The Representation of Complex Superficial Deposits in Regional Scale Water Resources Models

Introduction

Since 1999, the UK Environment Agency Anglian Region have been developing a suite of regional groundwater models to cover the major aquifers of the area. Six models are either complete or currently under construction, with the remaining two due to commence in 2006. Anglian Region forms one of the driest areas of the UK, with annual rainfall typically less than 600mm. There are a number of large towns, but much of the area is relatively sparsely populated: here, intense agricultural development places large demands on water supply, which is heavily dependent on groundwater. Furthermore, the region is host to the largest concentration of water-dependent protected habitat sites in the UK, generating considerable ecological and amenity interest in the area. These competing requirements demand that the water resources must be understood and carefully managed, hence the development of this strategic programme of model development (Grout, 1998).

The Study Area

The oldest formation of hydrogeological interest in the Yare & North Norfolk area is the Cretaceous Chalk, which is a major source of water, both for public supply and agricultural use (Figure 2). The chalk is overlain in the east by the poorly-permeable London Clay and the Crag, a group of marine sands also used for water supply. These are overlain by a very complex sequence of glacial, fluvial and lacustrine deposits which range from boulder clays and glacial tills to coarse gravels.

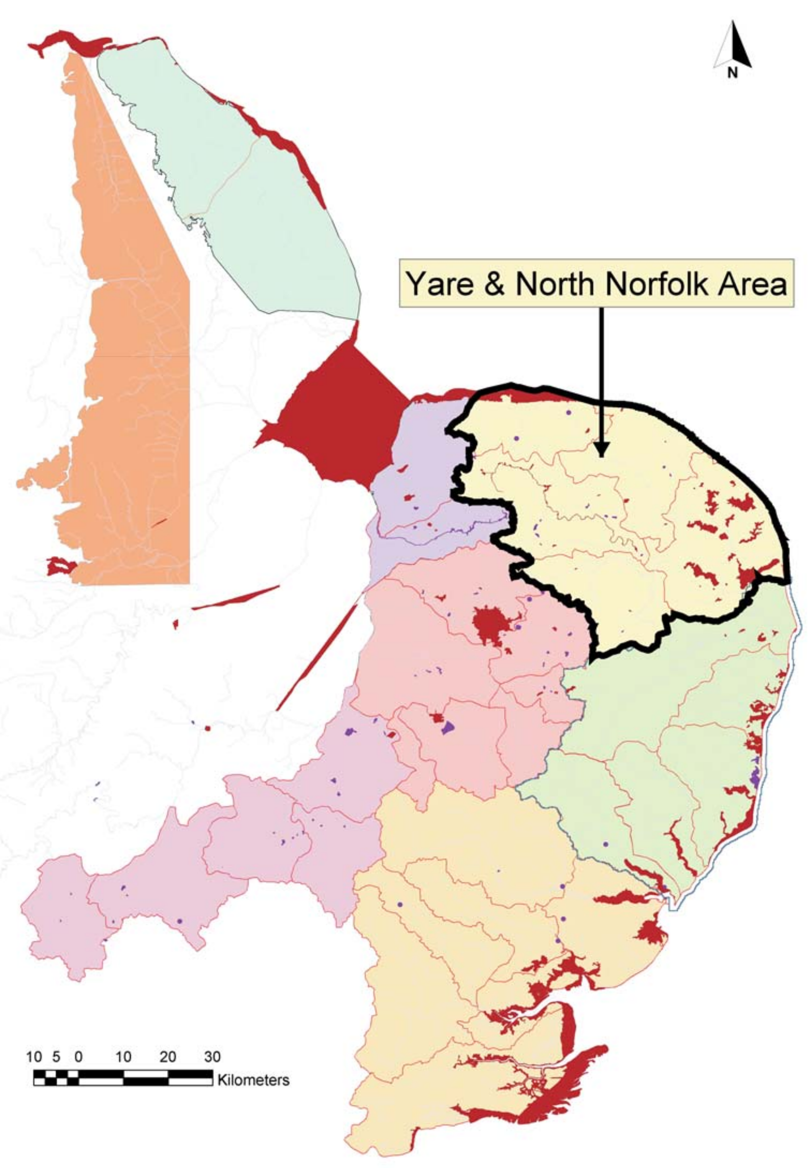


Figure 1. Anglian Region Strategy Areas, with sites of ecological interest

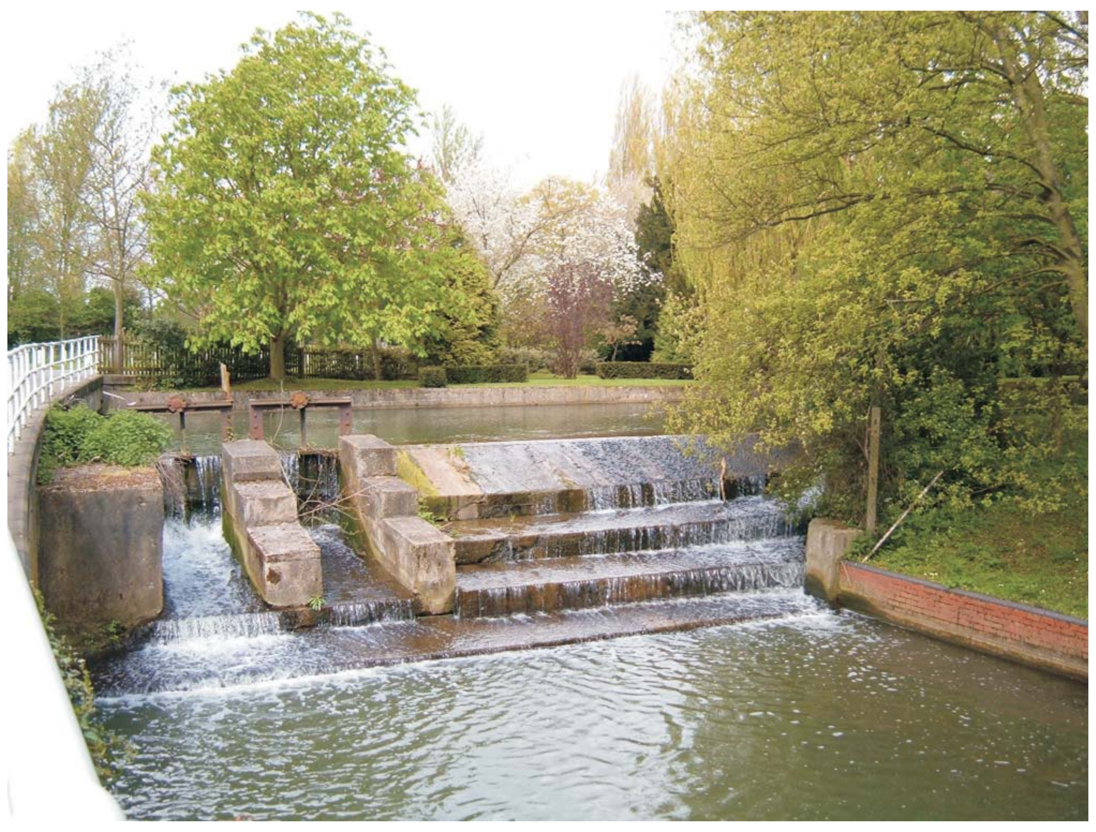
Figure 3 illustrates some typical cross-sections, although note that the representation of superficial deposits is much simplified. The Chalk rarely appears at outcrop in this area (Figure 4) being mainly limited to an area in the north-west, but with thin linear outcrops along two of the main rivers: replenishment of resources in the Chalk is therefore governed by the nature and distribution of the overlying superficial deposits.

Period	Epoch	Formation Name	Component Member	Composition
Recent			Blown Sand Alluvium Lacustrine Mud Head River Terrace Deposits Sand and gravel of unknown age Marine (Beach, shoreface, tidal river and creeks)	
Quaternary	Holocene	North Denes Formation 0.25		Sand
		Breydon Formation	Upper Peat 0.2 Upper Clay 4-6 Middle Peat 2-4 Lower Clay 0-15 Basal Peat 0-2	
	Pleistocene	Yare Valley Formation 0-11		Gravel with subordinate sand
			Haddiscoe Sands and Gravels 0-15	Sands and gravels
			Corton Woods Sand and Gravels 0-7	
		Overstrand Formation	Harworth Till Member	Till and associated sands and gravels
		Lowestoft Formation	Lowestoft Till/Walcott Till Member	
		Corton Formation	Happisburgh Till Member/Carton Sands	
		0-13 Kesgrave Formation or Cromer Forest-bed Formation	Kesgrave Sand	Pebbly sands, gravels and silt
Plio-Pleistocene		Crag Group 0-70: Weybourne Crag, Norwich Crag, Red Crag, Coralline Crag		Shelly sands and interbedded clays
Eocene		London clay Formation 0-50	Walton Member 0-50 Harwich Member 0-26 Hales Member 0-15	Silty Clay Sandy siltstone Clay
Palaeocene		Thanet Formation/Ormesby Clay Formation 0-27		
Cretaceous	Upper Cretaceous	Chalk Group 0->556: Upper Chalk 0-470, Middle Chalk 35-75, Lower Chalk 10-38		

mainly sands and gravels
tills and clays
Crag
London Clay etc.
Chalk

Figure 2. Geological Succession in the Yare & North Norfolk area

The need to produce a numerical model that could be used as a tool to assist in the equitable management of water resources in this complex area meant that the superficial deposits had to be simulated adequately, but it was clearly not feasible to include every detail of the heterogeneity. Potential methods of simplification, whilst still retaining the character and overall influence of the formations, were therefore sought.



Consideration of recent geological, glacial and geomorphological history, together with careful analysis of geological logs from over 5000 boreholes, allowed a simplified representation of the superficial deposits to be established. This essentially comprises poorly permeable tills 'sandwiched' between relatively permeable sands and gravels in a '3-layer' sequence. Variations across the area permit one or more of these 'layers' to be absent.

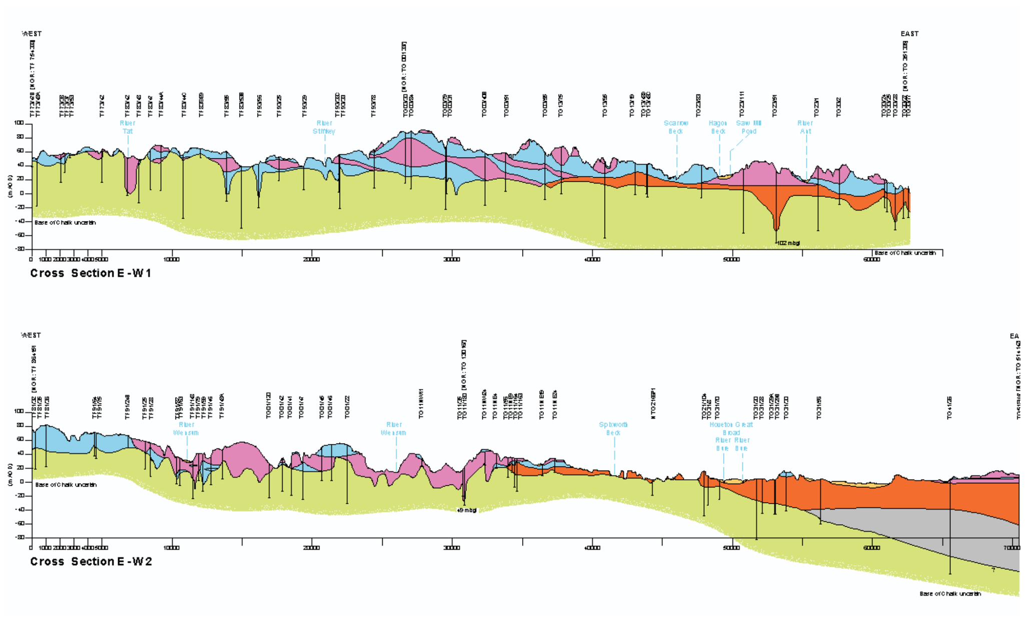


Figure 3. Typical east-west geological cross-section

The borehole logs were categorised into this simplified sequence. Using outcrop information to supplement these, a series of formation surfaces was built up, discretised onto the uniform 200m grid to be used for the numerical model. An automated process was used to combine these surfaces into a three-dimensional model, following certain 'rules' to preserve geological credibility by ensuring that, for example, surfaces did not intersect. The resulting structure was visually checked: in some areas with relatively sparse, or possibly ambiguous geological information, it was found that the automated build would produce unrealistic structure, and some adjustment was found to be necessary (best achieved by adding 'artificial' borehole information and repeating the build process). The end result of this process was a model that honoured the outcrop and borehole information as closely as possible, with internally consistent and realistic interpolation between boreholes (Figures 5 and 6).

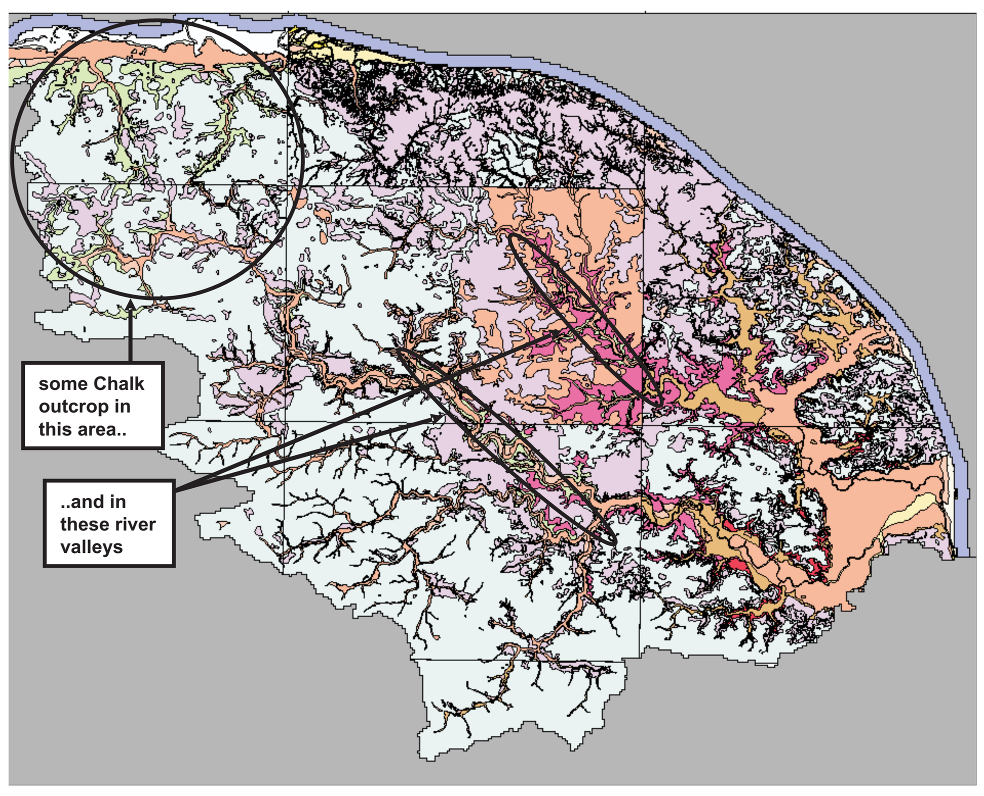
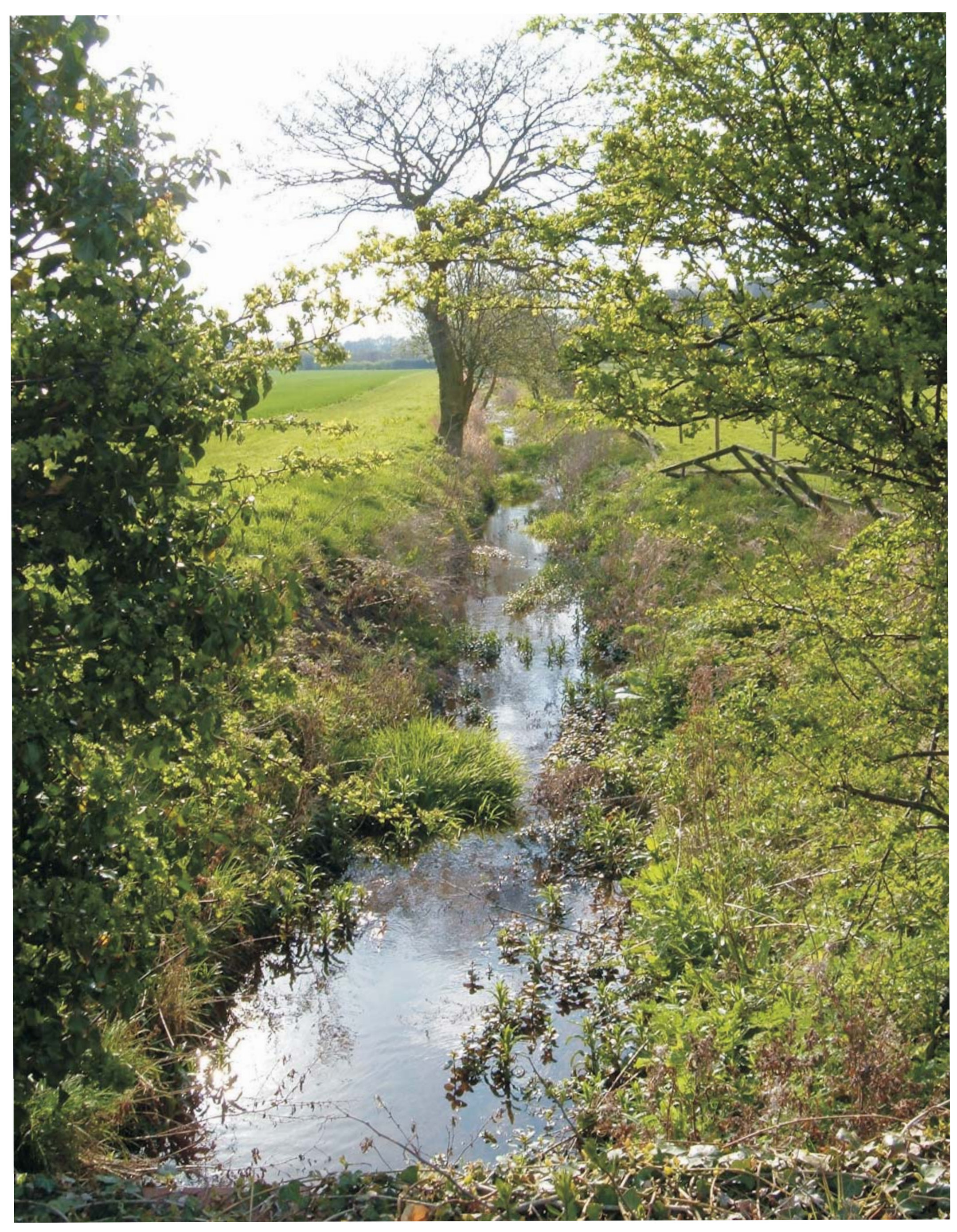


Figure 4. Geological map of the area

Local modifications to incorporate peat on wetland sites and alluvium in river valleys were also accommodated within the model. Although the 200m grid size cannot necessarily represent the full detail of wetland sites (some of which are quite small), careful consideration of model structure and behaviour allows development of a thorough understanding of how abstractions affect the water regime in the vicinity of the wetlands.



Authors:
Keith Phillipson, Tim Lewis, Gordon Coombs, Mark Grout, Michael Hutchinson
Entec UK Ltd, philk@entecuk.co.uk, lewit@entecuk.co.uk, coomg@entecuk.co.uk, Shrewsbury, Shropshire, UK
Environment Agency, Anglian Region, mark.grout@environment-agency.gov.uk, michael.hutchinson@environment-agency.gov.uk, Peterborough, UK

Environment Agency
Entec

The Representation of Complex Superficial Deposits in Regional Scale Water Resources Models

This structure has been embodied in the groundwater model. The outcrop distribution forms part of the input to a distributed rainfall-runoff and recharge calculation code (4R, as described in Heathcote et al, 2004). This considers differences in land use (i.e. crop and soil type) and near-surface geology to calculate effective recharge and runoff: the latter is routed through a comprehensive drainage network, derived from a DEM. Depending on the distribution of superficial deposits, 'runoff-recharge' may occur where streams (or overland flow paths) flow off poorly permeable surfaces, such as till, onto more permeable strata (sand and gravels or outcrop chalk).

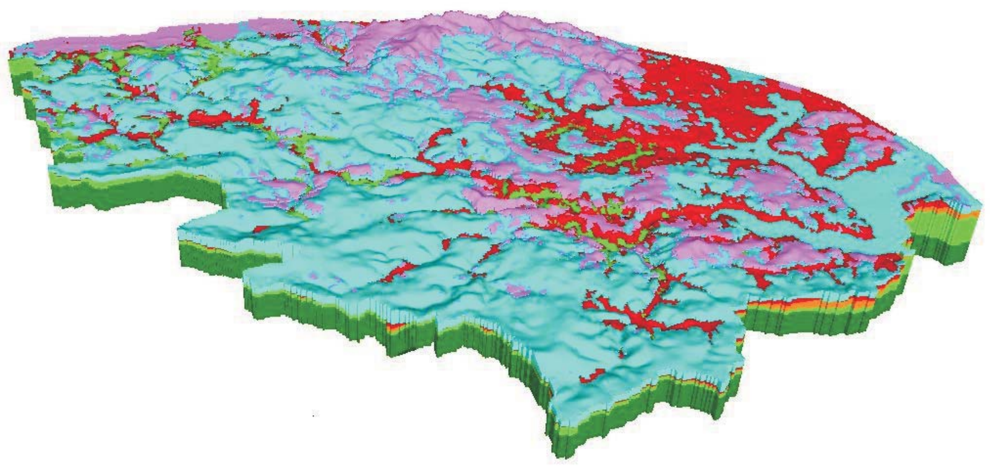


Figure 5. Block diagram of the groundwater model

The code also writes a recharge and stream file suitable for direct input to a modified version of MODFLOW (Environment Agency, 2003), including tributary topology and spatially and temporally variable runoff: this is vital given the large volume of information produced (there are over 30 000 stream reaches, including many anthropogenic drainage channels). The combination of 4R and MODFLOW therefore allows simulation of total river flows, not just the rtant factor for these investigations. Surface water movement occurs by simple transfer: no hydrodynamic equations are solved. Whilst this would not be adequate for investigation of 'fast' processes such as flood response, it is perfectly acceptable as a means of incorporating surface water flows into what is essentially a groundwater dominated problem.
The importance of the superficial deposits is illustrated in Figure 7, which shows modelled flow in one of the main rivers. It is clear that the contribution from the superficial deposits forms the majority of the river flow.

One of the key uses of the model is exemplified in Figure 8, which shows simulation of a 'signal test', in which the abstraction from a large public water supply borehole was ceased for two short periods. Water levels were monitored by data logger in many piezometers in the Chalk and in the superficial deposits, most importantly in a nearby wetland of interest. There was concern that the abstraction had had a deleterious effect on the ecological health of the wetland. The complex three-dimensional geological structure has been included as closely as possible in the model, allowing investigation of the propagation of abstraction effect from the Chalk to the near-surface. The model was run using daily stress periods over this time.

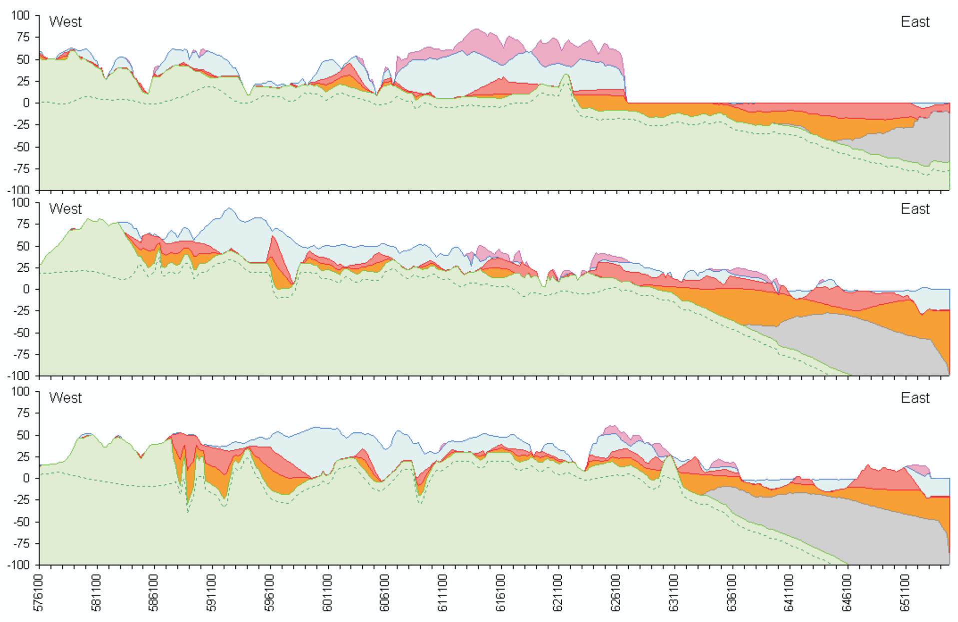


Figure 6. Example cross-sections through the model

Demonstrating realistic model performance in this way allows us to be more confident in assessment of predictive runs aimed at mitigating possible adverse effects on the ecology of the wetland.

Summary

The hydrogeology of an area of extremely complex geology in the UK has been successfully embodied in a combined recharge calculation and groundwater model. The model is currently being used to quantify available water resources at a catchment scale, and also to investigate the effect of groundwater abstractions on numerous wetland sites, which will lead on to assessment of possible mitigation measures. Because of the large number of wetlands and abstraction points, and their close proximity, a distributed numerical model is the only way in which this can sensibly be achieved.

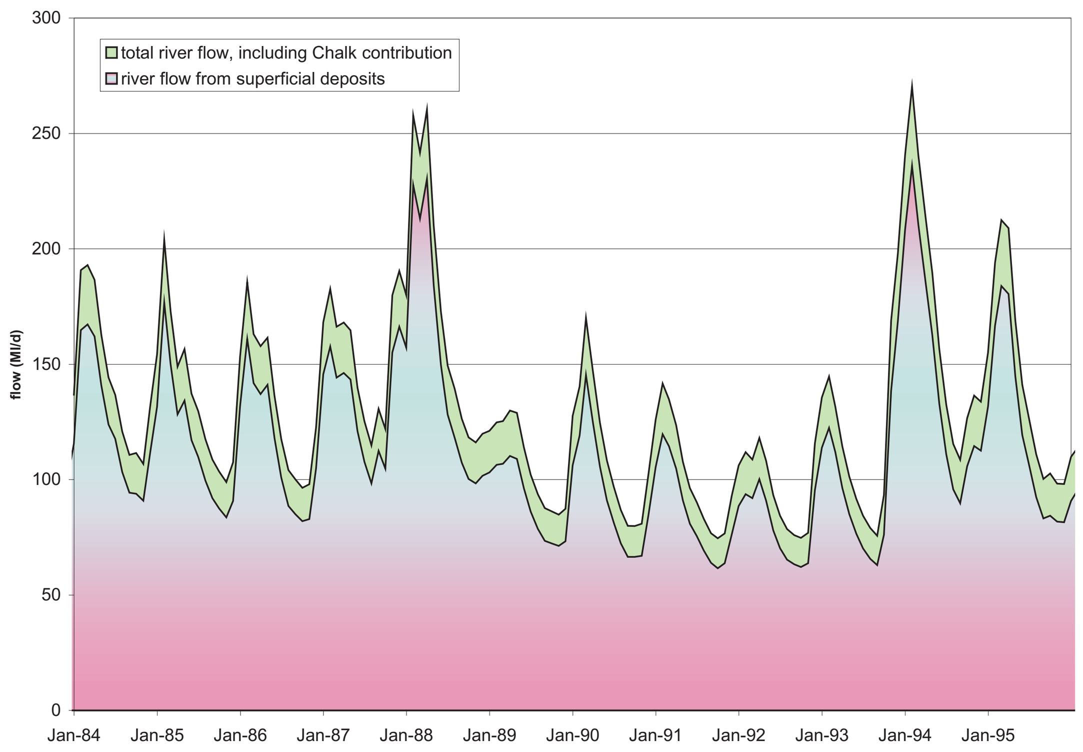


Figure 7. River flow contribution from superficial deposits

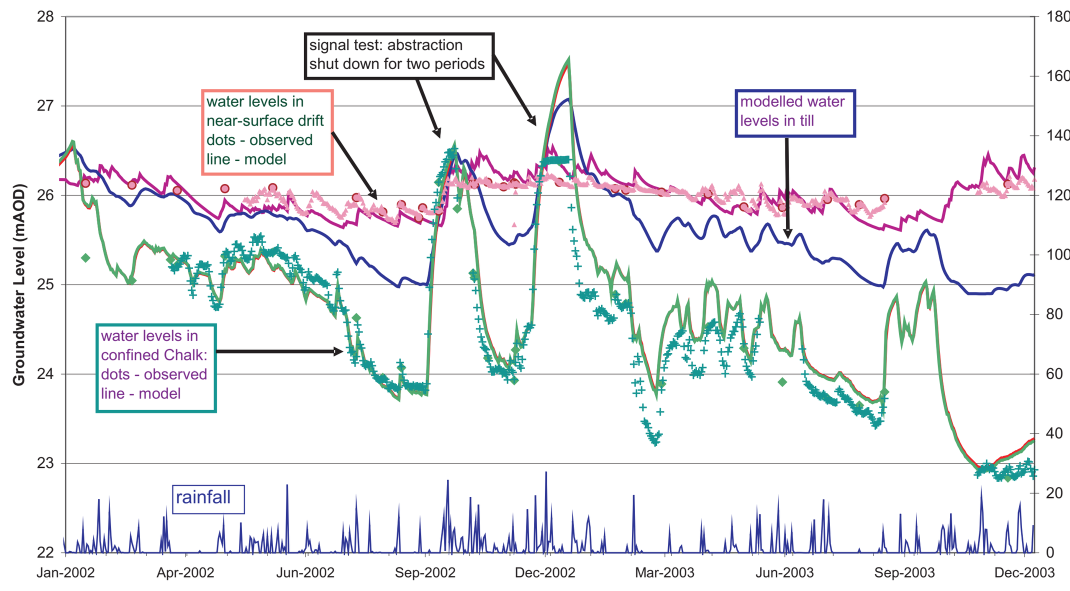


Figure 8. Model simulation of an abstraction 'signal test'

References

Environment Agency, 2003. Enhancements to MODFLOW, User Guide for MODFLOW-VKD a Modified Version of MODFLOW-96 to include Variations in Hydraulic Properties with Depth. National Groundwater & Contaminated Land Centre Project NC/00/23.
Grout, M.W. 1998. Strategy for Groundwater Investigations and Modelling: A framework for managing groundwater resources. Environment Agency Anglian Region
Heathcote, J.A., Lewis, R.T. and Soley, R.W.N., 2004. Rainfall routing to runoff and recharge for regional groundwater resources models. Quat. J. Eng. Geol. & Hyd., 37, 113-130.

Authors:
Keith Phillipson, Tim Lewis, Gordon Coombs, Mark Grout, Michael Hutchinson
Entec UK Ltd, philk@entecuk.co.uk, lewit@entecuk.co.uk, coomg@entecuk.co.uk, Shrewsbury, Shropshire, UK
Environment Agency, Anglian Region, mark.grout@environment-agency.gov.uk, michael.hutchinson@environment-agency.gov.uk, Peterborough, UK

Entec

Environment Agency