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A scenario analysis of climate change and adaptation measures to inform Dutch policy in The Netherlands

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Abstract: The Drentsche Aa catchment in The Netherlands, which has nearly untouched natural river valleys, is a designated Natura 2000 area. Agriculture is practiced on the adjacent higher-lying ground. A set of measures was drafted to achieve climate-proof solutions in the short term by reducing the effects of a drier climate on nature and agriculture. These measures must have no adverse effects. In order to check this, the Hunze and Aa's Water Board investigated the feasibility of using groundwater for sprinkler irrigation in parts of the catchment. In the study, the SIMulation of GROundwater and surface water levels (SIMGRO) hydrological model was used in order to model future scenarios with different water level strategies and climate scenarios. The modelling examined various measures in the nature and agricultural areas to optimise the hydrological situation for both land use functions. In addition, the effect on the nature areas of abstracting groundwater for irrigation was determined for buffer zones of different widths. The findings have indicated the policy direction to be taken by both the water board and the province, as well as offer them opportunities to deal with the requests for withdrawals in the near future by the means of future-proof general rules.

Keywords: buffer zones, climate change, Drentsche Aa, hydrological modelling, policy rules, strategy water management

INTRODUCTION

The water table in many parts of The Netherlands is shallow. There is a dense network of watercourses, primarily to drain the agricultural land in wet periods, but also sometimes to supply water in periods of water shortage. The water levels in Dutch nature areas are often kept high throughout the year in order to preserve wet conditions. All this can have a significant impact on the entire hydrological system of a catchment, where groundwater and surface water are closely interlinked [Dufour 1998]. A change in one of these systems can significantly affect the other.

Although much of the country lies below sea level, further east there are higher-lying areas and the typical polder system with canals is replaced by catchments with natural stream valleys. One such catchment is that of the Drentsche Aa in the northern part of The Netherlands, which has nearly untouched natural river valleys that have been designated a Natura 2000 area. Agriculture is practiced on the adjacent higher ground.

Dutch wetland systems like the Drentsche Aa are vulnerable and particularly susceptible to changes in quantity and quality of water; even small hydrological changes can lead to major changes in plant communities and habitats [Richards *et al.* 2020]. To achieve climate-proof solutions in the near future, a set of measures was drafted to reduce the effects of a drier climate on nature and agriculture in the Drentsche Aa catchment. Very limited groundwater sprinkler irrigation is currently permitted because the stream valley has high ecological value, but such sprinkling is considered an essential measure for agriculture, to mitigate the increasing drought damage resulting from climate change.

An important precondition for allowing groundwater sprinkler irrigation is that it must have no adverse effects: for example, nature in the stream valley, particularly the seepage zones along the brook, must not be significantly influenced in a negative way. The local water board, Hunze and Aa's, therefore started a study under the aegis of the EU's Interreg VB North Sea Region TOPSOIL project, to investigate whether it is feasible to abstract groundwater for irrigation in some areas of the Drentsche Aa catchment.

The TOPSOIL project [Interreg ... undated] explores the possibilities for dealing with current and future water challenges such as summer droughts and greatly improving climate resilience. There are 16 pilot projects, three of which are in The Netherlands. One of these is the Drentsche Aa project. Its objective is to find measures to mitigate the increased water shortage in summer due to climate change in the catchment. The modelling experiments in this project are intended to clearly indicate where solutions might be found or to reveal feasible measures, so that general future-proof rules can be drawn up in a broader policy context, to assist the water board and provincial authority when deciding on how to respond to farmers' requests for water use.

In this pilot project, a groundwater model was used to study the effect of increased drought due to climate change and to develop measures to reduce the increasing drought risks for nature and agriculture. Stakeholders were involved in the actualisation of the model and during the evaluation of measures.

For the situation in the Drentsche Aa, a regional conceptual hydrological model can be used to describe the system [Blair, Buytaert 2016; Ho *et al.* 2016; Thomson *et al.* 2017]. Analytical models are often used to predict the changes to the hydrological system, but these models cannot handle complex situations, like climate change. A simulation model should be physically based so that it can be used to synthesise past hydrological events and future climate change conditions and to evaluate the effects of measures applied to the hydrological system. Spatially distributed hydrological models are useful tools to support policy making. They enable the dynamics of flow between aquifer systems and interconnected streams to be explored using coupled stream–aquifer interaction models that can take account of the interdependence of groundwater and surface water [Bradley 2002; Thompson *et al.* 2009].

To ensure that a nature area is conserved, its eco-hydrological functioning (groundwater flow pattern, groundwater quality, and surface water conditions) must be assured [Gulbinas *et al.* 2007; Wassen *et al.* 2006]. It is, therefore, crucial to understand such hydrological systems by using hydrological models and to predict the effect of measures in combination with climate change. This entails analysing and assessing the groundwater and surface water system as a whole, not separately, and not decoupling the unsaturated zone from the saturated groundwater system [Thomson *et al.* 2017; Yassin *et al.* 2019]. To do so, an integrated modelling approach on a regional scale is required, combining both groundwater and surface water. It was for such practical situations that the SIMulation of GROundwater and surface water levels (SIMGRO) model was developed and refined [Querner 1997; Querner, Rakhorst 2006]. The model simulates the flow of water in the groundwater and the surface water. As it is physically based, it is suitable for use in situations with changing hydrological conditions, such as those resulting from climate change. Such a hydrological model can be used in complex catchments for a scenario analysis that focuses on identifying feasible measures for underpinning decision-making.

In the ongoing Drentsche Aa pilot project, we use a regional hydrological model to analyse the complex situation in a catchment where groundwater is the source of water for sprinkler irrigation. When considering a short scenario horizon of, say, 2050, it is also necessary to investigate the effect of climate change and drought conditions. We applied the model to the Drentsche Aa catchment and its surroundings, to illustrate the methodology development and the results obtained.

MATERIALS AND METHODS

SIMulation of GROundwater and surface water levels (SIMGRO) is a physically-based spatially distributed hydrological model that simulates regional transient saturated groundwater flow, unsaturated flow, actual evapotranspiration, irrigation, stream flow, groundwater and surface water levels as a response to spatially and temporally distributed precipitation, potential evapotranspiration, and groundwater abstraction (Fig. 1). For a compre-

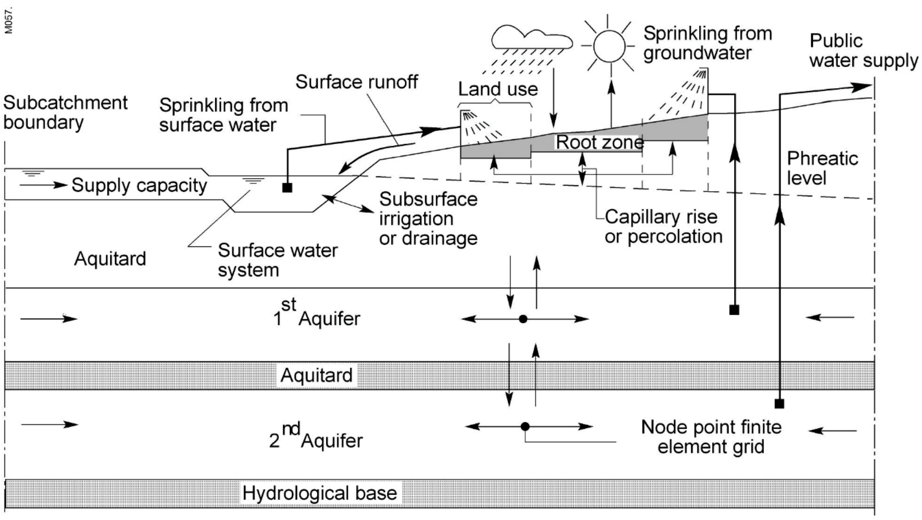

Fig. 1. Schematisation of water flows in the SIMulation of GROundwater and surface water levels (SIMGRO) model; the main feature of this model is the integration of saturated zone, unsaturated zone, and the surface water systems within a subcatchment [Querner 1997]; source: own study

hensive description of SIMGRO, including all modules and model parameters, see QUERNER [1997]. For a case study in a river basin see QUERNER and POVILAITIS [2009].

To model regional groundwater flow in SIMGRO, the hydrological system must be schematised geographically, both horizontally and vertically. The groundwater system is schematised through a finite element network. The horizontal schematisation allows different land uses and soils to be input, to simulate spatial differences in the transient evapotranspiration and moisture content in the unsaturated zone. The unsaturated zone is represented by two reservoirs, one for the root zone and one for the underlying soil [WÖSTEN *et al.* 1985]. For the saturated zone, various aquifers and aquitards can be considered, and SIMGRO permits spatially distributed parameters (e.g., transmissivity) to be specified. In the model, the surface water system is considered to be a network of reservoirs. The inflow to one reservoir may be the discharge from the various streams, ditches, and surface runoff. The outflow from one reservoir is the inflow to the next downstream reservoir. The stage depends on surface water storage and reservoir inflow and discharge. In the model, three drainage subsystems are used to simulate the interaction between the aquifer and surface water. This interaction is simulated for each drainage subsystem, using a drainage resistance factor and the difference in level between groundwater and surface water [ERNST 1978]. Parameters for the drainage subsystems may vary over the modelled area. Snow accumulation and melting have also been accounted for in the model, based on mean day temperature.

The SIMGRO model operates within a geographic information system (GIS) environment. This allows digital geographic information (e.g., soil map, geo-hydrological characteristics, land use, streams) to be easily converted into model input data. Furthermore, it is extremely valuable for the presentation of the results; more importantly, it helps to understand the effect mitigating measures have on geo-referenced catchment characteristics.

The modelling area covers 1200 km^2 and is in the north of The Netherlands (Fig. 2). The area of main interest is approximately 310 km^2 and covers the basin of the river Drentsche Aa. There is a south–north gradient from about 24 m above Amsterdam Ordnance Datum (NL: Normaal Amsterdams Peil – NAP) to about –2 m NAP. The soils are sandy in the higher parts, with clay and peat in the stream valleys and the lower parts. Mean annual rainfall is about 800 mm and potential evapotranspiration is around 500 mm. The main land uses are agriculture (46%), nature reserves (41%), and built-up areas (13%). The subsurface is complex and consists of subglacially deposited till of Saalian origin, in which periglacial snow meltwater runoff has eroded shallow valleys [MENTING, MEIJLES 2019]. Overlying the till are undulating aeolian cover sands and periglacial fluvial deposits of about 0.5–2.0 m thick. Peat formation and local alluvial deposition used to occur in the valleys, but since the valleys have been taken into agriculture, the peat layer has been slowly oxidising and subsiding. In the stream valleys, there is strong seepage of groundwater from the higher-lying areas.

For the SIMulation of GROundwater and surface water levels (SIMGRO) model, the groundwater system needs to be schematised by means of a finite element network. The network in our study comprises 49,050 nodes spaced about 200 m apart in

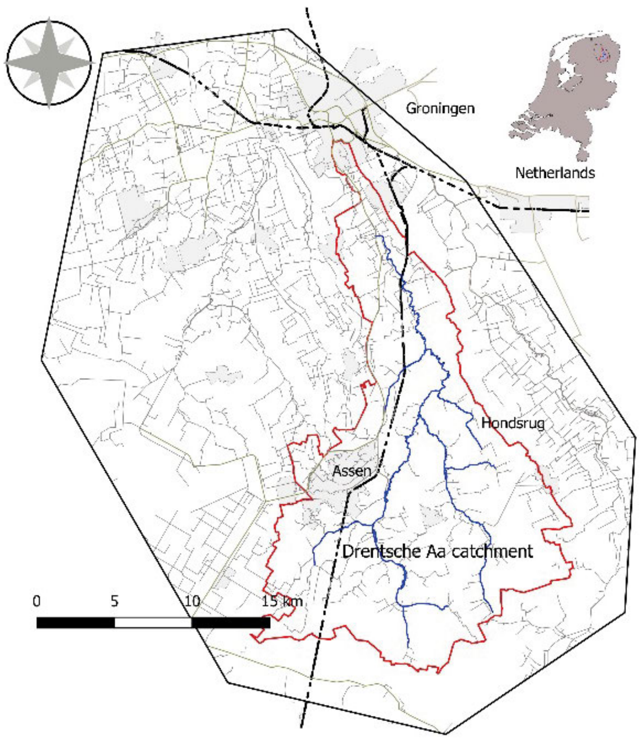

Fig. 2. Map showing the northern part of The Netherlands, the modelling area, and the Drentsche Aa catchment; background lines are the water courses controlled by the water board; source: own study

the area of interest and 75 m apart in the stream valleys. To model the surface water, the basin was subdivided into 5625 subcatchments [QUERNER, RAKHORST 2006]. The geology of the area is quite complex, due to influences from the Pleistocene period, permafrost, tectonic movements, and influences from wind and water. Of major influence on the groundwater flow patterns are the resistant layers formed by boulder clay, which result in large areas with perched water tables. The initial SIMGRO model was unable to simulate these perched water tables (model layer 2): in some areas, the phreatic groundwater levels were about 2 m too low. Therefore, it was necessary to improve the model, so that on the basis of the hydraulic head below and above the boulder clay, the vertical resistance is adjusted to simulate the flux through this clay layer correctly. In addition, the storage coefficient above and below the clay layer needed to be changed during the calculations, depending on whether a perched water table was present. After improving the model, the calculated phreatic levels were close to the measured ones [QUERNER 2018].

The spatially distributed features in the Drentsche Aa catchment were modelled using the available digital data, which included the topography (scale 1:10,000): the boundaries of the polders in the northern part, and the free draining areas in the higher areas of the Drentsche Aa, the land uses, soil types, also the hydrogeological parameters (the hydrographic network); and the positions of hydraulic structures. A summary of the input data is given in Table 1, together with the value or range used in this model application. Meteorological data were taken from four weather stations covering the modelling area.

During the implementation of the Drentsche Aa project, various improvements were made to the model input, for example, relating to the anisotropy, tube drainage data from field inventories, and the evapotranspiration of forests. In

Table 1. Overview of data input for the SIMulation of GROundwater and surface water levels (SIMGRO) model

Parameter	Source of data	Required in schematisation	Range of value or reference
Surface water			
Invert levels and dimensions water courses, sluice gates, and weirs	G	W	–
Flow resistance	L	W	33 $m^{1/3} \cdot s^{-1}$
Map of subcatchments	G	–	–
Groundwater			
Land use	G	N	digital data base
Physical soil properties	L	N	WÖSTEN *et al.* [1985]
Thickness of root zone per land use	L	U	0.40–1.00 m
Elevation	G	N	from −2 to +24 m MSL
Transmissivity aquifers (layers 1, 3, 5 and 7)	L	N	range 5 to 7000 $m^2 \cdot d^{-1}$
Thickness of aquifers (layers 1, 3, 5 and 7)	L	N	from 0.1 to 180 m
Vertical resistance aquitard (layers 2, 4, 6)	L	N	range 5–100,000 d
Thickness of aquitard	L	N	from 0.5 m to 180 m
Drainage resistance of major streams	F	N	20–1200 days
Depth of ditches	F	N	<1.50 m
Drainage resistance of ditches	F	N	50–500 days
Drainage resistance of subsurface drains	F	N	<200 days
Measured data			
Meteorological data, groundwater levels, and discharges	F	N, W	daily data

Explanations: G = GIS data, F = field data, L = literature, N = nodes of finite elements, U = land use and soil unit, W = watercourse.
Source: own study.

addition, specific input data was required for some scenarios, such as sprinkler irrigation, autonomous developments, the climate data for 2050, and the anticipated raising of the invert of the mainstream.

Simulations were carried out for a period of eight years (2000–2008). The year 2003 was exceptionally dry: a 10% dry i.e., conditions that occur once in ten years. The model results were compared with measured river discharges (nine locations) and groundwater levels (about 800 piezometers). Details are given in QUERNER *et al.* [2005] and QUERNER [2018]. The differences between measured and calculated results were deemed to be small, so it was concluded that the final model could be used to analyse climate change and anticipated mitigating measures in the catchment.

The modelling assumed that by about 2050 the winters will be wetter and summers drier, and more groundwater will be needed to irrigate crops. To prevent the nature areas in the valley along the Drentsche Aa from being negatively influenced by the resulting increased groundwater abstraction and irrigation, adaptation measures will therefore be required. Buffer zones could protect the nature areas against the effect of lowering groundwater levels or a reduction of seepage toward the nature area.

For sprinkler irrigation, a worse case situation was considered in which sprinkler irrigation is applied to all the agricultural areas in the catchment except in buffer zones around the nature areas. The width of the buffer zone varied between 300 and 1000 m in the different scenarios. In this way, the potential cumulative effect of all sprinkling in the area was taken into account. Preliminary model runs with different widths of buffer zones revealed that 500 m was a feasible width with few adverse effects (lower groundwater levels) and could be combined with effective adaptation measures. Initially, the amount of irrigation required for the entire agricultural area was based on what was required in the very dry year 2003, so the amounts considered were 100 and 75 mm. However, the effects on the nature areas were unacceptable and therefore the amounts were reduced to 50 and 25 mm.

Mitigating measures to cope with the autonomous developments foreseen by the water board and provincial authority include re-meandering the main stream, retaining water by removing or blocking small ditches, and removing small embankments along the Drentsche Aa. These measures were considered because they are part of the water management strategy for applying the Water Framework Directive [Directive 2000/60/EC] in The Netherlands.

One measure considered in the agricultural areas was to raise the tube drains from their current depth of 1.1–1.4 m to 0.8 m. In nature areas, a measure considered entailed replacing 40% of the pine forest with deciduous forest, as this vegetation requires much less water. After running the simulations, it was attempted to optimise the measures for nature and agriculture by agreeing on a combination of measures that benefit both land uses, as this would improve the likelihood that stakeholders will support the climate adaptation initiatives.

The climate conditions around the year 2050 were based on meteorological data for the years 2000–2014. Changes in temperature, precipitation, and evapotranspiration for the most extreme scenario W_H from the Dutch Royal Meteorological Institute [KLEIN TANK *et al.* 2014] were used for the scenario calculations. This climate scenario has a temperature rise of 2°C (warm) and a big change in air flow (high value), because the climate becomes wetter in winter, and much drier in summer.

The calculation focused on the effects in the 10% dry year (2003) and the groundwater level in the following spring. The fall in the groundwater level and the change in the seepage in the nature reserves were quantified. For the nature areas, the change in the groundwater level at the end of summer, average lowest groundwater level over a period of 8 years (GLG – NL: Gemiddeld laagste grondwaterstand), the average spring groundwater level over the same 8 years (GVG – NL: Gemiddelde voorjaarsgrondwaterstand), and the seepage are important. The following criteria were set, to preclude significant effects on wet nature: no significant ecological effects are to be expected if the reduction of GLG is <5 cm, the reduction of GVG is <1 cm and the change in seepage during the period of August 15 to September 15, 2003, is <0.1 mm·d^{-1}.

After some preliminary analyses, four scenarios were chosen to clearly distinguish the effects of some measures and to assist the water board and the province when deciding on farmers' requests for water use. The benchmark scenario was the current situation with no sprinkler irrigation. In the first two scenarios, the current climate was assumed but the amount of irrigation differed. In the third scenario, the effect of climate scenario W_H for 2050 was considered. The fourth scenario considered that scenario but with mitigating measures (see Tab. 2).

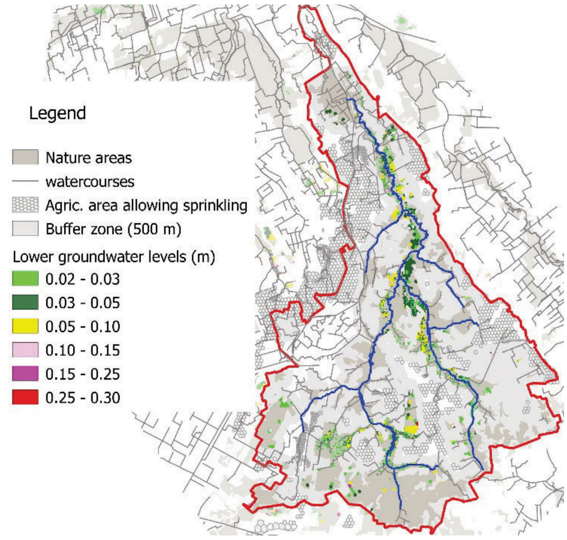

Fig. 3. Scenario 1, in which zones can be irrigated with 50 mm·y^{-1} from groundwater; the width of the buffer zone around the nature areas was assumed to be 500 m (light gray area); source: own study

Table 2. Overview of the scenarios and the main assumptions

No.	Climate	Name	Description
0	2000	Benchmark	Current situation (no sprinkler irrigation)
1	2000	Irrig-50	Groundwater irrigation 50 mm·y^{-1} and a buffer zone of 500 m around nature areas without abstractions
2	2000	Irrig-25	Groundwater irrigation 25 mm·y^{-1} and a buffer zone of 500 m around nature areas without abstractions
3	2050	W_H-climate	Effect of climate change on water-dependent nature in 2050
4	2050	W_H-measures	Effect of adaptation measures in groundwater-dependent nature in 2050. Measures considered: autonomous developments, raising riverbeds, raising tube drain levels, and converting coniferous forests into deciduous forests

Explanations: W_H = extreme scenario from the Dutch Royal Meteorological Institute.
Source: own study.

RESULTS

In scenario 1 we considered 50 mm·y^{-1} of irrigation and a buffer zone of 500 m as shown in Figure 3. The results showed for the year 2003 that the change in groundwater level exceeded the acceptable 0.05 m criterion in some areas only (yellow shading, see Fig. 3). A refinement of the legend, below the 0.05 m criteria, shows that there are large areas with changes in groundwater level between 0.02 and 0.05 m (dark and light green areas). Scenario 1 can be combined with additional mitigation measures so that the criteria are met. Scenario 2 with less irrigation (25 mm·y^{-1}) meets the criteria everywhere, i.e., the change in groundwater level is less than 0.05 m.

Climate scenario W_H with drier conditions in summer results in lower groundwater levels (see Fig. 4). Due to climate change, in winter the groundwater levels rise by as much as 0.05–0.3 m and the lowest groundwater levels are approximately 0.05–0.30 m lower (Fig. 4). On the Hondsrug (a ridge formed in the ice age), the higher groundwater levels in the winter still affect the levels at the end of the summer. More water is drained away in the valley, because of the higher precipitation in winter, but the discharges in summer decrease further due to less precipitation and higher evaporation.

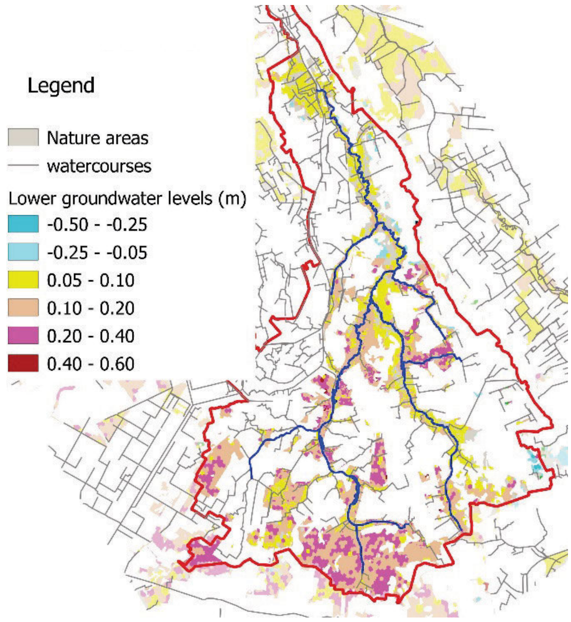

Fig. 4. Scenario 3, with the climate scenario W_H with groundwater level change (in m) at the end of a dry summer; source: own study

Figure 4 shows the effects of the climate change; Figure 5 shows the combined effect of climate change and mitigation measures. In some parts of the stream valley the impact of climate change (lower groundwater levels) is noticeably reduced by the measures. In addition, in parts of the stream valley, climate change is reasonably mitigated by new measures, but in the main part of the valley it is not. In the southern part of the catchment area in particular, mitigating measures have less effect on the change in GLG, but in the northern part there are fewer possibilities for mitigation.

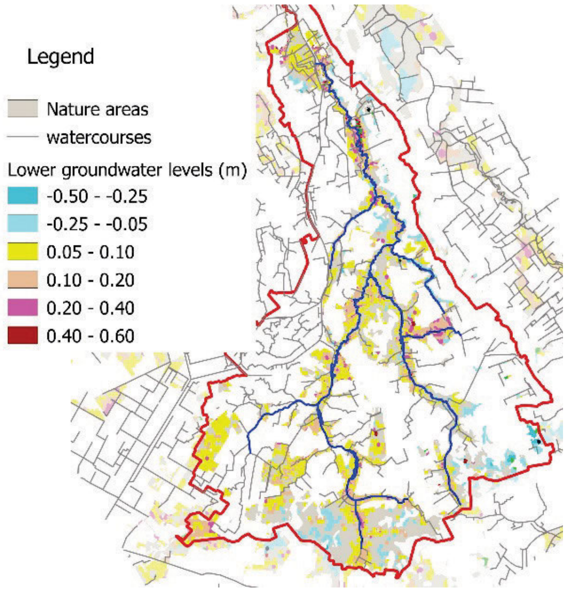

Fig. 5. Scenario 4 shows the effect of scenario 3 together with mitigating measures such as raising riverbeds, raising tube drain levels, and converting coniferous forests into deciduous forests; source: own study

DISCUSSION

The modelling investigated scenarios drawn up in consultation with the project team and stakeholders and in which measures were applied in the nature and agricultural areas to optimise the hydrological situation for both land use functions. The effect on the nature reserves of groundwater abstraction for irrigation was determined, assuming buffer zones of different widths. Subsequently, it was attempted to optimise the measures for nature and agriculture because a combination of measures in which both nature and agriculture benefit makes it more likely that stakeholders will support climate adaptation initiatives.

After discussing the most effective measures with policymakers from the province, the water board (as regional water authority), the farmers' association, and the nature organisations, it was agreed that the proposed policy measure for the Drentsche Aa catchment should be to raise the levels of the tube drains [Querner Consult, SWECO 2020]. The measure that entails converting pine forest into deciduous forest has been included in several policy documents as a serious option to consider for increasing the deep groundwater recharge. The measure of raising riverbeds has already been implemented in pilot projects along stretches of several kilometers of the river. The large-scale implementation of this measure will depend on the outcome of these pilots and the associated costs.

The water board is currently engaged in a study to refine the buffer zones around nature areas. Once the buffer zones have been decided, sprinkle irrigation with groundwater will be permitted only in the agricultural area outside these buffer zones.

CONCLUSIONS

In the northeastern part of The Netherlands, with sandy soils, agricultural systems often rely on sprinkler irrigation, which can conflict with nature conservation targets and with domestic water demand because water resources are limited. Climate change could aggravate these conflicts by bringing a drier climate, and hence, reducing water availability and increasing irrigation demands, thus creating a need for adaptation actions. However, the creation of adaptation plans requires local policymakers and stakeholders to be involved to ensure that the plans are adjusted to local physical conditions and to secure investment in the implementation phase. This involvement requires innovative methodologies to ensure that knowledge gained from advanced hydrological methods can be effectively transmitted for use.

Climate change is already being experienced in the Netherlands: the most recent three years have been extreme, with warm and dry summers, while spring 2020 was much wetter than average. In the Drentsche Aa, falling groundwater levels in summer will have a great impact on nature in the stream valleys. Few measures are available to counteract this negative effect of climate change.

Implementing the Water Framework Directive poses a challenge for water managers in the Drentsche Aa catchment. First of all, they are faced with a system that is physically complex and for which expert knowledge is largely based on computer models and is often associated with uncertainty. Decision-making is participative in The Netherlands, and hence water-related decision processes must deal with competing values, preferences, and perspectives of many different stakeholders. As water is a vital resource, the stakes are high. The climate adaptation measures applied to nature and agricultural measures should be optimised so that there is agreement on a combination of measures that benefit both nature and agriculture. An analysis like the one described in this paper gives all stakeholders the feeling that climate adaptation measures are in the interest of all parties, which makes it more likely that they will support the initiatives.

The research has given a clear indication of the direction a common policy for water board and province should take and offers them opportunities to use general future-proof rules to deal with requests for groundwater withdrawals in the near future.

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