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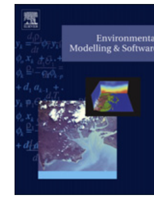

Stakeholder driven update and improvement of a national water resources model

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ABSTRACT

It is generally acknowledged that water management must be based on an integrated approach, considering the entire freshwater cycle. This has in particularly been endorsed in Europe by the European Water Framework Directive (WFD) imposing integrated management considering all waters. Although not prescribed by the WFD, integrated hydrological modelling may be necessary to support the management according to the directive as also suggested by several research projects initiated by the EU commission. To ensure a coherent and consistent management across various institutions and authorities, having different responsibilities and operating at various scales, a common tool integrating all relevant knowledge and data is imperative. By the end of 2003, a numerical national water resources model was constructed for Denmark, which has been applied in several national assessments. At the regional level there has, however, been some reluctance to use the model, primarily because the model did not contain the most recent data and understanding obtained from detailed local studies. The model has therefore been subject to a comprehensive update focussing on utilising the system understanding from the local studies. This process was largely stakeholder driven by involvement of predominantly the technical staff at the regional water authorities. Local knowledge is continuously improved urging the model update to be an on-going process. Based on experience from the update of the Danish national water resources model, three levels of model updating have been identified: 1) Basic data update – keeping the model up-to-date with respect to input data, 2) improving the model description by including new or more detailed data, and 3) reconstructing the model concept. The three levels vary with respect to technical tasks, challenges and stakeholder involvement. Two utility programs developed to optimise the updating process and support the uptake of data and knowledge from local users are furthermore presented. Finally, some of the challenges in operating a national model with multiple users belonging to different institutions with varying demands are discussed.

1. Introduction

Endorsed by the European Water Framework Directive (WFD) (EC, 2000), detailed knowledge of the physical system is required in order to relate stresses to impacts on the hydro-ecological system at site-specific locations. Although not prescribed by the WFD, models can be used as support in the different phases of the implementation (Cools et al., 2006; Hattermann and Kundzewicz, 2009; Højberg et al., 2007; Rekolainen et al., 2003; Wasson et al., 2003). Distributed and physically based hydrological modelling is in particular attractive for site-specific assessments. The use of complex and distributed models may, however, be limited by the understanding of the physical system and data availability, as noted by Beven (2007) for integrated environmental models. A key challenge in modelling of complex systems is thus how the process descriptions of the models can be improved based on new process understanding and when and how to update existing models based on new or improved site-specific knowledge and data.

Site-specific system understanding and data are improved only by detailed studies, which are commonly carried out at local to regional scales by different authorities and institutions involved in water management at various levels. Knowledge, being the conceptual understanding of the system by people with local experience, and hard data therefore emerge gradually and form a spotted pattern at the national scale stored by different institutions. Although the detailed studies improve the system understanding markedly, it is very difficult to employ this understanding in national scale assessments, unless the knowledge and data from the detailed studies are transferred into a coherent nationwide understanding and integrated in large scale/national scale models.

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Examples of large scale/national models covering more than 10,000 km^2 have been reported in the literature (Belcher, 2004; Sophocleous and Perkins, 2000). These models are, however, generally constructed from interpretation of raw data in an ad hoc manner to support specific decisions. Few large scale models have been developed with the aim of supporting water resource management in general and to provide the off-set for detailed modelling or on-going update to include new knowledge obtained at various scales. In the Netherlands, a national hydrological model, the National Hydrological Instrument (NHI) (http://www.nhi.nu), has been developed (de Lange et al., 2011; Delsman et al., 2008), which is an integral water management model-instrument focussed on water shortage and on the very detailed surface water distribution system in the country. The model was developed by research institutions but local knowledge has been adopted in cooperation with the national water boards. The U.S. RASA program (http://water.usgs.gov/ogw/rasa/html/introduction.html) running from 1978 to 1995 was established to develop a common nationwide conceptual understanding of the major aquifer systems in U.S. and develop a framework of background information that can be used for regional assessment of groundwater resources and in support of detailed local studies. By the end of 2003 the national water resources model for Denmark (DK-model) (www.vandmodel.dk) was established (Henriksen et al., 2003) for nationwide assessment of the exploitable groundwater resources for Denmark. Similar to the NHI, this first version of the DK-model was constructed as a research project by a research institution, namely the Geological Survey of Denmark and Greenland (GEUS). Local knowledge has afterwards been integrated into the model by collaboration with the regional water authorities during an extensive model update process, hereafter referred to as the recent model update and recent model.

Experience with the DK-model is that it has been widely utilised for national and regional scale assessments but its reliability and uncertainty has been subject to on-going debate. Willingness to use the model is not only linked to model performances as described by the model's ability to simulate observed quantities. Equally important is that the description of the physical system included in the model (the conceptual model) is in accordance with the present understanding obtained by the local authorities from local studies and concurs with the scale at which the local studies were carried out. To accomplish this, active stakeholder involvement is required through which the local data, conceptual understanding and model knowledge are extracted, evaluated and made available for the national model.

Participatory modelling has evolved significantly during recent years. Voinov and Bousquet (2010) define two main objectives for participation in modelling, where the first is related to improved system understanding, and the second to the identification and clarification of the impacts of different solutions (in line with direct decision making and/or social learning e.g. as a decision support tool). The use of decision support tools commonly involves scenario building and has received most attention in the literature (Holzkamper et al., 2012; Inman et al., 2011; Krueger et al., 2012; Mysiak et al., 2005). Examples of active involvement of stakeholders in the construction of complex hydrological models by sharing data and knowledge are less developed, probably because these simulation models are often too difficult to understand for non-experts (Molina et al., 2011) and because it is difficult to translate information between stakeholders and scientists (Leenhardt et al., 2012). Nevertheless, utilisation of local knowledge and data, to the extent possible, are prerequisites for a modelling tool to be accepted by stakeholders (McIntosh et al., 2011; Oliver et al., 2012).

The recent update of the Danish national water resource model only considered model improvement, where a technical integration of knowledge and understanding is enabled bridging the local stakeholders' knowledge with the national model researchers' knowledge. However, participatory model update cannot be carried out as a strictly technical task, but also involves dealing with stakeholder knowledge and relations that influence the way stakeholders are positioning, evaluating and developing ownership of the national water resource model and its credibility. Experience from the update is described in the present paper with focus on how and to what extent stakeholders were involved. Based on such experience, model updating as a continuous process is conceptualised into three levels involving various degrees of model reconstruction and stakeholder involvement. The paper starts with a short description of water management in Denmark related to the implementation of the WFD and use of hydrological models. After this, an overview of the DK-model is provided followed by a section describing the three levels of model update. The next section describes two utility programs that were developed parallel to the updating process to support the uptake of data and knowledge generated by local users. The paper concludes with a discussion of the need for and challenges in maintaining a common modelling tool at national scale.

2. Water management in Denmark

The Danish water supply relies 100% on groundwater extraction and is characterised by a decentralised extraction strategy. Approximately 10,000 wells are associated to the more than 2600 public well-fields extracting water for domestic and industrial use. Of the additional ~70,000 private wells ~40,000 are registered for irrigation purposes, which are concentrated in the western part of the country, dominated by sandy outwash planes. Extraction wells have historically been located close to surface water systems, thus competing for the water otherwise available to the environment. A cornerstone in the implementation of the WFD in Denmark is thus to balance utilisation of the groundwater for human activities and at the same time assure that sufficient water is available for sustaining groundwater dependent ecosystems. Such management requires solid knowledge of the groundwater system with respect to hydrogeology and the interaction between surface and groundwater systems.

Several players with different responsibilities at various scales are involved in the Danish water management. After a governance reorganisation in Denmark in January 2007, the state, represented by regional environmental centres, became responsible for implementing the WFD, including the coordination and preparation of regional water plans and corresponding programme of measures. At the same time, the 98 Danish municipalities were made responsible for practical implementation of detailed programmes of measures and for ensuring that the goals set in the water plans are achieved. An important activity of the municipalities is renewal of licences for groundwater abstractions, where they are in dialogue with a third important player in the water management area, namely the water companies, operating at the scale of individual wells and well-fields.

Hydrological models (considering only the groundwater system or both the surface and groundwater systems) have been used routinely to support water management in Denmark and have in particular matured during the last decade (Refsgaard et al., 2010). The widespread use of models can partly be attributed to a national Water Supply Act designating approximately 40% of the country as particularly valuable for groundwater withdrawal. These areas are subject to detailed hydrogeological mapping and the establishment of well-head protection zones, generally determined by hydrological modelling. Another important reason for the wide use of models is the tradition for technical training of the staff involved in