


climate changes spatial planning


Mitigation

The effect of the spatial arrangement of wetlands on water quality improvement and carbon sequestration

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Summary

Summary in Dutch

De interactie tussen nutriëntendynamiek en broeikasgasemissies is onderzocht in veenweidepolders. Rietmoerassen kunnen een deel van de nutriëntenbelasting bufferen maar staan ook bekend als belangrijke bronnen van methaan, terwijl ontwaterde, mineraliserende weidegronden op veen juist kooldioxide uitstoten.

Voor dertien polders zijn sluitende nutriëntenbudgetten opgesteld. Dynamiek noch retentie van nutriënten konden door variatie in landschappelijk patroon verklaard worden. De hoeveelheid land in gebruik voor melkveehouderij was de primaire verklarende factor. Stikstofbudgetten waren in balans, maar voor fosfor werd een overschot geconstateerd. Het surplus aan stikstof werd namelijk gecompenseerd door denitrificatie in de veenbodem. Het surplus aan fosfor kwam goed overeen met elders gemeten jaarlijkse netto fosfor-aanrijking.
Methaanfluxen namen af met toenemende intensiteit van landgebruik (ontwatering, bemesting), en konden goed voorspeld worden met behulp van vegetatiesamenstelling en grondwaterpeil. In het oppervlaktewater was het juist andersom: methaanemissie was het hoogst in sloten tussen intensief gebruikte percelen en het laagst in onproductieve natuurgebieden. Dit alles betekent dat de verdeling van landgebruik en water van belang is voor totale broeikasgasemissie uit het veenweidelandschap.

Een en ander is geïntegreerd in een dynamisch waterbalansmodel in SOBEK, dat eerst gekalibreerd en geverifieerd is voor twee bestaande, goed gedocumenteerde polders. Vervolgens zijn de KNMI-klimaatscenario's doorgerekend aan een nieuwe, synthetische polder. Met name het W+-scenario (warmer en droger, sterkere atmosferische circulatie) lijkt tot aanmerkelijk wegzakken van het grondwater te leiden in de nazomer, en dus tot toenemende mineralisatie, kooldioxide-emissie en nutriëntenbeschikbaarheid. Dit wegzakken van het peil kan in droge periodes waarschijnlijk niet gecompenseerd worden door extra waterinlaat, omdat het slootpeil weinig verandert.

Summary

This project assessed whether the allocation of land use types and water in Dutch peat polders affected nutrient budgets and carbon sequestration. Since eutrophication is a major water quality concern, nutrients are the major water quality variables deserving attention. Similarly, peat wetland types are thought to be highly variable in their methane emissions, whereas carbon dioxide is thought to be governed mainly by mineralization and ground water level depths, hence this project focused on methane emissions from different types of wetlands.

Nutrient budgets were established for 13 polders of variable land use, and nutrient dynamics as well as retention were found not to be affected strongly by spatial pattern. Instead, the prevalence of intensive dairy farming in was found to be of primary importance for nutrient budgets. Whereas the resultant nitrogen surplus was compensated by intensive denitrification, this was not the case for phosphorus, and a net cumulative P-enrichment of the soil found elsewhere agreed with the annual surplus established in our budgets.

Methane fluxes were found to vary strongly across two gradients of land use intensity, and among wetland types. Vegetation composition as well as mean ground water level could be used well to predict methane fluxes: probably the shallower groundwater of wetlands with rare vegetation in nature conservation areas led to higher net fluxes. In contrast, the surface waters in these polders showed an opposite pattern: methane fluxes from ditches and ponds in unproductive nature reserves had the lowest methane fluxes, and productive ditches in intensive dairy land the highest. Hence allocation of land use and water types, together with groundwater level, would strongly affect carbon sequestration at the landscape scale. Observed methane fluxes were aggregated to higher order vegetation types and these were found to predict observations well that had been made previously by others in known vegetation types.

Together, these findings are integrated in a dynamic water balance model made in SOBEK. This model is first calibrated and verified for two existing, data-rich polders. KNMI climate scenario runs have been carried out and suggest that particularly the W+ (warmer and drier) would lead to substantial drops in ground water level, hence would lead to increased mineralization which is probably not compensated by increased water inlet, because ditch levels did not drop correspondingly.

1. Project context

For the Netherlands, climate change scenarios foresee increasing annual precipitation and more intense summer rain events (Van den Hurk et al., 2006). To cope with this, increased water storage and infiltration capacity is needed in the low-lying peatland polders of the Netherlands ('Veenweidegebied'). These polders are dissected by a dense network of ditches and canals, together a substantial area and volume of water, as well as of fringing wetland habitats. In addition to their function for drainage and water storage, these shallow waters and their fringes form complex wetland networks, which can also have a function in water quality improvement, biodiversity conservation, carbon sequestration and recreation. Optimization of these functions of the Veenweidegebied in relation to the climate-related changes in hydrology may well depend strongly on the spatial arrangement of wetland and drainage networks. Currently, there is limited knowledge about the way in which the spatial arrangement of ditch network wetlands can be optimized. Given the high economic value of the Veenweidegebied and the strong spatial claims on this area, this knowledge is highly needed. Their prudent positioning, however, will greatly improve storm water quality during and after intense rainfall events. This may also affect carbon sequestration, for example through inundation effects on mineralization. Thus, the multifunctional use of the Veenweidegebied will change under pressure of changing climatic conditions. Well-informed spatial planning would be able to benefit from these hitherto insufficiently charted possibilities to improve water quality and carbon sequestration.

The spatial arrangement of wetlands may affect the residence time of water in a network but also affect the contact of this water with permanently or temporarily submerged surfaces of vegetation and sediment. A complex wetland landscape may be considered to act as a sort of "sponge": the architecture of the sponge, that is the number and size of the cavities and the way these are connected, determines its efficiency. However, landscape sponges may function as sinks as well as sources.

The hydrology of the Veenweidegebied has important implications for its carbon storage function. It has been calculated (Aerts 2000) that if only 5% of the area of Dutch grasslands on peat would be rewetted a carbon sequestration would be achieved which equals the present carbon sequestration in Dutch forests. Thus, rewetting of peat soils in the Veenweidegebied potentially has a great impact in terms of emission compensation. However, raising water tables to increase both water storage capacity and the area of mesotrophic fens with high botanical diversity, probably will also increase the emission of methane, an important greenhouse gas. At the same time, present agricultural land use practice is at odds with the raising of water tables. However, given a probably changing land use policy in the EC and the targets that are required to meet the demands of the Kyoto protocol, wetlands should be managed to serve as additional carbon sinks.

For nutrients, wetland sediments may cause similar complications. For example, phosphorus-saturated lake sediments such as present in many Dutch artificial lake complexes ('plassen' originating from peat excavation) may continue to cause internal loading (e.g. Smolders et al. 2006) long after the external loading has ceased.

In short, we have studied possible effects of variable spatial pattern of wetland networks on their biogeochemical functioning in a changing (hydrological) climate. Spatial pattern in this study is used to mean connectivity between water bodies or their degree of reticulation, the proportion of wet areas and their size distribution in the landscape. A priori theoretical considerations suggest that both nutrient retention and carbon sequestration may be enhanced in wetland networks of increasing complexity. However, this may be confounded by counteracting processes as well as variability in local patterns of soil and vegetation composition, underwater sediments and water level fluctuations. Our limited knowledge of the concerted operation of all these processes in their spatial arrangement may lead to unexpected interacting feedbacks. Furthermore, there is clearly a practical need to know what will happen in real polders that will become re-wetted.

The present study sought to provide scientists, water managers, nature conservation organizations, and policy makers with the knowledge required to take appropriate decisions regarding the spatial arrangement of wetlands and ditch networks in peatland for multifunctional use. The project was broken down into three main components, or tasks, attributed to the two participating teams:

1. Water quality variability in peatland polders with different spatial pattern (Vermaat, IVM)
2. Carbon sequestration in peatland wetlands of variable land use intensity (Aerts, IES)
3. Integration: modeling the effects of climate scenarios on water level, nutrient dynamics and greenhouse gas emissions from peatland polders (both)

2. Project aims

The approved project proposal listed the following overall objectives:

1. To analyze the effects of climate-related changes in hydrology (water input and water levels) in the Veenweidegebied on water quality change and carbon storage in polder ditch networks of variable connectivity and spatial extent;
2. To use this knowledge in phrasing guidelines for the optimization of the spatial arrangement of wetlands and ditch networks in the Veenweidegebied for the maximization of flood-, sediment- and nutrient retention as well as carbon storage.

These two generic objectives have been translated into a range of specific research questions for water quality (task I, questions 1-3), for carbon sequestration (task II, questions 4-5) and their interaction (task III, question 6). These questions are:

1. Can enhanced reticulation increase water quality improvement in wetland-ditch networks of peatland polders and can optimal arrangements be delineated?
2. What is the effect of surface water inflow-outflow regulation (and their water level consequences) within practical water management bounds?
3. What is the importance of sediment composition, thickness and its spatial distribution?
4. How should water levels in spatial networks of wetlands be regulated to increase net storage of carbon and to decrease methane emissions?
5. Can the greenhouse gas emissions of these wetlands be predicted from chemical fingerprints of the soil organic matter?
6. How do water quality parameters interact with the carbon balance of these wetlands?

However, given the logistic as well as computational constraints encountered, we have not been able to address all of these questions. Notably, in the water quality task, our dependence on data availability with water boards prohibited the detailed analysis of the role of aquatic sediments (question 3). Secondly, we replaced chemical finger-printing of soil organic matter (question 5) with a more readily available indicator, the composition of standing vegetation. Thirdly, we stress that our analysis of interactions among hydrology, water quality and greenhouse gas fluxes as well as an assessment of climate change effects is carried out with a modelling tool, SOBEK. The development and population with relevant data could only be finalised when the other tasks had been completed in as much was we could be confident on their analyses and interpretations. This has led to delays in our modelling work. Still, the last analyses and write-up could be finalised in early 2011.

3. Approach

For water quality we primarily made use of the substantial quantity of existing data available in water boards and we added our own GIS analyses of the polder landscapes studied. This was justified by the necessity of a comparative analysis of as many real polders as possible. We constructed annual water, chloride and nutrient budgets for each polder and were able to do so for 13 polders with sufficient confidence (for details, see Vermaat & Hellmann 2010). A polder is taken here to consist of all land and water within the bounds of that polder as a drainage unit (fig 1), but deeper groundwater and ditch sediment is excluded. Aggregate data were then used to define and populate spatially explicit models (fig 3) of water flow and nutrient dynamics in SOBEK, a modelling tool developed and maintained by Delft Hydraulics (now DELTARES; see http://delftsoftware.wldelft.nl/index). We chose this tool after being advised to do so in consultation of our water board representatives during the first stakeholder workshop in December 2006. First, SOBEK models of two real polders were calibrated and verified until satisfaction. We then developed a synthetic polder reflecting the median conditions of all 13 covered by Vermaat & Hellmann (2010) and used this artificial polder to carry out scenario runs. We applied the time series data that reflect the KNMI climate scenarios (Van den Hurk et al., 2006), made available by KNMI. These four scenarios are labelled G, G+, Wand W+, respectively. The lettering W and G contrasts a warmer climate (a stronger increase in temperature by 2050 of +2 °C) with a moderately increased temperature (+1 °C), whereas the affix '+' implies a stronger air circulation involving wetter winters and dryer summers.

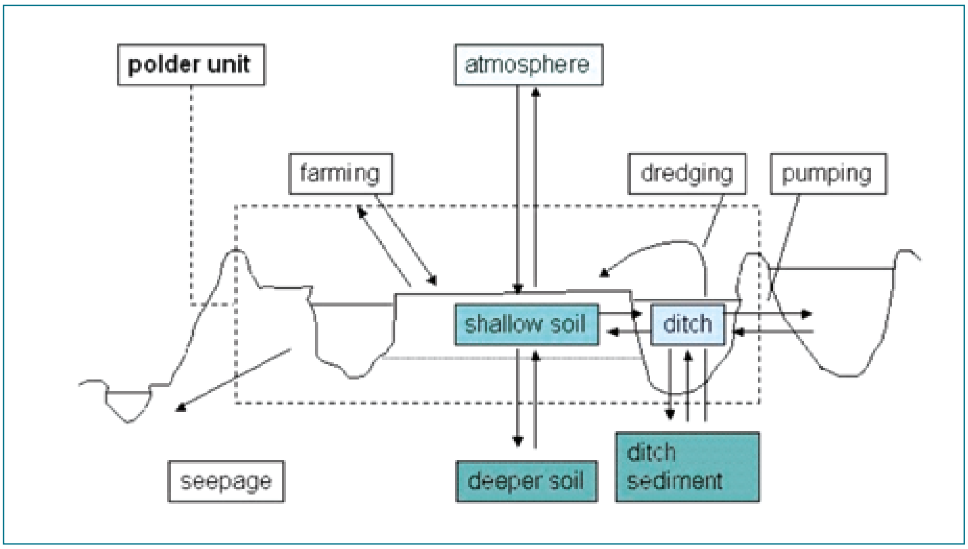

Figure 1.
Conceptualisation of a polder as a separate entity, and major outside sources/sinks of water and nutrients.

Figure 2.
Spatial SOBEK schematisation of the Hilversumse Bovenmeent polder, overlain over Google Earth image. Note the main routing channels of water, connectors to specify land run-off, and engineering works, all customary designed to reflect the in-situ situation.

The carbon sequestration team delineated two landscape-scale transects from nutrient poor nature reserve wetlands to intensively used pastureland, which was fertilized, cut and grazed. One transect was adjacent to the Nieuwkoopse Plassen north of Woerden (fig. 3), the other in Oostzaan, just north of Amsterdam. Along these transects, sites were chosen and replicate plexiglas chambers used to repeatedly quantify greenhouse gas fluxes from these habitats (also for methodological details, refer to Dias et al., 2010). Groundwater level, pH, land use, surrounding vegetation composition and soil organic matter were used as potentially explanatory factors.

Integration is carried out using the SOBEK modelling environment (Hellmann & Vermaat, 2010) and a GIS analysis at landscape scale (Dias et al., in prep).

Figure 3.
Cooperation in the field. Left: Bart Hoorens preparing chambers to measure lake methane fluxes on the Nieuwkoopse Plassen; right: Andre Dias and Fritz Hellmann installing a chamber on wetland vegetation in Nieuwkoop in spring (photos Jan Vermaat).

4. Synthesis: main findings vis-à-vis the research questions posed

4.1 Can enhanced reticulation increase water quality improvement in wetland-ditch networks of peatland polders and can optimal arrangements be delineated?

To our surprise, we found very little effect of the spatial arrangement of ditches and other water bodies on variables reflecting nutrient retention (Vermaat & Hellmann, 2010). We have explained this with the argument that the organic peat soils of these polders probably are the main agent for sorption and denitrification. The zone where the water table fluctuates is probably the major interface. The total area of this interface available for retention processes is probably much larger than the littoral interface available at the ditch edge. At the same time, we were able to establish convincingly closing budgets for water, chloride and nutrients, we demonstrated that agricultural activities are the major source and sink for both N and P, and P-budgets display a net surplus, which corresponded well with independently established stocks of P in soils under agricultural land use and soils that had never been fertilized (Beltman et al., 2009). Overall land use patterns in these polders were found to govern most of the geochemical variability (fig 4; taken from Vermaat & Hellmann, 2010). Since variation in water flowing into a polder depended on land use as well, and had little impact on nutrient budgets, variation in spatial arrangement of ditch networks would not have a major impact on nutrient dynamics. Presence of lakes, larger areas of open water with deeper sediment sinks, however, could have a major impact. Also, in polders where the peat cover is shallow or has disappeared, the impact of organic matter in the soil is probably less and littoral margins may be more important. For example, denitrification potential of stream bank buffer strips can be enhanced by organic matter richness of the soil (Vermaat et al., 2009).

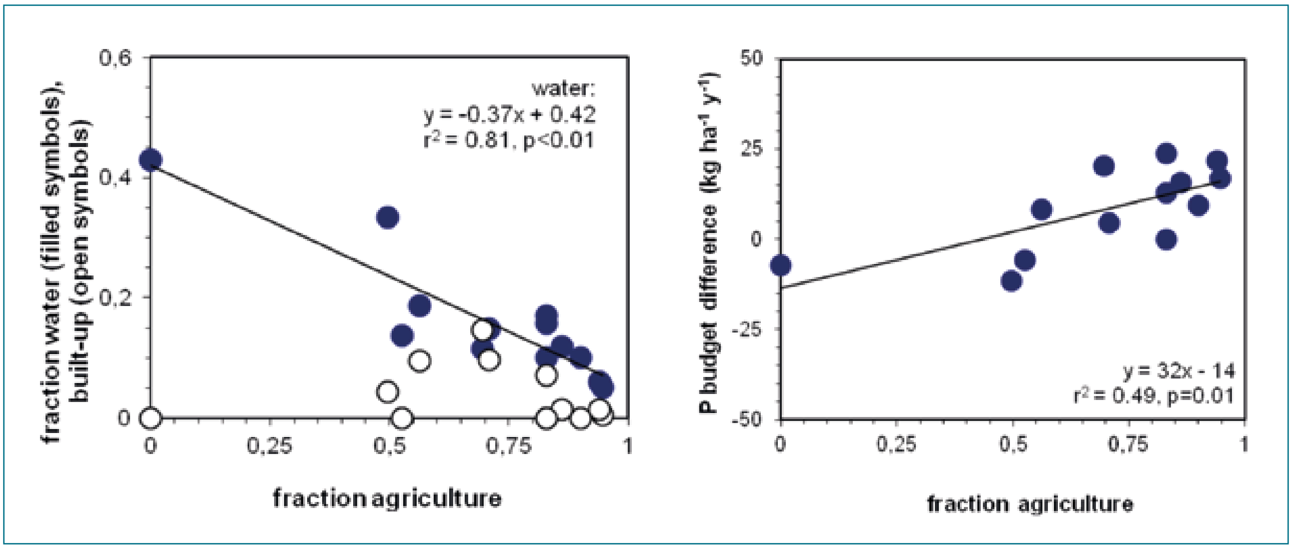

Figure 4.
Relation of the proportion of agricultural land use in a polder with open water and built up area (left; note that the proportion of built-up land shows little relation), and with the annual P-surplus (right). Note that area in this figure is total polder area, hence land and water.

4.2 What is the effect of surface water inflow-outflow regulation and water level consequences within practical water management bounds?

Although the quantity of water that is pumped in or out of a polder probably has little direct impact on the stocks and fluxes of nutrients, the ground water level (and its seasonal fluctuation), which is the consequence of a pumping regime, will have a major impact at least on annual denitrification rates (Fig. 5) and possibly also on phosphorus dynamics, a.o. through the interaction with bivalent/trivalent iron. Hence indirect effects of inflow-outflow regulation are probably mainly operating through the variation of groundwater level and its consequences. In addition, groundwater level was found to be a major determinant of methane fluxes across the land use gradients studied by Dias et al. (2010; Fig. 6). Finally, our modelling results (Hellmann & Vermaat, submitted) stress the impact of late summer groundwater level drops as contributing to enhanced carbon dioxide emission.

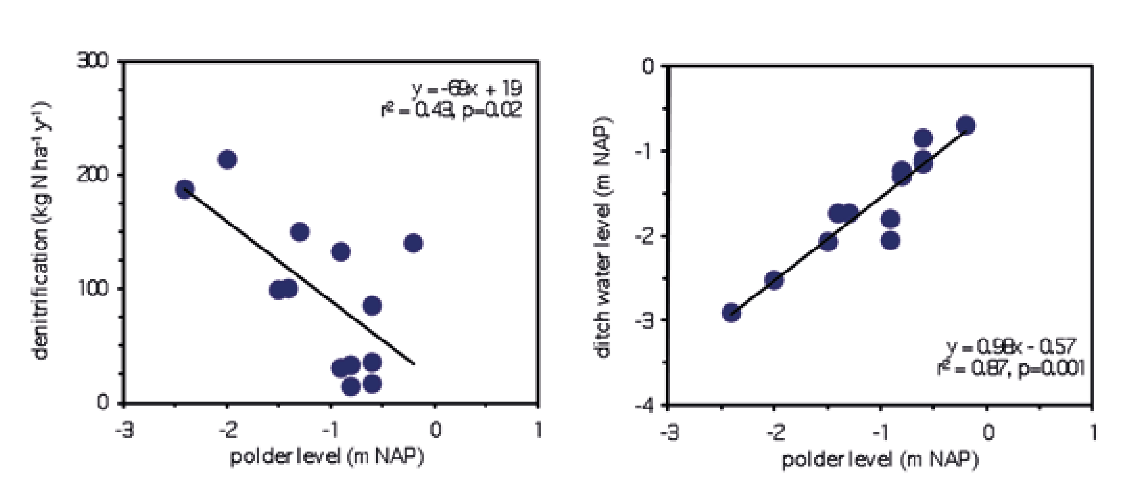

Figure 5.
Denitrification (left) and ditch water level (right) as a function of polder level. Polder level is mean level of the land above Dutch ordnance. Ditch water level (freeboard) governs ground water level, with a lag due to soil resistance and confounding by variation in seepage and upwelling.

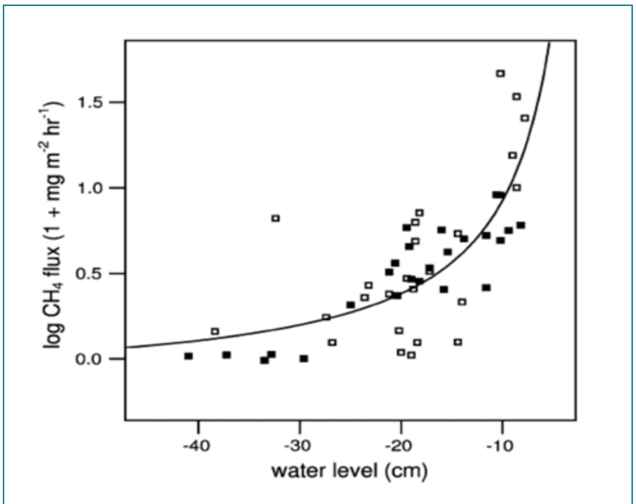

Figure 6.
Methane fluxes from different wetlands as a function of groundwater level.

4.3 How should water levels in spatial networks of wetlands be regulated to increase net storage of carbon and to decrease methane emissions?

Based on figure 6, one concludes that shallower groundwater will lead to increased methane emissions from wetland plots, hence re-wetting would be adverse. The total carbon balance of a landscape, however, also includes carbon dioxide, emissions from cattle and other land-use related practices, as well as the variation in emission factors of different types of land use and emissions from water. Vermaat et al. (in revision) observed much higher methane fluxes from highly productive ditches in intensively used pastureland than from ditches in unproductive nature reserves or from larger, deeper water bodies. Aquatic fluxes observed by Vermaat et al (in revision) were quite comparable to those of Schrier-Uijl et al (2010; fig. 7; see also Schulp et al. 2010). Methane emission estimates from representative peat landscapes based on vegetation composition are the subject of Dias et al. (in prep). Vermaat et al. (in revision) suggest that landscape- scale methane fluxes of intensively used well-drained dairy pastures and wetland nature reserves with shallow groundwater have a break-even point at a percentage open water of 65%. If the area of open water drops below this proportion, dairy land probably emits less methane. Dias et al (in prep.) work on more nuanced estimates for peat landscapes incorporating carbon dioxide and N_2O.

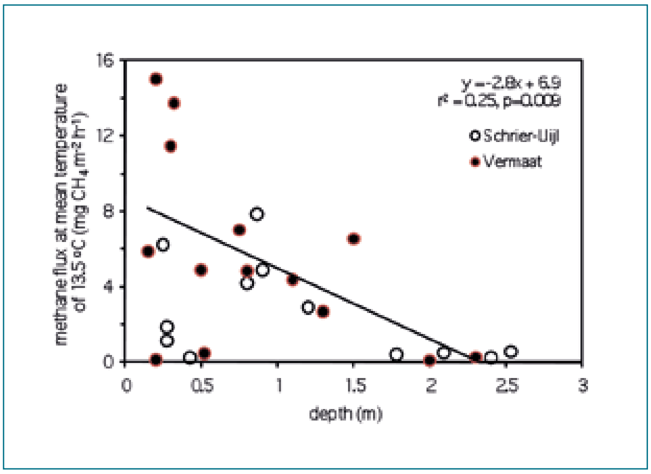

Figure 7.
Methane fluxes from Dutch water bodies (ditches, artificial lakes) as a function of depth. Field-observed fluxes were corrected to a mean annual water temperature (derived from an unpublished database on peatland ditch and pond water quality data in the surroundings of Amsterdam provided to Vermaat by WATERNET. Note that the three shallow stations with the highest methane fluxes are highly productive ditches in intensively used dairy land.

4.4 How do water quality parameters interact with the carbon balance of these wetlands?

The primary interaction is through the influence of water level, as indicated in the previous section. Spatially explicit modelling as a function of KNMI climate scenarios (Hellmann & Vermaat, submitted) suggest: (a) that we have modelled the water flow quite well and nutrients satisfactorily (cf chloride and total P budget of the Nieuwe Keverdijkse Polder, fig 8); (b) that long-term scenario runs do not lead to substantial changes in polder hydrology as witnessed from ditch water levels, but do lead to increased late summer drought in the W+ scenario, when ground water level sinks deeper than currently or under the G scenario (fig. 9). These drops in ground water level would lead to increased mineralization since it is not compensated by increased water inlet. Hence, the possibility to manage subsidence by managing ditch water level may meet its limits in case the W+ scenario materialises. Consequences for nutrients are possibly counterintuitive on first sight. The results show only different nutrient levels in the W+ scenario and not in the G scenario, with higher nitrogen concentrations and lower phosphate concentrations. Probably the reduced stream velocity in the W+ scenario results in an increased sedimentation of (adsorbed) phosphate and reduces the overall phosphate concentrations. Sedimentation is a much smaller term in the nitrogen cycle, and the increased nitrogen concentrations anticipated in summer according to the W+ scenario are therefore probably the consequence of a reduced outlet of water due to increased evaporation plus an increased delivery of nitrogen through mineralization. Possibly we incur a potential underestimation of denitrification because sediment and benthic processes are not incorporated well in SOBEK. Sediment denitrification and periphyton as well as macrophyte dynamics are now combined in an algal component in SOBEK.

As a consequence, our modelling suggests that future climate scenarios do not have major repercussions for present land use since falling groundwater in late summer is not directly detrimental to dairy farming. At the same time, given the W+ scenario, we do foresee substantial effects: increased subsidence, increased greenhouse gas emission, and increased nutrient release from mineralisation hence deteriorating water quality (Hellmann & Vermaat, submitted).

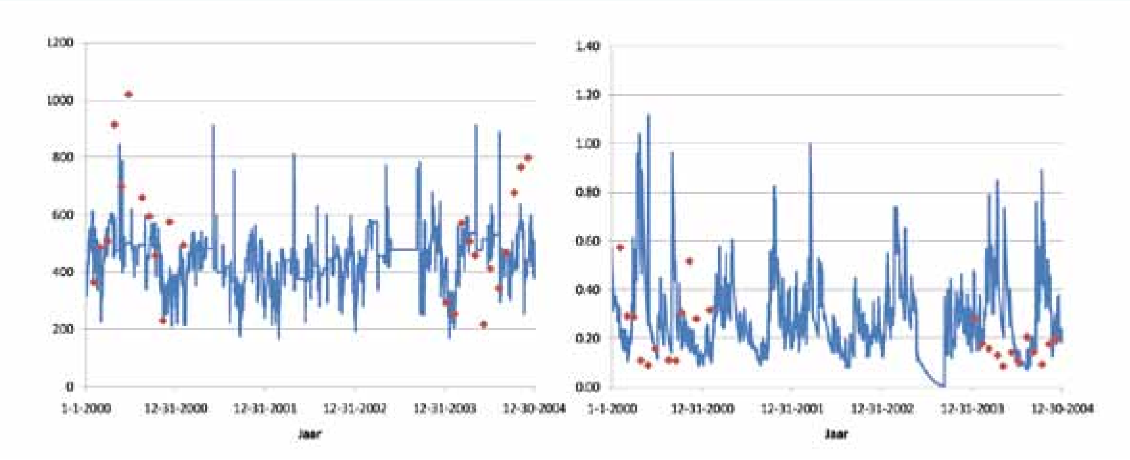

Figure 8.
Observed (diamonds) and modelled (running line) variability in chloride (left) and total P (right; both mg/L) in the main outlet of the Nieuwe Keverdijkse Polder.

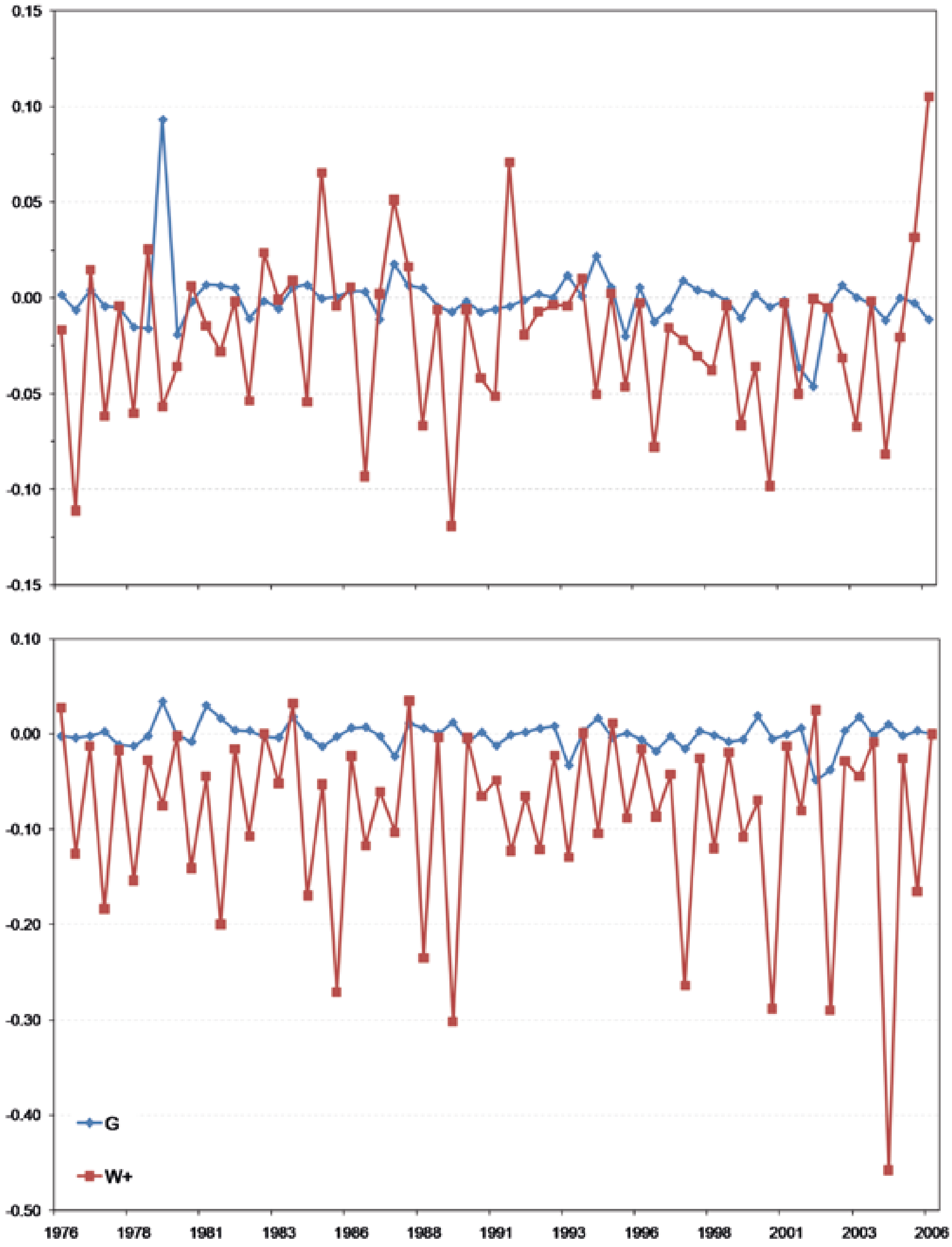

Figure 9.
Comparison of average surface water level (upper) and groundwater level (lower) in imaginary peat polder in the scenarios (i.e. period 2036-2065) vs., the current period (1976-2005) in m difference. The water level was taken at the same point near the water outlet both for the scenarios and the current period. Groundwater levels were taken from the same (arbitrarily chosen) agricultural land both for the scenarios and the current period. For each scenario, surface water level and groundwater level were compared with the water level on the corresponding date of the current period (i.e.: 1/1/2036 vs. 1/1/1976, 2/1/2036 vs. 2/1/1976, ..., 31/12/2065 vs., 31/12/2005). Thereafter, the calculated differences were averaged for each 1st part (= 1 January - 30 June) and 2nd part (= 1juli - 31 December) of each modelled year. The average difference in surface water level is -0.019 m ± 0.006, and the average difference in groundwater level is -0.086 m ± 0.013. Simulated ground water level fluctuation during 2065 in a synthetic, median peat polder as a function of KNMI climate scenario.

A full answer to the question raised in this section will remain speculative at present. Several indirect interactions can be sketched. We have interpreted water quality in the present project as nutrient availability, which is justified since eutrophication is the major water quality issue in peat polders. Firstly, we observed that highly productive ditch systems in intensive dairy land produce higher methane fluxes. This is one link, where nutrients derived from agricultural practice enhance ditch productivity, which leads to accumulation of readily degradable organic matter in the anaerobic ditch sediment, more strongly reduced conditions and a higher methane production. Water quality, hence, is an intermediate component in this causality chain, but water quality improvement would lower greenhouse gas emission, notably of methane from ditches. Secondly, enhanced mineralisation of the peat may well lead to enhanced N_2O delivery which may also contribute to enhanced direct N delivery to the ditch, hence deteriorating water quality. Here increased greenhouse gas emission and water quality deterioration are both the consequence of managed lowering of the water table, hence land use practice. In both arguments, land use appears the paramount driver.

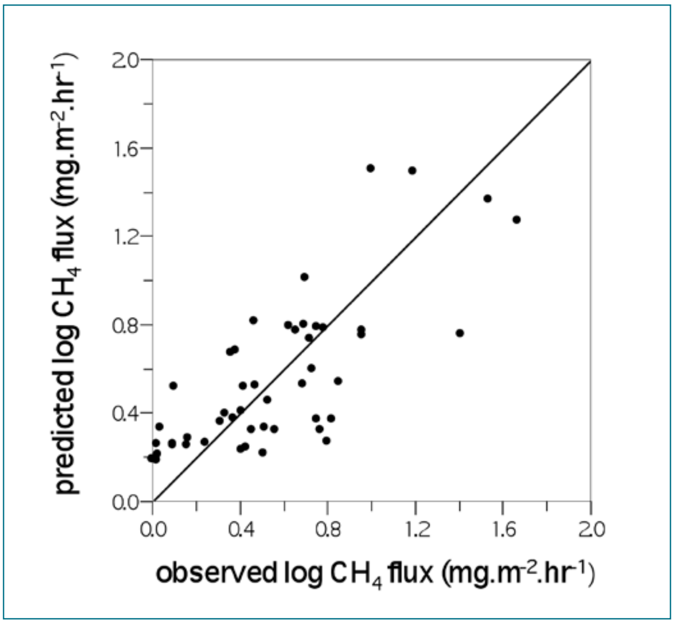

Figure 10.
Methane fluxes from different wetland communities as predicted by plant species composition (WA-regression, RMSE = 0.26, r^2 = 0.76; cf Dias et al (2010).

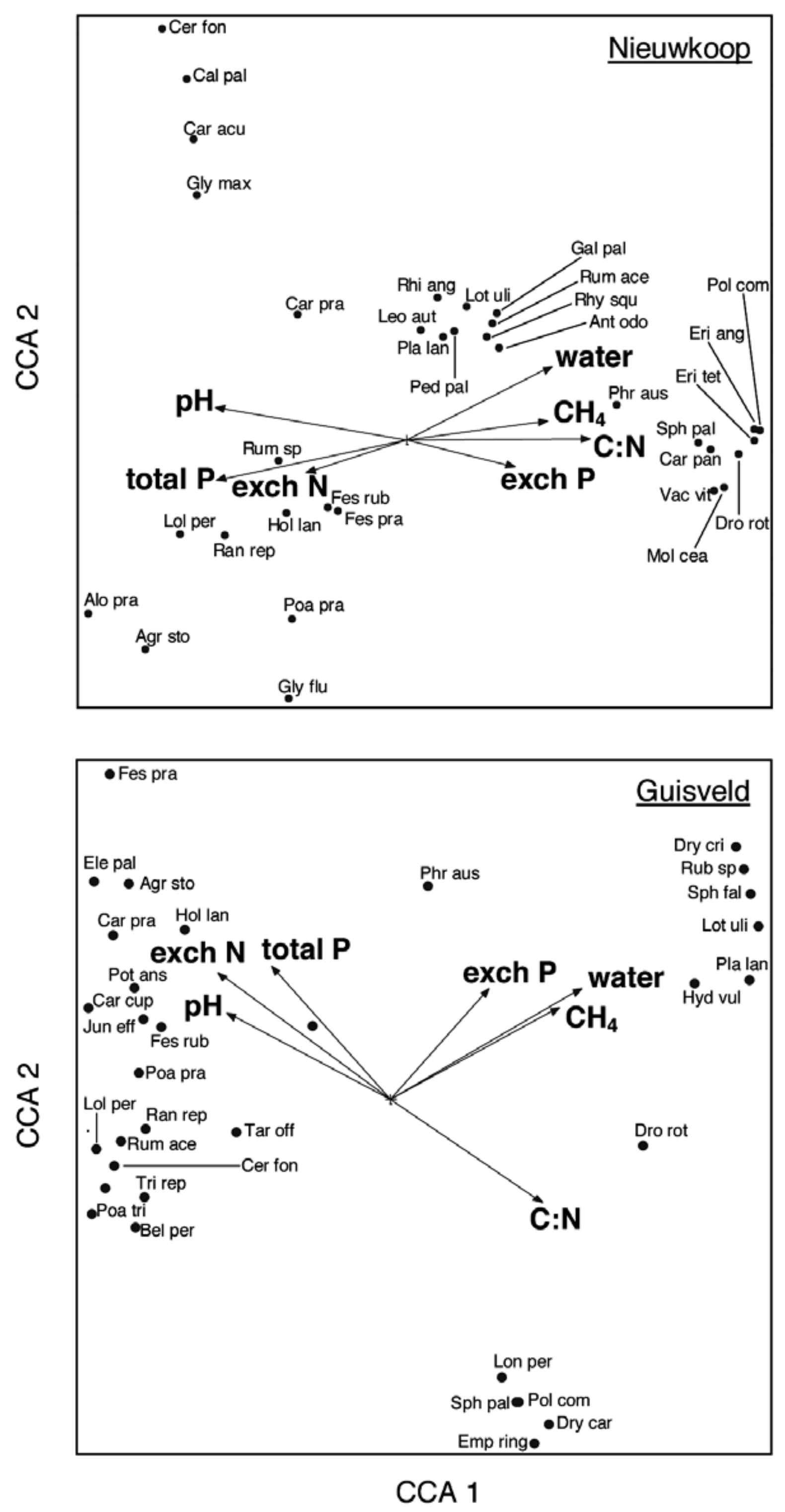

Figure 11.
CCA-plot of the covariance of species abundance and habitat variables quantified for the transects measured in Nieuwkoop and Guisveld (From Dias et al., 2010).

Table 1.
Relations of quantified habitat variables with CCA-axes for the wetland series of Nieuwkoop and Guisveld. Presented are the significant correlations among CCA axes and variables as well as two generic CCA statistics (explained variation in the species data and species-environment correlation per axis). See figure 11.

	Nieuwkoop		Guisveld	
	Axis 1	Axis 2	Axis 1	Axis 2
Explained variation in the species data by both axes	35%		34%	
Species-environment correlations	0.97	0.95	0.99	0.95
Groundwater level	0.64	0.68	0.72	-
Methane flux	0.66	-	0.64	-
Exchangeable P	0.49	-	-	0.45
Total P	-0.87	-	-0.65	0.57
Exchangeable N	-	-	-0.65	-
Total N	-	-	-	-
C/N ratio	0.83	-	0.58	-
pH	-0.86	-	-0.65	0.54

4.5 Other emerging results

Predicting methane fluxes from wetland plant community composition

Dias et al. (2010) demonstrated that plant community composition could be used very well as a predictor of methane fluxes from wetlands of contrasting land use intensity using weighted-averaging regression (WA, Fig 10). We assessed the correspondence between in situ measured methane fluxes, soil characteristics and vegetation composition in a canonical correspondence analysis (CCA, fig 11, table 1). The two landscape gradients studied (Nieuwkoop and Guisveld) reflected increasing intensitiy of land use, from a strict nature reserve to intensive dairy farming. Vegetation composition corresponded well with soil variability as grasped in groundwater level, total P, C/N ratio and pH reflecting a gradient from higher nutrient availability in dairy land coupled with higher pH, lower groundwater level and lower C/N ratios to poorer, less productive, wetter, more acid peat soils.

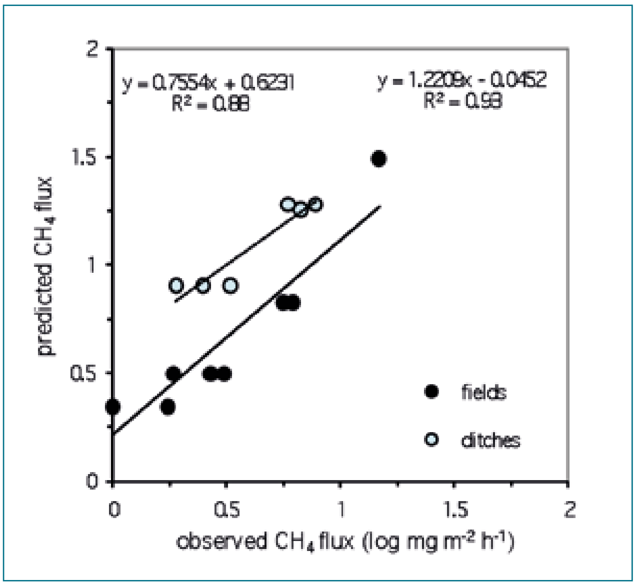

Figure 12.
Observed and predicted methane fluxes from different wetland habitats available in the literature (Dias et al., in prep). The following non-wooded habitat types have been distinguished: lolion, cynosurion, filipendulion, calthion, junco-molinion, caricion, oxycocco-ericion. These types are comparable to the alliances distinguished by vegetation scientists (cf Schaminée et al., 1995). For wooded marsh vegetation, typically birch and alder carr, no fluxes have been estimated due to the absence of data. Conversion of different classification typologies in use in the Netherlands is possible with Staatsbosbeheer et al. (2008).

We used the equation from the WA regression (figure 10) to predict methane fluxes from comparable studies where plant community composition was sufficiently well known and reached remarkable similarity. When we aggregated our findings to higher order plant community or habitat types, such as are in use in nature conservation planning, we could still predict observed fluxes reasonably well (Fig 12, from Dias et al., in prep). We are presently upscaling these to predict landscape-scale predictions of annual greenhouse gas emissions (Dias et al., in prep).

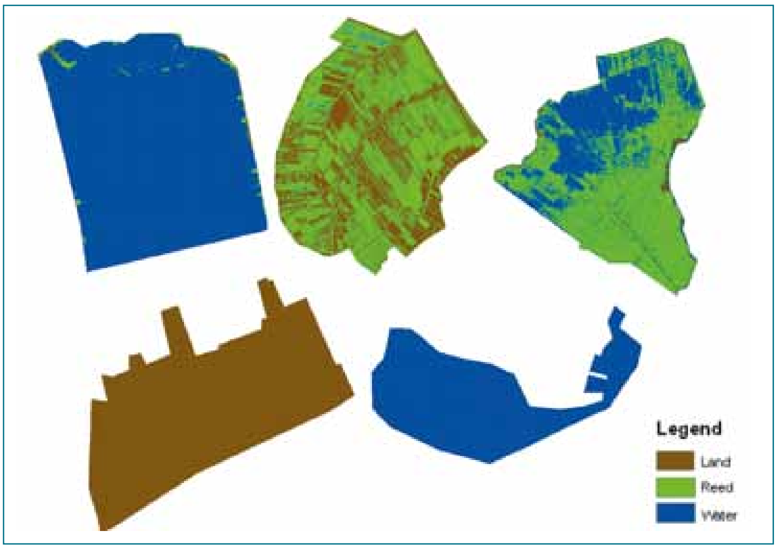

Figure 13.
Steady state allocation of land and water in 5 peat polders where pumping was terminated. All used a business as-usual climate scenario (labelled "0"). From left to right: Vlietpolder after 15 year, Rottige Meenthe after 15 year, Groot Zegveld after 50 year, the Deelen after 10 year and the Hilversumse Bovenmeent after 10 years.

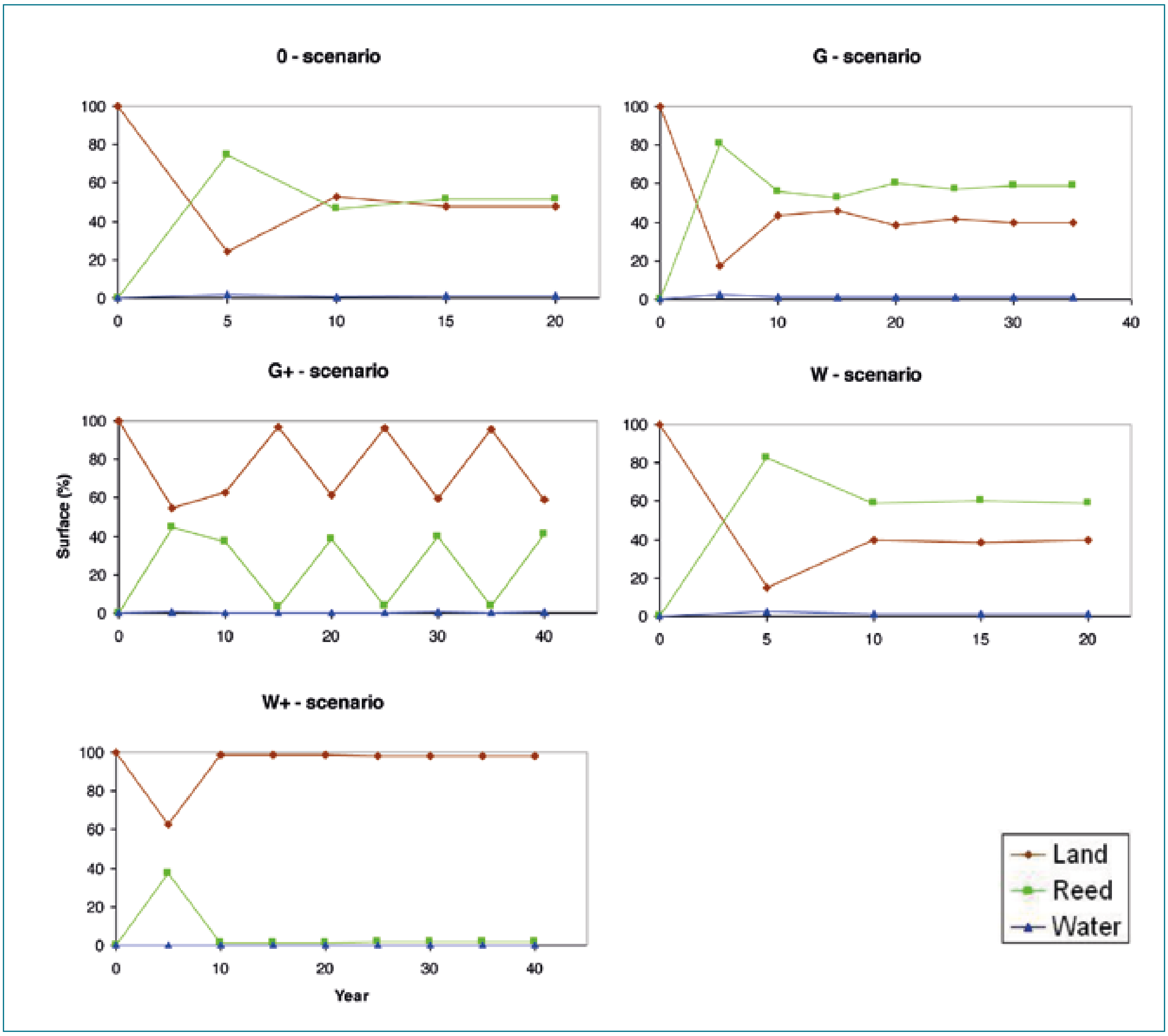

Figure 14.
The development of land, reed and open water in the Rottige Meenthe for the different climate scenarios over time. In this polder, the area of 100% corresponds to 1132 ha. Note: the time scale varies, GIS-modelling was terminated at apparent steady state. G, G+, W and W+ are the four KNMI climatre scenarios.

Flooding polders may have unexpected results

Vernooij & Vermaat (2009) estimated the landscape-scale consequences of a major change in water management, a full termination of drainage pumping in five peat polders. Depending on seepage intensity, topography and changes in evapotranspiration with changing vegetation, these polders did not all inundate homogeneously (Fig 13). Also, implementation of the four KNMI meteorological scenarios (Van den Hurk et al. 2006) led to major differences in the distribution of land and water (Fig 14).

5. Conclusions and recommendations

We follow the numbered research questions posed in section 2 here:

1. The network of ditches in peat polders was not found to contribute substantially to nutrient retention. Rather the peat soil itself is the major stock and site of retention processes. Hence landscape pattern was not found to affect nutrient retention in these peat polders.
2. Water level variability has a major effect through variation in groundwater level. This affects subsidence, greenhouse gas emissions, and nutrient availability measurably if climate change will develop is described in the W+ scenario. A more modest climate change scenario (G) will have little consequences.
3. Methane fluxes differ substantially among different types of peatland habitats, both on land and in water. Thus carbon sequestration is strongly influenced by landscape pattern. Inclusion of this variability in landscape scale emission estimates is warranted.
4. To reduce greenhouse gas emissions, eater levels in polder ditches should be managed to keep groundwater levels high and nutrient availability low. This is at odds with current land use practice.
5. Estimation of wetland methane fluxes can be done satisfactorily with help of wetland vegetation composition
6. The interaction of foreseen climate change, nutrient dynamics and greenhouse gas fluxes operates mainly through the effect of ditch water level including seepage and run-off on groundwater level. This is driven by present land use practice.

Recommendations

- We recommend carrying out experimental and in situ assessments of greenhouse gas budgets of alder, birch and willowing carrs, since these have hitherto been neglected, although they are considered alternatives for landscape scale carbon storage and potential biofuel crops.
- We also recommend reconsidering SOBEK as a modelling tool suitable to study land-water interactions that involve nutrient biogeochemistry as well. Important pathways are either not modelled or not modelled with satisfactory spatial resolution. We had to resort to manual or spreadsheet calculus for several of these during standard model runs.

6. Project output

Publications

The following papers have been published or are scheduled to be produced from the present project:

Dias. A.T.C., Hoorens, B., Van Logtestijn, R.S.P., Vermaat, J.E., & Aerts R., 2010. Plant species composition can be used as a proxy to predict methane emissions in peatlands after land-use changes. Ecosystems 13: 526–538 DOI: 10.1007/s10021-010-9338-1.

Hellmann, F., Dias. A.T.C., Hoorens, B., , Vermaat, J.E., & Aerts R., in prep. Methane emission factors for vegetation types and water bodies can be used to upscale emissions from peatland ecosystems in the context of land-use change.

Hellmann, F. & Vermaat, J.E., 2010. Hoe beïnvloedt klimaatsverandering de samenhang tussen waterhuishouding, nutriëntenstromen en broeikasgasemissies in veenweidepolders? Een samenvatting voor de praktijk. IVM report R10-10.

Hellmann, F. & Vermaat, J.E., 2011. Het effect van klimaatverandering op de waterhuishouding en nutriëntenstromen in veenweidepolders? H_2O 44(3): 25-28.

Hellmann, F. & Vermaat, J.E., in revision. Impact of climate change on water management in Dutch peat polders. Ecological Modelling.

Schulp, N, Jacobs C, Duyzer J, Van Beek C, Bosveld F, Jans W,Schrier-Uijl A, Dias ATC & Vermaat JE, 2010. Wat is de variabiliteit van emissies binnen en tussen verschillende landschapselementen en wat gebeurt er bij verandering in landgebruik? Landschap 26: 67-79, thematic issue of a range of BSIK-KvR projects on mitigation. Also refer to www.landschap.nl

Vermaat, J.E. & Hellmann, F., 2010. Covariance in water- and nutrient budgets of Dutch peat polders: what governs nutrient retention? Biogeochemistry 99:109-126 DOI 10.1007/s10533-009-9395-8.

Vermaat, J.E., Hellmann, F., Dias, A.T.C., Hoorens B, Van Logtestijn, R.S.P. & Aerts R. , 2011. Greenhouse gas fluxes from Dutch peatland water bodies: are they affected by land use? Wetlands 31:493–498 DOI 10.1007/s13157-011-0170-y.

Vernooij M., Vermaat J.E., 2009. Stoppen met pompen? Hoe verandert het waterpeil in vijf veenpolders? Landschap 26: 57-65.

Media attention, workshops and lectures

The media are sought with a press release when (a) the SOBEK models is running satisfactorily and the modelling paper accepted; (b) the paper by Hellmann et al is accepted. Jan Vermaat has participated in a public debate on surface water level adjustments in Frisian peat polders organised by the Fries Dagblad and VU-CONNECTED in Leeuwarden, March 30 on 2010.

The project organised two workshops with stakeholder representatives, as scheduled. The first workshop was held on December 11, 2006, and focused on a verification of the approach chosen, data exchange and the modelling platform to be used (SOBEK or DUFLOW). A concluding workshop was held on May 21, 2010. Project results were discussed with representatives of water boards, regional authorities (provinces), and fellow scientists. The lively debate focused on the representativity of SOBEK, the modelling environment selected following advice from the first workshop, and the consequences of KNMI-scenario outputs generated with the SOBEK model.

7. Acknowledgements

We thank our FALW technical workshop staff for help in designing and building the chambers to measure methane fluxes from terrestrial vegetation and water. Richard van Logtestijn helped in maintaining the GC in good shape. Nancy Omtzigt and Alfred Wagtendonk of IVM assisted our GIS analyses. The KNMI made its daily time series of climate scenario projections available. The water boards Waternet, Rivierenland, Rijnland, Groot-Salland and Fryslan were of great help by providing data on water quality, polder and ditch levels, as well as water budgets. Natuurmonumenten and Staatsbosbeheer are thanked for access to the Nieuwkoopse Plassen and the Guisveld reserves. The SOBEK helpdesk provided the frequently necessary elucidations of this elaborate modeling tool. Maarten Ouboter, Elmar van Veenendaal, Arina Schrier-Uijl and Christy Verbeek contributed more to our thinking than they probably are aware of. The financial and administrative staff at FALW and the KvR office assisted us with the necessary project administration and accounting.

8. References used in the text and not produced by the project team (see 6 above)

Aerts R, 2000. Possibilities for carbon storage in grasslands on peat in the Netherlands. Pp. 25-27 in Van Amstel. A. (Editor). Monitoring CO2 sinks in the Netherlands. Priorities for improvement. Wageningen University, Wageningen.

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Smolders AJP, Lamers LPM, Lucassen ECHET, Roelofs JRM, 2006. Internal eutrophication: How it works and what to do about it, a review. Chemistry and Ecology 22: 93-111.

Van den Hurk B, Klein Tank A,Lenderink G, Van Ulden A, Van Oldenborgh G.J, Katsman C, Van den Brink H, Keller F, Bessembinder J, Burgers G, Komen G, Hazeleger W, Drijfhout S, 2006. KNMI Climate Change Scenarios 2006 for the Netherlands KNMI Scientific Report WR 2006-012006.

Vermaat JE, Gilbert AJ, Hellmann F, 2009. Riparian nitrogen retention along streams and rivers in intensively used catchments in NW Europe – technical note. Report IVM 09/09.

9. Annexes

Annexe 1

Greenhouse gas fluxes from Dutch peatland water bodies: are they affected by adjacent land use?

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Abstract

Ditches and open water bodies in peatlands can contribute significantly to methane and carbon dioxide emissions to the atmosphere. These fluxes were quantified for 14 ditches and larger water bodies in Dutch peatlands, surrounded by different habitat types, using concentration changes in floating flux chambers fixed over the water surface. The grand mean greenhouse gas fluxes from peatland surface waters, aggregated across habitats, amounted to 11 ± 2 (mean ± SE) mg CH_4 m^{-2} h^{-1} (n=66) and 86 ± 21 mg CO_2 m^{-2} h^{-1}. Spatial variability in both greenhouse gas fluxes was substantial among sites and chambers, and could be explained by water depth and temperature (CO_2) and surrounding habitat (both gases; variability explained respectively 15% for CH_4 and 37% for CO_2). Ditches in intensively used or rough pasture land had significantly higher CH_4 emission rates (17±6 and 18±8 mg CH_4 m^{-2} h^{-1}) than those in reed and sedge beds or open water (7±1 and 5±2 mg CH_4 m^{-2} h^{-1}). The estimated contribution of ebullition bubbles to the total CH_4 flux varied between 34 and 69% (mean 50%), with higher proportions observed in ditches sheltered by tall vegetation (rough pasture with tall sedges, reed beds). Observed day-time CO_2 fluxes were either positive (shaded ditches in reed and sedge stands or rough pasture; 120 – 150 mg CO_2 m^{-2} h^{-1}) or did not differ from zero (open water, ditches in intensively managed pasture). Hence, these waters were generally net heterotrophic. Since these peatlands have substantial areas of permanent water (6-43%), landscape-scale carbon flux estimates are improved by incorporating type-specific flux estimates for these waters. It is estimated that well-drained dairy farmland and its cattle emits more methane than eutrophic natural wetlands when the percentage land is below 55%.

Annexe 2

Methane emission factors for vegetation types and water bodies can be used to upscale emissions from peatland ecosystems in the context of land-use change

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Abstract

Aggregate indicative methane fluxes were derived for a range of peatland vegetation, or CORINE-based habitat types of variable species composition, fertility and structure, and for peatland surface waters. These were then used to predict methane emissions measured by others for similar types of vegetation. Predictive capacity was found to be considerable: $y=2.1x-1.5$; $r^2=0.95$ $p<0.01$ for terrestrial vegetation and $y=2.3x+3.9$, $r^2=0.40$, $p=0.09$ for aquatic systems. These results allow upscaling to landscape-scale estimation of emission factors and an update of the overall estimate of methane emission from the Dutch low-lying peatlands. This is done with a GIS-analysis of the cover of relevant vegetation types in 10 peatland polders. Landscape-scale annual emissions varied considerably among polders, and this variability was dictated mainly by the proportion of open water and the intensity of agricultural land use.

Annexe 3

Front Page Fries Dagblad March 31, 2010, reporting on the public debate on water level adjustments in Frisian peat polders, and impression of the debate.

raadsma

IJzersterk in Noord Nederland

Friesch Dagblad

CHRISTELIJK DAGBLAD — Woensdag 31 maart 2010

Bartje hield niet van bruine bonen; zijn bedenker was er juist dol op *Cultuurbijlage*

De Holle Poarte is een naam van niks; Strand Makkum is veel beter *Pagina 14*

Wisselvallig weer

Bayern München 'op z'n Duits' langs Manchester United *Pagina 19*

Oplossingen voor paalrot zijn er wel, maar niemand wil betalen

tijd voor

Climate changes Spatial Planning

Climate change is one of the major environmental issues of this century. The Netherlands are expected to face climate change impacts on all land- and water related sectors. Therefore water management and spatial planning have to take climate change into account. The research programme 'Climate changes Spatial Planning', that ran from 2004 to 2011, aimed to create applied knowledge to support society to take the right decisions and measures to reduce the adverse impacts of climate change. It focused on enhancing joint learning between scientists and practitioners in the fields of spatial planning, nature, agriculture, and water- and flood risk management. Under the programme five themes were developed: climate scenarios; mitigation; adaptation; integration and communication. Of all scientific research projects synthesis reports were produced. This report is part of the Mitigation series.

Mitigation

The primary causes for rising concentration of greenhouse gases (GHG) in the atmosphere are fossil fuel combustion, land use and land use change (deforestation). Yet our understanding of interactions between land use (change) and climate is still uncertain. Climate changes Spatial Planning contributed to the development of a system that allows both the best possible 'bottom-up' estimate of the GHG balance in the Netherlands, as well as independent verification 'top-down'. This system supports better management, i.e. reductions of GHG emissions in the land use sector. In this context it addressed a.o. the possibilities and spatial implications of second generation biomass production.

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