Knowledge for Climate

Midterm Review Report

Hotspot Shallow waters and peat meadow areas

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Contents

Pre-amble

This report presents a summary of the results of the first half of the activities carried out in the hotspot Shallow Waters and Peat Meadow Areas (Hotspot Ondiepe wateren en Veenweidegebieden, HSOV) of the national research program Knowledge for Climate. More specifically, a short overview will be given of the activities by research consortia in the first and third tranches of the program, which have been initiated and coordinated directly from the hotspot. Some attention will also be paid to the research in progress in Theme 2 (Fresh water supply) and Theme 8 (Decision support tools) in tranche 2, which are coordinated by the respective theme consortia. This report will start with an introduction of peat meadows and shallow lakes in the Netherlands and a sketch of the general policy context regarding climate change effects in these areas, with special attention to bottlenecks and opportunities for adaptation and mitigation. The final goal of the activities in the hotspot is the compilation of the ORAS manual (Options for Regional Adaptation Strategies), which will present all important information in a user-friendly, accessible way. This manual can then serve as a background document facilitating the decision making progress in climate adaptation. A road map towards this ORAS document is given in this report.

1. Introduction

Peat meadows are drained peatlands that are in use for agriculture. Peat meadow areas in the Netherlands have mostly originated from drainage and reclamation of bogs and fens in the coastal plain in the 12th – 15th century. These 'polders' (diked areas with a manipulated water level) have been in agricultural use for centuries. Right from the start, these areas have been subject to peat shrinkage and soil subsidence. The rate of subsidence has risen strongly in the past 50 years as a result of deeper drainage and intensive agricultural use and has increasingly been accompanied by deterioration of water quality. There is concern that climate change will further aggravate the problems in these areas and necessitates adaptations of land use and water management. In the hotspot 'Shallow waters and Peat Meadow Areas' of the Knowledge for Climate program (KfC), these issues are being studied and discussed with stakeholders at the local and regional scale.

There are two regions with substantial areas of peat meadows in the Netherlands, i.e. the western peat meadow area and the northern peat meadow area (Fig.1). The western area encompasses parts of the provinces of Noord- and Zuid-Holland and Utrecht, whereas the northern part is located in the provinces of Friesland, Overijssel and Drenthe. The largest area in the western region is characterized by its location within a ring of urbanized and densely populated areas (the 'Randstad') and is often called the 'Green Heart'. The peat meadow areas are in use for intensive dairy production, but at the same time are visited by large numbers of people from the surrounding cities for recreation and leisure. The northern area has more of a rural character with agriculture as a central function.

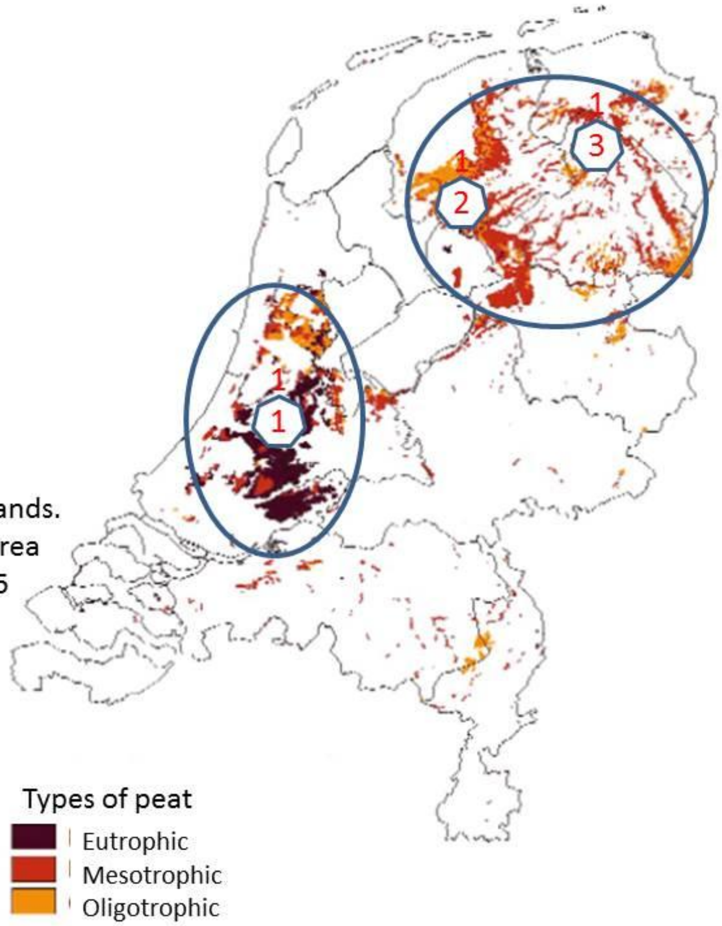

Fig.1. Peat soils in The Netherlands. Northern area (left), western area (right). Rienks & Gerritsen 2005
1: Zegveld; 2: Tjeukemeer;
3: Bovensmilde

Shallow lakes and wetlands are prominent in both regions and play an important role for water recreation and nature conservation.

The water management in the peat meadow areas is complex and primarily geared towards the current agricultural use. To maximize agricultural production, water tables are kept low (0.6 – 1 m below ground level) by collecting drainage water in ditches and reservoirs eventually pumping it out of the polders. Current agricultural practice requires relatively dry field conditions in early spring to enable access by heavy machinery and pasturing of dairy cattle. Land use planning programs in the 1960s-1990s have aimed at maximizing agricultural production by reallotments and by deeper and more effective drainage. The soil subsidence as a result of the oxidation of peat after exposure to oxygen has been accelerated substantially in this period. This process has also led to enhanced Greenhouse Gas (GHG) emissions and eutrophication of the surface water. The expectations are that climate change will further increase the rates of these processes and lead to a non-sustainable situation bringing about high costs for land and water management.

The height of the water table in polders is fixed by the water authorities based on the requirements of agriculture, nature conservation or housing. Individual landowners often install small-scale pumps for additional water level control. This implies that there are various water level sections ('peilvakken') within one polder. Decisions on the height of the water tables are made every 10-15 years, to adapt to subsidence of the ground level and to new insights in optimal land use. In the western peat meadow region, current water tables are mostly around 60 cm below ground level, whereas in the northern peat meadows (Friesland) water tables down to 100-120 cm below ground level are common. This reflects a greater emphasis on agricultural targets and smaller interest of nature conservation values in the latter region. As a result of the actions of private land owners (farmers), the lowest parcels in the landscape are the ones with the most intensive agricultural use.

The maintenance of fixed water tables all year round leads to an output of surface water through pumping in winter and in wet periods in summer, as well as an input of surface water from the rivers (Rhine, IJssel) during dry summer periods. The river water flows into the polders through inlets in the reservoirs ('boezems'). As a result of climate change, the occurrence of more severe droughts in summer is expected to become more frequent, leading to an increase in the demand for fresh water from outside. Apart from soil subsidence and water quality deterioration, the availability of fresh water in dry summers is another point of great concern in discussions on the future management of these areas.

2. Existing policies and adaptation strategies

The national Dutch planning policy for peat meadow areas is reflected in the policy documents "Nota Ruimte" (VROM, 2004) and the "Programma voor de westelijke veenweidegebieden"(VROM, 2004). The Nota Ruimte calls for conservation of the peat soil and the peat meadow landscape. Vulnerability for soil subsidence is given as the main criterium for regional development. Grassland-based dairy production is an important economic function which is required to conserve the typical peat meadow landscape. However, farmers must respect the ecological and cultural-historic value of this region. Areas with rapid soil subsidence or saltwater intrusion should be considered for a new water management with higher water tables. The Agenda for the western peat meadow areas proposed to make water management schemes leading for land use decisions ('function follows water table'), implying that land uses have to be adapted to the water tables arising from a water management scheme that is most sustainable. This is in contrast to current practice, where water management is always adapted to the needs of farmers, nature conservation and settlements. This new policy is still in the discussion and planning phase; it is definitely controversial in some parts of the region. As indicated earlier, the problems identified for these regions (soil subsidence, but also drought, flooding, eutrophication and salinization) are not caused by climate change but they are certainly accelerated and aggravated by it. So far, the climate effects have not been made explicit in the regional or national policies regarding peat meadows. Hence, there are no explicit climate adaptation strategies for these regions yet. Development of options for adaptation strategies is the main objective of the Knowledge for Climate hotspot HSOV.

3. Research approach adopted by the Hotspot

The hotspot consists of the researchers from knowledge institutions carrying out the various studies and representatives of stakeholder organizations. The hotspot is coordinated by prof. Jos Verhoeven of Utrecht University (UU) and further consists of researchers of Wageningen University and Research (WUR), Institute for Environmental Studies of the Free University Amsterdam (IVM-VU) and Kiwa Water Cycle Research (KWR). Stakeholder organizations represented in the hotspot are provinces of Utrecht and Friesland, the water boards Hoogheemraadschap De Stichtse Rijnlanden, Waterschap Noorderzijlvest and Wetterskip Fryslan, and STOWA (Foundation for Applied Water Research). These organizations are cofinancing the research in the hotspot. Other stakeholders have been active as well in following the results of the research and participating in the stakeholder workshops (Provinces of Zuid-Holland, Drenthe, Noord-Holland, LTO Noord (organization of agriculture and horticulture) and other farmer's organizations).

A primary objective in the hotspot Shallow waters and peat meadow areas has been to build a good collaboration between knowledge institutions and stakeholders. We initiated our activities with a number of broad workshops to identify the most stakeholders in the peat meadow and shallow lakes regions and to articulate their questions into focused, major research activities. These workshops were very well attended and created an atmosphere of intensive interaction between scientists and practitioners from regional and local governments, water authorities and consultants. The questions from practice were leading the agenda and several rounds of discussions resulted in the compilation of a set of three linked research proposals for Tranche 1 of the KfC program (see Annex 1).

Tranche 1: 2008-2013

The project HSOV1A *Climate effects on decomposition in drained peat meadows: implications for peat subsidence and water quality* encompassed a thorough study of the relation between water table management and peat oxidation with repercussions for the rate of peat subsidence and water quality. This Ph.D. student project is still ongoing at Utrecht University.

The second project in the first tranche HSOV1B *Climate influence on water quality: which trends are already apparent?* has assessed the effects of climate change on water quality in shallow lakes. The project has been carried out by Wageningen University and KWR Water cycle Research.

The third project HSOV1C *Managing climate effects in peat meadows and shallow lakes* has investigated stakeholder interests and has used innovative decision making facilitating tools to explore regional and local knowledge in various scenario analyses with different management options. This project was carried out by the Institute of Environmental Studies of the VU University Amsterdam.

The four knowledge institutions (UU, WUR, KWR and IVM-VU formed a consortium to carry out the work in the first tranche. The co-financing by stakeholders amounted to 70% of the total project costs (€ 956.000).

Tranche 2: 2010-2014

The second tranche of the KfC program has been organized around 8 broad research themes[1]. These themes have mostly a research focus and are managed independently of the hotspots, by the respective theme consortia. Work packages relevant to the hotspot HSOV are present in Theme 2 (Freshwater supply) and in Theme 8 (Decision Support tools).

Theme 2's Work Package 3, 'Adaptation to limited freshwater supply' has a case study focusing mainly on effects of salinity on peat meadows. This is WP3.3 'Predicting effects of changing salinity on natural systems to the land side of the Dutch coastal plain''. This study focuses mainly on the (semi-)natural terrestrial ecosystems in the peat meadow areas and generates information that is complementary to the studies carried out in the Tranche 1 and 3 projects in the hotspot.

Theme 8's WP3, 'Interactive development of spatial adaptation strategies' is developing novel techniques for stakeholder interaction and negotiation. The methodologies developed are being tested and used in the stakeholder workshops in the hotspot (Eikelboom et al. 2010; 2011a,b)

Tranche 3, 2012-2013

For Tranche 3, two project proposals have been submitted on March 31, 2012 (see Annex 2). Both proposals have been approved by the Programming Council and KfC Board after peer review. The two projects will start on 1 September 2012 and run for one year.

Project HSOV3.1 *Manual for Options for Regional Adaptation Strategies in peat meadow areas including shallow waters* encompasses the compilation of a manual with Options for Regional Adaptation Strategies (ORAS), on the basis of all results of the research in the hotspot.

Project HSOV3.2 *Designing regional adaptation strategies in the Frisian peat meadow areas: evaluating the effectiveness of management options to maintain or transform this landscape under different scenarios of change* will be carried out in close association with a task force of the Province and Water Board of Friesland to develop a long-term policy vision for the peat meadow areas in that province. It will bring in all existing information and new knowledge generated in the KfC program. This project will enable the hotspot to work out all previous activities towards the final goal of creating Options for Regional Adaptation Strategies (HSOV3.1), which will be developed and evaluated in close collaboration with authorities and stakeholders. The consortium is almost similar to that in Tranche 1 (UU, WUR and IVM-VU). The stakeholders (Province and Water Board Friesland) provide 50% cofinancing of the total project costs of €240.000.

The projects in Tranche 1 and 3 are carried out in close collaboration with the stakeholders. The workshops are very important for communicating results and exploring their relevance in scenario analysis and development of management options. Regular hotspot meetings further ensure the necessary contact and interaction.

[1] More information: www.knowledgeforclimate.nl

Cooperation with other hotspots and theme consortia

There is cooperation with the hotspot Haaglanden, where a peat meadow project has been carried out in the Midden-Delfland region (HSHL02, 2012). Further, there is contact and exchange of information with activities in the second tranche consortia of themes 2 and 8 (see above).
Internationally, there are contacts with the EU-FP7 projects EUROLIMPACS and REFRESH. UU and WUR are partners in these two programs.

4. Stakeholder workshops

The hotspot has focused initially on three regions in The Netherlands, i.e. the western peat meadows, with the polders around Zegveld, Zuid-Holland as major working area, and the northern peat meadows, with the polders near Tjeukemeer (Friesland) and the crop fields on peat near Boven-Smilde (Drenthe) as working areas (Fig. 1). In each of the three working areas, workshops have been organized for exchange of knowledge and opinions among stakeholders, authorities and scientists. These workshops are of fundamental importance for the process of policy development and planning of adaptation and mitigation activities. The workshops are technically supervised by IVM-VU, where social scientists and economists have developed methodologies to present and evaluate information in a spatially explicit way by the use of 'touch-table' technology; a large computer screen on a table which enables interactive planning and learning by workshop participants. The touch table can display a whole range of different spatial characteristics on maps in a GIS. The system is also underlain by spatial models that relate environmental characteristics such as water table and fertilizer use to costs and benefits, such as profits for farmers.
The social-political context in the areas under investigation is that important socio-economic functions, i.e. agriculture and the maintenance of a safe and healthy environment, are threatened on the long term because of the deep drainage and the impacts of climate change. Another important issue is that the continuation of the deeper and deeper drainage in the subsiding polders will require costly measures to facilitate water level management. Choices that have to be made are to reduce the degree of drainage while at the same time conserving the socio-economic functions in the area. A range of different technical measures are available to slow down soil subsidence and enhance water quality. These will have to be evaluated in terms of cost effectiveness. The activities in the hotspot will support future decisions by providing tailored knowledge for various subregions and individual polders.
The workshops intend to (1) identify scenarios of future change, taking into account climate change and economic development; (2) identify bottlenecks in land and water management; (3) evaluate the effectiveness of packages of measures (the management options) to improve or mitigate the situation. Ideally, a sequence of different types of workshops is organized; first, an 'internal' workshop for evaluating information, scenarios and possible measures among scientists and regional authorities;

Fig. 2. Soil profile of peat meadow in Friesland. The top 80 cm are well-drained and show amorphic, well-decomposed peat, while the layers beyond 90 cm are clearly much less decomposed and show plant remains.

second, a workshop with a broad range of stakeholders representing all major interests in the region for exchange of information, scenarios and measures as well as discussions to exchange opinions and preferences. Finally, to help authorities in the formulation of policies and strategies, a workshop involving higher-level administrators as well as stakeholders is the most far-fetching.
During the first tranche, workshops have been held in Zegveld, Tjeukemeer and Boven-Smilde. The results have been summarized in reports (Eikelboom et al. 2010, 2011a, b), which will become important sources of information for the ORAS. Workshops will be instrumental in the third tranche projects as well, towards the final goal of creating Options for Regional Adaptation Strategies in close collaboration with authorities and stakeholders.

5. Major challenges for future development and the impact of climate change

Climate change will aggravate the complex set of problems in peat meadow areas (Woestenburg et al., 2009). Soil subsidence, water quality deterioration and greenhouse gas emissions are the most important direct effects of the current land use and water management in the polders of the Dutch peat-meadow region. In general terms, the effects of climate change on these processes are expected to result in an even more precarious situation.

Soil subsidence

Soil subsidence has been a common feature in the drained peatlands for a long time, with general subsidence rates of up to 1 m per century. Climate change will result in an acceleration of the subsidence rate. Estimates by Alterra (WUR, Van den Akker et al. 2006, 2011) have indicated that the average subsidence rate will raise to 2 cm per year for the 21st century in the W+ scenario[2] for climate change without adaptation measures. This study also showed that the requirements for fresh water to maintain the water tables in a dry summer could increase from 90 $m^3 s^{-1}$ to 200 $m^3 s^{-1}$ in 2050.
There is quite some spatial variation in the vulnerability of peat soils for subsidence. Peat soils with a clay layer on top are less vulnerable than pure peat soils, that often have still recognizable plant remains in the zone that has never been exposed to oxygen (Fig. 2, study area Friesland, project HSOV1A)).
Variation in soil quality, drainage depth and land use have resulted in differences in elevation, even within the same polder. The parts with the lowest elevation often are the most intensively used meadows which have the deepest drainage. The nature reserves have higher water tables are often located in the highest parts of a polder.
Research by K. Brouns (HSOV1A) has revealed that the content of soluble phenolics in peat soils declines going from deeper, undrained layers towards the superficial layers, where the availability of oxygen has led to their decay (Fig. 3). This is extremely relevant in the context of peat subsidence, because the phenolics have been shown to strongly inhibit the decomposition of peat. Once the phenolics have disappeared, the organic material as a whole starts to decompose rapidly and the peat subsides. The subsidence rates are dependent on drainage depth and amount to 2 cm/year in Frisian meadows. There are strong indications that subsidence increases with temperature. The effect of contact with brackish water has been shown to have no significant effect on peat breakdown and subsidence. Current research into the role of sulphate as an electron acceptor in the breakdown of phenolics will shed more light on the impact of brackish water (project HSOV1A).

[2] One of the scenarios provided by the KNMI describing climate effects on temperature and atmospheric flows.

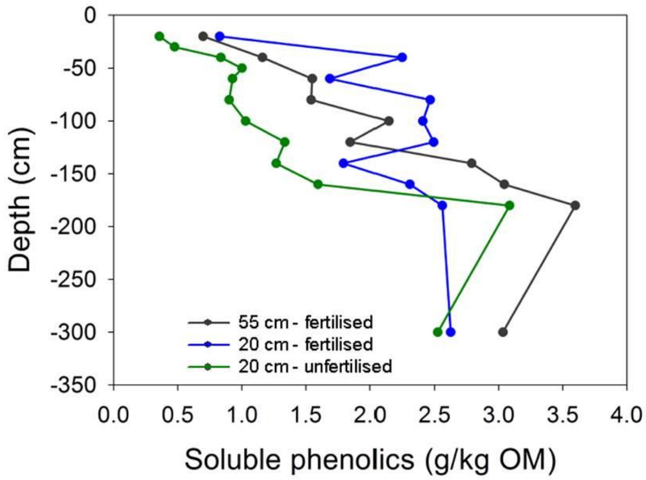

Fig. 3. Concentrations of soluble phenolics in soil profiles of peat meadows in Zegveld. There is a clear gradient with low values at the top and high values in deeper layers where oxygen has no access.

Water quality

Higher temperatures as a result of climate change lead to an accelerated decomposition of the aerated top layer of the peat and higher nutrient mineralization. Enhanced leaching of mineralized nutrients and added fertilizer towards the surface water will result in higher nutrient loading and aggravated problems of eutrophication, particularly in the W scenario with high summer extremes (rainfall and drought). Well-known effects of eutrophication are cyanobacteria blooms, fish kills and the occurrence of botulism. Many measures associated with the European Water framework Directive (WFD) are expected to improve the water quality in the peat meadow areas, but the situation will remain vulnerable and could deteriorate quickly as a result of climate change.

The final document of project HSOV1B encompassed a review of international climate research, specially oriented to scientists and practitioners in water management. This document, a manual for practitioners, contains the results of analyses of Dutch water quality data sets for potential climate related trends (Kosten, 2011). The focus was on water vegetation in ditches and nutrient and phytoplankton concentrations in canals and shallow lakes. For the *ditches*, correlation analyses indicate a relationship between the North Atlantic Oscillation (NAO) winter index and the coverage of different types of water vegetation possibly related to the overwintering strategies of different plant species (Fig. 4). The coverage of free-floating plants (such as duckweed, *Lemna* sp.) are positively related to the NAO winter index indicating that their coverage tends to be higher after mild wet winters. Climate change scenarios indicate that the occurrence of mild wet winters will likely increase in the future. Unless nutrient loadings are reduced this may thus lead to more duckweed dominated ditches.

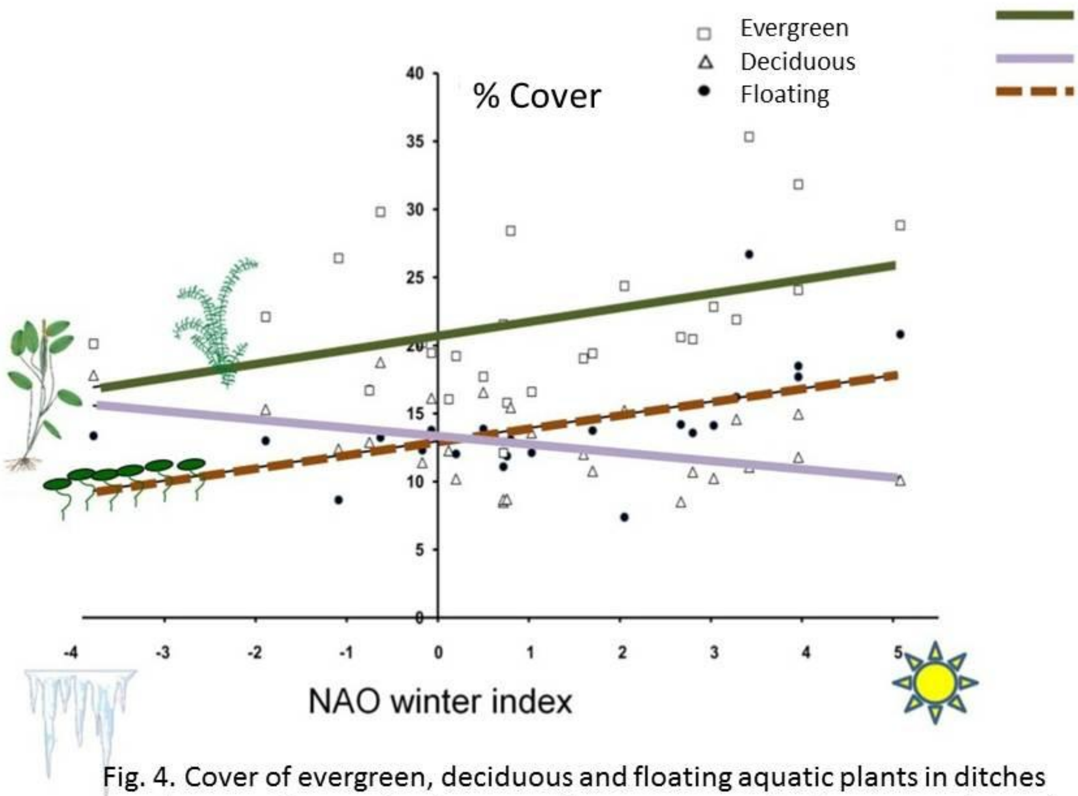

Fig. 4. Cover of evergreen, deciduous and floating aquatic plants in ditches in relation to the North Atlantic Oscillation winter index (Kosten et al. 2011)

The correlation analyses focusing on summer average weather conditions and water quality in *canals* and *shallow lakes* did not reveal an unambiguous relationship between weather conditions and water quality. For a single water body, this relationship is often more pronounced. In the shallow lake Tjeukemeer, for example, water quality strongly depends on wind velocity: high wind speeds resuspend the sediment, increasing nutrient concentrations and decreasing transparency. The decreased wind velocity over the past decades may have been partially responsible for the improvement in water quality. Statistical analyses indicate that, on the one hand, a decrease in nutrient concentrations masks possible effects of climate change on water quality. On the other hand, however, climate change – and particularly a decrease in wind velocity - may lead to an overestimation of the effectiveness of anti-eutrophication measures.

The presence of a large number of toxins, encountered in Dutch surface waters on earlier occasions has been confirmed. The toxins cylindrospermopsin, deoxy-cylindrospermopsin, nodularin and the saxitoxin dcGTX3 have now been found in Dutch surface waters for the first time. High concentrations of cyanobacteria do not necessarily lead to high concentrations of toxins, although a strong relationship between the concentration of toxins and the concentration of cyanobacteria was found in this study Kosten et al. 2011). From a climate change perspective this is worrying as earlier studies as well as a study partially developed within the Knowledge for Climate program indicate that warming leads to more cyanobacteria (Kosten, 2011, project HSOV2B).

Greenhouse gas emissions

The peat meadow region is a major source of greenhouse gases (GHG). Emissions of CO_2 amount to 2.26 tons per ha for each cm of soil subsidence, so that they are directly proportional to the depth of the water table below soil surface. In areas which are intensively used for dairy production there is an additional emission of N_2O, whereas wet fen and marsh areas are subject to CH_4 (methane) emissions. A recent compilation of emission studies at different scales in the peat meadows of The Netherlands in the framework of the research program 'Climate Changes Spatial Planning' has demonstrated that rewetting of previously drained peat meadows has a strongly reducing effect on the GHG emissions, with reductions in CO_2 by far outweighing increases in CH_4 emission (Schier-Uijl, 2010). Fig. 4 shows that total GHG emissions expressed as CO_2 equivalents were lowest in the rewetted polder Horstermeer, mostly because restored peat formation fixed carbon rather than releasing it as in the two polders where drainage had continued. Stopping fertilizer use did reduce the N_2O emissions (polder Stein in comparison with polder Oukoop), but that only marginally affected the GHG balance.

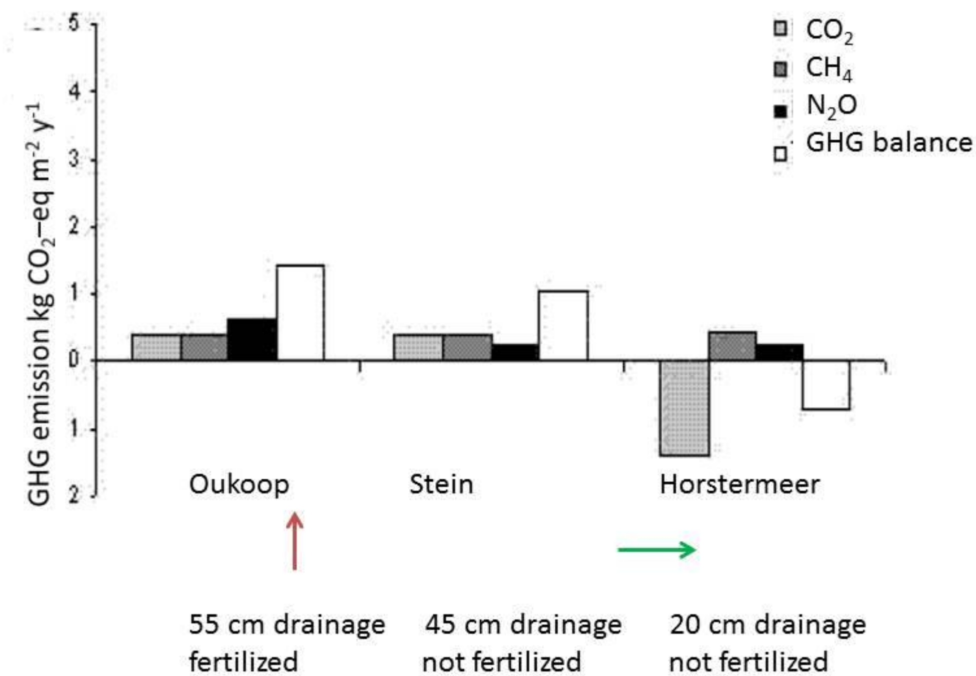

Fig. 5. GHG emissions in three peat meadow polders with different land use and water table management (Schier-Uyl 2010)

Effects on agriculture

The peat meadow regions are primarily in agricultural use. The dominant land use type is dairy production with less than 5% maize fields. In the western peat meadows (provinces of Noord- and Zuid-Holland and Utrecht) the farmer incomes are at or just below the national average owing to the optimal spatial allotment. There are opportunities for broadening the sources of income by providing facilities for recreation, health care and nature conservation. In the northern peat meadows (provinces of Friesland and Drenthe), the dairy farmers are among the strongest in The Netherlands and will see agriculture as their main economic function in the future. It is to be expected that the tendency towards larger farms will be continued. The requirements for fresh water will become imminent at times that the availability of high-quality fresh water is limiting at the national level. The accelerated soil subsidence will lead to major problems of dike maintenance and uneven elevations within polders.

Effects on nature

There are two types of 'nature' in the peat meadow area, both of which are strongly controlled by human management, i.e. the peat meadow vegetation and bird fauna and the peat-forming fen ecosystems (Verhoeven et al. 2010). Peat meadow nature reserves are characterized by species-rich grassland communities and dense meadow bird communities. They have high water tables and low fertilizer additions and are not in commercial agricultural use (Van de Riet et al. 2010). Large fractions of the European Godwit and Lapwing populations are breeding in these meadows, which has created a special responsibility according to EU legislation. Shallow ponds and lakes are inhabited by a range of plant communities characterizing the succession from open water to marsh habitat to fen or carr vegetation.

In the western peat meadows, the national government has allocated 12,000 ha of (semi-)natural areas to the Ecological Main Structure (EHS). Both types of natural systems described above are part of these areas. For thousands of hectares, this objective still has to be realized by buying land and modifying the land and water management. In the northern peat meadow areas, the nature areas have been identified and separated from the farming areas at a higher scale, resulting in large areas of either complete agricultural use or complete nature protection. In the western areas, there are more transitions between the two, and opportunities for dual-purpose land uses.

6. Technical measures for adaptation and mitigation

In the past decade, studies have been carried out to identify the problems in the peat meadow areas when current land use and water management will continue in a context of climate change (Woestenburg, 2009). At the same time, measures have been designed to improve the situation, which could decrease the rate of soil subsidence and enhance water quality without harming the most important economic functions in the area, i.e. agriculture and recreation, mostly 'ecotourism' linked to nature values. The technical feasibility of these measures has been evaluated and their costs and benefits have been initially explored during the first tranche and will be further tested in the third tranche of KfC. The 'Inspiration Book Future of Peat Meadows' (HSHL02, 2012) gives an overview of the most important measures, which can be seen as building blocks for Regional Adaptation strategies. These measures can be subdivided into two major categories, i.e. (1) measures affecting the *water system*, mostly by modifications of physical water control structures and of the water regime and (2) measures affecting *land use and economic functions*. Some major examples of such measures are:

(1) Water system
   a. Flexible water level regime; increasing water levels in ditches; larger units with equal water levels; larger shallow ponds and lakes. These measures can prevent extremely low water levels in dry summers and slow down subsidence.
   b. Buffer zones bordering ditches and canals, wetlands for water quality improvement.
   c. Drainage systems (tubing) below the water table, which deliver water to the central parts of grassland parcels so that water levels do not become extremely low in summer. This is a measure reducing subsidence by 30-40%.

(2) Land use and economic functions
   a. Robust and climate-proof crops; salt-tolerant crops; energy crops.
   b. 'Green-blue services', i.e. farmers allow water to be stored in reservoirs to be used in dry period or to mitigate flooding.
   c. Maintaining biodiversity in the landscape by funding farmers for measures stimulating meadow birds and botanical diversity.
   d. Measures to stimulate recreational use (swimming, camping at the farm, hiking).
   e. Building residential areas in a robust, 'water-proof' way.

In practice, Regional Adaptation Strategies will consist of packages of such adaptation and mitigation measures. Although most of the measures have been tested for efficacy and cost effectiveness, it is quite complicated to evaluate which combination of measures is optimal in a particular area. This will be done for the Friesland study area in the third tranche, in interactive sessions where different stakeholders can be informed about the future scenarios, the problems and bottlenecks anticipated, the effectiveness of measures and their cost-benefit balance.

7. Road map to the ORAS

The fact that the problems in the peat meadow areas are strengthened rather than caused by climate change, may be a benefit in disguise. Analyzing scenarios where climate change worsens the situation to the point that major economic damage is caused, could spur the consideration of measures that would otherwise be unthinkable. Climate effects could be viewed as an opportunity to break through long-lasting disagreements among stakeholders. A large number of technical measures have been identified and tested to slow down the process of soil subsidence in peat meadows. These measures require interplay between water management, land use planning, governance resulting in policies and common ground for implementation. The explicit compilation of possible adaptation strategies helps to identify the main direction for solutions and to evaluate the pros and cons of choices for implementation of combinations of measures. These options for adaptation strategies need to be worked out for the different regions, which each have their specific characteristics with respect to geomorphology, soils and governance structure.

Primary management options can be focused on three aspects, i.e. water table management, land use planning and private/public collaborations supported by knowledge institutions. This is often called 'the golden triangle'. Provinces and water boards have come up with initiatives to re-evaluate the policies for the peat meadow areas. Stakeholders from the sectors agriculture, nature conservation and recreation play an active role and are supported by studies on the efficacy of the various proposed measures. Climate change effects are increasingly important in these assessments. The program Knowledge for Climate has supported these processes with specific research and by organizing regional workshops in which stakeholders evaluate the consequences of combinations of measures in several scenarios for the 21st century.

Two essential bottlenecks have been identified in these activities, i.e., a lack of understanding of the costs and benefits of the current water management and the occurrence of stalemates in governance, where discussions perpetuate without reaching a basic level of consensus. Continued studies of cost-benefit analyses, together with stakeholder workshops using spatial decision support tools are underway to help resolving these bottlenecks. These activities will be intensified in the third tranche of the program and are planned to result in a Manual with Options for regional Adaptation Strategies (ORAS), the final product of the work in this hotspot. This manual will give a complete overview of the problems and solutions in the peat meadow areas, as sketched above. It will also give evaluations of the efficacy of (combinations of) different measures and will provide recommendations for further applications of the knowledge for specific areas other than the ones for which the ORAS have been tested and evaluated. The manual will be specifically oriented towards practitioners working for regional governments and stakeholder organizations and will be discussed with representative higher-ranking administrators of these organizations.

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Annex 1. Short description of three projects carried out in Tranche 1.

HSOV1A *Climate effects on decomposition in drained peat meadows: implications for peat subsidence and water quality*

This research project aims at quantifying the effects of climate change (temperature increase, long wet and dry periods, increasing salinity of soil pore water) on the rates of decomposition and mineralization of peat in the drained peat meadows used for agriculture in The Netherlands. The consequences of these effects for soil subsidence and nutrient release from peat soils will also be quantified. Decomposition rates of peats at different soil depths will be measured under controlled conditions (temperature, water chemistry, soil moisture, aerobic as well as anaerobic conditions). Methods applied will include mass loss, microbial respiration, enzyme analysis and nutrient mineralization in the laboratory. Soil subsidence and leaching will be measured in the field at sites contrasting in water table and water chemistry. Data will be analyzed in models to investigate consequences of changes in peat decomposition for soil subsidence, nutrient leaching and water quality.

Research questions:
1. What is the effect of brackish water on the decomposition and mineralisation of peat soils? Thereby considering the roles of peat type and land use
2. What is the effect of summer droughts on decomposition and mineralization of Sphagnum and Carex peat samples under natural and agricultural land use?
3. What is the vertical profile of phenolics in Dutch peat meadows?
   - How does the concentration of phenolics relate to factors as the degree of humification, GW level, nutrient concentrations, pH and potential phenol oxidase activity?
4. Does nitrogen addition affect aerobic decomposition of Carex and Sphagnum peat samples with and without history of fertilisation?
   - Does phenol oxidase addition affect aerobic decomposition of Carex and Sphagnum peat samples with and without history of fertilization?
   - Is there an interaction effect between N and PO addition?

Project leader: prof.dr. Jos Verhoeven; Ph.D. student: Karlijn Brouns
Duration: 1 May 2009 – 15 July 2013
Institution: Utrecht University, Dept. of Biology
Products: Inputs in spatial analyses and workshops (together with project 1C); Input in ORAS manual (2013); Ph.D. thesis (2013); scientific publications (2013-2014).

Publications, posters, presentations:
- Brouns, K., J.T.A. Verhoeven, M.M. Hefting (2012) Do vertical profiles of drained and fertilised peat meadows reflect the Enzymic Latch Theory? Poster presentation at BES/IUCN Peatland meeting, Bangor, United Kingdom, 25-28 june 2012
- Brouns, K., M.M. Hefting, J.T.A. Verhoeven (2012) Decomposition of peat during simulated summer drought, Oral presentation at the International Peat Conference, Stockholm, Sweden, 3-8 june 2012

- Brouns, K., Hefting, M.M., Verhoeven, J.T.A. (2011)Decomposition of peat in lab experiments simulating summer drought. Poster presentation at the Wageningen Soil Meeting, Wageningen, the Netherlands, 18-22 September 2011
- Brouns, K., Hefting, M.M., Verhoeven, J.T.A. (2011) Effects of brackish water on the mineralisation of peat soils, 2011, Netherlands Annual Ecology Meetings, Lunteren, the Netherlands, 7-8 January 2011
- Brouns, K. (2010) Invloed van klimaatverandering op de afbraak van veenbodems, Province of Utrecht, the Netherlands, 19 September 2010
- Van de Riet, B.P., A. Barendregt, K. Brouns, M.M. Hefting, J.T.A. Verhoeven (2010) Nutrient limitation in species-rich Calthion grasslands in relation to opportunities for restoration in a peat meadow landscape. Applied Vegetation Science 13: 315-325.
- Verhoeven, J.T.A. (2010) Climate change and aquatic ecosystems: introduction. Presentation for international symposium organized by Stowa, January 2010.

HSOV1B *Climate influence on water quality: which trends are already apparent?*

Surface waters form a characteristic environment of the low delta in which The Netherlands are situated. Over the last decades they have been severely impacted by a surplus of nutrients which resulted in massive blooms of duckweed, algae or cyanobacteria. Mayor investments have been done to improve this situation and just as the water quality is improving climate change may cause the water quality and ecological state to deteriorate again. Climate change has complex influences on the aquatic ecosystem difficult to unravel. Through the proposed statistical analysis of some huge Dutch data sets we will obtain insight in the nature and scale of already observable and expected impacts of climate change on water quality and aquatic ecology and the implications for the achievement of different management objectives. We will furthermore highlight management actions that may ameliorate the water quality. One of the expected consequences of climate change is an increase in potentially toxic cyanobacterial blooms both in time and in space. As we are confronted with a serious lack of information on the occurrence of cyanobacterial toxins in Dutch surface waters we propose to fill this gap by implementing a state of the art toxin analysis and an extensive field survey.

Research questions:
1a. What is the nature and scale of the already observable and expected impacts of climate change on water quality? We will specifically focus on:
- effects on nutrient concentrations and salinity;
- effects on (blue-green) algal concentrations and the timing and duration of their blooms;
- effects on the presence and abundance of submerged plants;
- presence and abundance of floating plants;
- presence and abundance of exotic algae and aquatic plants.

1b. How will these changes influence the achievability of the Water Framework Directive objectives and what are the consequences for management.
2. What is the current distribution of different types of cyanobacteria and cyanobacterial toxins in the Netherlands and how may this be influenced by climate change?

Project leader: prof.dr. Marten Scheffer; Postdoc: Dr. Sarian kosten
Institution: Wageningen University, Aquatic Ecology and Water Quality Management
Dr. Sonja Vernooij, KWR
Duration: 1 March 2009 – 1 March 2011

Products: Publications:
- Kosten, S. (2011) Een frisse blik op warmer water, Over de invloed van klimaatverandering op de aquatische ecologie en hoe je de negatieve effecten kunt tegengaan, STOWA -rapportnummer 2011-20, ISBN 978.90.5773.524.0.
- Kosten, S., Kardinaal, E., Faassen, E., Netten, J. & Lürling, M. (2011). Klimaatinvloed op waterkwaliteit en het voorkomen van cyanobacteriële toxines. Kennis voor Klimaat KvK043/2011, ISBN/EAN 9789490070489.
- Kosten, S., Faassen, E., Lurling, M. (2009). Blauwalgen binnen het Kennis voor Klimaat Programma. Cyanonieuws, #10.
- Penning, E., Kosten, S., Hospers, H., Van der Wal, B., (2009). Warmer klimaat vergroot eutrofiëringsprobleem, H2O 3: 7.
- Kosten, S. (2009). Invloed van klimaat op waterkwaliteit: welke trends zijn al zichtbaar? Poster gepresenteerd op Projectendag KvK, september 2009.
- Kosten, S. en Claassen, T. (2010). Klimaatverandering en waterkwaliteit: Wat staat ons te wachten, presentatie gehouden op het STOWA klimaatsymposium te Arnhem
- Kosten, S., Huszar, V.L.M., Bécares, E., Costa, L.S., Van Donk, E., Hansson, L.A., Jeppesen, E., Kruk, C., Lacerot, G., Mazzeo, N., De Meester, L., Moss, B., Lurling, M., Nõges, T., Romo, S. & Scheffer, M. (2011). Warmer climate boosts cyanobacterial dominance in lakes. Global Change Biology.

HSOV1C *Managing climate effects in peat meadows and shallow lakes*

The overall project deals with the prediction of the effects of climate change in peat meadows and shallow lakes. The information generated is to be used to define and evaluate adaptation strategies. This part of the project intends to develop approaches to match the complex information generated by the project with the objectives of the stakeholders. Both the effects and the adaptation strategies have a clear spatial, temporal and uncertainty dimension. The complexity and amount of information to be processed makes it necessary to develop techniques to structure and present the information in such a way that it can be managed by the stakeholders.

Within this project the relevant decision processes are described and the information needs by the various stakeholders at different stages of these processes are monitored. We will develop interactive workshops to facilitate problem analysis, problem identification, design of management alternatives evaluation of alternatives and feedback to design. The project will focus on the development of spatial design approaches using a mixture of formal design routines, visualization techniques and structured feedback from participants in workshops. Techniques will be integrated in a spatial decision support framework implemented in hardware suitable for interactive use in a workshop.

Research question:
How can the development of adaptation strategies to manage the effects of climate change on peat meadows and shallow lakes be supported by using interactive spatial decision support approach?

Subquestions

- What are the characteristics of the evaluation problem: model output, performance indicators, stakeholders, preferences, objectives etc.?
- Which methods are available or can be developed to support the design and evaluation of adaptation strategies?
- What are the information needs of the stakeholders in the development of adaptation strategies?
- Can the use of spatial decision support systems in the context of interactive workshops meet these needs?
- How can the design of the workshop process and the design of the decision support tools be integrated to improve the combined use of both types of support?
- What can be learned from these experiences for similar processes in other regions and for similar processes in other policy fields?

Project leader: Dr. Ron Janssen; postdoc: dr. Nancy Omtzigt, Fritz Hellman
Institution: Vrije Universiteit, Instituut voor Milieuvraagstukken.
Duration: 1 March 2009 – 1 September 2012

Products: stakeholder workshops, reports of these workshops, publications.

- Arciniegas, G.A., Janssen, R., Rietveld, P., (2012). Effectiveness of collaborative decision support tools: Results of an experiment. Environmental modelling & Software, doi:10.1016/j.envsoft.2012.02.021
- Arciniegas, G. A., R. Janssen, and A. Q. A. Omtzigt (2011). Map-based multicriteria analysis to support interactive land use allocation, International Journal for Geographical Information Science (2011): 1-17.
- Eikelboom, T. & Janssen, R. (work in progress), Report 'Experimental workshops to evaluate negotiation tools for local adaptation'. IVM Report, Institute for Environmental Studies (IVM), Vrije Universiteit Amsterdam, The Netherlands.
- Eikelboom, T. , F. Hellmann, N. Omtzigt, R. Janssen, S. Kosten, K. Brouns, J. Verhoeven, (2011). Workshopverslag 'Peilvakalternatieven voor veenweidepolders in Friesland'. IVM Report, Institute for Environmental Studies (IVM), Vrije Universiteit Amsterdam, The Netherlands, 35 p.
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- Hellmann, F., Amerom, J. van, Janssen, R, Omtzigt, A. Q. A., and Verhoeven, J. T. A. (2010). Verslag van de onderhandelingsworkshop "Planvorming in veenweidegebieden en ondiepe meren?", 17 juni 2010, Utrecht, Instituut voor Mileuvraagstukken, Vrije Universiteit.

Funding (all three projects together):

Project nr.	Project type	Time span	Institute	Amount
HP-12A	PhD	4 years	UU	€ 461.000
HP-12B	Postdoc	1 year (1242 hours)	WUR	€ 175.000
HP-12B	Team research	1 year	KWR	€ 60.000
HP-12C	Team research	3 years (2209 hours)	IVM	€ 220.000
HP-12 classified under HP-12A	Coordination	1 year (200 hours)	UU	€ 20.000
HP-12 classified under HP-12B	Coordination	1 year (164 hours)	WUR	€ 20.000
HP-12 classified under HP-12A,B andC	Knowledge transfer	5% of budgets ABC	UU/WUR/ IVM	p.m.
	Contribution	Knowledge for Climate		**€ 290.000**
	Cofinancing	Stowa, provinces, water boards		**€ 666.000**
TOTAL				**€ 956.000**

Annex 2. Short description of two projects accepted for funding in Tranche 3.

HSOV3.1 *Designing regional adaptation strategies in the Frisian peat meadow areas: evaluating the effectiveness of management options to maintain or transform this landscape under different scenarios of change*

This proposal describes a project to design regional adaptation strategies for climate change in the peat meadow areas of Friesland, the Netherlands, in liaison with the development of a strategic long-term planning policy by the Province and Water Board. The activities will encompass the compilation of data on water levels, soil subsidence, agricultural land use (including innovative approaches) and their application to (1) identify bottlenecks; (2) design measures for adaptation and mitigation; (3) evaluate the efficacy of these measures in terms of feasibility and cost-benefit aspects and (4) compile packages of these measures as options for regional adaptation strategies for Friesland.

Research questions

- Which combinations and spatial patterns of management options are the most effective to mitigate problems (i.e. enhanced soil subsidence, deterioration of water quality, decreasing availability of fresh water, changing perspectives for sustainable agriculture) in the context of policy targets?
- How is the attitude of regional and local stakeholders (farmers organizations, nature organizations, entrepreneurs, water authorities, provincial authorities) towards the various packages of measures in terms of costs and benefits, compliance to legislation, environmental and economic targets?
- What are the main technical, spatial and political trade-offs in the development of adaptation strategies?
- How can the scientific knowledge of adaptation measures, built up in this Hotspot, successfully be integrated in long term development policies for peat meadow areas?
- What is the link between local and regional development of adaptation strategies (scale issues in environmental processes and governance)?

Project leader: Prof.dr. Jos T.A. Verhoeven, Utrecht University
Partners: Dr. Cees Kwakernaak, Wageningen University and Research, Dr. Ron Janssen, Instituut voor Milieuvraagstukken, VU Amsterdam
Cofinancing partners: Province of Friesland, Wetterskip Friesland (50% of total budget)
Total budget: € 240,000

HSOV3.2 *Manual for Options for Regional Adaptation Strategies in peat meadow areas including shallow waters*

The proposed project aims at the scoping, compiling and writing of a manual which will contain the current state to the art of Options for Regional Adaptation Strategies to climate change for the Shallow Waters and Peat Meadow Areas in The Netherlands. The manual will describe bottlenecks, mitigation measures and evaluation procedures in land and water management on the basis of scientific research and its application in the hotspot itself and in other related research programmes.

Research questions

- How can the scientific knowledge of effectiveness and feasibility of adaptation measures, built up in this Hotspot and elsewhere, successfully be integrated in options for long term adaptation strategies for policy and management in peat meadow areas?
- What are the options for regional adaptation strategies to climate change in peat meadow areas and shallow lakes, and how can these options be evaluated depending on characteristics of physical environment, policy targets and socio-economic development?

Sub-questions:

- Which combinations of measures in water and land use management are most effective to mitigate the adverse impacts of climate change (i.e. enhanced soil subsidence, deterioration of water quality, decreasing availability of fresh water, changing perspectives for sustainable agriculture and nature areas), in the context of different physical conditions within the peat areas?
- How can regional and local stakeholders (provincial and water board authorities, farmers and nature organizations) evaluate the efficacy of the various possible measures and adaptation strategies, in the context of policy targets and perspectives for sustainable agriculture under changing European regulations?
- How can adaptation strategies at the local scale be linked at strategies at the regional scale in such a way that realistic options will be available for governing bodies at each scale that strengthen rather than hamper each other?
- How can this knowledge be translated in a realistic set of Options for Regional Adaptation Strategies, taking account of physical differences in soil conditions and water infrastructure?

Project leader: Dr. Cees Kwakernaak, Wageningen University and Research
Partners: Prof.dr. Jos T.A. Verhoeven, KNW, Dr. Ron Janssen, Instituut voor Milieuvraagstukken, VU Amsterdam, Dr.ir. Henk Smit, Wing Procesbegeleiding, Wageningen
Budget: €104.000