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Data processing in hydrogeology

5.1
Modelling as a tool of groundwater assessment

title: **A novel approach to groundwater model development**

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INTRODUCTION

The hydrogeologic conceptual model is a key source of uncertainty in predictions of groundwater flow. This is however an area of uncertainty that is frequently unaddressed in model analysis, while say parameter uncertainty is explored. In part this has been due to the availability of tools, like PEST (Doherty, 2005), that ease parameter uncertainty analysis. Another problem that hinders the exploration of geological uncertainty is the time required to develop alternative conceptual models.

We present a method that addresses the key issues that hinder the development of multiple competing conceptual models: the methodology facilitates the creation of multiple conceptual models; and by accessing modern IT methods it facilitates the model building process by increasing transparency and speed of development.

We show how hydrogeological models can be created from the 3 and 4-dimensional data sets using Radial Basis Function (RBF) models. We develop RBF models for the components in a hydrogeological model: aquifers, aquitards, boundaries, drains, and rivers. This approach has significant advantages. Firstly, the models are consistent with the known data and can be automatically updated when new data comes to hand. Secondly, the models can be influenced by both the choice of high level parameters such as anisotropy while maintaining consistency with the data. Thirdly, the user can add manual interpretations (trends or a priori information) that are maintained separately from measurements, but are then merged in the model building process to produce a model consistent with both measured and interpreted data. Once created, the model can be isosurfaced or gridded at any resolution or fitted to any mesh, a process that provides a flexible interface to flow simulators.

RADIAL BASIS FUNCTIONS

The equations used to represent hydrogeological system elements are developed by fitting RBF's to the data set. RBF's are well established set of methods used in scattered data interpolation, signal processing and artificial intelligence methods. RBFs are real valued functions defined as:

$$y(x) = \sum_{i=1}^{N} w_i \, \phi(\|\boldsymbol{x} - \boldsymbol{c}_i\|)$$

Where, c is the ith center, $\boldsymbol{x}$ is locations in space (or space-time), w is a weight and function ϕ can be any one of a number of functions but typically is either, gaussian, quadratic, or a type of spline function. We apply a polyharmonic (thin-plate) splines function for ϕ. The key factor in the application of a RBF is the determining the weights w_i associated with centers $\boldsymbol{c}_i$, which is a straight forward optimization problem.

DATA MODEL

Today a huge amount and a wide variety of data are collected for hydrogeological problems. To develop a complete understanding of the system it is necessary to integrate all of these data into the analysis. Figure 1 shows a simplified example of the data that can be used in Hydro in the development of a conceptual model for a hydrogeological system.

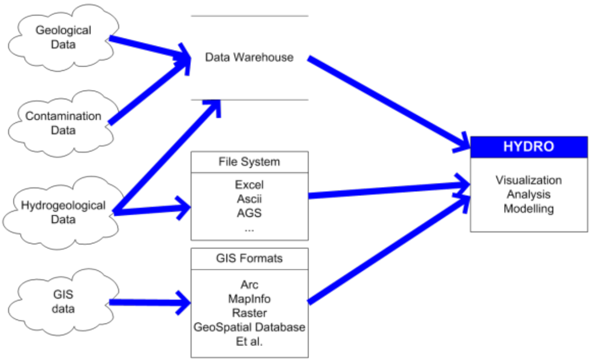
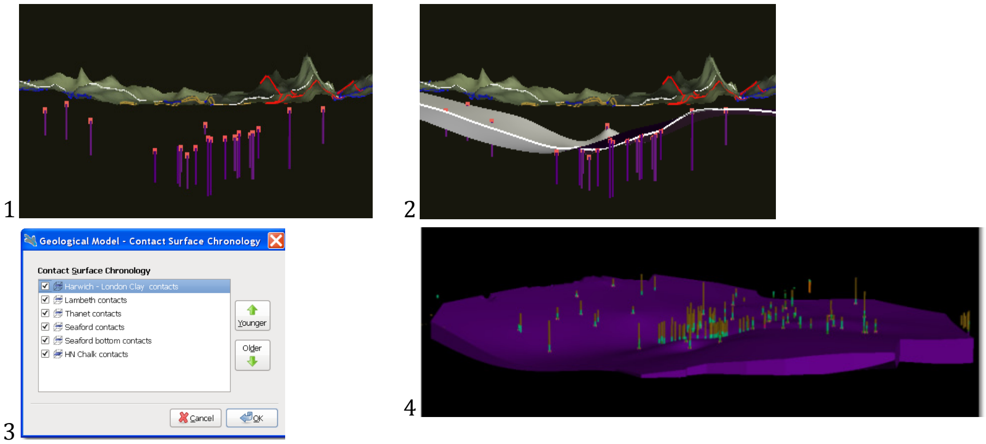


Figure 1. RBF's are used to describe geological units as bodies, the method ensures the entire subsurface is described.

An example of the type of analyses that Hydro can carry out is; geophysical data can be isosurfaced for a specific value (e.g. 20 ohm-m for a clay horizon) which can then be combined with well log data to define a contact surface.

CONSTRUCTING GEOLOGICAL MODELS

The data used to develop hydrogeologic conceptual models include geologic sample descriptions, interpretations of geophysical data, geochemical information et al. Frequently there is insufficient information to fully describe the hydrogeology without considerable interpretation from an expert. Existing methods for capturing this expert knowledge rely on solely manual interpretation of hydrogeological structures. This procedure is time consuming, difficult to update and also makes it difficult to maintain alternative interpretations of the hydrogeology. The methodology automatically captures data based geological contacts (Figure 2). Furthermore, the methodology documents in a clear manner the interaction of data versus manual interpretation.



Contact Surface Chronology

- ☑ Harwich - London Clay contacts
- ☑ Lambeth contacts
- ☑ Thanet contacts
- ☑ Seaford contacts
- ☑ Seaford bottom contacts
- ☑ HN Chalk contacts

Figure 2. Process in developing a geological model (1→2→3→4). The user defines a set of contacts (Hydro can automatically extract these from well logs), a surface is fitted and put into a stratigraphic order, and finally a volume is created. The contact points are selected using database technology.

We show how hydrogeological models can be created directly from the 3 and 4-dimensional data sets using Radial Basis Function (RBF) models (Figure 3). We can develop RBF models for all the components in a hydrogeological model: aquifers, aquitards, boundaries, drains, and rivers. This approach has three significant advantages. Firstly, the models are consistent with the known data and can be automatically updated when new data comes to hand. Secondly, the models can be influenced by both the choice of high level parameters such as anisotropy while maintaining consistency with the data. Thirdly, the user can add manual interpretations (trends or a priori information) that are maintained separately from measurements, but are then merged in the model building process to produce a model consistent with both measured and interpreted data. The method is not restricted to simple layer based geological structures (Figure 5).

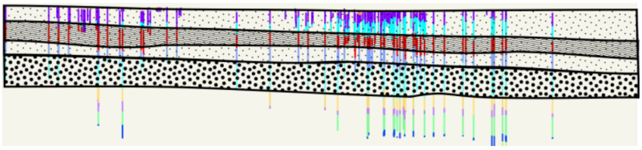


Figure 3. RBF's are used to describe geological units as bodies, the method ensures the entire subsurface is described.

DJURSLAND AQUIFER SYSTEM

In Djursland, Denmark a series of glacial and postglacial sediments lie on top of an erosion surface which consists of chalk. The glacial sediments have been partially reworked by subsequent glaciations and Quaternary sedimentation. The result is a far more complex geological setting than what is seen in the previous example. Here we have non-layered geology (till complex) resting on an erosion surface (Table 1). The main hydrogeologic issue in the region is quality degradation due to nitrates.

Table 1. Hydrogeology for the djursland aquifer system.

Formation	Environment	Type	Chronology
Postglacial sediments	***Various***	***mainly aquitards***	***youngest***
Till	***Glacial***	***Aquitard***	***same age***
Sands and gravels	***Glacial***	***Aquifer***	
	Erosion surface		
Chalk	***Marine***	***Aquifer***	***Oldest***

The data for the development of the hydrogeologic framework are 3851 well logs of varying depth. In addition to the well logs there is a digital elevation model and groundwater chemistry data. It is very time consuming if one is to group formations by hand for 3851 well logs, though one can learn by inspecting cross-sections and from experience, which formations are hydrogeologically similar. Our knowledge extraction process quickly resolves the hydrogeological formations at the site.

The hydrogeologic problem is to define sand and gravel aquifers and specifically identify where there is good groundwater protection, i.e. thick tills overlying sand and chalk. The upper 10–30 meters of the chalk is a fractured aquifer, regardless of the type of chalk. The geology is simplified into hydrogeological formations in the following manner: tills and silts and other fine grain sediments form one hydrogeologic formation; while sands and gravel form a second formation; finally chalk formations are placed into a 3rd formation. The surface between chalk and the other formations is defined as an erosion surface.

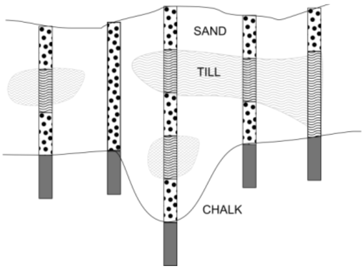


Figure 4. Conceptual problem in the Djurs hydrogeology.

Figure 4 shows the conceptual problem that is solved in the Djursland hydrogeology; that is we have a non-layered system overlying a layered system. The proposed method is ideal to addressing this type of problem because the RBF based model is not constrained to a layered system.

Another problem that needed to be addressed here is that as Djursland is a peninsula, there are no wells to the north and south. This causes a problem with the chalk surface as most interpolation routines will result in the chalk being exposed in the fjords north and south of Djursland. However, the addition of dip points just off shore for the erosion surface "forces" the chalk surface deeper, as we know is the case from wells north of the fjord.

Since an RBF is a function; once created, the model can be isosurfaced or gridded at any arbitrary resolution or fitted to any mesh or grid, a process that provides a flexible interface to flow simulators. This does not require re-fitting the data and interpretations, as opposed to say a Kriging approach that would require re-solving the Kriging equations if new grid resolution was chosen.

Hydrogeologic parameters are assigned to geological units and transferred to gridded models by the application of scaling relations. The long term goal is to develop models that can be more easily refined, either coarser or finer, without significant loss of simulation accuracy.

The method is implemented in a novel 3D user interface and is demonstrated on data from New Zealand and Europe.

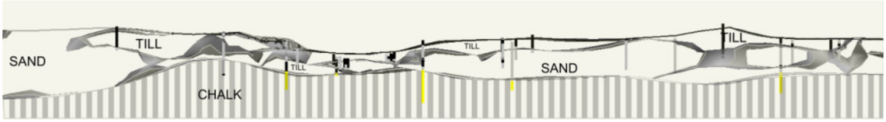


Figure 5. The method is not restricted to describing continuously layered systems.

CONCLUSIONS

We have presented a methodology that can be applied to develop hydrogeological models in complex hydrogeological systems. We believe the method shows advantages in extracting knowledge from the data and developing grid free hydrogeological models. The method also shows advantages in clearly indicating knowledge that comes from data versus expert opinion/a priori knowledge.

A significant part of the advantage with the method is how it is employed in the implementtation and is experienced carrying out the work flow in developing a hydrogeological model as well as in the collaboration between the geologist and hydrogeologist. This is difficult to demonstrate in a technical article.

The method was illustrated for an example one from Denmark. This example shows advantages in modeling non-layered aquifer systems.

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