Applying MIKE SHE to define the influence of rewetting on floods in Flanders

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Abstract The last century has witnessed a change in the landscape of Flanders, and an increase in flooding intensity and frequency that has been observed in Europe over the last decade. Reverting to states existing prior to the introduction of intensive farming practices is being considered as a potential remedy for mitigating these flood events. Rewetting is one such, which is believed to have environmental benefits including flood mitigation. However, such actions need to be built on sound scientific arguments, and here there exists a gap. This research study builds on the need for scientific arguments for or against restoration. A MIKE SHE model was built incorporating a root zone component, a comprehensive three-dimensional groundwater component, and a river component. The surface water – groundwater interactions within the catchment could then be deciphered. The study established a positive flood mitigation effect of restoration.

Key words: Calibration, Hydrological modeling, MIKE SHE, Nete river basin, Validation

INTRODUCTION

Over the last century, the land use map of Flanders has been dramatically altered with large areas of agricultural land being drained and put into intensive agricultural production. At the same time Europe has experienced a number of unusually long-lasting rainfall events in the last decade that produced severe floods, *e.g.* in the Netherlands, Belgium, France and Germany (1993, 1995), the Czech Republic, Poland and Germany (1997), in North Italy (1994, 2000), in the UK (*e.g.* 1998, 2000), and recently in Germany, Austria, the Czech Republic, Slovalia, Russia, and Romania (2002) (Institute for Environment and Sustainability, 2004). The issue of restoring wetland areas is now receiving increasing attention as a means of promoting the environmental benefits that are thought to be associated, including the mitigation of severe flooding. Water retention within catchments is an emerging concept that has been receiving increasing attention in the recent past as a result of the changing climatic conditions being experienced. Collective action is required for restoration of a basin as it involves the participation of the landholders and benefits from economies of scale. In addition, enhanced environmental benefits are mostly achievable at larger scales. Changing people's views on water use and making them understand the meaning and necessity of good water management requires convincing scientific arguments. Such arguments can be communicated to the parties involved through the use of examples and models. Models can also be used to answer the research questions that arise with water retention, such as, what are the risks of water conservation, to what extent should the basin be restored, and do other options exist to address the primary problem of hydrological extremes.

Hydrological models, sometimes termed rainfall-runoff models, provide a framework to conceptualize and investigate the relationships between climate, human activities, and water resources (C. Jothityangkoon *et al.*, 2001;G. H. Leavesley, 1994). They can be broadly classified into three categories: empirical or black-box, conceptual or grey-box, and physically based distributed or white-box models. Physically based distributed models are those which are able to explicitly represent the spatial variability of some, if not most, of the important land surface characteristics such as topographic elevation, slope, aspect, vegetation, soil as well as climatic parameters including precipitation, temperature, and evapotranspiration distribution. Because they relate model parameters directly to physically observable land surface characteristics, spatially distributed hydrological models have important applications to the interpretation and prediction of the effects of land use change and climate variability (J. Andersen *et al.*, 2001;A. M. Binley *et al.*, 1991;I. R. Calder, 1993;I. R. Calder *et al.*, 1995;D. Conway, 1997;C. Jothityangkoon *et al.*, 2001;J. K. Lorup *et al.*, 1998;J. C. Refsgaard, 1987;J. C. Refsgaard *et al.*, 1999).

This study builds on the need for scientific arguments for or against restoration. The study applied the physically based distributed MIKE SHE model to study the effects of restoration in the Nete basin. The flood routing processes were simulated by the MIKE 11 model, and were based on the Saint-Vernant equations. The effects of retaining water for longer periods in the drainage ditches was studied, as well as the effects of reducing the drain level.

BACKGROUND

The Nete basin is a middle-sized hydrological catchment located in the northeast of Belgium. It is predominantly composed of sandy loam to sandy soils, is of flat topography ranging from 12m in the west to 69m in the east, and has a shallow water table. The area is well drained by the Nete River and its tributaries (fig. 1), and by a whole series of drains and ditches. The basin area is 384.77km^2.

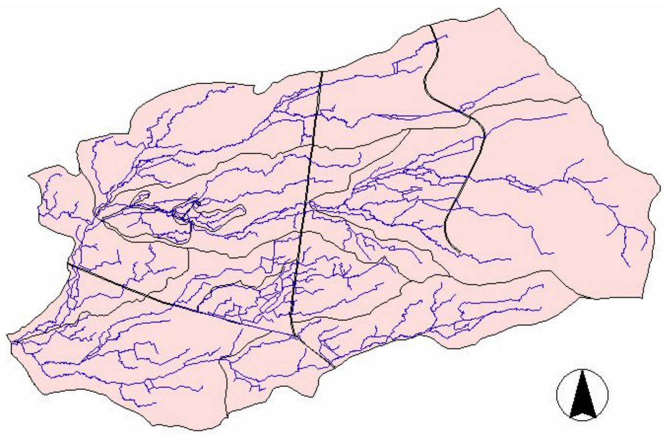

Fig. 1 The study area

Small-scale water retention measures have been undertaken in the Central Benelux area, of which the catchment is a part of, primarily through retention of drainage water in the ditches for longer periods of time thus allowing more of it to infiltrate into the vadoze zone. However, as only a limited number of weirs and dams were constructed for water retention in the Central Benelux area and the locations were sparsely distributed over a wide area, it was not possible to evaluate the effects of restoration based on this undertaking. In addition, it is essential that an alternative method of assessing the effects of restoration be sought for the following reasons: firstly, high costs are involved in construction of many more water retention structures. Secondly, many years of studying the catchment behavior would be required in order to establish trends. Lastly, the potential for participants to lose interest in better water management practices may be realized if they perceive no immediate benefits of restoration. The alternative chosen was to apply the MIKE SHE model to the study area and undertake simulations of restoration, with particular interest in extreme value statistics of the catchment.

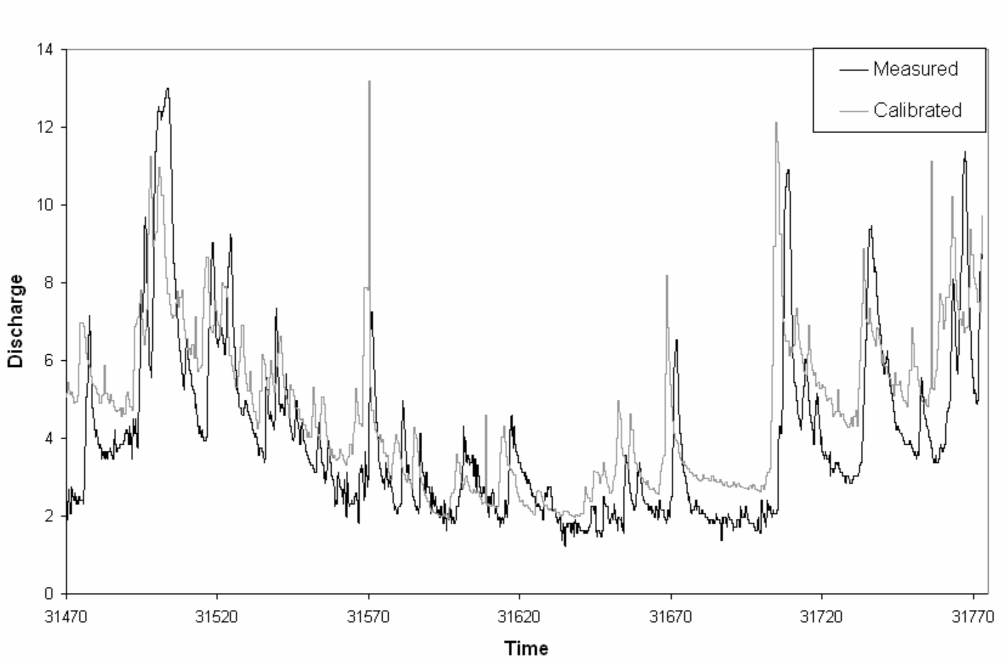

Fig. 2 Hydrographs of measured and calibrated discharges at Varendonk

METHODOLOGY

The MIKE SHE model was adopted as it incorporates the different components of the hydrological cycle. The model is composed of three components, namely a root zone component for estimating the net precipitation, a comprehensive three-dimensional groundwater component for estimating recharge to and hydraulic heads in different geological layers, and a river component for stream flow routing and calculating stream–aquifer interaction. Water Engineering Time Series PROcessing tool (WETSPRO), a tool for time series analysis (Willems P., 2003), was used in this research for implementing the multi-criteria calibration protocol. This model incorporates a recursive digital filter for exponential recessions to split total rainfall-runoff discharges into its three component sub-flows, and is able to determine the recession constants for each component. The calibration was performed manually, on the basis of multivariable measurements within the catchment. During the calibration and validation of the model, both the split-sample approach and goodness-of-fit statistics were adopted as measures of performance. The restoration scenario was then generated as would be done in practice by modifying the process of conventional drainage. Land drainage in the Nete involves digging ditches by which water is drained off the land immediately. This process is further supplemented by drain pipes. In order to simulate ancient conditions in the catchment, the restored model considered a state whereby the time taken to drain the land was decreased.

RESULTS

A model of the Nete catchment was built in the MIKE SHE code. During parameterization, the different input parameters were varied, the simulated hydrographs from each parameter set were inputted into WETSPRO, and Extreme Value analyses were applied. The Varendonk station was used for split-sample calibration of the model parameters, during which process a multi-criteria calibration protocol was followed. This protocol obtained simulated and observed discharge hydrographs that were acceptably similar. The individual flow components of the rainfall-runoff discharge were well simulated. Furthermore, the recession constants of the simulated individual flow components were comparable to those from the observed hydrograph. Values of MSE < 0.2 were obtained, along with $R^2 > 0.8$. Fig. 2 shows part of the measured and calibrated hydrographs for the discharge measurement station at Varendonk. This calibrated model was then taken as a reference or calibrated state.

The restored state scenario was run over the same period as the reference model, and results of the two simulations were analyzed using the WETSPRO tool. The return discharges for different time periods were plotted on a log scale for both states in fig. 3.

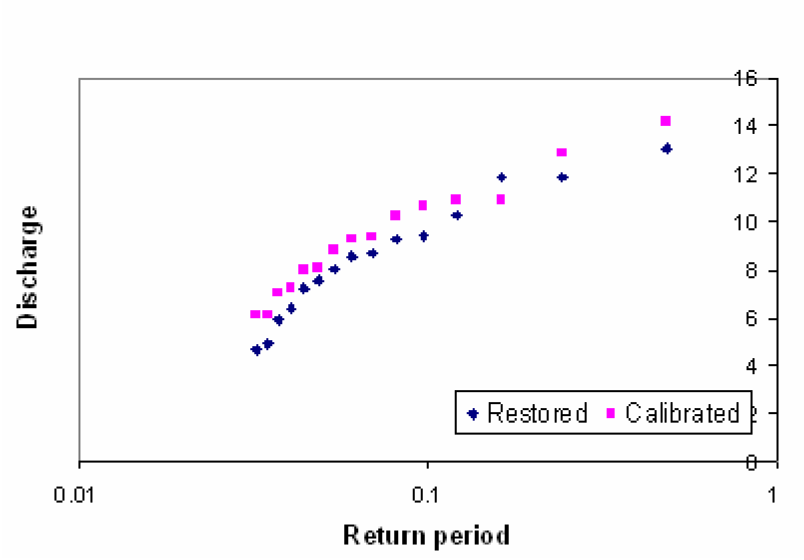

Fig. 3 Return period (logarithmic scale) for peak discharge simulations

Finally, the volume of flow being simulated past the Varendonk discharge station was cumulated for a period of time for both the calibrated and restored states, and the results were represented in fig. 4.

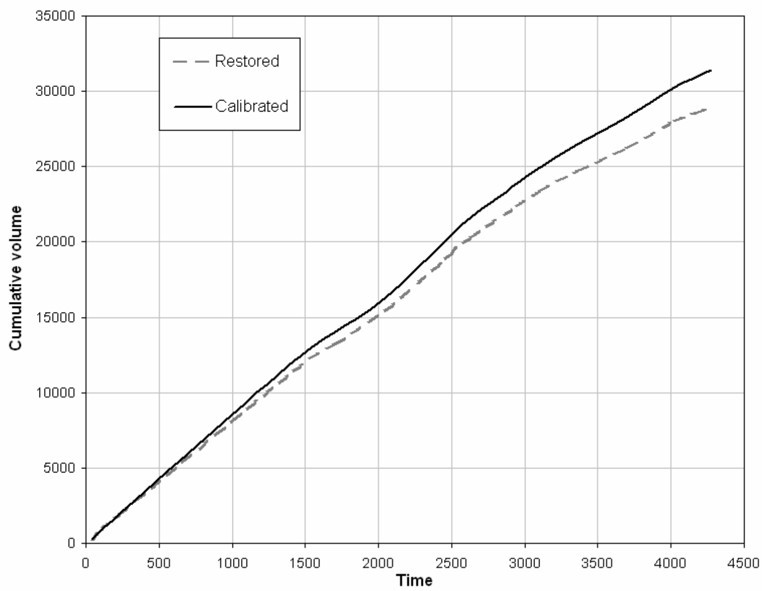

Fig. 4 Cumulative volumes for calibrated and restored states

DISCUSSION

With the 3-dimensional flow model that was built for the Nete catchment it is now possible to simulate and study the surface water - groundwater interactions that naturally occur in nature. On analysis, the flow hydrographs for the reference and the restored states followed a similar trend with the restored state showing a reduced discharge and cumulative volume. However, the return flows for different periods showed a 4% reduction in the 5-year return discharge and a 6% reduction in the 100-year return discharge for the restored state as compared to the reference state. Over-bank flooding occurred earlier for the reference state than for the restored state.

This study assumed a restored state, which in practice would require a large capital investment in remodeling the drainage network within the catchment. It further assumes that there will be complete participation of the stakeholders as restoration is a regional undertaking. Finally, it assumes that monitoring and maintenance will be carried out. The latter is most probable and is presently being practiced to some extent. On a practical note, it is impossible for landholders to practice water retention measures without affecting or being affected by the degree of wetness of their neighbor's plots. The drain level of the different plots influences the final resting position of the water table. Thus, restoration should be viewed as a collective effort at alteration of the regional wetness.

CONCLUSIONS

First, the surface water - groundwater interactions within the catchment are now better understood with regard to their response to restoration. The simulation of a restored state has enabled the generation and analysis of long term trends in river discharge that would accrue as a result of the intervention. This has been accomplished without resorting to a field study, which study would be costly, time consuming, and organizationally intensive. Second, the analysis of results revealed that restoration has a positive effect of reducing flood peaks and the frequency of their occurrence. However, this effect appears to be minimal as illustrated by the 6% reduction in the 100-year return discharge. When this is weighed against the backdrop of the investment required for this change of state, it may represent a small dividend on the undertaking. In addition, since most of the drainage activity was initiated over 75 years ago, restoration alone does not provide a solution to the problem of severe floods produced by unusually long-lasting rainfall events in the last decade. Restoration may however be undertaken as part of a broader solution to the flooding problem, and for its other potential environmental benefits that are believed to be associated.

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