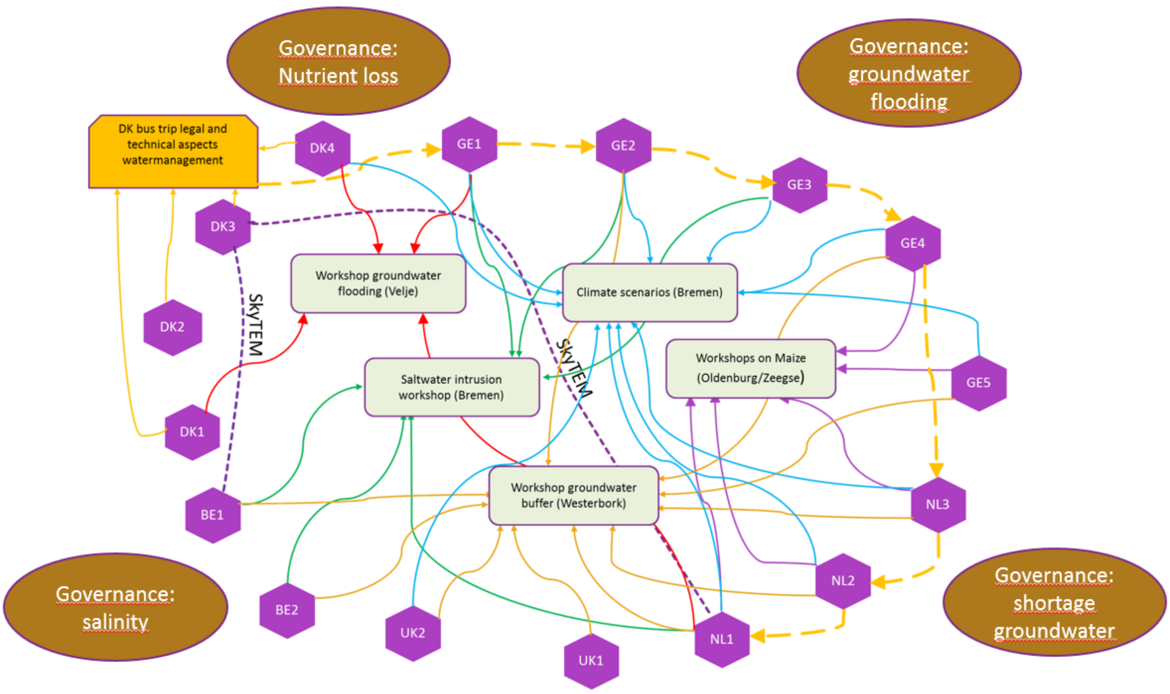


Figure 14 Intensity of international exchange between pilots.

The transnational exchange also facilitated an interdisciplinary discussion since the TOPSOIL partnership included experts from a number of fields such as geophysics, geology, hydrology, communication, policy, groundwater management, agriculture, and environmental protection. Transnational discussion make it easier to acknowledge differences and search for shared issues because you have to explain to colleagues from other countries what the challenges are. Often this also improved discussion between the partners from the same country. The transnational context provided space and time for both in depth knowledge development and staying connected to management questions. All partners repeatedly confirmed that discussing methodological and management challenges with colleagues from the other North Sea countries was very beneficial.

Workshops and knowledge exchange consultations were also organized as stand-alone meetings. In the beginning of the project Danish partners were welcomed in the Netherlands and Germany to learn about water management in cities and along the coast. Pilot areas with drought problems also attended a workshop on groundwater buffering in the Netherlands. In Denmark flooding problems in cities, as a result of rising groundwater, were discussed with representatives from Germany and the Netherlands. Bremen hosted an exchange on salinity issues which reached out to the experts network on salinity in Lower Saxony. Also, three workshops between Dutch and German partners (together with stakeholders such as farmers and water companies) discussed Growing Maize in a sustainable way (less/no leaching of nitrate). This was a topic we shared with several other countries and we learned from each other how to cope with this in an technical/ agricultural way and from a governance aspect (payments for good practice by farmers). Climate change is a central theme within the TOPSOIL project and addressed during most discussions. In addition, the use of different climate scenarios was discussed in Bremen in stand alone workshop.
The international exchange has led to new solutions for water management issues, transfer of techniques, benefits for public bodies and cooperation with other European projects. Examples are listed down below.

Finding new solutions

- BE-1/2: Knowledge on the depth of the fresh-saltwater interface gives farmers a better comprehension of fresh water availability and the collected data provided the basis for designing the infiltration system
- DK-1/2/3: The tTEM system has been newly developed by HydroGeophysics Group Aarhus University to provide resistivity information in the target depth range of 0-100 m. It has been proven as a relevant and strong tool for topsoil mapping in general.
- DK-4: Use of the modelling approach as a solution for a climate-robust risk assessment of the contaminated point sources.
- DK-1/NL-2: Sharing and inspiring each other on legislation for groundwater flooding. Experiences from the Netherlands are used on a political level to change legislation.
- GE-1/2: New ideas and methods on groundwater buffering were found, combined with artificial groundwater recharge, to reduce saltwater intrusion.
- GE-2: Knowledge on the use of drainage for groundwater buffering has been used to adapt new drainage options to control the salt-freshwater interface.
- GE-3: A new detailed model to investigate and increase knowledge about the influence of control parameters on the dynamical freshwater-saltwater interface and the influence of climate. A groundwater management system has been launched that will give users, residents and stakeholders access to current groundwater levels.
- GE-4: Managed aquifer recharge (MAR) has been recognized as a basic practical tool.
- GE-4: Work with the Stakeholder Involvement Guideline opened eyes to the systematic involvement of stakeholder.
- NL-1: A new permit system on groundwater recharge has been developed based on international discussion.
- UK-1: Awareness of partner's sensitivities and possible farm and soil management responses to agricultural nitrate pollution to groundwater are relevant, both technically and in terms of how to effectively engage with farmers.

Transfer and use of techniques

- NL-3/BE-1: The Danish system SkyTEM was used in the Netherlands and Belgium. Knowledge exchange has started and is ongoing between geological experts from Denmark and the Netherlands.
- NL-3: The Dutch water company (WMD) has been able to exchange knowledge on nutrient loss in groundwater protection areas, and more specifically related to maize growth and groundwater monitoring. This has provided new insights regarding the timing of groundwater sampling.
- GE-5: The project led to new insights about possible measures to decrease nutrient loss with maize growth. Exchange of expert knowledge between Germany and the Netherlands has started.
- DK-2A and DK-3: tTem mapping has proven to be a relevant and strong tool for TOPSOIL management.
- DK-3: German seismic expertise was used to discover geological layering.
- NL-2: Use of an extreme, recent, hydrological period in order to explain the impact of climate changes, to gain support for climate resilient management measures.
- BE-1/2, GE-2/3/5, UK-1/2, NL-1B/3: tTEM mapping has been tested in different areas and proved to be a strong instrument to describe the subsoil in detail.

Benefit for local (semi) public bodies

- NL-3: The Dutch water company (WMD) has been able to exchange knowledge on nutrient loss in groundwater protection areas, and more specifically related to maize growth and groundwater monitoring. This has provided new insights regarding the timing of groundwater sampling.

Cooperation with other European projects

- TOPSOIL reached out to other Interreg North Sea Region projects: Together with six other Interreg
- projects on climate adaptation a full application for the project C5a (Cluster for Cloud to Coast
- Climate Change Adaptation) has been approved (https://northsearegion.eu/c5a/).
- There is also a link with the Coast to Coast Climate Challenge (C2C). See for further information: https://www.c2ccc.eu/

5. Overview technical solutions in the New Management Plans

Within the different pilots, measures have been taken to adapt the effects of climate change. These measures are listed in the figure below. The challenges have been compressed while challenge 4 (soil conditions) and 5 (break down capacity) are both strongly connected to water quality. This can refer to technical measures but also administrative solutions or change in legislation. Some measures influence only one of the challenges and some measures have an impact on different challenges.

Challenge	1	2	3	4 and 5
	Groundwater buffer	Saltwater intrusion	Groundwater flooding	Water quality
Drought resistant crops	✔			✔
More efficient use of chemicals				✔
Level-controlled drainage system	✔	✔	✔	
Reduction of drainage level	✔	✔		
Drainage systems			✔	✔
Infiltrate water (storage groundwater)	✔	✔		
Soil structure (no compaction)	✔			✔
Organic material	✔			✔
No tillage	✔			✔
Root depth	✔			✔
Impact yield				✔
Targeted fertilizer allocation				✔
Early/late crops				✔
Irrigation	✔			
Controlling abstraction rates	✔		✔	
Controlling options dam for freshwater-saltwater interface on river		✔		
Raising bottom river beds	✔			
Changing coniferous into deciduous forest	✔			
Knowledge vulnerable / less vulnerable soils (infiltration maps)	✔			✔
Preferential flow				✔

Figure 15 Measures within the TOPSOIL pilots

6. Captilization of the results: How to increase TOPSOIL's impact beyond the project end

The TOPSOIL partnership aimed to expande the reach of TOPSOIL results, and to disseminating results to reach both regional stakeholders as well as European policy makers. The pilots have revisited their results and - although limited by Covid 19 pandemic measures - held regional meetings with stakeholders who can contribute to the further development of the TOPSOIL results after the project. The consortium also considered how methods can be part of new business models.

The TOPSOIL capitalization strategy consisted of two parts: the first is a communication strategy, since communication is key to understanding and involving. The second part is the technical capitalization. This part focusses on the technical aspects, the costs and potential risks.

For further detail see report "Capitalization strategy Interreg NSR Topsoil".

Communication strategy

Communication has been an important aspect of the Topsoil project. Ongoing communication is important for the dissemination of the outcomes to stakeholders and to implement the results, also after the pilot has ended.

New contacts have been built with stakeholders, community involvement within catchment areas will enable continued work after the project (UK-2). This includes developing additional funding mechanisms and stronger multi-sectoral support for continuing the work. In NL-2 the farmers within the catchment of the pilot have been mobilized to take measures by using field demos to demonstrate new sustainable machinery and farm management practices. A longer transformation to a more sustainable farm management is possible by combining it with a subsidy arrangement which can be extended after the project.

Within UK-1, three demonstration farms will continue to host the soil monitoring stations beyond the project period. The idea is to extend the monitoring to other areas/farms to further build the knowledge base. It is vital with the establishment of long term datasets that long term relationships with farmers are maintained.

Technical capitalization

One of the most promising new business models which has been developed is linked to the development of the tTEM method. The tTEM method is now being used and offered by consulting companies and the production of instruments has been outsourced to a new private company. Knowledge of the use of tTEM has been spread over the participating countries.

Different hydrological models have been built to emphasize the importance of groundwater and seasonal balancing. Models can be used to predict the impact of climate change and to calculate the impact of measures. In GE-2 a highly detailed flow model has been used to show the effects of managing the aquifer recharge. Potential stakeholders are advised to use the surplus water required for dry periods and to push back the infiltrating saltwater. Also in Bremenhaven (GE-3_ a groundwater model has been built to develop adaptation strategies concerning the salinization of the area. The controlled water-level of the area seems to give a good opportunity for seasonal water management.

In NL-1 the built model forms a base for new regulations on irrigation and drainage. It is already part of the strategic Water Plan of the Province. After the last details are worked out, especially in relation to the N2000-requirements, it will be part of regional regulations.

Not only models are important but also an up to date monitoring system. In GE-4 a stakeholder integrated groundwater monitoring system has been developed. It is used to identify the amount of groundwater which can be used for irrigation under the premises of WFD requirements for the nearby surface water. This concept will be transferred to other areas where groundwater is used for irrigation.

In Bremenhaven-Luneplate (GE-4) a groundwater management system has been launched that will give users, residents and stakeholders access to current groundwater levels.

The TOPSOIL project showed that the impact of climate change is comparable in the North Sea Region but the approach to water management and climate adaptation is handled differently. This has helped the existing partner network within TOPSOIL to capitalize the results. Discussions between partners added knowledge, helped to develop models and supported the acceptance of solutions. The project also made it possible to test the new tTEM system in different pilot areas and supported the interested stakeholders in gaining more knowledge on the relationship between soil and management. Within the TOPSOIL network authorities, water managers, universities , experts and stakeholders were included. This made it possible to have collaboration between the end users - the regions, farmers, and the experts.

The COVID-19 outbreak was an unexpected incident which influenced the project. Some pilots were delayed, physical events were changed to online events, field demos were scaled down or postponed, surveys were delayed or cancelled and not all monitoring systems could be installed on time. Most important impact was that the contact between organizations and stakeholders was partly cancelled. Nevertheless, the project has successfully been concluded with most of the targets reached.

7. Topsoil as a contribution to the Sustainable Development Goals

On 25 September 2015, 17 "Goals for Sustainable Development" were adopted by the United Nations General Assembly at the World Summit on Sustainable Development. These goals set indicators that must be achieved by 2030. The 17 overall objectives are complemented by 169 sub-objectives. The TOPSOIL project has various connections to several of the goals and sub-objectives. In this chapter selected connections are described.

Goal 2: Zero hunger
"End hunger, achieve food security and improved nutrition, and promote sustainable agriculture"

For sustainable food production the soil is a very important basis. The Topsoil pilots that worked with the challenge of soil quality and its capacity to break down substances have a clear connection to this goal. Sustainable agriculture needs data and information about the soil to use fertilizer in the most effective and ecological way.

Goal 3: Good health and well-being for people
"Ensure healthy lives and promote well-being for all at all ages"

This goal has a close connection to goal 6 with regards to increasing access to clean water and sanitation to prevent illnesses. While this mainly is seen as an urgent need from a global perspective, we also need to improve and especially protect the water quality in the North Sea Region. Monitoring shows that drinkable groundwater is not guaranteed if the current use of fertilizer and pesticides continues. On the other hand, some Topsoil pilots managed to combine climate adaptation actions with a recreational benefit for people by creating nice surroundings, with ponds for instance, or developing an integrated water management that helps to reduce heat stress in cities in summer.

Goal 6: Clean water and sanitation
"Ensure availability and sustainable management of water and sanitation for all"

On a global scale, ending open defecation is the main goal of this issue. But the European Union and all member states have created their own indicators for Goal 6. In Germany, for example, the Federal Government has defined objectives in the areas of water supply, sanitation and water protection (SDG6) within the framework of the German sustainability strategy. Two objectives for improving water quality have been set for Germany: Reduction of phosphorus inputs into watercourses, and Reduction of nitrate concentrations in groundwater. These topics were directly addressed by several Topsoil pilot projects and by transnational workshops.

Goal 9: Industry, Innovation, and Infrastructure
"Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation"

The sub goal 9.1 is "Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all". One can see a connection between the flood risk in some of the Topsoil areas and the resilience of the infrastructure. This is connected with goal 11.

Goal 11: Sustainable cities and communities
"Make cities and human settlements inclusive, safe, resilient, and sustainable"

By adapting cities and regions to climate change, the cities and communities become more sustainable and resilient. This also applies for rising groundwater levels and the threat of flooding, as well as local problems caused by droughts.

Goal 12: Responsible Consumption & Production
"Ensure sustainable consumption and production patterns"

The efficient management of our shared natural resources, and the way we dispose of toxic waste and pollutants, are important targets when aiming to achieve this goal. Encouraging industries, businesses and consumers to recycle and reduce waste (and water) is equally important, as is supporting developing countries to move towards more sustainable patterns of consumption by 2030

Goal 13: Climate action
"Take urgent action to combat climate change and its impacts by regulating emissions and promoting developments in renewable energy"

Considering the potential effects of climate change was an essential part of the Topsoil project.

Goal 14: Life below water
"Conserve and sustainably use the oceans, seas and marine resources for sustainable development"

Not only in the Topsoil project is it important to keep the whole water cycle in mind when developing measures. The strong connection between surface water (like rivers) and groundwater was dealt with in the UK pilot. The high connectivity of the soil with the water made it important in all pilots to keep the water quality in mind.

Goal 15: Life on land
"Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss"

The holistic approach in TOPSOIL also included the investigation of a sustainable water system as part of solution to climate change adaptation within the Topsoil project.

Goal 17: Partnerships for the goals
"Strengthen the means of implementation and revitalize the global partnership for sustainable development".

Transnational cooperation is at the heart of the Topsoil project. During the internal project evaluation many partners emphasized the benefits of the interregional cooperation and knowledge exchange.

8. Transnational and regional lessons learnt

The results of the TOPSOIL project were presented, per challenge, on Policy Day in Brussels (March 2019) and at the end conference in Horsens (October 2019). The challenge "soil conditions" and "break down capacity" are both strongly connected to water quality. The "better management of soil conditions" and the "capacity to break down nutrients and hazardous pollutants" were combined into "Healthy soils and nutrient break down".

Groundwater flooding in towns and agricultural areas

Because of climate change, groundwater levels are rising, at least part of the year. The challenge is to control groundwater levels to prevent flooding both in urban and agricultural areas. Groundwater flooding can cause damage to private houses (water in cellars), has an impact on public assets like buildings and roads, and leads to a public alert for flooding. But flooding can also be affected by human behaviour changing groundwater recharge or renewal of sewage systems, for instance. The monitoring system, well known in the Netherlands, seems to be much needed in Denmark to raise awareness on these issues. There is also another urgent and important need: new legislation on the issue in order to take a responsibility, and to find ways to fund the adaption of the solutions.

Rising groundwater levels in urban areas can also change the groundwater flow and/or velocity. Problems arise partly because of the increased precipitation and partly because of decreasing abstraction rates in the waterworks. Rising groundwater levels can affect contaminations, which are typically located in the industrial areas of the cities. Mobilized contaminants can affect the quality both of surface water and groundwater. This is a particularly crucial problem, because the groundwater is the only drinking water source and the abstraction wells for the cities are often located in the city.

In comparison to Denmark, flooding in urban areas is more common in Germany and the Netherlands. The transnational discussion helped to find new ways of solving these problems through discussing approaches, management issues, responsibilities and legislation. Furthermore, new and innovative investigation methods have been used to get a more detailed overview of the soil.

The other great challenge caused by rising groundwater is the flooding in agricultural areas. The economic and social consequences are huge. Two problems can be distinguished. First, groundwater levels are too high to sow or plant in spring or to harvest in autumn as a result of extreme precipitation over a longer period. Secondly, extreme rainfall can cause floods during growing season, causing a lot of economic damage.

However, TOPSOIL modelling approaches were also able to point out, if the risk is – at least for the current data – lower than expected. This helps to prioritize.
The main lesson learnt is that the call for integrating different sectors and responsibilities is still true for management groundwater levels. A comprehensive approach is required to solve the problem since different users are affected by flooding and measures can also influence drought and water quality.

Saltwater intrusion into freshwater reserves

Climate change will cause sea levels to rise, impacting the fresh groundwater. The challenge is to control salinity in groundwater. Without measures the saline water will intrude further inland and push away the fresh groundwater (see figure 16). This problem can worsen by excessive pumping, intensive drainage, alternative land use, recharge reduction and overtopping. The impacts are saltwater intrusion, contamination of fresh groundwater resources, contamination of fresh surface water due to saline seepage, deterioration of the soil, crop yield losses, economic and social influences on rural and urban communities and negative effects on the ecological balance in streams.

Figure 16 Mechanisms for seawater intrusion; 1 excessive pumping, land use change (e.g. canal development), 3 reduction in recharge, 4 overtopping, 5 sea level rise (reference "Understanding Seawater Intrusion" (Poster designed by Adrian D. Werner; Peta E. Jacobsen & Leanne K. Morgan)

Within TOPSOIL we have used innovative techniques to describe the saline groundwater in some coastal areas and combined this with existing data. Stakeholders have been consulted to improve the understanding of the saline challenge. We have discussed best measures to adapt knowledge in this issue, for instance, in the saline workshop in Bremen. In Belgium, management of stakeholder intrusion was modelled, developed and implemented on an agricultural farm. Here, TOPSOIL enabled the opportunity to test a monitored groundwater recharging measure as part of an agricultural drainage system.

Figure 17 Rising sea levels will impact The Swinn on the coast of Belgium

Preventing salinization may also require small scale measures for which e.g. in Belgium the planning and approval process needed to be adapted to the size of the measure. In TOPSOIL we learnt that to adapt the impact of rising sea levels we need short and long-term strategies for water shortage and the risk of saltwater intrusion. Legislation also needs to allow for small scale measures, such as creek infiltration. We need more up-to-date indicators on saltwater intrusion to support policy/decision making. If we want to keep the same amount of fresh water in the coastal zone, we need transboundary agreements regarding the provision of fresh surface water to areas facing saline seepage during dry periods.

The need for a groundwater buffer to store excess rainwater for later use

While groundwater flooding is an issue in some areas, shortage of water in the growing season is an increasingly important threat in the North Sea region. In future summers precipitation is expected to decrease and because of higher temperatures evaporation will increase, leading to drought problems. Seasonal balancing is necessary.

The impacts of drought are seen in crop yield losses, negative impacts on nature, increased demand for drinking water and irrigation water, and a lowering of river levels and stream velocity. But there is also an impact on water quality. Because of less yield, nutrients are not assimilated by plants but leach to the deeper groundwater or impact surface water quality during heavy rain events. Lower river levels will also have a negative impact on the surface water quality. In 2018 the whole of the Sea Region experienced these effects.

The knowledge generated in TOPSOIL has helped to understand the groundwater system better and to find locations where rainwater can be infiltrated. But there are no simple solutions for increasing the amount of groundwater.

To identify the influence of different geological settings on runoff from small watercourses, new measuring techniques were identified, successfully tested and integrated into the monitoring of the possible effects of groundwater abstraction
While methodologies can and have been transferred between areas, it is important to note that the heterogeneity of the first 30 m below our feet requires both local and large scale approaches. Today's impact and the uncertain development of climate change needs, in addition, a flexible long-term strategy for groundwater shortage to adapt to the impact of drought. When designing the best strategy, modelling is necessary to make the right decisions and that's only possible if there is enough data to fill the models. One recommendation would be to make groundwater data freely available. Most of the land is used by farmers. They should be encouraged to infiltrate more water more often so there will be more groundwater available in summertime. Although measures are taken, we must realize that groundwater levels are changing and that should be included in the EU goals for the WFD and Nature2000.

Healthy soils and nutrient break down.

TOPSOIL started with two challenges, namely: "better management of soil conditions" and the "capacity to break down nutrients and hazardous pollutants". However, from a management perspective we combined them here into "Healthy soils and nutrient break down".
One of the elements of climate change is an increase in heavy rain. This will lead to an increase of leaching (30% in the UK) but also the loss of pesticides in a flat country like the Netherlands is mainly caused by heavy rain and leaching. The increased leaching is exacerbated by the degradation of our soils due to maximised food production. The challenge is to stop the degradation of the soil and stimulate good soil management.

The increased leaching has a negative impact on the quality of the surface water, coastal waters and groundwater. The degraded soils cause reduced resilience for crop demands, rivers flow and aquifer recharge. Soil fertility will be lost and consequently also soil diversity. This will lead to more nutrient loss and a reduction in organic matter and minerals.

TOPSOIL increased the collective understanding of soil and groundwater systems as key component of natural ecosystems between the partners and stakeholders. A strong lesson learnt that soil and groundwater legislation need to be better connected.

To adapt to the impact of heavy rain on water quality the following points should be taken into consideration:

- Healthy soils are key to sustainable and resilient ecosystems and the economy;
- Promote a framework for delivering sustainable soil and water management, based on the principles of ecosystem services and public goods;
- Complex processes that require open & transparent collaboration to achieve shared understanding are challenging, but essential;
- There is a need for a fair and consistently applied regulatory baseline;
- There is a need for improved soil management supported by appropriate incentive mechanisms, monitoring and good quality, impartial farm advice;
- Review the need for an EU Soil Directive

9. Recommendations

In March 2019 the first results of the TOPSOIL project were presented at a policy day to members of the European Parliament. The project partners had the opportunity to inform - and impress -politicians with their approach to the negative effects of climate change on water, nature and agriculture. General. Elena Visnar-Malinovska, Head of the DG CLIMA Adaptation Unit, also emphasized the importance of soil management. Building on this discussion in 2019 and reviewed by the results of the last year of TOPSOIL, the partnership developed the following recommendations regarding future groundwater management but also with an emphasis on knowledge exchange, technical recommendations, policy making and stakeholder involvement.

General

1. Integral catchment approach is needed to solve groundwater problems.
   Groundwater is not a stand-alone part of the water system. It is connected to and influenced by land use, soil, surface water and groundwater extractions. This means that when looking for solutions an integral approach on catchment level is needed.

2. Climate adaptation should integrate all five challenges at the same time.
   The five investigated challenges of groundwater flooding, saltwater intrusion, groundwater buffering, soil conditions and breakdown capacity are also strongly related. Climate adaptation should provide integral answers to all five challenges.

3. Good soil management should be stimulated.
   One of the challenges is to stop the degradation of the soil and stimulate good soil management. The increased leaching has a negative impact on the quality of the surface water, coastal waters and groundwater. The degraded soils will cause reduced resilience for crop demands, river flows and aquifer recharge. Soil fertility will be lost, and consequently the soil diversity. This will lead to more nutrient loss, and a reduction in organic matter and minerals.

Knowledge exchange

4. Knowledge exchange between NSR partners proved to be very fruitful.
   Knowledge exchange between partners has led to new insights in solving climate problems by discussing the approach, management issues, responsibilities and legislation. One of the reasons is that the state of the “new” climate problem is different from region to region. For instance, in East Niedersachsen the drought problem has been occurring longer than in other areas and flooding in urban areas is more common in Germany and the Netherlands than in Denmark. Different governance also leads to other insights on how to cope with various problems.

5. Detailed data is needed and should be freely available.
   Models are used to show the unseen world of groundwater and calculate the impact of climate change and adaptation. But detailed data is needed to build reliable models. One of the problems is that not all available data is freely available, or it is unknown which data is available.

Technical

6. New innovative techniques are available to improve soil data.
   With the newly developed tTEM technique more accurate data of the soil can be collected. The use of tTEM was so promising that in the extension the tTEM system was tested in all participating countries and proved to be of value. This offers the possibility to make more detailed models to predict the impact of climate change and adaptation measures. The TOPSOIL project has shown that a detailed modelling approach is necessary in order to identify the risk and choose the right solution for each challenge.

7. International exchange has led to the use of techniques from abroad.
   By using the SkyTem and tTEM techniques (from Denmark) a more detailed description has been made of the saline groundwater in Belgium and the meltwater till in the Netherlands.

Policy making

8. Climate adaptation demands a short and long-term strategy, both locally and regionally.
   Because a specific climate scenario cannot be predicted, we need to develop a long- and short-term policy on drought, salinity and flooding. Depending on the costs of investigation and a risk analyses, decisions can be taken for the short term, and for the longer. This facilitates the "blue" transition of groundwater and soil management.

9. Climate change should be incorporated within the EU-WFD and EU-Nature2000.
   As a result of climate change, water quality and the conditions within the nature2000 areas will also be affected. It is possible that the set goals cannot be reached because of climate change.

10. Legislation should be flexible to allow for the implementation of innovative measures.
    TOPSOIL has showed that different implementation of legislation also leads to different solutions. Flexibility could provide new answers to the climate challenges.

11. Transboundary agreements are needed in the coastal areas.
    If we want to keep the same amount of fresh water in the coastal zone, we need transboundary agreements regarding the provision of fresh surface water to those areas facing saline seepage during dry periods.

12. Farmers should be encouraged to take action on climate adaptation.
    A framework for delivering sustainable soil and water management, based on principles of ecosystem services and public goods, should be promoted more strongly. Because farmers manage most of the rural land, the impact of their climate adaptation measures can be large. Farmers could be influenced to infiltrate water more often (drought), minimise physical cultivation (soil health) or reduce nitrate leaching.

Stakeholder involvement

13. Stakeholder involvement is crucial.
    Within the TOPSOIL pilots it has been proven that stakeholder should be included at the start of the project to gain a broad understanding of the challenges and proposed measures. Stakeholders have been consulted to improve the mutual understanding of the saline challenge and possible solutions.

14. Seek to align project delivery with other related projects and initiatives.
    While their contribution is a central part of a comprehensive and integrated approach, stakeholder engagement draws also draws on their resources. Stakeholder engagement needs to link between initiatives and other projects. This fosters at the same time integration of the different aspects of climate change.

15. Think about capitalisation actions during the preparation of your project.
    Although many results in TOPSOIL are a big step towards climate change adaption, the pre-defined problem is fully solved only occasionally. Capitalisation activities will give your project the legacy it deserves. Including them from the start maintains an open mind towards the long-term perspective and the different economical aspects of your project activities.

In 2021, these recommendations are confirmed by the pilot results. They show the need for a more comprehensive transition in water management. The TOPSOIL partners see a large need for working together on these issues and are committed to jointly developing the Interreg NSR project "Blue Transition towards Climate Resilient Regions" towards climate resilient regions" in further transnational cooperation. The approach of combining the knowledge on geological and geophyicals aspects of groundwater and involving stakeholders has led to many relevant improvement in the governance of groundwater resources in the North Sea Region. Integrating solutions for climate change adaptation for long term and short term impacts, as well as across sectors and spatial scale is still an important isse which needs to be tackled in transnational settings.

Annexes

1. References

1. Scientific paper – peer reviewed
2. Reports and publications
3. Poster presentations
4. Oral presentations

1. Scientific paper – peer reviewed

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7.	González, E., Deus, N., Elbracht, J., Rahman, M.A., Wiederhold, H	Current and future state of groundwater salinization of the northern Elbe-Weser region
8.	Rahman, M.A., Zhao, Q., Wiederhold, H., Skibbe, N., González, E., Deus, N., Siemon, B., Kirsch, R., Elbracht, J.	Coastal groundwater systems: mapping chloride distribution from borehole and geophysical data
9.	Fishkis, O., Noell, U., Diehl, L, Jaquemotte, J., Lamparter, A., Stange, C.F., Burke, V., Koeniger, P., Stadler, S.	Multitracer irrigation experiments for assessing the relevance of preferential flow for non-sorbing solute transport in agricultural soil.
9.	Wiederhold, H., Kallesøe, A.J., Kirsch, R., Mecking, R., Pechnig, R., Skowronek, F.	Geophysical methods help to assess potential groundwater extraction sites
10.	Tamiru, G., Wiederhold, H.*)	P- and S-wave reflection profiling for near-surface investigation of glacial sediments.

*) this paper is not a product of the TOPSOIL project itself, but a late output of the previous project BURVAL. Since it shows

Planned Journal
Engineering Geology, Volume 288, July 2021, 106125 https://doi.org/10.1016/j.enggeo.2021.106125
Near Surface Geophysics, June 2020, Vol 18 (3), 249-259 https://onlinelibrary.wiley.com/doi/abs/10.1002/nsg.12094
Environmental geophysics, June 2018 Doi: 10.1071/PVv2018n194p33 https://hgg.au.dk/fileadmin/HGGfiles/Papers/tTEM2018.pdf
IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING https://ieeexplore.ieee.org/document/9427988
Geoscientific Instrumentation, Methods and Data Systems, vol. 10, no. 1 (2020) https://doi.org/10.5194/gi-10-81-2021
Grundwasser – Zeitschrift der Fachsektion Hydrogeologie, 26, 73-85 (2021) https://doi.org/10.1007/s00767-020-00472-w
Grundwasser - Zeitschrift der Fachsektion Hydrogeologie https://doi.org/10.1007/s00767-021-00496-w
Grundwasser - Zeitschrift der Fachsektion Hydrogeologie, 26, 181-206 (2021) https://doi.org/10.1007/s00767-021-00475-1
Geoderma 371 (2020) 114386 https://doi.org/10.1016/j.geoderma.2020.114386
Grundwasser - Zeitschrift der Fachsektion Hydrogeologie https://doi.org/10.1007/s00767-021-00495-x
Journal of Applied Geophysics 183 (2020) 104216 https://doi.org/10.1016/j.jappgeo.2020.104216

s the different methods and how they work together well, it is also listed here.

2. Reports and publications

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2018

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2019

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Delsman, J., van Baaren, E., Vermaas, T., Karaoulis, M., Bootsma, H., de Louw, P., Oude Essink, G., Dabekaussen, W., Van Camp, M., Walraevens, K., Vandenbohede, A., Teilmann, R. & Thofte, S., 2019, TOPSOIL Airborne EM kartering van zoet en zout grondwater in Vlaanderen (FRESHEM Vlaanderen).
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3. Poster presentations

2016

Smith, R., Bracken, L.J. and Wainwright, J., 2016, Understanding Groundwater-Surface Water Connectivity. Poster, HYTECH Interfaces within aquatic ecosystems' Symposium, 29.-30.08.2016; Aberdeen, UK.
Smith, V., Bracken, L.J., and Wainwright, J., 2016, New ways to think about managing water resources: The role of gender. Poster, HYTECH Interfaces within aquatic ecosystems' Symposium, 29.-30.08.2016; Aberdeen, UK.
Vandevelde, D., 2016, Increasing the availability of freshwater for agriculture by improving local hydro(geo)logical conditions. Poster, Salt Water Intrusion Meeting, 04.-08.07.2016; Cairns, Australia.

2017

Andrews, G., Colling, M. 2017. TOPSOIL Banner: Surface water / Groundwater interactions. (20/09/2017); Brancepeth Castle, Durham, UK.
Johnsen, Rolf et al.; AquaConSoil Conference, Postersession 6B.01 no. 678: "TopSoil Resilient soil and water resources, understanding the water beneath your feet", 27.06.2017 Lyon, France.
Noell, U., Stadler, S. (2017): Limiting nitrogen and veterinary pharmaceutical input into groundwater: combining hydrogeophysics and soil science. EGU, 23-28.4.2017, Vienna, Austria.
Smith, R., Bracken, L.J. and Wainwright, J., 2017, Understanding Groundwater-Surface Water Connectivity and Interactions in Heavily Modified Rivers. Poster, British Society for Geomorphology (BSG) Annual Meeting, 04.-06.09.2017; Hull, UK.
Stadler, S., Noell, U., Stange, C. F. 2017: Understanding heterogeneities of flow paths for agricultural practice. Jahrestagung der Deutschen Bodenkundlichen Gesellschaft, 2.-7.9.2017. Göttingen, Germany.
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Wiederhold, H., Rahman, M.A., Grinat, M., Kirsch, R. & Scheer, W., 2017, The TOPSOIL project - Integrated approach of near surface geophysics and groundwater modelling. Poster, EAGE Near Surface Geoscience, 03.-07.09.2017; Malmö, Sweden.

2018

Colling, M. Feb 2018. Farming Up North (FUN): Topsoil project leaflet. (01/02/2018), Rushyford, Durham, UK.

Colling, M. Mar 2018. Magnesian Limestone Rural Diffuse Project: Topsoil project leaflet. (13/03/2018), Bowburn Hall, Durham, UK.

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González, E., Deus, N., Elbracht, J., Siemon, B. (2018): Large-scale geological structure model of the Elbe-Weser Region. Central European Conference on Geomorphology and Quaternary Sciences, 23.-27.09.2018; Giessen, Germany

Noell, U., Fishkis, O., Lamparter, A., Stadler, S. (2018): Multidisciplinary Study of Infiltration Processes. Jahrestagung der Deutschen Geophysikalischen Gesellschaft. Leoben, Österreich, 12. - 15.02.2018.

Rahman, M.A., Wiederhold, H., Stadler, S., Koeniger, P., Winter, S. & Siemon, B. (2018): Subsurface characterization of a fresh water lens barrier island using geological, geophysical, geochemical and hydrological data - case study Borkum, Germany. Poster, European Geosciences Union, 09.-14.04.2018; Wien, Austria.

Seiter, K. & Panteleit, B. (2018): Vorstellung und Präsentation des EU-Interreg Projektes Topsoil zum Tag des Weserwehres, Bremen den 17.07.2018.

Seiter, K. & Panteleit, B. (2018): Vorstellung und Präsentation des EU-Interreg Projektes Topsoil zum 10-jährigen Bestehen des Geologischen Dienstes für Bremen, Bremen den 28. 10.2018.

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Wiederhold, H., Scheer, W., Kirsch, R., Rahman, M.A., Ronczka, M., Grinat, M. & Siemon, B. (2018): Saltwater intrusion under climate change in North-Western Germany - mapping, modelling and management approaches in the projects TOPSOIL and go-CAM. Poster, 25. Salt Water Intrusion Meeting, 18.-22.06.2018; Gdansk, Poland.

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Fishkis,O., Noell, U., Diehl, L., Jaquemotte, J., Stange, C.F., Lamparter, A., Burke, V., Koeniger, P., Stadler, S. (2019): Multitracer irrigation experiment for assessing the relevance of preferential flow for non-sorbing solute transport in agricultural soils. DBG conference 2019.

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Noell, U., Fishkis, O., Wießner, C. (2019): The Interreg Topsoil Project: steps to understand nitrate variability in the near surface groundwater. Poster, 79. Jahrestagung der Deutschen Geophysikalischen Gesellschaft, 4.-7.03.2019; Braunschweig.

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Smith, V., Wainwright, J., and Cunningham, N. (March 2019) Analysis of the current state of water-resource management in the UK using social network analysis and agent-based modelling: a case study in the Wear catchment, County Durham.

Waterloo,M. J., Gevaert,A., Velstra, J., Hoogland,F., Assessment of the effect of water quality measures under current and future climate and farming scenarios using a two-step modelling approach. Aarhus Conference LUWQ, June 2019.

2020

S. Stadler, O. Fishkis, U. Noell and the TOPSOIL Team, Heterogeneity of unsaturated flow measured in the dry summer of 2018 in Germany recorded by the combination of ERT and soil data, EGU, 4-8. 5. 2020, online.

4. Oral presentations

2017

Colling, M. Dec 2017. Cut Throat Dene: Sampling update. (06/12/2017) Wear Rivers Trust, UK.

Colling, M. Dec 2017. Hawthorn: Sampling update (06/12/2017) Wear Rivers Trust, UK.

Melvej, Anja; Henrik Larsen; Rolf Johnsen; Anders Juhl Kallesøe; Thomas Gad; Benny Nielsen; Jesper Bjergsted Pedersen; AquaConSoil Conference, Session 6b.1 – "Water and subsurface management in the context of climate change". Presentation: "High groundwater table in a Danish town – Challenges and opportunities in a climate adaptation perspective" 30.06.2017; Lyon, France.

Specht, Anette, Johnsen, Rolf, Blæsbjerg, Helle, Pedersen, John and Pedersen, Jesper; AquaConSoil Conference, Session 1d.1: "Geophysical and geostatistic methods in site characterization". Presentation: "Improvement of traditional investigations by prior geophysical measurements" 29.06.2017 Lyon, France.

2018

Auken, E., Christiansen, A. V., Pedersen, J. B., Foged, N. & Eiskjær, T., 2018, A New Towed Groundbased TEM System for 3D Imagining of the top 70 meter of the subsurface, SAGEEP, March 2018, Nashville, USA.

Auken, E., Pedersen, J. B., Christiansen, A. V., Vilhelmsen, T. V. & Foged, N., 2018, A new towed groundbased TEM system for 3D imaging of hydrogeological structures, Danish Water Forum, January 2018, Denmark.

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2. TOPSOIL partners

Denmark
Region Midtjylland (WP1, Project Management)
Region Syddanmark
Horsens Kommune
Hydrogeofysik Gruppen, Institut for Geoscience Aarhus University
Geological Survey of Denmark and Greenland Herning Kommune

Belgium
Vlaamse Milieumaatschappij – VMM (WP2, Communication)

The Netherlands
Provincie Drenthe (WP7, New Management Regime)
Waterschap Hunze en Aa's
Waterschap Noorderzijlvest

Germany
Dachverband Feldberegnung Uelzen
Landwirtschaftskammer Niedersachsen
Bundesanstalt für Geowissenschaften und Rohstoffe
Universität Bremen Geologischer Dienst für Bremen
Landesamt für Bergbau,Energie und Geologie
Leibniz-Institut für Angewandte Geophysik (WP4, Field Investigation and Technical Development)
Oldenburgisch- Ostfriesische Wasserverband (WP6, Exploring Best Governance Practice)
Landesamt für Landwirtschaft, Umwelt und ländliche Räume Schleswig-Holstein

UK
The Rivers Trust (WP3, Stakeholder Involvement)
Wear Rivers Trust
Norfolk Rivers Trust
Essex & Suffolk Rivers Trust
Northumbrian Water Limited
Durham University

AARHUS UNIVERSITY

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Dachverband Feldberegnung Uelzen

GEUS

Durham University

Essex and Suffolk Rivers Trust

Herning Kommune

HORSENS KOMMUNE

LBEG Landesamt für Bergbau, Energie und Geologie

SH Schleswig-Holstein Landesamt für Landwirtschaft, Umwelt und ländliche Räume

Landwirtschaftskammer Niedersachsen

LIAG Leibniz-Institut für Angewandte Geophysik

NORFOLK RIVERS TRUST

NORTHUMBRIAN WATER

OOWV

provincie Drenthe

midt regionmidtjylland

Region Syddanmark

The Rivers Trust

Universität Bremen

WATERSCHAP Hunze en Aa's

Waterschap Noorderzijlvest

WEAR Rivers Trust

FLANDERS ENVIRONMENT AGENCY

3. tTEM survey

The tTEM system has been on tour in the different participating countries. Both in Belgium, Germany, the UK and The Netherland the system has been used to get more detailed information of the subsoil. tested in all participating countries. In this appendix some information about the results are shown.

Topsoil Extension – Belgium tTEM study

Where: BE-1 & BE-2 pilot areas in Belgium.
Sites investigated are situated in Koksijde, De Panne, Veurne, Damme and Knokke-Heist

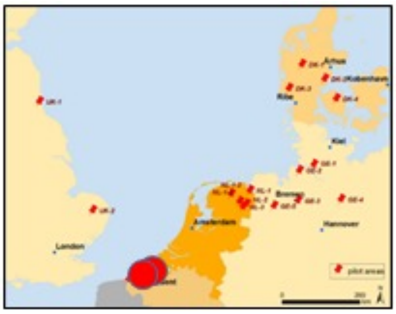
When: 4th – 8th of October, 2021.

Partners: Aarhus University (Denmark) & Flanders Environment Agency (Belgium)

Additional interest: AquaDuin (Belgium), Province of West-Flanders (Belgium)

Aim of the study:

- Mapping the saltwater – freshwater interface at several study sites in the coastal area of Flanders. Compare results to existing maps of the interface.
- Mapping thin impermeable clay layers the location of which is crucial to the understanding of managed aquifer recharge (Koksijde).
- Mapping clay layers and the saltwater-freshwater interface at a creek-ridge infiltration site (Veurne).



Main findings and outlook

- Several fields were investigated in the coastal area of Flanders to map the fresh-saltwater distribution in detail . The saltwater saturated sediments pose a good target for electromagnetic methods, so the tTEM results provided good insight into the depth of the fresh-saltwater interface. The results confirmed existing maps, but also revealed more structures on a field scale. The results will be used by water managers, drinking water companies and farmers.
- In the area of Koksijde, the company AquaDuin are conducting managed aquifer recharge in the dune areas. This is done by means of infiltration ponds, but a local impermeable clay layer has interfered with the infiltration, calling for a detailed mapping of the layers. tTEM was conducted around the infiltration ponds, and a clay layer was identified in the western part of the study area. The clay layer can now be taken into account for optimalisation of the infiltration .
- In the area of Veurne there is a high need for freshwater to support farming. New measures are being tested in the Topsoil project, including the process called creek-ridge infiltration. Creek ridges are former tidal gullies. They became small sandy ridges when land was reclaimed. The higher topography of these ridges led to higher groundwater tables above sea level and the development of fresh water lenses. These lenses are used for water supply, but pose a dynamic and vulnerable resource. tTEM was used to map the freshwater lens and the depth of the Tertiary clay layer, posing the aquitard and the saltwater layer below the freshwater lens. The image from the tTEM mapping will help with respect to design and management of the creek-ridge infiltration setup. Infiltration of excess surface water in creek ridges during winter could contribute to a further increase of the thickness of the freshwater lens and an increase of fresh water availability during summer.

Topsoil Extension - German tTEM study

Where: GE-2, GE-3 and GE-5- pilot areas in Germany. Sites investigated include Luneplate, Cuxhaven and Aurich.

When: 17th of August, 2020 & 8-10th of November, 2021.

Partners: Aarhus University (Denmark), Geologischer Dienst für Bremen (Germany), Leibniz-Institut für Angewandte Geophysik (Germany), Oldenburgisch-Ostfriesischer Wasserverband (Germany) & Landesamt für Bergbau, Energie und Geologie Niedersachsen.

Additional interest: Kloster-Ihlow (Germany).

Aim of the study:

- Mapping the saltwater – freshwater interface in the coastal area of Bremerhaven. Additionally, mapping the interbedded sand and clay layers (Luneplate).
- Mapping thin impermeable clay layers the location of which is crucial for understanding in regard to managed aquifer recharge (Cuxhaven).
- Mapping sand and clay layers as an active water abstraction area, which is also used for farming (Aurich).

Main findings and outlook

- The unpopulated area of the "Luneplate "in Bremerhaven is bordered by the Weser River, partly used for agriculture, and known as a bird sanctuary. The area has proven difficult to investigate in regard to the groundwater salinity due to the interference that occurs in dense populated habitats. In general, there is a low capacity of monitoring wells in this area, and hence the tTEM campaign was carried out. A number of several kilometers long tTEM lines was conducted in the area, and these revealed both shallow and thin clay layers of a thickness of 5-10 meters, as well as an accurate boundary of the freshwater-saltwater interface. Adjacent to the Weser river, the interface is almost at terrain, whereas it slowly dips in depth in-land. At a 1 km distance from the river, the interface is located at a depth of 45 meters. It is crucial to include this new information in the hydrological model and groundwater management of the area.
- In the area of Cuxhaven, LBEG is looking into measures to increase freshwater availability in an area surrounded by agriculture and the sea. The area is known to host saltwater intrusion at large depths. One option for increasing freshwater availability is managed aquifer recharge in the moraine ridges of the area. However, the location of local impermeable and shallow clay layers was yet unknown, and was mapped with tTEM. Several lines were driven in the area, and they revealed a number of west-east dipping clay layers corresponding to the direction that push moraines formed by glaciers would experience. The clay layers can now be included in the groundwater model in order to select the optimal site for infiltration of freshwater.
- In Aurich OOWV wants to utilize the tTEM method in order to better understand the geology in a rewetted moor area situated in an area with active groundwater abstraction. Adjacent to the moor area there are several agricultural fields, which could pose a threat to the groundwater quality. The tTEM mapping on the fields revealed a distance sand-clay-sand layering. At some fields the clay layer is thick enough to provide protection for the aquifer (15 m thick), but in most cases it is too thin, highlighting the fact that new measures are needed to protect our groundwater.

Topsoil Extension - UK tTEM study

Where: UK-1 pilot area in England.
Sites investigated include Stoneygate, Fulwell, Easington, Cleadon & Houghall.

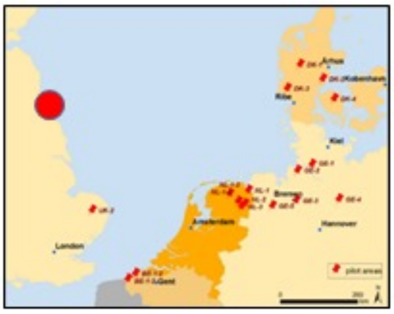
When: 25th October – 29th October, 2021.

Partners: Aarhus University (Denmark), Rivers Wears Trust (England) & Northumbrian Water (England).

Additional interest: Zetica (England) & Lancaster University (England).

Aim of the study:

- Mapping water-filled fracture systems within the Limestone units (Easington, Stoneygate Fulwell and Cleadon).
- Confirming existing geological maps from the British Geological survey on locations of fractures and superficial deposits (All sites).
- Mapping superficial geological units to inform on surface- and groundwater connectivity and implication for water resource protection and management (Houghall & Easington).
- Mapping saltwater intrusion and/or coal waters (Cleadon & Easington).



Main findings and outlook

- In the UK-1 pilot area, the topsoil is typically constituted of superficial clay layers with a thickness of 0-30 meters, and beneath there is often a several hundred meters thick Limestone sequence. The Limestone is typically impermeable, but in some sections there are fracture zones where water can flow freely. These zones can be anything from thirty to only a few centimeters wide. In some cases the fractures are used for water abstraction, like in the Fulwell & Stoneygate areas. In other cases, they could act as highways for pollution, and hence they are important to map like in the Cleadon and Easington site. In Stoneygate there seems to be elevated electromagnetic (EM) signals along south-northern trending fracture, which is being actively pumped from. There is no EM signal from a west-eastern trending fracture, which is believed to produce no water as per Northumbrian water and British Geological Survey (BGS) maps. This pattern is confirmed by the tTEM mapping and the fracture was mapped possibly updating BGS maps, in which the fracture pattern was found to be 50-100 m off. The pattern is based on outcrop information.
- In Cleadon there is no elevated EM signal indicating that the area is affected by saltwater intrusion (saltwater intrusion will appear in the EM data as a strong conductor) in the upper 100 meters of the topsoil. This implies that saltwater intrusion is occurring at so large a depth, that it most likely is not a risk for the surface water bodies in the area.
- In the Easington area there is a clear conductor in the limestone at -20 meter below the sea level. Deep boreholes from coal mining show that the conductive layer is found within the resistive limestone. This means that saltwater intrusion or polluted water due to coal abstraction is taking place at the coastline. The pollution is seen throughout the area, indicating that is taking place in a fractured part of the limestone.
- In Fulwell the tTEM results are of limited success. No signal is seen from superficial clays, which are also known to be of almost no thickness in this area. The Limestone sequence is so thick in the area, that the EM signal is poor. No fractures could be seen in the data either, indicating that they have a small dimension or are simply not filled with freshwater.
- In Easington and Stoneygate the superficial clay on top of the Limestone sequence is mapped with great certainty, and with these now updated results the BGS aquifer vulnerability maps can be updated.

- In Houghall the geological sequence is quite complex and consists of interbedded mudstone, sandstone, and measures layers. This sequence maps nicely into the tTEM results, and distinct zones of conductive (mudstone) and resistive layers (sandstone) is shown in the results. The area is next to the River Wear, and even a paleochannel which is filled by sand sediments can be seen in the tTEM maps. This old river section, which is constituted of sand with high porosity, would act as a highway for pollution from the fields and to the adjacent surface body, the Rivers Wear. Furthermore, some of the deeper sandstone sequences will have direct contact to the lakes and rivers in the area. With these new tTEM results showing the flow paths in the region, one would be able to inform to stakeholders such as the farmers and water agencies about needed measures to protect wildlife and water quality.

Topsoil Extension – Netherlands tTEM study

Where: NL-1 pilot area in the Netherlands.
Sites investigated are situated in Anloo, Hunzedal, Beilen & Assen.

When: 14th – 16th of December, 2021.

Partners: Aarhus University (Denmark), Province of Drenthe (Netherlands) & Geological Survey of the Netherlands - TNO (Netherlands)

Aim of the study:

- Mapping soil heterogeneity in the area of Beilen, where farm fields are dealing with rising groundwater level. The soil description on farm scale could facilitate implementing measures such as expansion of the nearby stream Beilerstroom in order to transport water from the fields.
- Mapping glacial complex settings to understand groundwater recharge and aquifers in the area of Anloo. Furthermore, deep conductive layers, previously discovered by older geophysics, indicate saltwater intrusion at depth.
- Assen is an area of big importance for groundwater extraction and storage. Nearby cities and agriculture poses a threat to the water quality, but shallow “potclay”layers (glaciolacustrine clay and sand deposits) could act as protection for the aquifers. However, the potclay distribution is poorly understood due to the erratic appearance of the geological unit.
- Additionally, in recent years there has been interest in renaturalization in the Assen area. For instance, to remove the weir and permit natural flooding of the area. Understanding the shallow geology for this purpose is also important.
- Hunzedal area for investigating occurrence of clay layers that protect the underlying aquifer.

Main findings and outlook

- The tTEM results from Beilen reveal a 4 layers model with resistive-conductive-resistive-conductive layering. The resistor at terrain, indicating sandy material, varies in thickness. The layer is thinning towards the northern part of the farm fields, whereas it is up to 10 meters thick near the stream of Beilerstroom to the south. A 50 ohmm layer, indicating glacial till deposits is situated below the resistor. The glacial till layer is up to 10 meter thick, and will consequently most likely be impermeable. This could explain the rapid flooding of the fields when there is heavy rain events. The soil maps will now be used to find suitable mitigation measures.
- Previous Topsoil studies has shown a glacial complex geological setting in Anloo. The area is, like many area in the Nature2000 Drenthe Aa area, important with respect to groundwater storage and recharge. Many of the aquifers in the Drenthe Aa area not only supply water for the Province of Drenthe, but also the neighboring provinces such as Groningen were the groundwater is to large extent saline. Understanding the build-up of glacial tills and sand, is crucial to evaluate the aquifer vulnerability. The tTEM results shows complex layering in the area with up to 6 different glacial deposits found in just the upper 100 meters of the soil. The results also show the connectivity of the glacial sand deposits, which could act is permeable transport ways for groundwater pollution. Interestingly there is also a deep conductor at 80 meters below the surface, indicating local saltwater intrusion. The saltwater deposits might be related to salt domes throughout the area, but that is yet to be confirmed. The structures could pose a threat to local water supply if the water is not managed accordingly.
- The survey in Assen is still being processed, but early results indicate thin layers which could compare to the potclay deposits. More work is needed to link to boreholes. Furthermore, the close proximity to the city, highlights the disadvantage of the tTEM method. A large portion of the data had to be removed in the Assen data due to nearby infrastructure such as live electric fences, cables and roads.
- In the Hunzedal area, preliminary results show the presence of a clay layer, but this layer is not present in some lines, indicating a discontinuous occurrence. This needs to be investigated in more detail.

4. New Management plans

In each pilot a new management plan is developed. It is not a management plan which describes the overall water management in a catchment area, but it is focussing on the approach of climate change within the pilot. The content of the plans is comparable and contains the objectives of the pilots, the management questions, the missing knowledge and steps taken to solve the problems. This has led to a new approach to manage the groundwater and surface water related to the condition of the soil.

Content

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DK-2A	Targeted regulation of fertilizers to obtain sustainable intensification. Investigating the potential for natural break-down of pollutants in the subsurface groundwater
DK-2B	Improvement of traditional investigations by prior geophysical investigations
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UK-1	Surface and groundwater connectivity and implication for water resource protection and management
UK-2	Holistic water and soil management in East Anglia

BE-1

Identifying the salinization of groundwater in the (Western) Flemish coastal area by collecting airborne electromagnetic data

1. What is the Objective of the pilot?
The objective is mapping the fresh-salt water distribution by using airborne electromagnetics.

2. Studied TOPSOIL Challenges
- Saltwater intrusion
- Groundwater buffer

3. Context of current water management
Groundwater in the Belgian western coastal plain is saline by origin, making sure fresh, salt and brackish groundwater are found there. This fresh-salt distribution was mapped in the 60s and 70s and published in a salinity map. However, half a century later, there is a clear need for area-wide mapping of the salinization of the area. The freshwater lenses in the area are frequently used as freshwater supplies. By comparing the newly collected data with the existing salinity map, the evolution of the freshwater-saltwater distribution can provide a reference in considering effects of climate change and sea level rise.

4. What is the expected impact of climate change on water management? (before project)
It is expected that sea level rise will cause more salinization in the area.

5. What are the main management questions at the start of the project?
In the future, freshwater shortage might occur due to climate change. Especially for agriculture this shortage can cause troubles.

6. Which knowledge has been missing to find the climate resilient solution (at the start of the TOPSOIL project)?
Updated data about the fresh-salt distribution in the Western Flemish coastal area.

7. Steps taken to get to the missing knowledge

Technical field investigations:	Mapping the salinity distribution in the area by using the SkyTEM system, an airborne transient electromagnetic sensor that measures ground conductivity using electromagnetic waves.
Analysing data:	The collected data was adjusted for measurement errors and verified by water samples and other 'ground truth' data.
Using models:	A 3D lithological model was used to become a detailed 3D image of the fresh-salt water distribution.
Measures taken:	measures were taken
Involvement of stakeholders:	The stakeholder involvement guidelines about transparent information were carefully followed. The kick-off meeting with stakeholders was held in May 2017. During this meeting, stakeholders were informed about the planned airborne survey in the summer of 2017. Before the helicopter flights, a press release was published to inform stakeholders about the purpose of the flights and possible consequences. During the process (flight preparation to reporting of the new salinity map), multiple stakeholder events were organised to inform about the progress and next steps in the pilot. Those events formed the stepping stone for engaging stakeholders in the second phase of the (pilot) project: BE-2. The results were released to the public during an event in April 2019 and was followed by a press release in June 2019.

8. Solutions found to solve the main management questions
Not applicable in BE-1, see BE-2.

9. New water management and advantages

The new knowledge on the area helps to foster a number of advantages in new management approaches:

	Advantages	New Management Option
Agricultural:	Farmers can consult the salinization map online which shows the depth of the fresh-salt water interface in their area Farmers know whether their land is located on a creek ridge (freshwater source)	See BE-2
Nature:	More knowledge about the fresh-saltwater distribution in nature conservation areas	Not applicable
Water abstraction:	Knowledge of fresh groundwater reserves in saline area	See BE-2
Water storage:	Knowledge of potential locations for infiltration	See BE-2
Spatial planning:	More accurate knowledge of the subsurface can be used to improve policy on water management	See BE-2
Stakeholders	Better understanding of the fresh-saltwater distribution	See BE-2

10. Benefits transnational exchange Topsoil

- How topsoil used the knowledge from different partners to find new solutions to complex challenges: Knowledge about (airborne) EM methods, salt-water intrusion processes, modelling and monitoring
- How transnational joint approach has led to new investigation and management methods:
  During the Workshop on salt water intrusion we learnt more about dealing with salt water intrusion
- The transfer of techniques and management between partners:
  New ways of monitoring saline environments
- How local public bodies, in charge of climate adaptation, have benefit from the transnational knowledge: A new salinization map is published online
- Describe if and how topsoil changed your future approach on climate change adaptation:
  See BE-2

11. Recommendations for future developments concerning climate change

See BE-2

BE-2

Increasing the availability of freshwater for agriculture by improving local hydro-geological conditions

1. What is the Objective of the pilot?

Finding measures to increase the availability of freshwater for agriculture in the polder area of West-Flanders. In the extension the objective was to build a pilot creekridge infiltration system.

2. Studied TOPSOIL Challenges

- Flooding
- Saltwater intrusion
- Groundwater buffer

3. Context of current water management

Farmers in West-Flanders make significant use of groundwater from the Paleocene confined aquifer for their water supply. For years, the level of the Paleocene aquifer is decreasing, compromising the water supply. In addition, shallow water resources are scarce because of the brackish nature of the top aquifer near the coast, and the shallow occurrence of aquitards (clay layers) deeper inland.

4. What is the expected impact of climate change on water management? (before project)

Possible shortage of freshwater for agriculture.

5. What are the main management questions at the start of the project?

- How can we improve the availability of freshwater in the area?
- How can we storage freshwater during wet periods so it can be used during periods of drought?

6. Which knowledge has been missing to find the climate resilient solution (at the start of the TOPSOIL project)?

Information about the soil and salinization of the area (delivered in BE-1). In order to investigate possible measures for freshwater storage it is essential to locate the freshwater sources in the area.

7. Steps taken to get to the missing knowledge

Technical field investigations:	In the extension soil investigation by drillings, monitoring hydraulic heads, monitoring surface water quality, tTEM investigation.
Analysing data:	The collected data in BE-1 provided the basis for the creation of a potential map showing the possibilities for freshwater storage in the area. In the extension the collected data provided the basis for designing the infiltration system and for modelling the effects on the environment.
Using models:	See BE-1
Measures taken:	5 measures were investigated and summarised in opportunity or potential maps. In the extension a pilot for creekridge infiltration was built.
Involvement of stakeholders:	Multiple workshops with stakeholders were organised to discuss the possibilities for implementing measures to improve the availability of freshwater. Also, a field visit to Zeeland took place where some of the possible measures (e.g. creek ridge infiltration) are already used for agriculture purposes.

8. Solutions found to solve the main management questions:

A potential map was produced. This map formed the base for the selection of two locations for trials to increase the availability of freshwater. On one of these locations a pilot for creekridge infiltration was built in the extension.

9. New water management and advantages

	Advantages	New Management Option
Agricultural:	Maps showing the potential to implement a measure	Dealing with precipitation excess in winter and water shortage in summer
Nature:	Maps showing the potential to implement a measure	Dealing with precipitation excess in winter and water shortage in summer
Water abstraction:	Maps showing the potential to implement a measure	Dealing with precipitation excess in winter and water shortage in summer
Spatial planning:	Maps showing the potential to implement a measure	Dealing with precipitation excess in winter and water shortage in summer

10. Benefits transnational exchange Topsoil

- How topsoil used the knowledge from different partners to find new solutions to complex challenges: Knowledge about (airborne) EM methods, salt-water intrusion processes, data processing, modelling and monitoring, stakeholder involvement strategies
- How transnational joint approach has led to new investigation and management methods: During the workshop on salt water intrusion we learnt more about dealing with salt water intrusion
- The transfer of techniques and management between partners: New ways of monitoring in saline environments
- How local public bodies, in charge of climate adaptation, have benefit from the transnational knowledge: of the fresh-salt water distribution, access to maps showing the potential for implementing a certain measure to increase the fresh water availability; sharing experience during field visits in partner countries
- Describe if and how topsoil changed your future approach on climate change adaptation. Participatory methods, with a focus on involving a broad net of stakeholders, in decision-making and consensus-building

11. Recommendations for future developments concerning climate change

The investigated measures show opportunities to store the precipitation excess in winter which leads to an increase of freshwater availability during summer.

DK-1

High groundwater table in a Danish town - Challenges and opportunities in a climate adaptation perspective

1. What is the Objective of the pilot?

The aim of this pilot is to better understand the challenges connected to the fluctuations of the high groundwater table. The town of Sunds is located on a meltwater outwash plain formed during the last Ice age and today it is dominated by agricultural areas. The groundwater table in the town and the surrounding areas is very close to the surface and reacts very fast to increasing rainfall. Due to renovation of sewage pipes and increasing precipitation groundwater levels are rising and the area is prone to flooding.

Possible actions to take against future groundwater flooding is investigated by new geophysical mapping methods and modelling procedures and by introducing knowledge from other partner countries with expertise within this field. This is leading to climate change adaption plans being established, tested and introduced to the relevant stakeholders.

2. Studied TOPSOIL Challenges

- Flooding: During recent years Sunds has been facing climate change related challenges with rising groundwater levels due to increasing precipitation in especially the winter period. One consequence is groundwater flooding of basements and low-lying areas. The local water utility company (Herning Vand) is currently renovating the old sewer system to decrease unintentionally inflow of groundwater into the old leaky sewers. One of the consequences of this renovation work is that it speeds up the problem of rising groundwater as the sewer pipes will no longer act as a groundwater drainage system. Accordingly, several measures are examined with the aim of ensuring a better future resilience towards groundwater flooding.
- Groundwater buffer: Groundwater aquifers and surface water basins, natural and artificial, can act storage reservoirs for excess groundwater collected in wet winter periods and used in dry summer periods. The analyses the groundwater buffer will focus on how much groundwater has to be removed during winter periods to reduce the risk of basement flooding, how much water is it possible to store from winter to summer, and what is the water demand in summer periods. Different measures will be tested. Examples of active measures by which winter surplus of groundwater can be used to summertime are targeted groundwater irrigation, open drainage channels in the town – a blue/green solution, forest plantation around the town, and utilization of groundwater for energy purposes.

3. Context of current management

The local authority (Herning Municipality) is legally required to manage sewage water, but not allowed to make any changes to the groundwater table. Due to the sealing of sewage pipes, the shallow groundwater is now less drained from the area. This adds to the problem of a generally rising groundwater table, and flooding of private basements are becoming an increasing problem in Sunds. The problem will only increase with continued climate change in the future.

Neither the municipality nor the local water waste company have any obligations towards handling excess water on private property, e.g. by establishing a third pipe along the sewage corridors for draining. In fact, the current legislation prevents them to take action.

At the moment private house owners keep their basements dry by illegally connecting a drain to the public sewage system without permission. The result is that large amounts of drainage groundwater (approx. 1.000.000 m³/year) are needlessly treated as wastewater.

4. What is the expected impact of climate change? (before project)

The groundwater level will most probably rise in the future due to the climate change. This is the major problem in the pilot.

5. What are the main management questions at the start of the project?

How do we avoid groundwater flooding in the area? The first and already existing problem is flooding of basements, but at a later stage flooding will also occur on agricultural areas and in low parts of urbanized areas.

6. Which knowledge has been missing to find the climate resilient solution (at the start of the TOPSOIL project)?

Detailed knowledge of the geology and the hydrogeological conditions in the area. Methods to collect detailed subsurface data and procedures to establish models to predict groundwater flows and their behavior in a changed climate have been lacking.

7. Steps taken to get to the missing knowledge / solve the problem

Geophysical field investigations:	WalkTEM, DCIP, GCM, and the new transient electromagnetic method tTEM and FlowTEM
Data analysis:	Data has been collected and processed by the Aarhus University and interpreted to a detailed 3D geological model by GEUS.
Model setup:	A hydrogeological model to predict the effects of different preventive measures was developed by GEUS based on the detailed 3D geological model.
Using models:	A series of scenarios involving different measures has been predicted with the model (1. The third pipe (drain) 2. Plantation of forest, 3. Lowering water level in Lake, 4. Groundwater abstraction, 5. Establishing a ditch).
Measures taken:	No measures have been taken so far.
Involvement of stakeholders:	Herning Vand (Wastewater company), local homeowners associations, landowners.

8. Solutions found to solve the main management questions

According to the model predictions, the most effective measure is to implement a third pipe or a ditch for flooding-water drainage along with the sewage system. This will require a change in the Danish groundwater legislation. A process for such change has been started based on the results from our pilot in Sunds.

Plantation of forest will have some effect, but very large areas around the town need to be forested before this measure will give a proper effect.

9. New water management and advantages

The new knowledge from the pilot helps to foster a number of advantages in new management approaches:

	Advantages	New management options
Wastewater management:	Better future management/ decision making. Avoiding treatment of drainage water (cost reduction).	Law amendment to enable wastewater utilities to manage terrain-near groundwater. This will result in a more holistic approach to the overall water management (capital cost, operational cost and value adding/ socio-economic assessment), and a more integrated cooperation between the different actors and les silo thinking.
Urban planning:	Lowering of groundwater table will enable more flexible urban planning and save costs for houseowners and new constructions	Urban ditches designed to be a part of the city's water/blue infrastructure can also add recreational value and a nature element to the city. Today there is no legislation limitations, but space is often the challenge in the existing areas.
Nature preservation:	Urban ditches and urban greening/forest will improve recreational values, biodiversity, and groundwater quality	Urban ditches designed to be a part of the city's water/blue infrastructure can also add recreational value and a nature element to the city. Today there is no legislation limitations, but space is often the challenge in the existing areas.
Stakeholders:	Reduced risk of basement flooding. Reduced damage costs on property and infrastructure	Involvement of citizens and awareness rising of the regulatory responsibilities of a house owner and their possibilities for solutions incl. establishment of local drain associations.

10. Benefits transnational exchange Topsoil

The novel use of geophysics in the pilot and the developed application of modelling techniques is useful in several other situations and for other purposes. Our approach is partly adopted in other pilots.

11. Recommendations for future developments concerning climate change

Danish Water and Wastewater Association, DANVA and The Association of Danish Municipalities, KL have carried out a socio-economic analysis of 4 different situations (cases), where an infrastructure is implemented for handling the upper and rising groundwater table.
The TOPSOIL project in Sunds is one of the 4 cases. The socio-economic analysis compares the costs of establishing such an infrastructure with the socio-economic benefits, including the reduction of damage. In addition, potential property value increases due to the management of the damaging groundwater have been calculated.
All 4 cases incl. the Sunds case shows a socio-economically positive result. The analysis must be included in a law-preparatory analysis work, and if possibly included in the climate action plan.

DK-2A

Targeted regulation of fertilizers to obtain sustainable intensification. Investigating the potential for natural break-down of pollutants in the subsurface groundwater

1. What is the Objective of the pilot?

The objective is to investigate whether increasing the fertilizer allocation on less vulnerable soils and reducing the allocation of fertilizers to vulnerable soils, can enable the farmer to achieve greater yields while reducing the overall leaching of nitrogen into surface water and groundwater. Furthermore, it is an objective to investigate how the soil can interact as a buffer component holding water for dry periods and retaining water in wet periods.

2. Studied TOPSOIL Challenges.

- Flooding
- Soil conditions
- Break down capacity

3. Context of current management

To meet the targets in the Water Frame Directive, plans are made for the aquatic environment. The latest plan is called Water Plan 2. According to Water Plan 2, leaching to Horsens Fjord must be reduced by approx. 420 tonnes of nitrogen per year in order to achieve a good condition in the aquatic environment of the fjord. About half of this reduction should be achieved before 2021 and the other half are planned to be achieved in the third water plan period.

4. What is the expected impact of climate change? (before project)

- Less precipitation in summertime, increasing precipitation in winter time.
- 40 % increase in nitrate leach is expected in 2100 due to more frequent and more heavy rainfall.

5. What are the main management questions at the start of the project?

- One of the instruments to reduce nitrate leaching could be targeted fertilizer allocation on the cultivation surface which requires detailed identification of vulnerable areas within the fields. Will new mapping methods (t-tem) be adequate?
- Will new mapping methods in combination with the farmer's knowledge give a better understanding on how water is retained in the soil, whether the drainage system can be used in buffering the water, and locate where groundwater is formed and finally locate where there is a more direct run-off from the field?
- Will new understanding develop, when the farmer and his advisor meets the new knowledge from the scientific /administrative level and vice versa, instead of using the traditional approach with a groundwater model followed by transition into planning maps and stakeholder involvement?

6. Which knowledge has been missing to find the climate resilient solution (at the start of the TOPSOIL project)?

- Detailed knowledge of the geological setting within the fields.
- Detailed knowledge of drainage impact.
- Groundwater model to calculate the effect of climate change.

7. Steps taken to get to the missing knowledge / solve the problem

Technical field investigations:	Geophysical mapping with Ground Conductivity Meter and T-tem Drill holes for geological description Drain water samples Drain water flow measurements Precipitation measurements N-min sampling Yield measurements
Analysing data:	Geophysical data has been analysed by the Aarhus University and transferred into a geological model.
Using models:	To calculate the effect of climate change and the impact of drainage in a conceptual groundwater model.
Measures taken:	No measures have been taken.
Involvement stakeholders:	See stakeholder involvement strategy.

8. Solutions found to solve the main management questions

Weather conditions prior and post seeding has a major impact on crop establishment as well as on nitrate leaching. Targeted fertilizer allocation will not achieve substantial reduction in nitrate leaching. If water retention in topsoil may be prolonged nitrate leaching may be reduced. Water retention in soil depends on content of organic material in soil and soil structure.

9. New management and advantages

The new knowledge on the area helps to foster a number of advantages in new management approaches:

	Advantages	New Management Option
Surface water	Drains control the majority of the water flow. Knowledge of location is critical when measures to reduce nitrate is prioritised.	Registration of drains is needed.
Ground water	T-tem mapping gives knowledge of infiltration areas.	Knowledge-based dialogue between farmer and authority Improves choice and effective placement of measures.
Soil quality	GCM mapping maps distribution of clay content in soils. Increasing organic content and reducing soil compaction makes soil robust to climate fluctuations.	Good soil is easy to manage and give better yields.
Buffer capacity	1) Soil quality relates to buffer capacity. Organic rich soils hold more water. 2) Root depth may be increased if drainage depth is increased. Buffer capacity is increased and crops will be more drought resistant.	1) Organic matter must be incorporated in soils. 2) Increase of drainage depth.
Spatial planning:	New and more accurate knowledge on the subsoil zones with extra attention for runoff, drainage and infiltration can be used to redistribute fields.	By redistribution individual fields will perform evenly. Fields on vulnerable areas can be managed accordingly. Nitrate vulnerable areas should be planted early to reduce nitrate leaching.

10. Benefits transnational exchange Topsoil:

t-TEM mapping has proven as a relevant and strong tool for top soil mapping and vulnerability mapping. The method provides high 3D resolution of the shallow subsurface and is relevant on field scale.

DK-2B

Improvement of traditional investigations by prior geophysical investigations

1. What is the Objective of the pilot?

The objective of this pilot is to clarify if expenses and/or time can be reduced by adding geophysical measurements prior to a point approach investigation on contaminated sites. The pilot comprises of four contaminated sites. On three sites, groundwater resources are threatened by the contaminants. The focus of the fourth site has been to evaluate the impact of seasonal changes in climate on the leakage from an old landfill to a local stream (TopSoil Extension).

2. Studied TOPSOIL Challenges

Break down capacity

3. Context of current management

Contaminated sites are traditionally investigated by drillings, soil- and water samples and soil gas measurements. In the initial phase, the existence of point source pollutions are detected from examinations of historical archives, by interviews etc. Based on the results from the initial phase, drillings are conducted in order to track and delineate the hotspot and/or plume. This approach contains a substantial uncertainty especially in heterogeneous geological settings, and a solid risk assessment requires a large number of expensive drillings.

4. What is the expected impact of climate change? (before project)

- Seasonal fluctuations will increase, investigations may be extended to include these measurements.
- Seasonal variations in groundwater abstraction may lead to local variations in substance transport.
- More frequent and heavy rainfall will increase leaching with a negative effect on ground- and surface water quality.
- Rising temperatures will intensify the decomposition of landfill waste and increase the generation of landfill gas.

5. What are the main management questions at the start of the project?

- Will the resolution of T-TEM measurements be sufficient?
- Will geophysical measurements shorten or lengthen the investigation period?
- Will geophysical measurements reduce costs?
- Where is it possible to perform tTEM mapping?

6. Which knowledge has been missing to find the climate resilient solution (at the start of the TOPSOIL project)?

- Detailed knowledge of the geological and hydrogeological conditions.
- A detailed groundwater model to calculate the effect of climate change.
- Impact of climate change and seasonal variations on near-surface solute transport.

7. Steps taken to get to the missing knowledge / solve the problem

Technical field investigations:	tTEM have been used where possible. GCM have been used as an alternative in cases where access was not possible with tTEM. Traditional field investigations involving boreholes, soil air measurements and water samples were added.
Analysing data:	The geophysical data have been analysed and interpreted to represent geological and hydrogeological conditions. Since most registered contaminated sites are situated in or close to urban areas, a GIS analysis was made to achieve an estimate of the applicability of tTEM for polluted site-investigations.
Using models:	Conceptual geological and hydrogeological models have been constructed at all the investigated sites. The models were used to set the plans for further field investigations
Measures taken:	
Involvement stakeholders:	Municipalities and consulting companies were involved through cooperation and information.

8. Solutions found to solve the main management questions

The investigations have addressed the questions, in detail, regarding the resolution capability and efficiency of the tTEM and GCM methods. Cost benefit analyses have been made on the use of tTEM. The results show that the implementation of tTEM as a part of the investigation programme will reduce the budgets used for site investigations and will simultaneously improve the validity and quality of the resulting risk assessments and/or subsequent remediation actions. The results of a GIS analysis show that it will be beneficial to use tTEM at between 1/3 and 1/2 of all the registered contaminated sites in the Central Denmark Region (between 116 and 152 sites). The tTEM method is now being implemented as a valuable tool for contaminated site investigations in Central Demark Region as well as in the other Danish regional authorities.

9. New water management and advantages

The new knowledge on the area helps to foster a number of advantages in new management approaches:

	Advantages	New Management Option
Costs:	tTEM surveys can substitute expensive drilling	Include tTEM in the toolkit for contaminated-site investigations
Risk management:	More robust evaluation of risk.	Include tTEM in the toolkit for contaminated-site investigations

10. Benefits transnational exchange Topsoil

Inspiration and experience were gained through close collaboration with the TOPSOIL partners in the other countries. The t-TEM method has proven as relevant and a strong tool for Topsoil. Topsoil top soil mapping in general. It has been tested and used for other climate-change relevant purposes in Denmark and in the other countries.

11. Recommendations for future developments concerning climate change

The geophysical methods tested in this pilot (tTEM and GSM) have proven very successful for investigation of contaminated sites. As contaminants are sensible to both seasonal and permanent variations in groundwater flow and level, the use of these methods is recommended for assessments of climate change impact.

DK-3

Development and testing of high-resolution near-surface methods for improved groundwater vulnerability assessment

1. What is the Objective of the pilot?

The town of Varde is located in the south-western part of Jutland. The area suffers from lack of clean ground water. Very often nitrate and pesticides pollute the known aquifers and it has for many years been difficult to find new clean aquifers. Recent investigations show that the area is heavily glacially deformed with thrusting and folding of the subsurface. This means that gateways for pollution along these structures to the aquifers frequently exist in the area. Due to the presence of the complex geology a new high-resolution mapping method is needed. New ways of data interpretation and modelling of dense data also has to be developed to make detailed vulnerability assessments. A thorough understanding of the subsurface supported by new mapping methods (Tow-TEM) will hopefully contribute to a future sustainable drinking water supply that also is resilient to future climate changes.

2. Studied TOPSOIL Challenges

- Groundwater buffer
- Soil conditions
- Break down capacity

3. Context of current water management.

Pilot area consist out of a catchment area with complicated geology and groundwater of poor quality. Initiatives are needed in order to secure future drinking water. Better geological understanding and possible change in land use regarding water protection

4. What is the expected impact of climate change on water management? (before project)

- Water quantity in summer will decrease, because of less precipitation
- Water quantity will increase in autumn, winter and spring because of increasing precipitation
- Change in water extraction in the town can result in rising groundwater table

5. What are the main management questions at the start of the project?

- How do we secure a future clean drinking water supply resilient to pollutants and climate change?
- How to engage stakeholders in areas of interest?

6. Which knowledge has been missing to find the climate resilient solution (at the start of the TOPSOIL project)?

Detailed knowledge of the upper geology. Distribution of glacial tills, interglacial clays, buried valley structures and glacial tectonics

7. Steps taken to get to the missing knowledge / solve the problem

Geophysical field investigations:	Geophysical mapping with the new transient electromagnetic method TowTEM Seismics (LIAG) Investigation drillings TEM40 soundings
Analysing data:	Data has been processed by the Aarhus University and LIAG and interpreted to a 3D geological model by GEUS
Using models:	To calculate the effect of climate change and change in/new water extraction groundwater modelling is in process
Measures taken:	No measures have been taken yet.
Involvement stakeholders:	Dialog with farmers and local authority (Varde Municipality)

8. Solutions found to solve the main management questions

- By combining the collected detailed geophysical data and existing geophysics with boreholes and regional geological understanding the knowledge on the subsurface structures have increased significant. New structures with clean groundwater potential have been mapped. Also the vulnerability of the aquifers from surface activities has improved.
- Groundwater modelling scenarios are not completed yet...these results are important in the decision making and management.

9. New water management and advantages

The new knowledge on the area helps to foster a number of advantages in new management approaches:

	Advantages	New Management Option
Water abstraction:	Knowledge aquifer structures and vulnerability	New well field. Stakeholder agreement. Land use restrictions?
Spatial planning:	Improved knowledge on geology leads to better decision making on the surface	Better future management /decision making

10. Benefits transnational exchange Topsoil:

We used a new geophysical method to describe detailed geology and identifying new subsurface structures.

DK-4

Integrated water management in Odense City for improved risk assessment

1. What is the Objective of the pilot?

The overall objective of the project is to create a tool which can be used for management of water flow in urban areas in climate change conditions and access the risk for contaminated point sources.

2. Studied TOPSOIL Challenges

- Flooding
- Groundwater buffer
- Break down pollutants

3. Context of current water management.

The pilot area consists of a catchment area with clayey soils, dominated by glacial till layers and very irregular meltwater sandy layers, including buried valleys. Groundwater is abstracted from the sandy aquifers by large well fields. The capture zones are located in rural areas use for farming but well are placed in the very eastern part of the pilot area, practically in the city. The quality of the abstracted water is threatened with pesticides, chlorinated solvents and hydrocarbons from numerous point pollution sources, both agricultural and industrial.

Water management is mainly influenced by quality issues in the abstracted water and by inundation problems due to decreasing abstraction rates and increasing rainfall due to climate change.

4. What is the expected impact of climate change on water management? (before project)

- Water quantity will increase, because of more precipitation with higher groundwater tables as an effect (inundation).
- Water quality will be affected and potentially mobilised due to higher groundwater table.

5. What are the main management questions at the start of the project?

- We know that high groundwater levels will become a problem and because of that we want to create measures to reduce the risk of flooding/inundation;
- Climate change may change the mobility of pollutants and the flow path from the source to the well fields
- Because of intensive rainfall more flooding will occur and have an effect on water quality but we don't know the most vulnerable parts of the area;

6. Which knowledge has been missing to find the climate resilient solution (at the start of the TOPSOIL project)?

Detailed knowledge on the geology in the capture zone to the well fields
Detailed modelling to delineate flow paths and groundwater levels in present and future climate
Detailed knowledge on the characteristic of the numerous pollution sources.

7. Steps taken to get to the missing knowledge / solve the problem

Technical field investigations:	Boreholes to map the lithology Groundwater levels have been measured
Analysing data:	Fine grain analysis of soil samples has been carried out. The geological architecture has been interpreted.
Using models:	The integrated modelling system MIKE SHE combined with MODFLOW-SURFACT has been used to calculate flow, particle tracking and reactive transport.
Measures taken:	No measures have been taken so far.
Involvement stakeholders:	Municipality of Odense, VCS Denmark (Danish water and wastewater company)

8. Solutions found to solve the main management questions

No solutions have been found so far. However, the foundation with respect to knowledge about the problem studied has almost been established. This provides the basis for finding the most optimal solutions.

9. New water management and advantages

The new knowledge on the area helps to foster a number of advantages in new management approaches:

	Advantages	New Management Option
Water abstraction:	Knowledge on where water infiltrates, the resulting flow paths to the well fields and the concentration levels of pollutants	The basis for controlling the abstraction rates in order to minimize inundation problems has been provided
Spatial planning:	More accurate knowledge on areas with inundation risk	The basis for urban planning and where not to build houses has been provided
Contaminated sites:	Knowledge has been produced on the risk associated with both point sources and nonpoint sources	The basis for priority among the many pollution sources has been provided

10. Benefits transnational exchange Topsoil:

We used a method with a high degree of cooperation to deal with diverse problems including geological setting, hydrological system (groundwater + surface water), and quality aspects (solute transport). The integrated and physical based model MIKE SHE combined with MODFLOW-SURFACT was found to be an efficient tool for the problem.

GE-1

Investigation of the geophysical, hydro chemical and hydraulic characteristics of the subsurface in a moraine area and adjacent marshlands as a basis for geological and hydrological modelling

1. What is the Objective of the pilot?

Provide stakeholders with an assessment of increased flooding risk and demand for drainage in the marsh areas. Risk assessment of sinkholes on top of the salt structure in Muensterdorf

2. Studied TOPSOIL Challenges

- Flooding
- Salt water intrusion
- Soil conditions

3. Context of current water management

Terrain heights of the area are in general below sea level, protection by dykes at the rivers Elbe and Stör and drainage is essential. Land-use in the area is dominated by agriculture. Some parts of the area are frequently flooded during the wet season. The groundwater of the area is influenced by intrusions of brackish water from the River Elbe.

4. What is the expected impact of climate change on water management? (before project)

Changes of the precipitation pattern will lead to enhanced groundwater recharge and rising groundwater table. Results are frequent flooding and higher demand for drainage. Rising level of the river Elbe as a consequence of sea level rise will obstruct the free outflow of drainage water and lead to higher demand for pumping. Salt water intrusion to the marsh area will increase, affected by the management of the drainage systems.

5. What are the main management questions at the start of the project?

The effects of climate change (longer flooding, higher demand for drainage) were not quantified.

6. Which knowledge has been missing to find the climate resilient solution (at the start of the TOPSOIL project)?

Detailed information on the underground structure, no geological and groundwater model was existing.

7. Steps taken to get to the missing knowledge / solve the problem

Technical field investigations

- geoelectrical measurements (2D) by LIAG,
- seismic survey
- direct push by contractor (planned)
- borehole NMR by LIAG (planned)
- SIP by TU Berlin (planned)

Analysing data

- evaluation of existing VES
- evaluation of HEM data
- evaluation of chemical analyses of ground water
- evaluation of hydrogeological data

Using models

- hydrogeological model is in progress
- ground water model is in process

Measures taken

- when model is finalized

Involvement of stakeholders

- reporting the results of the modelling when model is finalized
- informing potential stakeholders about the project’s goals

8. Solutions found to solve the main management questions

Influence of expected heavy rainfall and increasing ground water recharge on water table and flooding including demand for drainage will be quantified. The effect of salt water intrusion will be quantified.

9. New water management and advantages

Soil and drainage associations will obtain information of the future demand for pumping including the need for new technical installations and on the risk of salt water intrusion and rising of the salt water/ fresh water boundary in the marsh area.

10. Benefits transnational exchange Topsoil

- Knowledge from different partners will help to find new solutions for the managing of the drainage systems in the marsh areas;
- Transnational joint approach will help to find new investigation and management methods;
- The groundwater model can help to mode different scenarios for the managing of the drainage systems.

GE-2

Development of climate change effected saltwater intrusion in the Elbe-Weser-region

1. What is the Objective of the pilot?

The objective is to learn about how the salt-/freshwater interface (SFI) responds to water balance changes due to climate change.

2. Studied TOPSOIL Challenges

- Saltwater intrusion
- Groundwater buffer

3. Context of current water management

In our pilot area there are two different types of geological areas with different hydrogeological properties. In the geest areas (heights up to 70 m a.s.l.) we have a water level around 10 m a.s.l. and a high groundwater recharge with up to 400 mm/a. In contrast in the lower marsh areas (heights between -2 and 20 m a.s.l.) the water table is with 0 – 1 m a.s.l. close to the surface and the groundwater recharge ranges between 50 – 150 mm/a. As a special feature due to high water level the marshlands have to be drained to keep them dry and allow agricultural land use as well as settlement. This caused a complex drainage systems consisting of channels and pumping stations which are operated by different drainage associations.

4. What is the expected impact of climate change on water management? (before project)

Due to climate change the precipitation pattern will change to higher amount of precipitation in winter and lower in summer. That´s why the pumping rates in winter will increase. It is expected that the upcoming of the SFI, which is already today a big challenge for water supplier, will be worse due to higher pumping rates in winter.

5. What are the main management questions at the start of the project?

- How will higher pumping rates influence the SFI?
- Is it possible and where to store water in geest areas and reuse it in dryer periods for irrigation?

6. Which knowledge has been missing to find the climate resilient solution (at the start of the TOPSOIL project)?

Detailed knowledge of the geology, especially the distribution of till and the Lauenburg clay.
Detailed knowledge of the current state of the SFI.
How is the composition of the drainage water? Is it useable for ASR?

7. Steps taken to get to the missing knowledge

Technical field investigations:	For more information about the position of the SFI we used the direct push technique for taking groundwater samples per metre up to 25 m below ground level. Additionally we used the HEM data from the BGR to map the SFI by the distribution of the electrical resistivity in depth.
Analysing data:	For more information about the geology and hydrogeology (e.g. kf value, porosity) in the pilot area we took some sediment samples. To get information about the drainage water we took water samples and they were analysed in our laboratory. The groundwater samples (taken from the direct push) were also analysed in the laboratory.
Using models:	A detailed geological model has been created to get the information about distribution of till and clay. A groundwater flow model based on the geology is used to calculate the effects of the climate change on the water balance and especially on the SFI in the project area.
Measures taken:	Direct push measurements to get information about the chloride content in depth.
Involvement of stakeholders:	Stakeholder (farmer, water supplier, drainage associations) were involved by delivering data (e.g. pumping rates) and knowledge.

7. Solutions found to solve the main management questions

Possible solutions:

- Aquifer Storage and Recovery (ASR)
  Store freshwater in the higher areas would cause a surplus of water availability in dry periods and it could possibly pushes the salt-/freshwater interface a little bit towards the north sea (or into deeper parts of the coastal aquifers).
- Adapt drainage level
  The reduction of the drainage level of a few cm (10-25 cm) in combination with smaller distances between the drainage pipes (normally 10m between two drainage pipes, reduce this to 8m) would have a high impact on the salt-/freshwater distribution in the marsh areas.
  Another option is a water level controlled drainage system.

9. New water management and advantages

not yet implemented

10. Benefits transnational exchange Topsoil

- We had a great transnational knowledge transfer within the Topsoil project. Especially a lot of the knowledge from the Dutch colleagues on groundwater buffering and drainage systems could be adapted for our pilot.
  These new options could be used for optimizing the drainage in our pilot and could lead to new approval options for drainage systems.
- Describe if and how topsoil changed your future approach on climate change adaptation.
  In the beginning of the project we only thought about groundwater buffering (Aquifer Storage and Recharge) with drainage water as an option for the management and adaption of the salt-/freshwater interface in a resilient way. But after the fruitful discussions and knowledge transfer with the different partners we have some more adaption options (e.g. water-level controlled drainage systems or shallow and tight drainage).

GE-3

Bremen Dam: Effects of a dam on the surrounding Groundwater

1. What is the Objective of the pilot?

The objective is to gain experience about the changing groundwater –flow regime after the dislocation of the Weser dam in the 90s.
On large scales a distinguished knowledge from prediction models as high-resolution groundwater- and transport modelling is needed. We have to clarify: What impact does the climate change have on the interaction between aquifer and river? What does the rising sea level and changes in groundwater recharge mean for future groundwater use?

2. Studied TOPSOIL Challenges.

- Flooding
- Saltwater intrusion

3. Context of current water management

The pilot area consists of a catchment area with sandy aquifers, which is the main groundwater reservoir. The groundwater is used by local companies along and near the Weser River.
Water management is mainly influenced by the tides (lower part) and by saltwater intrusion (upper part). The saltwater load decrease but the groundwater recharge is predicted to decrease as well. These facts will have noticeable consequences to the groundwater regime and the groundwater quality by the communication between riverbed and aquifer on small and large scales.
Thus, the groundwater regime is influenced by the Weser dam and climate change.

4. What is the expected impact of climate change on water management? (before project)

Change of groundwater recharge
Increase of tidal impact (lower part, tidal pumping)
Increase of sea level => increase of the water level in the Weser River => dislocation of the dynamical fresh water –saltwater interface
Decrease of water level in the Weser river => decrease of gradient => dislocation of dynamical fresh water –saltwater interface

5. What are the main management questions at the start of the project?

- How important is the impact of the shifting dynamical freshwater-saltwater-interface for the adjacent companies?
- Is it possible to manage the saltwater content in the groundwater by regulating the gate height of the Weser dam?
- How can local companies regulate their pumping rate/extraction rate to control the ground water quality and adapt the pumping rate to the changing flow regime?

6. Which knowledge has been missing to find the climate resilient solution (at the start of the TOPSOIL project)?

- Detailed knowledge about the general changes in groundwater flow and quality in the project area after the new Weser dam was built.
- Detailed knowledge about the influence of the replacement of the Weser dam on the dynamical freshwater-saltwater interface.
- understand the communication between river bed and aquifer
- Impact of climate change, by increasing sea level changes and decreasing groundwater recharge

7. Steps taken to get to the missing knowledge / solve the problem

Technical field investigations:	Direct push Geophysical mapping
Analysing data:	Parameter: Chloride and hazardous substances (CHC). CHCs were used to investigate the former and recent groundwater flow.
Using models:	To calculate the effect of climate change and the impact of possible measures a groundwater model is built based on a high resolution structural geologicak model (10 x 10x 0.5 m Voxelmodel)
Measures taken:	still running (groundwater flow, transport model), conceptual model
Involvement of stakeholders:	B. Leferink (SUBV, Senator für Umwelt, Bau und Verkehr)
External Partner:	Dr. Pirwitz Consultancy

8. Solutions found to solve the main management questions

- Regulating extraction rates
- Regulating the groundwater recharge, unsealing of free areas
- Drainage/infiltration of the water flow (middle Weser)
- Regulation the damming height, gate height

9. New water management and advantages

	Advantages	New Management Option
Water management	Control the dynamical freshwater-saltwater interface	Drainage/Infiltration/regulate the gate height of the Weser dam
Water abstraction:	Knowledge about the impact of groundwater abstraction	possible adaption
Spatial planning:	Regulate groundwater recharge	Unsealing of free areas/artificial infiltration of groundwater

10. Benefits transnational exchange Topsoil

We will have a new detailed model to investigate and increase knowledge about the influence of control parameters on the dynamical freshwater-saltwater interface and the influence of climate change.

GE-4
AquaModul

1. What is the Objective of the pilot?
The aim of the pilot is to develop a stakeholder integrated groundwater, combined with small water courses, monitoring system ("Triple Monitoring") and to possibly identify a groundwater abstraction management to adapt to climate change by allowing increased groundwater extraction for agricultural irrigation under the premises of WFD-requirements (i.e. of protection of groundwater dependent ecosystems). A practicable and significant monitoring system and DSS need to be designed and installed in a large-scale groundwater extraction situation (ca. 1,500 km², < 2,000 wells) with erratic extractions for agricultural irrigation. Therefore, a pilot monitoring is to be developed as basis for a hierarchic large-scale monitoring system be the basis for future management of extraction as well as possibly artificial recharge.

2. Studied TOPSOIL Challenges
Groundwater buffer

3. Context of current water management
Due to sandy soils in combination with a highly negative climatic water balance during the vegetation period the region belongs to Germany's largest agricultural irrigation area. Mainly groundwater is used. The rather rural region is characterized by a weak infrastructure and loss of inhabitants. The limiting factors to the necessary additional groundwater extraction are the WFD requirements of preserving (and improving) existing protected groundwater dependent ecosystems. The sum effects of the collective wells have been investigated during the last decade with the help of iterative modelling. However, a practicable and significant monitoring system and DSS as basis for future management of extractions (as well as possibly artificial recharge) are missing.

4. What is the expected impact of climate change on water management?
- Less precipitation during the vegetation period and longer dry periods / droughts are resulting in an increasing need for agricultural irrigation.
- Due to increasing temperatures soil water reserves will be evaporated faster, i.e. field capacity will be exhausted earlier.

5. What are the main management questions at the start of the project?
- How can groundwater extractions be adapted to increasing need for irrigation without harming groundwater dependent ecosystems?
- Can therefore a hierarchic large-scale monitoring system (county level) be developed, practically handled, afforded and be combined with an existing groundwater model in order to make up new groundwater management plans with lowest possible restriction of irrigation?
- Will the stakeholders accept such a system?

6. Which knowledge has been missing to find the climate resilient solution (at the start of the TOPSOIL project)?
- Existence and practical handling / functioning of monitoring technology working in small natural streams?
- Functioning of combination of the measuring with groundwater measuring and inserting the results in hydrogeological stationary groundwater modelling?

7. Steps taken to get to the missing knowledge / solve the problem

Technical field investigations:	installation of four acoustic doppler elements (ADCP technology) at ecologically sensitive sites in combination with four times two aquifer gauges nearby. Triple monitoring" means measuring run off plus upper and lower aquifer and integrate rainfall and abstraction events.
Analysing data:	data has been analysed by external expert and been inserted into hydrogeological model
Using models:	the effects of increased (local / regional) abstractions shall be modelled and the impact on groundwater dependent ecosystems shall be investigated /predicted
Measures taken:	no measures have been taken yet, but will be in the near future.
Involvement stakeholders:	installation of stakeholder round table ("contact group") and information meetings for irrigators, drinking water suppliers and others

8. Solutions found to solve the main management questions

The triple monitoring was key to understanding the hydrogeological interdependencies at the four selected sensitive sites.

9. New water management and advantages

The new knowledge on the area helps to foster a number of advantages in new management approaches. In combination with the regional groundwater model, problematic abstraction sites (wells), which harm small watercourses, will be identified and be restricted or given up. More favourable well sites of wells can be identified.

10. Benefits transnational exchange Topsoil

We found new ideas and methods of groundwater buffering and artificial groundwater recharge (Belgium, GE-1, GE-2)

11. Recommendations for future developments concerning climate change

The WFD goal for continuity in heavily modified waterbodies must be reviewed, partially in order to increase the landscape water household by retention of run off.

GE-5

Enabling farmers to better protect the groundwater from nitrate and veterinary pharmaceuticals

1. What is the Objective of the pilot?

This pilot in the western part of lower Saxony aims to strengthen the precautionary drinking water protection at farm level. Research on soil and seepage water will lead to a better understanding of the process of infiltration.

2. Studied TOPSOIL Challenges

- Soil conditions
- Break down capacity

3. Context of current water management

Large parts of the provision area of the OOWV are characterized by intensive agricultural land use combined with little buffering soil conditions, i.e. with vulnerable underlying groundwater bodies. This pressure feeds concerns that pollutants (e.g. nitrates) are on their way to groundwater layers and constantly threatening drinking water production: if they reach the water procurement areas (i.e. the deeper groundwater layers), it will be very difficult for water suppliers to remove them again.

4. What is the expected impact of climate change on water management? (before project)

- Water quantity in summer will decrease, because of less precipitation. This might lead to a loss of arable crops and to a reduced absorption of fertilizer.
- The likelihood of heavy rainfall in spring, winter and autumn will increase. This will lead to a higher leaching of nitrate and veterinary pharmaceuticals to the groundwater.

5. What are the main management questions at the start of the project?

- It is known that the intensive use of fertilizer is a threat to groundwater quality. Farmers need more information on the soil and processes in the soil to optimize their use of fertilizer in balance of high yields and groundwater protection.
- Because of intensive rainfall more leaching will occur and have an effect on water quality in seepage and groundwater but we don't know the solute transport conditions in the ground due to preferential flow;

6. Which knowledge has been missing to find the climate resilient solution (at the start of the TOPSOIL project)?

- Detailed knowledge of the preferential flow of solutes in the soil and the relation to different application practices;
- Detailed modelling of farmland and testing if farm-based soil maps can help the farmer to better adapt the amount of fertilizer to the soil conditions.

7. Steps taken to get to the missing knowledge / solve the problem

Technical field investigations:	Plot-scale study to water flow heterogeneity and the relevance of preferential flow paths for groundwater contamination Field-scale study for identifying the heterogeneity in soil- and groundwater properties using geophysical tools Nitrate measurements on farms
Analysing data:	
Using models:	Digital and sub-area-specific soil maps
Measures taken:	Adapting fertilizer usage to measurements results
Involvement stakeholders:	Cooperating farmers and the Chamber of Agriculture are working with the measurement results and try to adapt the use of fertilizer

8. Solutions found to solve the main management questions

- BGR carried out field and laboratory investigations on agricultural soils as well as multi-tracer irrigation experiments, combined with electrical resistivity tomography measurements to assess soil features, soil moisture and the relevance of preferential flow for groundwater contamination In the Cloppenburg region, continuous preferential flow paths were observed below the plough pan. The same preferential flow paths seem to be used repeatedly by successive rain/irrigation events. However, the mobile-immobile regions appear to exist only for short periods of time, because fast matrix flow balances the spatial heterogeneity in leachate distribution. In total, preferential flow, though responsible for a high spatial heterogeneity in leaching loads within the study plots, increased only slightly the averaged cumulative solute leaching.

- Results of the geophysical survey (EM and Radiometry) in combination with soil- and groundwater sampling also showed that for a very sandy field the radiometry data showed contrasts in clay content in the northern parts of the field. The electromagnetic data mainly reflected the varying depth to groundwater. The deeper the groundwater level, the lower is the measured conductivity, because the saturated part of the soil column shows a higher conductivity than the unsaturated part. For the rather homogeneous sites with sandy soil the variability in soil organic matter content or in chemical composition of the top-most groundwater could not be explained by geophysical measurements.

9. New water management and advantages

The new knowledge on the area helps to foster a number of advantages in new management approaches:

	Advantages	New Management Option
Agricultural:	Farmers know more details about their soils and under which condition they can reduce the leaching of nitrate.	Farmers can now minimize their impact on nature and are better able to find a balance between high yields and groundwater protection.
Nature:		
Water abstraction:	Better protection of groundwater quality. Nature benefits from a reduction of nitrate in the ground.	Success-oriented and farm-based approach for payments.
Spatial planning:	More accurate knowledge on the subsoil flows and breakdown capacities can be used to improve policy on agricultural management	

10. Benefits transnational exchange Topsoil

Two workshops took place about the differences and similarities in maize growing and nutrient management. During intense discussions details regarding the cultivation of maize in relation to nitrate leaching, crop protection and fertilization were exchanged and compared. The geographical similarities in the North Sea region make comparisons and the exchange of best practises possible. A central objective of the workshops was to identify which measure can be transferred for reducing nitrate losses. Under the aspect of governance, experts from all Topsoil countries exchanged their experiences and ideas at the partner meeting in Durham.

11. Recommendations for future developments concerning climate change

The pilot shows the importance of cooperation between different stakeholders with sometimes divergent interests. This is necessary to combine research and practical implementation.

NL-1A
Freshwater - Drentse Aa

1. What is the Objective of the pilot?
A dryer climate due to climate change will increase water shortage in agriculture and in nature areas in the catchment of the Drentse Aa. The present policy is not to allow irrigation from groundwater in order to avoid drought damage to vulnerable wet nature in the nature 2000 areas in the river valleys.
The aim of the pilot is to determine where irrigation from groundwater can be allowed without damaging the wet nature and to find mitigating measures for the effect of increased drought due to climate change on nature in the catchment of the Drentse Aa.
We studied this in close alignment with representatives of the most relevant stakeholders.
An existing groundwater model of the area has been actualized. We used this model to determine and quantify the mitigating measures.

2. Studied TOPSOIL Challenges
Use of groundwater buffer.

3. Context of current water management
Drentsche Aa catchment: Pilot area about 300 km2, consist out of a catchment area with sandy soils, locally shallow glacial till layers and very irregular meltwater till layers. The rural area is in use for farming and a big part of the area, including the river, has a N2000 status.
Water management is mainly influenced by the fluctuation of the river level, especially on the meandering parts, some weirs and drainage of the agricultural land. There is no possibility for water supply in summer. The present policy is not to allow irrigation from groundwater in order to avoid drought damage to vulnerable wet nature in the nature 2000 areas in the river valleys.

4. What is the expected impact of climate change on water management? (before project)
- Water quantity in summer will decrease, because of less precipitation and more evapotranspiration with lower groundwater tables as an effect.
- Water quantity will increase in winter and spring because of increasing precipitation with a higher groundwater table as an effect.

5. What are the main management questions at the start of the project?
- Where can we allow irrigation from groundwater without damaging the wet nature in the nature 2000 areas in the river valleys in the catchment of the Drentse Aa.
- What measures are effective to mitigate the effect of a dryer climate due to climate change on nature in the catchment of the Drentse Aa.

6. Which knowledge has been missing to find the climate resilient solution (at the start of the TOPSOIL project)?
- A groundwater model based on the most recent geo-hydrological information.
- Knowledge about the effect of a dryer climate due to climate change on the vulnerable wet nature in the nature 2000 areas in the river valleys in the catchment of the Drentse Aa.

7. Steps taken to get to the missing knowledge

Analysing data:	the most recent geo-hydrological data have been analysed to find out what new data should be used to update an existing groundwater model (SIMGRO) of the catchment of the Drentse Aa.
Using models:	To calculate the effect of climate change and the effect of mitigating measures for increasing drought a groundwater model SIMGRO has been actualised and used.
Measures taken:	the groundwater model has been used to determine and quantify measures to mitigate the effect of increasing drought due to climate change. The implementation of measures will be done in follow-up projects.

8. Solutions found to solve the main management questions

The following measures proved to be effective mitigating measures:

Measure for agriculture:

- Irrigation from groundwater can be allowed in areas on a distance of more than 500 m from vulnerable wet nature on condition that no more than 50 mm/year is extracted (average over the whole agriculture area).

Before implementing this new policy for irrigation from groundwater in the catchment of the Drentse Aa the logistics for a new way of permitting and more intense enforcement have to be organised by regional Water Authority Hunze en Aa's.

Mitigating measures for nature:

- Changing coniferous forest into deciduous forest or into heather.
- Applying shallower drain tubes closer to each other (0,8m minus surface (instead of 1,1 m-surface) and 5 m distance between drainage tubes (instead of 10m)) in agricultural areas that borders nature areas with wet nature.
- Raising the bottom level of the rivers (that became too deep due to erosion).

These mitigating measures cannot be implemented everywhere. Furthermore, the effect of the mitigating measures is often limited to a certain distance from the place where the measures are implemented. Because of these limitations only in a limited part of the nature areas it is possible to mitigate the effect of increased drought due to climate change.

9. New water management and advantages

	Advantages	New Management Option
Agricultural:	More farmers can now reduce the impact of increased drought due to climate change by irrigation from groundwater.	Irrigation from groundwater can be allowed in areas on a distance of more than 500 m from vulnerable wet nature on condition that no more than 50 mm/year is extracted (average over the whole agriculture area).
Nature	In some nature areas the effects of increased drought due to of climate change can be mitigated (but not in all nature areas)	It is known now what can be done to mitigate the effect of increased drought due to climate change. And it is known now that it is not possible to mitigate this effect everywhere.
Regional water authority Hunze en Aa's:	More knowledge on impact of irrigation from groundwater on nature. More knowledge about the effect of increased drought on nature and on the possibilities and limitation to mitigate this effect.	The information can be used to develop a new policy for irrigation from groundwater: - Maps are available where irrigation from groundwater can be allowed. - the restrictions that have to be used in permits is known now.
Province of Drenthe	More knowledge about the effect of increased drought on nature and on the possibilities and limitation to mitigate this effect.	The information can be used to adapt the policy that describes where what type of nature is wanted ("natuurdoeltypen").

10. Benefits transnational exchange Topsoil

IN a special meeting on permits we learned from other partners about how they organise permits and enforcement for extracting groundwater for irrigation. This is helpful to organize a new way for permits and enforcement for extracting groundwater for irrigation in the catchment of the Drentse Aa.

11. Recommendations for future developments concerning climate change

Outcome of the pilot gives input for the measures to be taken up in the new Water Management Plan 2022-2027 of Hunze en Aa's.

NL-1B
Drentsche Aa and Hunze waterquality

1. What is the Objective of the pilot?
Climate change will affect the impact of agriculture activities on water quality of surface water. The aim of the project is to get better grip on the increased leaching of nutrients and pesticides due to climate change. And to determine measures together with farmers in the area best to be taken. A hydrological model and a quality model has been built to determine the high risk areas on leaching and run off of nutrients and pesticides for the catchments of the two brooks Drentsche Aa and Hunze.

2. Studied TOPSOIL Challenges
- Soil conditions
- Break down capacity

3. Context of current water management
Two pilot areas, of two brooks (Drentsche Aa and Hunze).
Drentsche Aa catchment: Pilot area about 300 km2, consist out of a catchment area with sandy soils, locally shallow glacial till layers and very irregular meltwater till layers. Soil is in use for farming and a big part of the area, including the river, has a N2000 status.
Water management is mainly influenced by the fluctuation of the river level, especially on the meandering parts, some weirs and drainage of the agricultural land. There is no possibility for water supply in summer.
Hunze catchment: catchment area: 400 km2 . River/ brook ends in Lake Zuidlaardermeer (area:8 km2), soil consist of Sandy and peat soil. Soil is in use for farming and nature conservation; about 20 % nature; 80 % agriculture. Water management is mainly influenced by the fluctuation of the river level, especially on the meandering parts, some weirs and drainage of the agricultural land. There is some possibility for water supply in summer. A sewage-treating plant is also situated in the catchment, impacting the water quality (P, N and pesticides)

4. What is the expected impact of climate change on water management? (before project)
- Because of more heavy rainfall the runoff will increase with a negative effect on water quality and more flooded land.
- Due to phosphate saturation in the soil leaching of P can increase.
- Due to climate changes and decreasing good soil conditions pesticides leaching to surface water takes place and leaching of nutrients increases.

5. What are the main management questions at the start of the project?
- Because of intensive rainfall more flooding will occur and have an effect on water quality but we don't know the most vulnerable parts of the area;
- Which are the areas in the catchment that have the highest risk on leaching and run off of pesticides and nutrients
- Which meaures can be taken by farmers to diminish the negative effects of climate change on waterquality;
- Which measures must be part of "Best Management Practises" to diminish leaching and run off of nutrients and pesticides in the two catchments of the brooks Drentsche Aa and Hunze

6. Which knowledge has been missing to find the climate resilient solution (at the start of the TOPSOIL project)?
- Detailed modelling of the catchment area in which landuse, soil conditions, geohydrological properties ; water recharge and discharge are taken into account.
- Detailed modelling to calculate the impact of measures taken by farmers on water quality
- Which measures together with farmers in the area can be taken best to diminish the negative effects of climate change on water quality .

7. Steps taken to get to the missing knowledge

Technical field investigations:	A Travel time research is carried out in the brook Drentsche Aa. In this research time is calculated that is needed to travel from one point in the brook to the intake point for the Drinking water Company. On basis of the hydrological model SWAP we could make a new travelling time map.
Analysing data:	existing data were put in for building the models; Data on land use, manuring and intensive data on soil types are collected for the SWAT model
Using models:	A hydrological model and a quality model has been built to determine the high risk areas on leaching and run off of nutrients and pesticides for the catchments of the two brooks Drentsche Aa and Hunze. The Reality check with the stakeholders in both catchments
Measures taken:	no measures were taken but the model is used to calculate the impact of measures on waterquality. Determine the top 5 measures to be taken by farmers Run through the model three of the measure programs Run through the model a climate scenario that is most important for having effect on surface water quality in relation to agricultural management
Involvement of stakeholders:	reality check is carried out in two sessions with farmers to discuss the outcome of the model, for example. The high-risk maps and gaining input from them for choosing the most effectiveness measures.

8. Solutions found to solve the main management questions

A reality check with the farmers was held to discuss the outcome of the modelling.
These top 5 measures were composed using stakeholders' input:

1. Create Buffer zones
2. Increase organic matter
3. Use machines to make threshold/sill in ridge cultivation to diminish run off
4. Sow catch crops after harvesting
5. Employ warning systems for best timing for fertilizing and spraying.

Two scenarios were run through the model:

- Using permanent 5 m wide buffer zones, predicted a decrease of 25-30 % run off of pesticides.
- Using half the amount of pesticides resulted in half as much leaching and run off.

9. New water management and advantages

	Advantages	New Management Option
Agricultural:	Farmers know which areas are most vulnerable in the way that more risk on leaching/ run off of nutrients can take place. Awareness and behavioral changes by the stakeholders is an important result as well.	Farmers have more knowledge on most effectiveness measures to be taken in "Best management Practises". The area in which measures has to be taken will be more accurate, less farmers have to take measures which will be more effective.

	Advantages	New Management Option
Drinking water company:	The water quality will improve when measures are taken, the drinking water company will have less costs to purify the intake water When a calamity takes place in the catchment of the brook in the way that run off of a pesticide or other polluting substance to the brook has taken place, it is important to know how much time is left to take measures, before the pollution arrives at the intake point De Punt.	Travel time research will give them information on time is left to take measures considering the intake of water
Regional water authority Hunze en Aa's:	More knowledge on impact of agriculture on water quality for nutrients and pesticides Decisions can be made on the outcome of the project where to encourage farmers to take measures and where not. More knowledge about the impact of agriculture om achieving ecological and drinking water targets of the WFD Sustainable improvement of water quality in the catchment area of two brooks	More accurate/ effective use of money in stimulating farmers to take measures Outcome of the project gives input for the measures to be taken up in the new Water Management Plan 2022-2027.

10. Benefits transnational exchange Topsoil

- Exchange on growing Maize In a sustainable way: gives input for the measures to be taken in Denmark.
- Exchange on management on dairy farms that is organised in the Netherlands and exchanged with Germany: the ANCA tool
- Exchange on methods how to measure nitrate in subsoil as indicator for leaching nitrate to groundwater
- Local drinking water companies have involved in the exchange to learn about organisation of drinking water companies in Germany
- Exchange on which climate scenario to be used by calculating effect on water quality or water quantity.

11. Recommendations for future developments concerning climate change

Outcome of the project gives input for the measures to be taken up in the new Water Management Plan 2022-2027.

NL-2
Sustainable Dwarsdiep catchment

1. What is the Objective of the pilot?
The goal of the TOPSOIL project is to find a set of measures on parcel level which improves agriculture circumstances but meets the goals of the regional water authority for quantity and quality as well, now and in future. The strategy is to emphasize the mutual benefit and the relationship between parcel and catchment level.

2. Studied TOPSOIL Challenges
- Flooding
- Groundwater buffer
- Soil conditions

3. Context of current water management.
A lot of activities will take place in the Dwarsdiep catchment the coming years. The activities are in terms of creating water storage, creek restauration and creating nature. Additional to these measures the TOPSOIl project 'Sustainable Dwarsdiep Catchment' focuses on the farmer parcels on the flanks of the catchment. Surface water supply during dry periods is on the flanks not possible.

4. What is the expected impact of climate change on water management? (before project)
- The expectation is that this area will be more drought sensitive in future;
- Because of more heavy rainfall the runoff will increase with a negative effect on water quality and more flooded land.

5. What are the main management questions at the start of the project?
- Which measures of field scale level are potential in terms of hydrological effect and supported by farmers, to implement in order to improve the agricultural circumstances and meet the goals of the regional water authority as well?
- Till what extent we as a regional water authority can interfere on field scale level in order to implement the proposed measures?
- While this TOPSOIL ends within 3 years from the start, how do we reach that this information obtained from the TOPSOIL is used even after finishing this TOPSOIL project?

6. Which knowledge has been missing to find the climate resilient solution (at the start of the TOPSOIL project)?
- Soil characteristics of representative soil profiles (like organic matter content, texture, grain size etc.)
- Detailed models to calculate the impact of the proposed measures on field scale level
- A regional model to calculate the impact of the proposed measures on the regional water system.

7. Steps taken to get to the missing knowledge / solve the problem

Technical field investigations:	We collected field data on 5 parcels
Analysing data:	We examined the soil samples
Using models:	We developed a 1D model on field scale level using SWAP
Measures taken:	The implementation of the proposed measures is outside the scope of this project.
Involvement stakeholders:	We organised two plenary meetings with the main stakeholders (the farmer) in order to explain our project and to get feedback on the results. A third plenary meeting is planned.

8. Solutions found to solve the main management questions

- Our approach is to iteratively switch between modelling and stakeholders. That means involve stakeholders in an early stage of your project in order to create commitment and support for the proposed measures;
- Assume a mutual benefit approach (instead of an approach based on legal reguirements);
- Use a recent, hydrological period which farmers still 'recognize', in order to validate the calculation and to gain trust by farmers in the models used;
- Use an extreme, recent, hydrological period in order to explain the impact of climate changes. In our case it was the summer 2018. Farmers can visualize the impact of climate changes even better.
- Do not limit yourself to hydrological effects of measures, but take impact on their business management based on their feedback in order to create a supported set of measures.

9. New water management and advantages

The new knowledge on the area helps to foster a number of advantages in new management approaches:

	Advantages	New Management Option
Agricultural:	Better drought resistant and therefore less nutrients which normally might used to compensate the loss of harvest. Less use of chemicals in order to get rid of the weed. Better agricultural circumstances with a higher yield as a result of it	Use (or at least advice the use of) certain measures on field scale level like other type of grass;
Water frame directive	Less run of nutrients and therefore higher quality of water	

10. Benefits transnational exchange Topsoil

The benefit of participating in the TOPSOIL program are:

- We are aware that our approach involving our main stakeholders in an early stage of our project is valuable.
- Comparing with other pilots the challenges we have regarding water quality are not that big (yet). That means we are on time and that a mutual benefit approach is still possible.

NL-3
GeoTOP

1. What is the Objective of the pilot?
The objective is to gain experience using more detailed soli information and models to solve water problems on a regional and local scale.

2. Studied TOPSOIL Challenges
- Flooding
- Groundwater buffer
- Soil conditions

3. Context of current water management.
Pilot area consist out of a catchment area with sandy soils, locally shallow glacial till layers and very irregular meltwater till layers.
Soil is in use for farming and a big part of the area, including the river, has a N2000 status.
Water management is mainly influenced by the fluctuation of the river level, especially on the meandering parts, some weirs and drainage of the agricultural land. There is no possibility for water supply in summer.

4. What is the expected impact of climate change on water management? (before project)
- Water quantity in summer will decrease, because of less precipitation (13%) with lower groundwater tables as an effect.
- Water quantity will increase in autumn, winter and spring because of increasing precipitation (7, 17 and 9%) with a higher groundwater table as an effect.
- Because of more heavy rainfall the runoff will increase with a negative effect on water quality and more flooded land.

5. What are the main management questions at the start of the project?
- We know drought will become a problem and because of that we want to create a bigger groundwater buffer but we don't know which areas can be used for infiltration;
- Because of intensive rainfall more flooding will occur and have an effect on water quality but we don't know the most vulnerable parts of the area;
- More rainfall will lead to more necessary drainage in agricultural land but we don't know the effect on the N2000 area.

6. Which knowledge has been missing to find the climate resilient solution (at the start of the TOPSOIL project)?
Detailed knowledge of the spreading of the glacial till and the melt water till.
Detailed modelling to calculate the impact of drainage on the N2000 area including the effect of climate change.

7. Steps taken to get to the missing knowledge / solve the problem

Technical field investigations:	Direct push Geophysical mapping with the airborne transient electromagnetic method SkyTEM
Analysing data:	Data has been analysed by the Aarhus University and transferred into a geological model by TNO-RGD
Using models:	To calculate the effect of climate change and the impact of drainage the groundwater model SIMGRO is used
Measures taken:	No measures have been taken.

8. Solutions found to solve the main management questions

- By using the more detailed soil map we could make a map of the resistance between the topsoil and the deeper groundwater. This gives knowledge on the possibilities of infiltrating more groundwater for storage in future.
- We also gained more knowledge on the impact of heavy rainfall at the water quality related to the high resistance just below the surface. Measures can be defined more accurate in future.
- Using the available soil data within the groundwater model SIMGRO we could make a map from the area just around the N2000 area were drainage is still possible under certain conditions without influencing the N2000 goals.

9. New water management and advantages

The new knowledge on the area helps to foster a number of advantages in new management approaches:

	Advantages	New Management Option
Agricultural:	Farmers know under which condition they can drain their soil without having an impact on Nature.	Farmers can now minimize better their impact on nature and still be able to drain the soil. The zone with extra regulations on drainage will get smaller and thus have less impact on farmers.
Nature:	No significant effect of drainage on N2000 goals	One of the measures in future will be to lay the drainage on a higher level which will even lead to a higher groundwater table within the N200 area.
Water abstraction:	Knowledge on where extra water infiltration in future can take place	
Spatial planning:	Because of more accurate knowledge on the subsoil zones with extra attention for runoff and infiltration can be used to improve policy on water management	

10. Benefits transnational exchange Topsoil

We found a new method to describe the subsoil with SkyTem and analysing the data by the Aarhus University. The result was a more detailed soil map especially on spreading of the meltwater till.

UK-1

Surface and groundwater connectivity and implication for water resource protection and management

1. What is the Objective of the pilot?

The project has two objectives:

- Technical objective. Explore the connectivity of surface water and groundwater to improve understanding of groundwater and surface water interactions in the Wear catchment.
- Engagement objective. Communicate our understanding of groundwater and surface water interactions and the implications of these for catchment management to stakeholders (including the general public) and catchment partners.

2. Studied TOPSOIL Challenges

- Soil conditions
- Capacity to breakdown

3. Context of current water management

UK-1 has primarily focused on the Wear Magnesian Limestone (WML) aquifer, used for drinking water abstraction, which is potentially at threat from surface activities as a result of surface water and land interaction with groundwater.

Large areas of the WML are interpreted to be covered with a relatively thin drift, which gives rise to a potential risk to the underlying WML aquifer from both urban and rural sources of contamination. Previously this drift was considered to provide a barrier between surface water and groundwater. However, recent work by the Environment Agency (EA) has challenged this understanding. Coastal valleys containing small streams (denes) are incised into the fractured bedrock offering potential pollutant pathways between surface and ground waters. Thus, polluted surface waters pose a risk to groundwater especially in catchments where surface water can enter the groundwater through fractures and faults in the stream beds. EA groundwater connectivity maps highlight potential zones of groundwater/surface water interactions

The potential for surface water to enter groundwater is exacerbated because the groundwater has been disconnected from the surface water due to de-watering operations from the coal workings which lie below the Wear Magnesian Limestone in the Wear Carboniferous Limestone and Coal Measures ground water body.. These hydrogeological conditions present new challenges to water and environmental management within the catchment.

4. What is the expected impact of climate change on water management?

More frequent, extended rainfall events and periods of drought are expected to impact on surface, land and water environments and infrastructure, with the potential impact on surface-groundwater connectivity and quality, subject to many natural and mining-related local variables.

Generally, climate change expected impacts include:

- Increases in surface water (pluvial) flooding as a result of higher flows in rivers;
- Groundwater flooding in Coal Measures areas;
- Increased river channel erosion due to higher flow velocities during more frequent and extreme storm flows;
- Reduced surface water quality due to: reduced dilution in summer, increased erosion, and higher storm flows contributing pollutants directly to surface waters;
- Reduced groundwater quality due to direct leaching of pollutants and/or interactions between surface and groundwater flows in areas of high connectivity.
- Changes to the established regional hydrogeology. Aquifer recharge may reduce, but continuity of water supply is not perceived to be an issue even under worst case scenarios to 2060.

5. What were the main management questions at the start of the project?

- Data. Which study areas would most assist to improve understanding of the processes, mechanisms and pathways for groundwater and surface water interactions?
- Inter-organisational working: How to improve inter-organisational visibility and more effective ways of working to improve surface and groundwater quality in the Wear catchment?
- Soil and Water Management. How best to work with farmers to influence soil management practices and protect groundwater and surface water quality?
- Topsoil Learning. How can knowledge and learning from the project be used to encourage and inform urban and rural land managers to actively protect groundwater as well as surface waters?

6. Which knowledge has been missing to find the climate resilient solution (at the start of the TOPSOIL project)?

Technical

- Understanding of highly variable sub surface geology and the movement of water from, to, and under the surface, in respect of the following:
  - Mechanisms of connectivity between surface water and groundwater;
  - Understanding of specific sources of rising nitrates in groundwater abstractions;
  - Interchange of in-channel surface-ground waters and pollutants within the hyporheic zone.
  - Role of small-scale interactions between pollution threats and fluxes between surface and ground waters.
- Limited visibility of groundwater quality from available Northumbrian Water (NW) and EA borehole data.

Stakeholder

- Appreciation by stakeholders of different regulatory authorities' responsibilities, alignments and constraints.
- Appreciation by stakeholders of Local Authority strategic spatial planning processes influencing land and water management.
- Appropriate means by which to engage with the farming community to share understanding and influence management practices effectively.
- Visibility of existing data held by partners and wider networks.
- Practical appreciation (in particular by the farming community) of the management of surface and groundwater Nitrate Vulnerable Zones (NVZs)
- Limited awareness of strategic decision makers and management practitioners of the interconnectivity of land, surface and ground water management.

7. Steps taken to get to the missing knowledge / solve the problem

7a. Technical

Investigations collected new data through the case studies listed below to explore the connectivity of surface water and groundwater to improve our understanding of groundwater and surface water interactions in the Wear catchment.

7a.1. Hawthorn Dene, Magnesian Limestone: Led by WRT with technical support from the EA

Investigation:

Hawthorn Dene is a surface water body which has the potential to enter groundwater through fractures in the stream bed during low flow conditions resulting from dry climatic periods. The surface water fails to meet WFD good chemical status due to waste water and agricultural phosphates. The Hawthorn Drinking Water abstraction borehole, which had been undergoing refurbishment is within the catchment.

Results and analysis:
The study confirmed that the Hawthorn Burn is ephemeral, identifying that flow does not re-emerge as was thought. Improved holistic understanding in SW/GW connectivity and confidence in both sources and current/future impacts of nutrients. No connectivity with poor quality surface waters was established when the borehole returned to service following refurbishment.
Modelling approaches:
The new data collected helped validate and improve the current conceptual understanding of surface to ground pathways and be used proactively to influence the adoption of best farming practice regarding nutrient management and mitigation of diffuse pollution.
Measures taken and planned:
The study has provided additional water quality data available for use and helped the EA identify the future representative monitoring points for this ephemeral catchment. Joint working with the EA as regulator will help maximize multiple benefits in undertaking their statutory role in investigating the Hawthorn Dene phosphate failure. A storymap is in place for this catchment.

7a.2. Cut Throat Dene, Magnesian Limestone: Led by NW in collaboration with WRT and EA
Technical field investigations:
Poor quality surface water is discharged into the stream network at Cut Throat Dene in close proximity to the Fulwell drinking water abstraction borehole. Surface water was believed to enter groundwater in this catchment via a major fault. The case study gathered data to understand the impact of surface water pollution sources on groundwater and allow evaluation of the risk to the abstraction.
Results and analysis:
The study confirmed poor surface water quality sources, and loss to subsurface from the surface water channel through a major fracture zone. No current impact has been found on the Fulwell borehole to date. but wider catchment connectivity testing will continue.
Modelling approaches:
Validating and improving the conceptual understanding of complex and variable surface to ground pathways at the specific catchment, with potential application on a regional scale in association with fractures within the Magnesian Limestone.
Measures taken and planned:
Connectivity between a nearby quarry and the borehole via the same fracture present within Cut Throat Dene will be investigated through tracer testing to confirm lack of viable pathway from the fracture to the Fulwell borehole. Further flow monitoring by Sunderland City Council is underway. A storymap is in place for this catchment. SCC completed the flow monitoring, concluding that the planned housing development in the lower catchment was at low risk of flooding. Discussions are ongoing with SCC to identify pollution sources in the upper catchment through additional water quality monitoring. A towTem geophysical assessment was completed in late October 2021 by Danish Topsoil partners. Results awaited.

7a.3. Stonygate Abstraction, Magnesian Limestone: Led by NW in collaboration with WRT and Durham University
Technical field investigations:
Nitrate levels at Stonygate abstraction borehole exceed the relevant regulatory environmental assessment levels, with the nitrate level in the groundwater increasing quickly after major rainstorm events and remaining at the new elevated level. Possible nitrate sources were investigated.
Results and analysis:
Research by NW and Durham University confirmed that the poor water quality in the Herrington Burn was not a contributory factor. NW ruled out the nearby Biffa landfill at Houghton Le Spring as the source of nitrate. NW also undertook catchment investigations into possible agricultural sources, which also proved to be negative. Studies undertaken as part of NW's WFD catchment investigations have ruled out leaking sewers and the nearby Herrington and Lumley Park Burns as potential sources. Current data suggest the nitrate concentrations in the borehole are depth specific, with the highest concentrations occurring near the rest water table. Stratigraphic chemical sampling of the Stonygate borehole found significant levels of nitrate ~70 metres below ordnance datum (mbod). This depth potentially marks inflow to the borehole from a major fracture which could be used to trace the

pollutant source. Subsequent investigations by NW have confirmed this is the most likely pollutant pathway.

Modelling approaches:

It is possible that a fracture flow connection between surface and the borehole provides a pathway for nitrate-rich groundwater (possibly from historic landfill sites in the area). This potential pathway is currently under investigation through refinement of the current conceptual understanding of the local Stonygate system (source > pathway > receptor).

Measures taken and planned:

Field investigations and tracer test and T-Tem investigations via Topsoil 2 to confirm current conceptual understanding of the source>pathway>receptor model are under discussion. A storymap is in place for this catchment. Given that other pollution sources and pathways have been discounted, it is believed that a nearby septic tank run off is potentially hydraulically connected to the abstraction through fissures in the Magnesian Limestone. A towTem geophysical assessment was completed in late October 2021 by DK Topsoil partners. Preliminary results exhibited positive correlation of the presence of a fracture within the expected field. Aarhus University to feed back after post analysis.

7a.4. Twizell Burn, Coal Measures: Technical lead: Durham University with support/data from WRT, EA and NW.

Technical field investigations:

The Twizell Burn is a heavily modified stream with multiple threats to surface water quality. Recovered mine water/ groundwater levels, following the cessation of mine water pumping are believed to provide base flow in the upper reaches of the stream. The interactions of surface waters and groundwater are not well understood. NW water quality investigations throughout the project provided contextual information to support the case study combined with bespoke data collection within the project.

Results and analysis:

The Integrated River Evaluation and Management (IREM) study gave an insight into the system dynamics of the Twizell Burn, demonstrating the importance of understanding groundwater – surface water connectivity. Sampling demonstrated that historic and contemporary threats impact stream-water quality. The Secondary A aquifer (Coal Measures) in the vicinity of the Twizell Burn acts as both a source and sink of flow and solutes into and out of the Burn. The streambed interactions are complex and could not be characterised solely on the rate of flow across the streambed, or the locations of up / down welling across the streambed.

Modelling approaches:

Research into shallow groundwater / surface water interactions in the Twizell Burn is being modelled in MODFLOW (v3.10) using the ModelMuse graphic user interface software. The groundwater model seeks to simulate fluxes of chemicals within the stream bed at various flow conditions.

Measures taken and planned:

Assessing both the spatial and temporal variations and likely drivers and controls, both above and below the streambed is crucial to develop an integrated understanding of the system on which to base management interventions. A storymap is in place for this catchment.

7b. Involvement of stakeholders

Utilise information from the technical case studies to communicate our improving understanding of groundwater and surface water interactions, and the implication of these for improving integrated land and water management. Specific activities include:

- Engagement with the Wear Catchment Partnership (WCP) steering group and the wider network of catchment partners (through the Catchment Based Approach) to inform practical planning and delivery of integrated land and water management opportunities within the Wear Catchment Business Plan. Specific engagement activities include:
    - Influencing Local Authority drainage/flood risk planning, including climate change resilience.
    - Influencing NW's prioritization, planning and delivery of environmental projects.
    - Supporting Partner organizations who have a policy and regulatory remit, to consider both groundwater and surface water issues in urban (e.g. Sustainable Drainage Schemes) and rural (e.g. mitigation of agricultural pollutants) catchments.

- Informing catchment partners' project planning and development to include consideration of groundwater, where appropriate.

- Utilising Agent Based Modelling to understand and inform Wear Catchment Partnership relationships and understand how stakeholders interact to share catchment understanding.
- Use of a demonstration site at Seaham Grange Farm to trial mitigation options for managing diffuse nitrate pollution from agriculture, and to run farmer engagement events.
- Creating and maintaining on-line interactive multi-media storymaps of key catchments investigations and topics.
- The Wear Catchment Partnership has evolved a Catchment Action plan, currently consisting of 17 individual projects with each project having a nominated catchment partner as project lead, coordinating the activities of participating partners. This process facilitates the practical sharing of all available information to ensure all potential multiple water management benefits are achieved. A 6 year partnership project has been established in the Twizell catchment to develop an replicable engagement process to enable the local community to design and manage SuDS installations. The Seaham Grange demonstration site is no longer active due to the owner's ill health. However, 3 other demonstration farms are now active:
  - Durham Fields
  - Houghall Agricultural College
  - High Sharpley

8. Solutions found to solve the main management questions

Data: EA groundwater connectivity maps. highlight potential zones of groundwater/surface water interactions A series of case studies investigated specific examples of possible surface-ground-surface pollution pathways.

6. Inter-organisational working. Use of agent-based modelling provides insights in the interactions between organisations and individuals. An agricultural case study presented at the Autumn 2018 conference highlighted governance challenges faced by regulators and stakeholders, which has acted as a springboard for action, e.g. regional joint roll-out of Farming Rules for Water. The Wear catchment business plan aims to improve visibility of regulatory issues to maximise environmental and financial multiple benefits.
7. Soil and Water Management: Regional partner engagement requiring farming businesses to apply Farming Rules for Water, specifically including groundwater protection. There have been a series of events aimed at farmers and supporting professionals. Farmer networks promote reduced tillage and innovative soil management approaches to deliver farm business, water management and wider environmental benefits.
8. Topsoil learning: Utilise Wear Catchment Partnership (WCP) relationships established since 2012, to cascade outputs from case studies and investigations to inform urban and rural decision making influencing more effective surface and groundwater management.

9. New water management and advantages

	Advantages	New Management Option
Agricultural:	Positive engagement with farmers (ideally supported by an effective regulator) provides opportunities to discuss potential farm business and wider environmental benefits on a win-win basis. The EA as regulator is becoming more active with the enforcement of Farming rules for Water.	Roll out of legal duties to protect water resources provides a basis, to be continued under Topsoil 2 to discuss and influence technical aspects of soil management. Opens opportunities for discussions on agricultural carbon emissions/sequestration. Projects previously centred on identifying and mitigating pollution sources and pathways from farm infrastructure now expressly include discussions on how soil management influences water infiltration and retention and carbon storage.
Wildlife and biodiversity:	Multiple benefits can be achieved through mitigation of urban and rural pollution sources, interrupting pollution pathways to surface and groundwater	Visibility and engagement with partners' strategic planning and management priorities through the WCP. Creation of a Wear Catchment Action Plan.
Risks to water abstraction:	Some certainty has been achieved where suspected surface ground connectivity through fracture flow has not been demonstrated at 2 drinking water abstraction boreholes. Although risk of connectivity now has a higher profile with decision-makers.	The potential vulnerability of groundwater contamination from surface water sources, has been highlighted, as has the complex geology which may provide or prohibit a pollution pathway to a receptor. Clear, professional advice on groundwater issues is essential in the development of future strategic plans. The tTEM surveys October 2021 will provide additional information and means of engagement.
Spatial planning:	Topsoil has raised the profile of critical and integrated roles of water governance, regulatory responsibility and spatial planning, amongst catchment partners, influencing Local Authority spatial and drainage/flood risk planning, including climate change resilience.	The WCP will work to improve visibility of regulatory and planning issues and opportunities, which will be documented in the Wear Catchment Business Plan 2017-30. . Ground-surface water interactions should be considered in planning decisions and policy. Creation of a Wear Catchment Action Plan

10. Benefits transnational exchange Topsoil

Many Topsoil partner projects have focussed on the relationships and connectivity between agricultural land management and water resource protection. The balance of agricultural practices, soil types and underlying geology and wider environmental pressures (e.g. groundwater competition for drinking water supply, irrigation, increasing salination and the maintenance of water dependent habitats) may be different in Germany, Belgium Holland and Denmark to those found in UK-1. There was however much learning available around the headline overall challenges of, for example, soil management techniques, nutrient management, cropping, residual nitrate leachates and potential mitigation measures.

Insights derived from the DK towTem surveys will provide inform management planning at:

- Stoneygate abstraction
- Fulwell abstraction
- Houghall Agricultural College Farm

Insights and imagery from the surveys will be used to further improve awareness of the function of groundwater-surface water interaction.

11. Recommendations for future developments concerning climate change

Water Framework Directive: More joined up focus by both regulators and stakeholders on dependencies between surface and groundwater bodies and the land adjacent to/overlying water resources. Pollution risks and Reasons for Not Achieving good status under WFD can be more holistically assessed and more effectively included in the third cycle River Basin Management Plan

Flood Directive: Improved soil health will absorb more moisture, improving resilience to both drought and flooding. Greater catchment roughness is an important element of Natural Flood Management. Positive farmer engagement will open the way for the construction of Natural Flood Management infrastructure. There will be continued strategic engagement through Local Authority Strategic Flood Risk Groups.

UK-2
East Anglia

1. What is the Objective of the pilot?
The objective is to improve the management of soil and water in the pilot region to increase the resilience of the ecosystem to climate change for the benefit of both people and the environment. A key component of this is developing a shared understanding of soil and groundwater interactions with the wider ecosystem at a catchment scale.

2. Studied TOPSOIL Challenges.
- Groundwater buffer
- Soil conditions

3. Context of current water management
The pilot area of East Anglia comprises highly productive agricultural land, rich in water dependent biodiversity (including internationally rare chalkstreams). The area is mainly low-lying with some major aquifers supporting river flows and abstraction for both industry (mainly irrigation agriculture) and public water supply. Water resources are already under significant pressure, the area is one of the driest in England and many abstractors are facing volume reductions to current licences and environmental impacts are increasingly apparent. Population growth and climate change will only exacerbate these problems further. At the start of the project a key feature of water management was a lack of integrated planning between water users/sectors, particularly with regard to the interactions of ground and surface water and the surrounding catchment.

4. What is the expected impact of climate change on water management? (before project)
- Based on climate change predictions it is anticipated that overall summer precipitation will decrease increasing the 'competition' for available water resources, impacting on the environment and access to water for agriculture and public supply
- Overall winter precipitation is likely to increase, but to potentially fall in a shorter 'season', with more frequent episodic heavy rain fall events. Giving rise to a number of issues;
  - If soils are not in suitable condition to receive and allow infiltration or winter rain this could reduce aquifer recharge and limit resource availability the following summer
  - Run-off from fields carrying soil and pollutants to nearby water courses – impacting on surface water quality and losing valuable soil and nutrients that sustain the regions agriculture.
  - Increased surface water flooding of land and properties

5. What are the main management questions at the start of the project?
- Can we increase stakeholder knowledge on water resources management - especially groundwater to create a greater shared understanding of the management challenge(s) and develop sustainable management solutions.
- Can we demonstrate ways to increase water retention/availability and ground water re-charge.
- Can we integrate traditional water resources management as part of a broader more integrated multi-sector approach to water management at the catchment scale.

6. Which knowledge has been missing to find the climate resilient solution (at the start of the TOPSOIL project)?
- Shared understanding of water resources management and how a more integrated multi-sector approach can be developed to deliver multi-objective outcomes
- Management measures to improve soil health and resilience

7. Steps taken to get to the missing knowledge / solve the problem

Technical field investigations:	Managed Aquifer Recharge trial, Soil and water run-off trials, soil m
Analysing data:	Data has been analysed by the Aarhus University and transferred into a geological model by TNO-RGD
Using models:	Existing data models have been used.
Measures taken:	Farm advice and interventions to improve soil structure, reduce water and soil loss, Improving data availability and accessibility,
Involvement stakeholders:	Key stakeholders involved include representatives from water utilities, farmers, NGO's, regulators and catchment partnerships.

8. Solutions found to solve the main management questions

- Importance of making data available and accessible in a format that all stakeholders can understand.
- Benefits of an independent organisation/facilitator to broker discussion between stakeholders with perceived conflicts
  - Knowledge on novel equipment
  - Working thorugh the process of rcharge scheme
  - Increased traction in the catchment approach – now being used for abstraction reform etc.
  - We also gained more knowledge on the impact of heavy rainfall at the water quality related to the high resistance just below the surface. Measures can be defined more accurate in future.
  - Using the available soil data within the groundwater model SIMGRO we could make a map from the area just around the N2000 area were drainage is still possible under cetain conditions without influencing the N2000 goals.

9. New water management and advantages

The new knowledge on the area helps to foster a number of advantages in new management approaches:

	Advantages	New Management Option
Agricultural:	Building knowledge capital and trust between sectors enables more effective water resources planning for farmers and new ways to access water and avoid crop loss/damage.	Farmers can demonstrate their farming operations are minimizing their impact on nature and public water supplies. In return for being a good "water steward" they may be able to receive additional benefits such as access to water.
Nature:	Reduced negative impacts on river flows and the wider water dependent environment as a result of water scarcity and drought	Additional data and knowledge will help to target restoration activities that increase resilience and improve the management decision framework to ensure environmental protection.
Drinking water abstraction:	Increased reliability of groundwater resources in terms of both quantity and quality.	Building knowledge capital and trust between different sector (especially agriculture) enables the identification of novel solutions that deliver multiple objectives and secure resilient water supplies.

10. Benefits transnational exchange Topsoil

Understanding different governance approaches to groundwater management in the NSR has been extremely useful for us to explore alternative approaches in the UK. Knowledge exchange with other pilots working on practical measures to reduce nitrogen leaching to groundwater and developing suitable incentive mechanisms to adopt alternative management practices have also been very Beneficial. In addition, the use of smart data collection techniques to describe the subsoil e.g. SkyTem and T-Tem has been very inspiring.

11. Recommendations for future developments concerning climate change

Further work is required to develop a multi-sector approach to managing groundwater resources as part of an integrated approach to water management. This includes improving the understanding of groundwater resources and developing new tools and processes (including regulations) to enable more effective planning to increase supply resilience to climate change. Groundwater is also the source of potable water with the lowest carbon footprint so it is important from a climate change mitigation perspective to ensure that supplies are resilient.

Final Report