

Spatial planning for adapting to climate change

P.E.V. van Walsum*, J. Runhaar* and J.F.M. Helming**

*Alterra, Wageningen University and Research Centre, P.O. Box 47, 6700 AA Wageningen, The Netherlands (E-mail: paul.vanwalsum@wur.nl; han.runhaar@wur.nl)

**Agricultural Economics Research Institute (LEI), Wageningen University and Research Centre, P.O. Box 29703, 2502 LS, The Hague, The Netherlands (E-mail: john.helming@wur.nl)

Abstract During the past decades human interference in regional hydrologic systems has intensified. These systems act as an integrating medium. They link climate, human activities and ecologic processes through groundwater and surface water interactions. For simulating these linkages an integrated regional hydrologic model has been coupled to an ecologic evaluation model. The simulated ecologic effects of climate change on mesotrophic riverine grasslands are clearly positive. Simulation results also indicate a high sensitivity of the peak discharges to the precipitation. For modelling the long-term development of land use and water management an integrated 'bio-economic' model has been constructed. It includes a model for the development of agriculture. Results for the autonomous development in reaction to climate change indicate a strong increase of field drainage by agriculture. This development would substantially reduce the predicted positive effects of climate change on riverine grasslands. The challenge is to guide regional developments in such a manner that opportunities for improving nature are not lost, but that at the same time the peak discharges are kept under control. Flow retardation in the 'fine arteries' of the upstream areas appear to be a viable option for the latter. The bio-economic model can provide help in anticipating on climate change through spatial planning.

Keywords Bio-economic model; climate change; desiccation; peak discharges; spatial planning

Introduction

During the past decades human interference in regional hydrologic systems has intensified. These systems act as an integrating medium, linking climate, human activities and ecologic processes through groundwater and surface water interactions. For more than a decade now the 'desiccation' of Dutch rural areas has been the subject of many studies. This desiccation is for instance caused by the artificial drainage of agricultural lands. Of more recent date is the interest in the potential impacts of climate change. That interest has mainly focussed on peak river discharges, and not without reason. Given the apparent severity of the effects, it is becoming increasingly clear that a paradigm change is needed in water quantity management, involving a shift from 'battling against water' to 'living with water'. But the latter requires a lot more space for (temporary) water storage. So the success of this new strategy depends heavily on an adequate co-ordination with spatial planning. At the same time 'old' issues of nature desiccation and agricultural productivity should of course not be forgotten, and comprehensive solutions should be sought that provide a blueprint for a balanced regional development.

In the following we first describe the simulation of the integrated water and land system. Then follows a brief description of the integrated 'bio-economic' model for predicting the long-term development of a region. This model can provide suggestions with respect to cost-effective spatial developments and the accompanying regional water management. An example is given of a blueprint for a development involving peak-flow reduction and reduction of nature desiccation.

Methods

Linked simulation models

For predicting effects of measures on a regional hydrologic system and its dependent functions the following models have been coupled:

- SIMGRO (Van Walsum *et al.*, 2004) for the regional hydrology; SIMGRO is an integrated finite-element model with a two-way coupling of submodels for soil water, groundwater and surface water;
- NATLES (Runhaar *et al.*, 1999) for evaluating soil and water site-conditions in terms of the potential type of natural vegetation that can develop; the outcome of NATLES is here given as 'percentage desiccated area', applied to the stream valleys, because they are the most valuable;
- DRAM (Helming, 1997) for the development of agriculture; DRAM is a regionalized mathematical programming model of agriculture in The Netherlands.

For understanding the simulated effects of climate change on natural vegetations, special attention is paid here to the coupling between SIMGRO and NATLES.

The model NATLES for effects on the potential value of vegetation in nature areas requires data with respect to the management (mowing or grazing of grasslands), soil type, soil water and groundwater conditions. The soil moisture conditions are expressed in terms of the average number of days with a pressure head less than -12 m. This measure for the moisture stress was found by Jansen *et al.* (2000) to be a good predictor for the number of xerophytes. These are species adapted to dry conditions in a number of different ways. For example, by being able to reduce the transpiration in dry periods, or by surviving dry periods in the form of seed. The groundwater conditions are given in terms of the so-called Mean Spring Water table (MSW) and the 'gross seepage flux to the root zone'. The availability of calcium-enriched upward seepage for pH-buffering is of crucial importance for the development of valuable mesotrophic riverine grasslands in stream valleys. In the prediction of climate-change effects this availability plays a key role. In Figure 1 a schematic diagram is given of the manner in which the seepage to the root zone is computed as a post-processing step of the model SIMGRO.

The mechanism at play involves the build-up of a rainwater-lens (area enclosed by water table and dotted line in Figure 1) on top of the groundwater that seeps up from the deeper aquifer. This lens is thickest in winter and becomes thinner during the summer

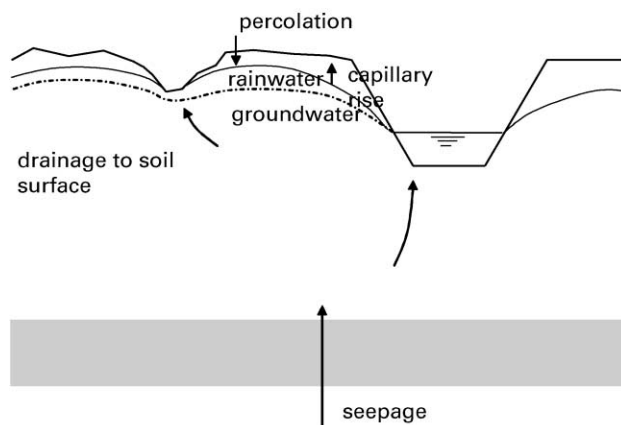


Figure 1 Calculation of the 'gross seepage flux to the root zone', involving a dynamic simulation of the rainwater-lens. Drainage to the soil surface and capillary rise are counted as seepage to the root zone at times when the rainwater-lens is not present

half-year. A simple approach is followed for computing the seepage flux to the root zone, by making an upper-bound estimate. The assumption is made that as long as there is a rainwater-lens and at the same time there is drainage to ditches, the drainage water will purely consist of rainwater stored in the lens. When the lens has vanished, the drainage to the soil surface and capillary rise is counted as seepage to the root zone. In reality some of the drainage to ditches will consist of deep seepage water long before the rainwater-lens has completely gone. So the lens will exist longer than is predicted in the simplified approach, and thus the seepage to the root zone will in reality be less than what is calculated (Van Walsum *et al.*, 2002a).

Bio-economic model

The model coupling mentioned above is of the conventional type; the models are run one after the other. Questions can be answered of the type ‘What is the effect of removing all agricultural drainage on the (potential) value of wet nature areas?’ The models cannot, however, be used for answering questions of the type ‘What is the most cost-effective way to increase the percentage of valuable wet mesotrophic natural grasslands by 10%?’ To answer such questions a model is needed that is more fully integrated. We developed such a ‘bio-economic’ model using large-scale linear programming (LP) as the integration framework.

For obtaining a LP-model of a regional hydrologic system and its dependent functions there are two main techniques available, as e.g. explained in Gorelick (1983). The first is that of *embedding*, which involves the wholesale inclusion of (part of) a model. The second is that of first deriving a *repro-function*, which reproduces the behaviour of the simulation model for a specific type of measure. The repro-function is then included in the LP-model. Both techniques have been used for constructing the bio-economic model ‘WATERWISE’. Full details of the model (including the modelling of regional nutrient fluxes) are given in Van Walsum *et al.* (2002b); a brief description is given in Van Walsum *et al.* (IAHS/IWRM, submitted).

For relating land and water management measures to peak discharges of the streams a sensitivity analysis with SIMGRO is performed. The incremental peak-flow contributions of the spatial planning units are stored as coefficients of the bio-economic model. For handling the multiple goals the simple constraint method is used: the user/stakeholder sets constraints on the desiccation of nature areas and on the desired reduction of the peak discharges (taking into account the effects of climate change). The bio-economic model first ascertains whether there is a solution at all, and (if there is one) then finds the land and water use pattern that satisfies the constraints and at the same time optimizes the revenue from agriculture.

The bio-economic model has been implemented with the XPRESS-mathematical programming package of Dash (Dash, 2003).

Case study

Study region

The models have been applied to the Beerze and Reusel stream basins in The Netherlands. The twin basins cover an area of some 45 000 ha. The subsoil mainly consists of sandy deposits formed in the Pleistocene. The region gently slopes in a north to northeast direction, from an altitude of 45 m+MSL (m above Mean Sea Level) down to 3.7 m+MSL.

The simulation model involves roughly 12,000 nodes for the spatial discretisation (soil water and groundwater modelling) and 3000 trajectories for the surface water modelling. For the bio-economic model the 12,000 nodal subdomains are grouped into 4000 spatial planning units. The implemented LP-model has roughly 200,000 functional decision

variables, 60,000 active equations, and about 2 million coefficients in the matrix. A single run requires roughly 0.5 hour.

Climate scenarios

For the climate scenarios we used a weather series generated for 2070–2100 by the General Circulation Model (GCM) of the Hadley Centre for Climate Prediction and Research (Viner and Hulme, 1998). The mean temperature of this weather series shows a 2.8°C rise compared to the current climate (1980–1998). In the Hadley scenario the long-term mean of the precipitation does not differ much from the current climate. But this is not in agreement with the prediction given by Können *et al.* (1997, KNMI) that per °C rise of mean temperature there will be a 6% increase of the winter precipitation. So we also included scenarios with the precipitation of Hadley adjusted in a manner that is consistent with the KNMI prediction. These scenarios are then used in a ‘what if...’ manner. And for making the GCM-results usable at the regional scale we devised a simplified down-scaling procedure, as described in Van Walsum *et al.* (2002a). For the results described here the used climate scenario differs from the current situation in the following manner:

- winter precipitation: +17%
- summer precipitation: +3%
- potential evapotranspiration: +5%

Given the uncertainty with respect to the future climate this scenario is just one example of what could happen.

Autonomous developments

As part of a master plan for the nature development in The Netherlands, a national ecologic network (NEN) is being established. In the study region this plan has been made concrete, but not yet implemented. For the region the nature development involves roughly the conversion of 1500 ha from agriculture to natural grassland, situated mainly in the stream valleys, as indicated in the right-hand map of Figure 2 (red area (dark grey as printed)). Along with the conversion of agricultural land the small ditches and watercourses (and field drainage, if present) will be removed for counteracting the desiccated current state.

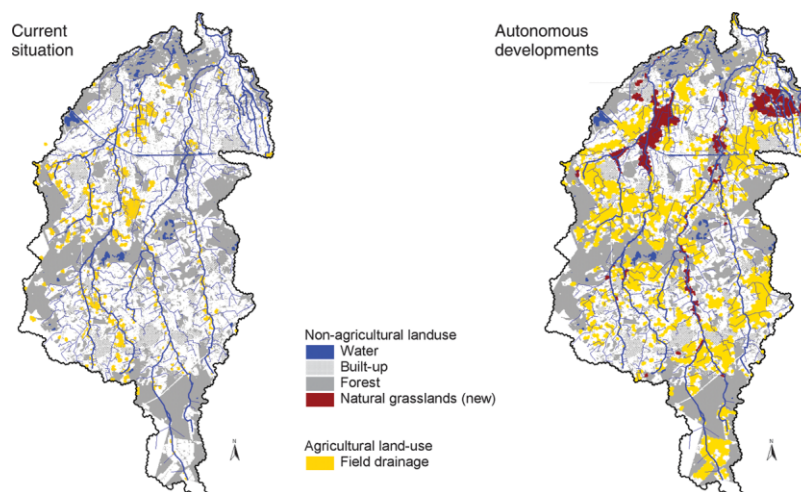


Figure 2 Current situation (left) and autonomous developments (right) for field drainage and nature area: existing forests (mid-grey), new nature in right-hand map (red (dark grey)). Subscribers to the online version of *Water Science and Technology* can access the colour version of this figure from <http://www.iwaponline.com/wst>.

This results in a reduction of the percentage desiccated nature area from 73% to 68%, as given in [Table 1](#).

The climate scenario affects the natural grasslands in stream valleys through the following mechanisms (+/- for positive/negative effects on nature):

1. more upward seepage from the regional system, due to higher recharge of upstream areas in the drainage basin: +
2. wetter conditions in the stream valleys: +
3. less seepage to the root zone due to a higher counter pressure from higher phreatic hydraulic heads in the stream valleys: -
4. more seepage to the root zone due to increased evapotranspiration: +
5. increased moisture stress: -

A seepage flux to the root zone of 0.5 mm/d is seen as critical for mesotrophic stream valley vegetations ([Runhaar *et al.* 1999](#); [Van Walsum *et al.*, 2002a](#)). From results obtained for the Beerze and Reusel region it appears that the positive effect of mechanism 1 is slightly higher than the negative effect of 3, resulting in a net increase of the area that fulfils the seepage criterion by <10% ([Van Walsum *et al.*, 2002b](#)). By contrast, the effect of increased evapotranspiration on the seepage to the root zone appears to be more significant: the extra 'pull' caused by the 5% increased evapotranspiration gives a >30% increase of the area that fulfils the seepage criterion. No significant change is predicted as regards the soil moisture conditions: wet and very moist sites with large moisture stress (>30 days with a soil water pressure head <-12 m) are absent in *both* the present and the predicted situation. In the balance, the predicted effects are clearly positive for the assumed climate scenario, reducing the desiccated area from 68% to 51%.

Given the increased precipitation, it can be expected that agriculture will want to increase the area with artificial field drainage. The WATERWISE model predicts the expansion as shown in the right-hand map of [Figure 2](#). The extra drainage will substantially reduce the expected nature benefits of the climate change, meaning that - if expansion of field drainage is left uncontrolled - an opportunity will partly be lost for reducing the nature-desiccation problem.

As shown in [Figure 3](#) the peak discharges react very sharply to the increase of 17% in the winter precipitation: the peak discharge (upper curve) is roughly 50% higher than in the current situation. Analysis of the model results showed that this nonlinear reaction is for 2/3 due to the peak discharge effect of saturated zones along the stream valleys, and for 1/3 due to the statistical parameters (autocorrelation) of the precipitation time series. [Figure 3](#) also shows that due to the autonomous development of field drainage the expected increase is roughly cut in half (second highest peak).

This result is due to the fact that drainage increases the amount of 'free' storage capacity in the subsoil, for being available in situations with extremely high precipitation. This free capacity can then be used for storing part of the precipitation. For less extreme events (occurring more often than once a year) the drainage causes an *increase* of peak discharges.

Table 1 Effects of autonomous developments on the 'percentage desiccated area' in stream valleys

Situation	Desiccated area (%)
Current	73
After implementation of national ecologic network	68
Climate scenario	51
Autonomous development of agriculture	57

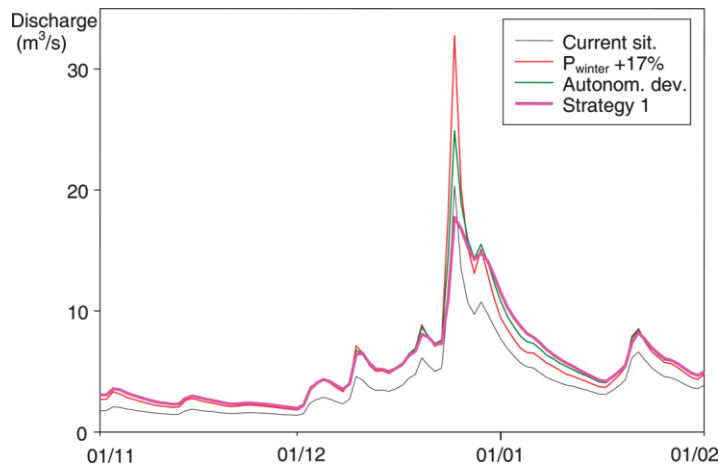


Figure 3 Predicted discharges (10 year extreme event) for the current situation, the climate scenario with +17% precipitation in winter, idem with autonomous developments in land use, idem with water management strategy 1. Subscribers to the online version of *Water Science and Technology* can access the colour version of this figure from <http://www.iwaponline.com/wst>.

Blueprints for future developments

For guiding possible future regional developments aimed at controlling the peak discharges a number of options were formulated for land-use in combination with water management:

- construction of flow retardation structures in the main arteries ('streams');
- construction of flow retardation structures in the fine arteries ('ditches').

The latter option involves the damming of ditches, with the dams perforated by small culverts. Both types of construction are designed to work 'out of themselves', i.e. that no water management decisions have to be taken when a peak event actually occurs. Crucial for the effectiveness of the mechanism is that the flow is not retarded too much; otherwise there is no free storage capacity available in the soil and surface water at the time of an extreme peak-flow event. So judicious dimensioning of the structures is a key success factor. Locally, both types of measure are combined with a low-intensity form of agriculture or (new) nature, because the retarding structures cause more frequent inundations. It is, of course, not logical to combine that with high-intensity horticulture. Even less compatible is the presence of a built-up area. In the model, the flow retardation is only allowed as an option if there is less than 2% built-up area.

By way of a computational experiment the WATERWISE model was asked to generate a spatial pattern of measures, for:

1. reduction of the (10 yr) peak discharge to 20% below the current situation (pink line Figure 3);
2. reduction of the desiccated percentage of nature areas to 43%, compared to the 71% in the current situation and 57% in the autonomous development (Table 1);
3. combined strategy.

The results are shown in Figure 4 for the combined strategy. For simultaneously achieving these goals the agricultural income will reduce by 3.3M€/year from the 95.6M€/year that is predicted for the autonomous development (of which 2/3 is land-use related).

Analysis of the separate effects of the peak discharge reduction target and the desiccation reduction targets are shown in Table 2. These results show that there is an implicit conflict between the targets for reduction of peak discharge and reduction of nature desiccation: the costs of the combined strategy are 1.4M€/year higher than the total costs of

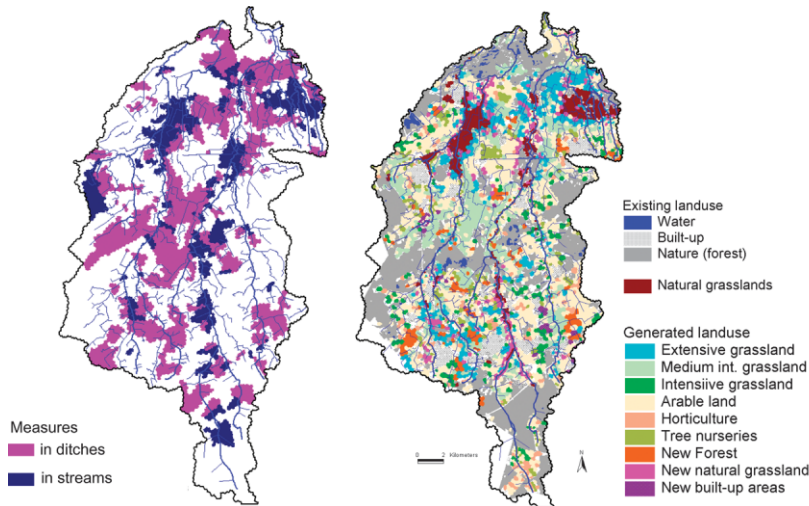


Figure 4 Generated patterns of measures (water management, land use) for the combined strategy (#3) with simultaneous targets set on peak discharge reduction (10 yr event) and reduction of the desiccated nature area. Subscribers to the online version of *Water Science and Technology* can access the colour version of this figure from <http://www.iwaponline.com/wst>.

Table 2 Costs of strategies for reduction of peak discharge (10 yr event) and nature desiccation; comparison to costs of combined strategy

Strategy	Loss of income (M€/year)
Reduction of peak discharge by 20% (#1)	0.7
Reduction of desiccated nature area to 43% (#2)	1.2
Total	1.9
Combined strategy (#3)	3.3
Extra cost of combined strategy	1.4

the separate strategies. This implicit conflict is related to the fact that expansion of drainage has a peak-reduction effect on the one hand but increases the desiccation of nature on the other.

Conclusions

For predicting effects of climate change it is essential to use an integrated regional hydrologic model, otherwise important interactions will be missed. Simulation results indicate a high sensitivity of the peak discharges to the precipitation. For nature areas climate change provides an opportunity to improve the conditions. But if the regional development is left uncontrolled, a large part of the benefits of climate change will be lost due to the expansion of drainage by agriculture.

For counteracting the increased peak discharges due to climate change it appears that flow retardation in upstream areas is a viable option. But in order to implement such a strategy it is important for the authorities involved in spatial planning to avoid the cluttering of rural areas with housing estates, because otherwise the cost of peak-flow reduction ‘at the source’ will become unnecessarily high. If not, anticipated climate change is indeed a threat; but that does not have to be the case if regional developments are guided with *water* as one of the leading principles.

References

- Dash (2003). *XPRESS-MP Reference Manual*, Dash Associates, Blisworth, UK.
- Gorelick, S.M. (1983). A review of distributed parameter groundwater management modelling methods. *Water Resources Research*, **19**(2), 305–319.
- Helming, J.F.M. (1997). *Mogelijke ontwikkelingen van landbouw en milieu bij een strenger milieubeleid voor de Nederlandse landbouw (UK: Possible developments of agriculture and the response of Dutch agriculture to stricter environmental measures.)*, Publication 1.30, LEI, The Hague, The Netherlands.
- Jansen, P.C., Runhaar, J., Witte, J.P.M. and Van Dam, J.C. (2000). *Vochtindicatie van grasvegetaties in relatie tot de vochttoestand van de bodem*, Report 57, Alterra, Wageningen, The Netherlands.
- Können, G.P., Fransen, W. and Mureau, R. (1997). *Meteorologie ten behoeve van de 'Vierde Nota Waterhuishouding'*, KNMI, De Bilt, The Netherlands.
- Runhaar, J., Boogaard, H.L., Van Delft, S.P.J. and Weghorst, S. (1999). *Natuurgericht Land-evaluatiesysteem (NATLES)(UK: Nature oriented land evaluation system)*, Report 704 SC-DLO, Alterra, Wageningen, The Netherlands.
- Van Walsum, P.E.V., Verdonschot P.F.M. and Runhaar, J. (2002a). *Effects of climate and land-use change on lowland stream ecosystems*. Report 523, Alterra, Wageningen, The Netherlands (<http://www.alterra.nl/english>).
- Van Walsum, P.E.V., Helming, J.F.M., Schouwenburg, E.P.A.G., Stuyt, L.C.P.M., De Bont, C.J.A.M., Vereijken, P.H., Kwakernaak, C., Van Bakel, P.J.T., Van Staalduinen, L.C., Groenendijk, P. and Ypma, K.W. (2002b). *Waterwijs; plannen met water op regionale schaal (UK: Waterwise; planning on the basis of water at a regional scale)*. Report 433, Alterra, Wageningen, The Netherlands (<http://www.alterra.nl/english>).
- Van Walsum, P.E.V., Veldhuizen, A.A., Van Bakel, P.J.T., Van der Bolt, F.J.E., Dik, P.E., Groenendijk, P., Querner, E.P. and Smit, M.F.R. (2004). *SIMGRO 5.0; Theory and model implementation*. Report 913.1, Alterra, Wageningen, The Netherlands (<http://www.alterra.nl/english>).
- Van Walsum, P.E.V., Helming, J.F.M., Groenendijk, P., Stuyt, L.C.P.M. and Schouwenberg, E.P.A.G. (submitted). Spatial planning for lowland-stream basins using a bio-economic model. *IAHS/IWRM conference in South Africa, 2003*.
- Viner, D. and Hulme, M. (1998). *The climate impacts LINK Project: Applying results from the Hadley Centre's climate change experiments for climate change impacts assessments*, CRU, University of East Anglia, Norwich, UK.