Integrating 3D geological models with surface-subsurface flood models

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Background

In contrast to river (pluvial) flood modelling, the winter 2013/14 floods have highlighted the relative lack of capabilities in modelling flooding from groundwater sources. Recent developments in digital 3D geological models have opened up the potential for their use in support of numerical flow models for a wide range of applications, including flooding from multiple sources.

Aim

The aim of this study was to develop, demonstrate and critically evaluate a new methodology for conceptualizing and modelling geologically controlled groundwater flooding by integrating a digital 3D geological model and an integrated surface-subsurface numerical flow model.

Models used

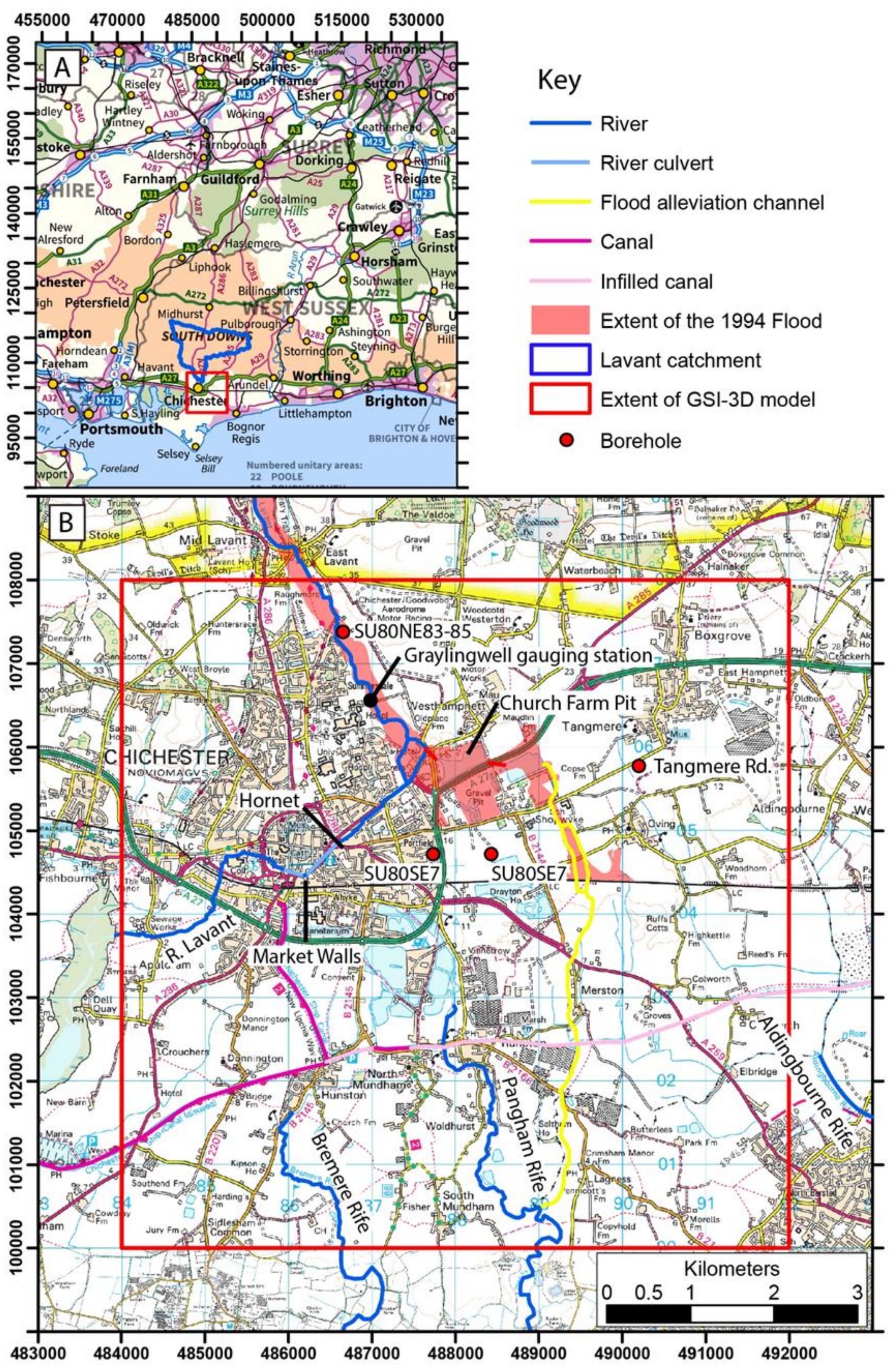
GSI3D is a methodology and associated software tool for 3D geological modelling which provides a powerful means to conceptualise shallow aquifers (http://www.bgs.ac.uk/research/environmentalModelling/GeologicalModellingSystems.html).

SHETRAN is a physically based spatially distributed numerical modelling system which simulates integrated surface and subsurface flows (http://research.ncl.ac.uk/shetran).

The Environment Agency's East Hampshire and Chichester Chalk (EHCC) regional groundwater model was used to provide groundwater head boundary conditions for the 8 x 8 km study area.

Study site: Chichester

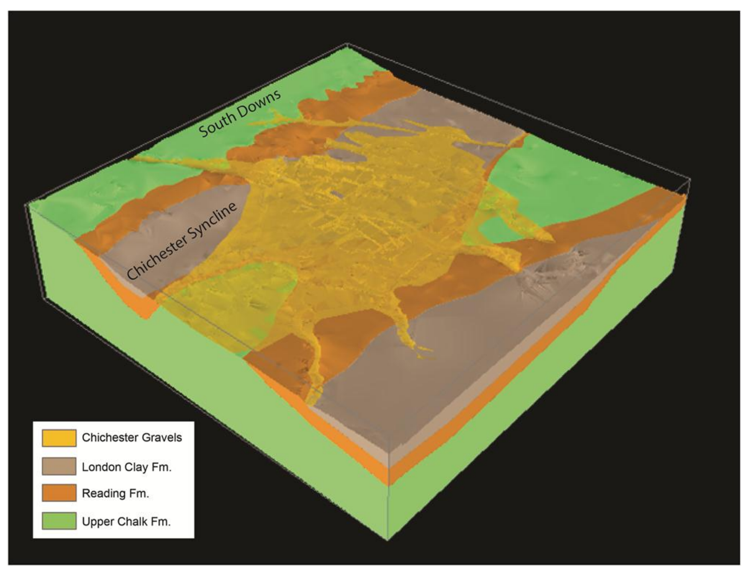
Chichester is a city in West Sussex on the south coast of England, situated on the coastal plain at the foot of the South Downs. The town has a long history of groundwater flooding, with significant flooding events in 1994, 2000-1, 2004, 2008 and 2013-14. This study focusses on the 1994 event, since when major flood alleviation works have been installed.



Location of the study area on the south coast of England, showing the extent of the GSI-3D model, the main surface water features, and the extent of the 1994 flood

Geological model

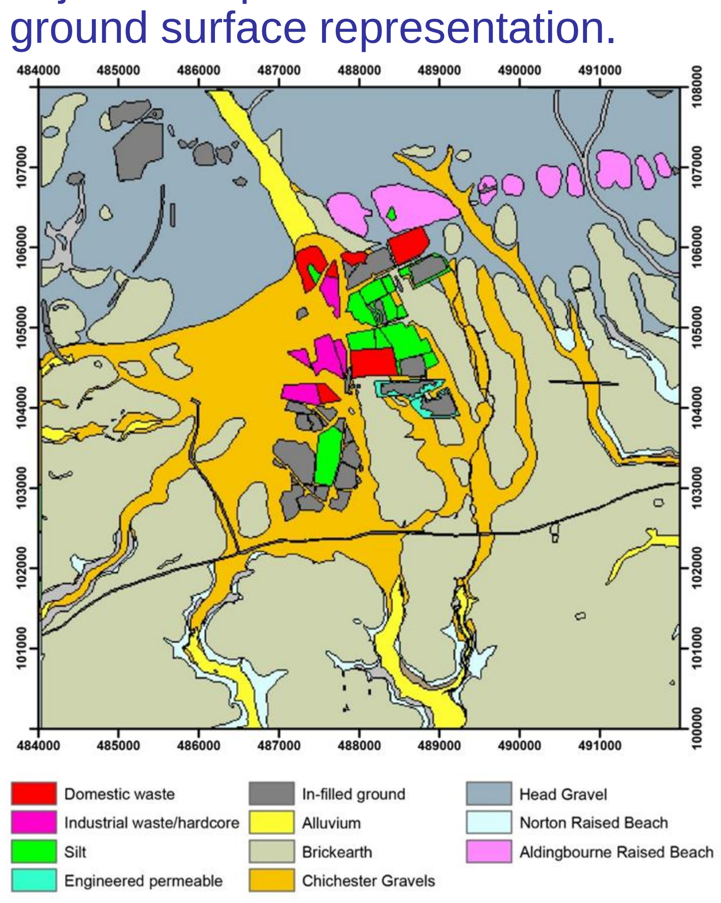
Eleven geological units are represented in the GSI3D model. The Cretaceous Upper Chalk Formation is the regional aquifer, overlain by the Palaeogene Reading and London Clay formations. The Chichester Gravels, a coarse clayey gravel unit that forms a large fan shaped body, is the most significant of the seven Quaternary units.



Simplified GSI3D model showing folding of the Upper Chalk, London Clay and Reading formations. The extent of the Chichester Gravels (translucent) is also shown. 10x vertical exaggeration.

Conceptual model

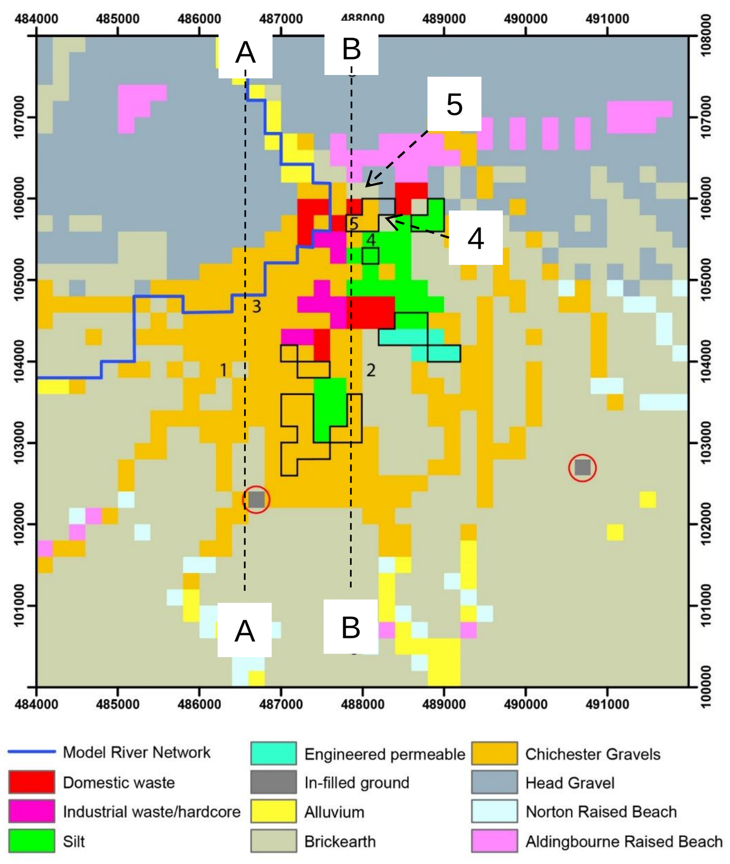
Both filled and open gravel pits control shallow groundwater movement, especially through interaction with the River Lavant. Made ground hydrostratigraphy was expanded to include the five main types of infill materials, and the geometry of the gravel pits was adjusted to provide a correct ground surface representation.



Revised GSI3D geological model surface features, showing reclassified gravel pits.

Numerical model

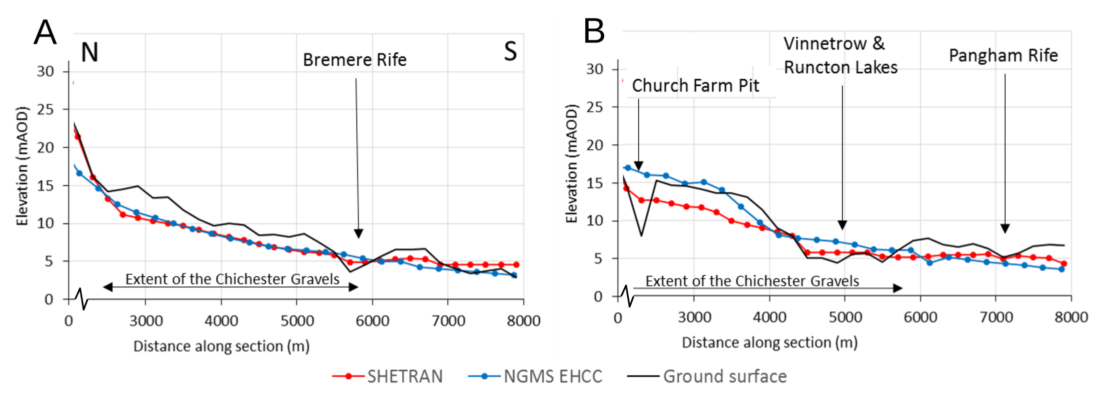
The 3D geological structure was imported into a 200m Shetran grid. A deep and a shallow model were implemented (with/without the Chalk). Boundary conditions of time-varying heads were imported from the EA regional groundwater model, and observed inflows were used for the River Lavant.



Representation of surface geology and River Lavant in the Shetran model (showing results locations)

Results

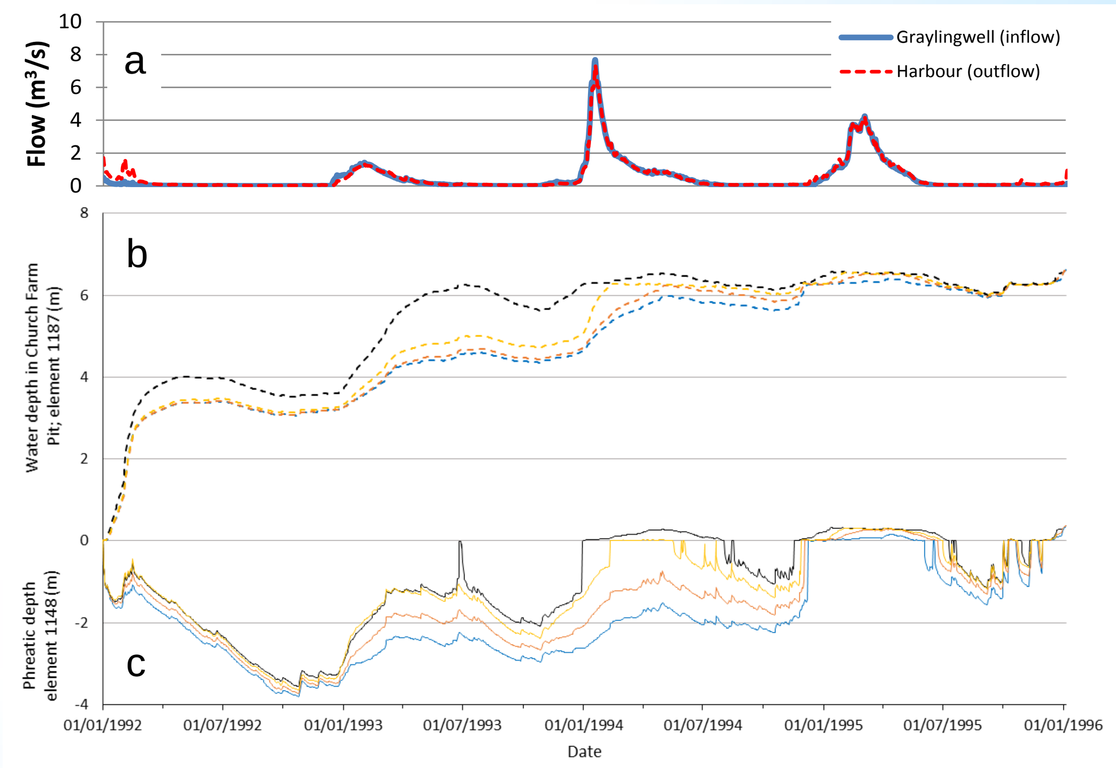
Comparison of simulated groundwater levels between Shetran and the EA regional groundwater model show good agreement for cross-section A which does not intersect any gravel pits. Slight differences near the coast are due to the coastal streams (rifes) not being included in this model. For cross-section B, Shetran simulates more realistic lower water levels due to dynamic interaction between groundwater and surface water providing surface runoff away from the pits.



Cross-sections of simulated groundwater levels from Shetran and East Hampshire and Chichester Chalk (EHCC) models for July 1993.

The time-series graph a) shows the observed inflow boundary condition in the River Lavant, with seasonally ephemeral flows related to groundwater level fluctuations in the Chalk. The simulated outflow shows a slight difference in flows as some river water exchanges with the Chichester Gravels.

Time-series of water levels in gravel pits near to the River Lavant (b) and groundwater levels at a location just downstream of the gravel pits (c) are shown from a set of sensitivity runs using varied hydraulic properties for gravel pit infill materials. These show interactions between surface water and groundwater levels, and illustrate the necessity for proper characterization of anthropogenic features such as made ground.



Simulated results from Shetran models (1992-95):
a) flows in River Lavant (inflow and outflow);
b) water levels in Church Farm Pit (element 1187, location 5);
c) water table levels (element 1148, location 4).

Conclusions

A new combined modelling approach has been developed to simulate flooding from multiple sources, and demonstrated for the 1994 historical flooding at Chichester, west Sussex.

The modelling has highlighted critical differences in how the ground surface and near-surface geology is represented in geological models and integrated surface-subsurface flow models. Our study has shown that:

- anthropogenic features, particularly made ground and worked ground (including voids), need to be correctly classified and assigned appropriate hydraulic properties in digital 3D geological models
- soil layers should be included in digital 3D geological models, as part of the critical zone which controls water infiltration and runoff
- consistency is required between representation of the ground surface in Digital Elevation Models, paying particular attention to changes in grid scales between models

These issues need to be addressed by inter-disciplinary collaboration, which will help to make digital 3D geological models better able to be used in support of flood modelling and management.

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