The use of groundwater models as arbiters: a case study from the UK

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ABSTRACT

A pipeline to carry natural gas from two Liquefied Natural Gas terminals being built at Milford Haven, West Wales to the demand centres in the English Midlands is currently under construction. The pipeline has to cross a number of river valleys. One of these river crossings involved digging a trench through a sensitive shallow alluvial aquifer, which is currently being exploited for public water supply. There was a concern that both the construction work and the pipeline itself will impact the groundwater abstraction. All the stakeholders were involved in discussions about the likely impact, which was simulated in a hydrogeological and modelling study. The study concluded that the long-term impact of the pipeline on groundwater flows and heads was negligible, although concerns over the temporary impact of dewatering and the short-term introduction of turbidity into the aquifer remain. All parties accepted the model results and the model became an arbiter in the process of engineering the pipeline. The use of groundwater models as arbiters is useful, but cannot be realised without the agreement of all the parties involved that the model development produces results that are representative of the situation being investigated.

Keywords: groundwater flow, model, ZOOM, stakeholder, arbiter

INTRODUCTION

The Brecon to Tirley gas pipeline is being constructed by Murphy Pipelines Limited for National Grid. It will cross the River Dore in the Golden Valley at Vowchurch, Herefordshire, through shallow alluvial valley fill deposits which include a gravel aquifer utilised for public supply. The public supply boreholes are situated are less then 1 km downstream from the crossing. Concerns over the impact that the pipeline could have on the public supply abstraction regime led to the British Geological Survey being commissioned to investigate the aquifer, specifically:

1. to investigate the probable impact of pipeline construction, through trenching and associated dewatering, on the shallow alluvial aquifer and the river;
2. to investigate the post-construction, long-term effect of trenching and pipe laying, specifically the possible damming effect of the pipeline to groundwater flow and the possible increase in permeability of the trench backfill with a hydraulic connection to the river, which could introduce river water to the aquifer.

The investigation was focussed on informing the various stakeholders of the likely impact the proposed pipeline would have on the hydrogeological regime which includes public supply boreholes in a shallow and sensitive aquifer. Simple Darcian estimates of impact indicated that it was likely to be small, but when statements such as this were addressed to the problem holders they were rejected as indefensible, despite them being presented by professional hydrogeologists with extensive experience. Modelling was deemed the way forward, with each step of the model development presented to and accepted by the stakeholders so that the results and outcome were acceptable to all and perceived to be robust and defensible.

All available data on the aquifer, surface water, meteorology and land use were gathered together and used to assess and quantify the recharge processes in the catchment. Numerical radial flow modelling (Mansour, 2003) of the data produced from the original pumping tests at the Vowchurch abstraction wells yielded formation constants for the aquifer. These data were then incorporated into a numerical groundwater flow model using the object oriented ZOOM suite of modelling software (Jackson & Spink, 2004) to replicate the available historical data for the aquifer. The best-fit model has been used to run a variety of 'what if' scenarios.

HYDROGEOLOGY

The Vowchurch boreholes are drilled into alluvium which rests on Devonian age siltstone. The thickness of the alluvium varies between 5 and 10 m. Four boreholes were originally drilled (Vivash, 1983), but only three are used for supply purposes. The boreholes are adjacent to the River Dore, which has a number of small tributaries, the most significant is the Slough Brook.

The key considerations in the Vowchurch reach of the River Dore are:

- The River Dore is largely underlain by low permeability silt deposits that inhibit infiltration, although it is in direct hydraulic contact with the gravel aquifer in some reaches.
- The flood plain is underlain by 2 to 4 m of till that has low to moderate permeability.
- The gravel aquifer is 'dirty' containing a sand and silt grade matrix and pebbles and cobbles. It is of variable, generally high permeability with the vertical permeability less than the horizontal permeability.
- The deepest parts of the Dore Valley are located along a central buried valley, whilst the current course of the Dore hugs the eastern flank of the alluvial plain.
- The Slough Brook is perched on a fanglomerate, and only loses water in the lower reaches of the area of interest.

Recharge to the gravel aquifer may occur from direct rainfall recharge through the overbank deposits and the till, by secondary recharge from river and stream losses, or overland flow down the valley sides. The gravel is poorly to moderately sorted and contains material as fine as silt grade. The permeability varies areally and with depth, but transmissivity is greatest along the buried valley which continues downstream through the public water supply wellfield. The observed water table reflects the increased transmissivity along the central portion of the gravel, the buried valley, with leakage from the River Dore on the east and ingress from overland flow in the west. Upstream loss of water from the River Dore to the gravel flows down the buried valley where it is partly abstracted at the Vowchurch boreholes, the remainder flows past the wellfield to rejoin the river before the gravel pinches out downstream.

GROUNDWATER MODELLING

The ZOOMQ3D groundwater flow model (Jackson and Spink, 2004) was used to investigate the impact of the pipeline on the groundwater system and on the public supply boreholes in particular. ZOOMQ3D allows the refinement of the model grid to provide more detail for the areas of most interest, i.e. the abstraction boreholes and the pipeline.

The structure of the model is shown in Fig. 1a. The area is discretised using a base grid of 100 m square cells. This grid is refined around the boreholes by reducing the cell size to 25 m and along the path of the pipeline to 20 m. While the refinement around the pumped boreholes improves the positioning of these boreholes in the model, the refinement along the pipeline improves scaling and allows a more realistic investigation of the system.

The boundaries of the model are based on the extent of the gravel aquifer as shown in the BGS 1: 50 000 geological map sheet. The gravel aquifer thins to the north-western and south-eastern ends of the model grid. The adjacent and underlying Devonian siltstones and mudstones are modelled as impermeable. The groundwater heads at the upstream and downstream ends of the aquifer are controlled by the river stage.

The gravel aquifer is represented in the model by one numerical layer, the saturated thickness of the aquifer is set to 6 m and it is assumed that this thickness remains constant during the whole simulation period. In the numerical model, the riverbed elevations at the nodes representing the River Dore and the Slough Brook are set to values obtained by an earlier detailed river-bed survey.

Since the model is calibrated against available historical groundwater level data, the long-term impact of the pipeline on the groundwater flow system can be studied under steady state conditions. It is assumed that rainfall recharge and the water gained via the bed of the river (which includes overland flow from the greater catchment area) are the only sources of water entering the system and that groundwater leaves the system through the abstraction boreholes and downstream, where the shallow aquifer pinches out, back into the River Dore. A numerical recharge model ZOODRM (Mansour and Hughes, 2004) was used to estimate the recharge values distributed over the aquifer.

The recharge values obtained from the recharge model, ZOODRM, were applied to the whole groundwater model area. Since the rivers are truncated by the edges of the groundwater model, river flow inputs must be specified at the upstream and downstream ends of the model. The flows at these stations are monitored over the simulation time and average river flow values are calculated. These river flow values at the upper part of the River Dore and the Slough Brook are 17 Ml day^{-1} and 6.1 Ml day^{-1} respectively.

Pumping test analyses at abstraction boreholes A and C show that the horizontal hydraulic conductivity for the gravel is about 250 m day^{-1} although it can be as low as 120 m day^{-1} when sand and silty clay are present. In addition, a vertical hydraulic conductivity value of 5 m day^{-1} was adopted throughout the aquifer.

The numerical simulation used a horizontal hydraulic conductivity of 250 m day^{-1}. The transmissivity value calculated with an aquifer-saturated thickness of 6 m is 1500 m^2 day^{-1}. Fig. 1a shows a plot of the simulated groundwater level contours against the average observed groundwater levels. They are in good agreement especially in the southern part of the groundwater model around the abstraction boreholes. The comparison between the observed and simulated groundwater levels in the northern part of the model area suggests that the transmissivity value is too high for this area. However, because there are few available observed groundwater levels, the derived groundwater heads are assumed to be acceptable and both the distributed recharge values and transmissivity values are used for the subsequent runs.

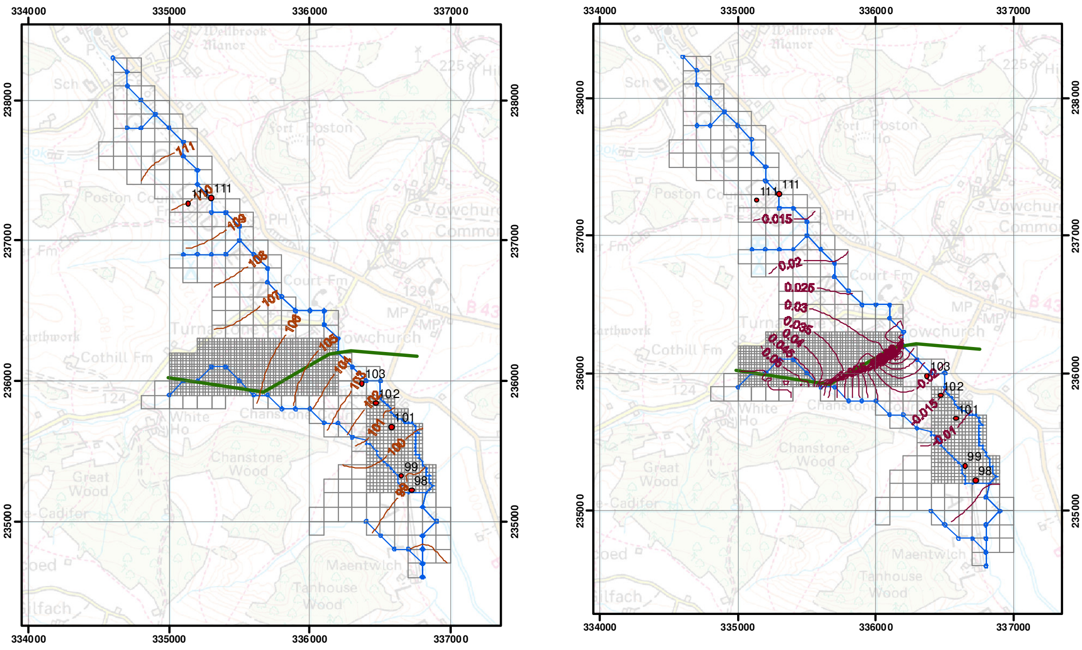

Fig. 1 Model results (a) Comparison between the simulated groundwater level contours (red lines) and the observed groundwater heads (black spots and numbers), (b) Contours of the differences between the simulated groundwater heads with and without the presence of the pipeline.

IMPACT OF THE PIPELINE ON THE GROUNDWATER SYSTEM

The trench in which the pipeline will be laid will be approximately 3 m deep. The pipeline will cause a reduction in the transmissivity for groundwater flowing perpendicular to the pipe down the valley towards the wellfield. A single layer numerical model is used. The effects of constructing the pipeline and its surrounding materials are accounted for in the model by reducing the values of aquifer transmissivity at the nodes located along the path of the pipeline. Assuming that only the pipeline will inhibit the groundwater flow and that the pipeline diameter is 1.2 m, then one quarter of the aquifer will be made impermeable when the pipeline is constructed. The new transmissivity value at the node representing the pipeline trench is reduced, therefore, from 1500 m^2 day^{-1} to 1125 m^2 day^{-1}. This simulation does not reveal any significant changes in the groundwater heads from the original simulation without the pipeline. The plot of the differences between the simulated groundwater heads of this run and those of the original run is shown in Fig. 1b. This plot shows that the pipeline may cause a 0.06 m groundwater head to build up directly to the north of the pipeline and that a slight decrease (0.02 m) in groundwater head may occur directly to the south of the pipeline.

The actual groundwater head changes are expected to be lower than the derived values because the modelled pipeline trench is 40 m wide due to the node separation, whereas the real trench will be only 1.5 m wide. The results of simple analytical solutions confirm the range of the simulated head differences (Fig. 2a) and show that groundwater differences can be as small as 0.003 m if a trench width of 2 m is used in the calculations (Fig. 2b). These figures derive from an aquifer transmissivity of 1500 m^2 day^{-1} and a hydraulic gradient of 0.005 along the main flow direction. The transmissivity along the line of the pipeline trench is set to 1125 m^2 day^{-1} in both cases and this increases the hydraulic gradient to a value of 0.007 yielding a groundwater head differences of 0.083 m and 0.003 m with trench widths of 50 m and 2 m respectively.

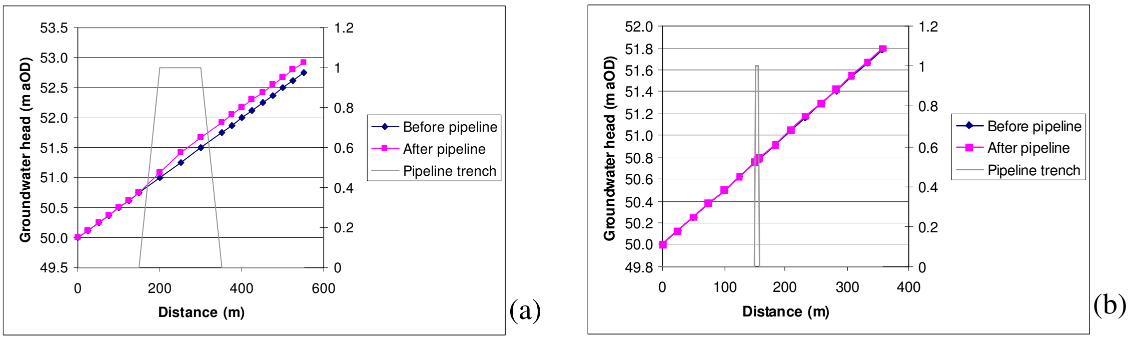

Fig. 2 Spreadsheet calculations to investigate the pipeline impact on the groundwater heads. (a) Width of pipeline trench is 50 m. (b) Width of pipeline trench is 2 m.

INTERACTION BETWEEN STAKEHOLDERS

There were a large number of stakeholders involved in the process of developing a model of the groundwater system (Fig. 3). The problem holders, i.e. owners of the abstraction boreholes, are Welsh Water supported by their hydrogeological consultants Celtic Water Management. The pipeline construction team led by National Grid were Murphy Pipelines Ltd assisted by STATS to provide hydrogeological support. The organisations controlling the planning process are the Environment Agency and the local planning authority. The BGS, as model developers, assisted STATS in developing a hydrogeological understanding.

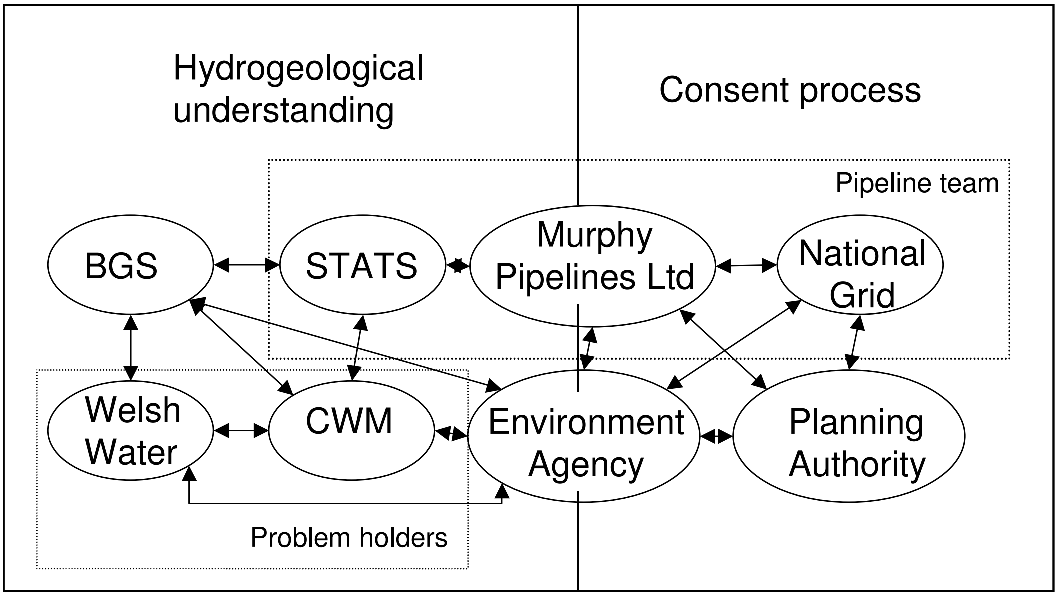

Fig. 3 Key stakeholders and their interaction

The interaction between each stakeholder was undertaken in either small, informal meetings or field visits or as large, formal meetings. For the groundwater modelling, the results were discussed informally at small meetings or the full range of results were presented at large "set-piece" meetings. Of particular importance, was the visit of the client to BGS offices to examine the model and discuss its output. This demonstrated that the model development process was transparent and open and that the model was robust and defensible and aided the development of trust between the parties.

With the large number of stakeholders and the complexities of interaction between them, there was considerable potential for dispute. That this did not happen was due in part between the trust that developed between the individuals involved in the project and the acceptance of the model results. The model results showed that there was likely to be a limited long-term impact of the trench on the aquifer and this was supported by simple, Darcian calculations. The short-term impact during construction was less certain, but the impact was unlikely to be critical to the water supply boreholes. The use of simple calculations helped build confidence in the model results, especially as data were limited.

SUMMARY AND CONCLUSIONS

This study has demonstrated that groundwater flow models, even when data are limited, can be used as arbiters between the different stakeholders involved in the decision-making process. A relatively simple groundwater flow model was developed and applied to investigate the impact of trenching a pipeline through a shallow, sensitive alluvial aquifer. The model results demonstrated limited long-term impact from the placement of the pipeline. These results were accepted by all the stakeholders involved. Given the complexity of the relationships between the stakeholders, and the potential for conflict, this was a welcome outcome. The process of developing the model in discussion with the stakeholders enabled everybody to see that the modelling process was representing the technical issues sensibly and reasonably. In this way the model output was accepted by all the stakeholders and the model acted as the arbiter for all the parties involved in the decision-making process.

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