An Interactive Model Development and Implementation Framework for Regulating Groundwater Use

Edwin Welles[1], Bennie Minnema[2], Dan Palombi[3], Steve Wallace[4], Brent Welsh[5], Amandeep Singh[3], Rolf Farrell[6], Mark Whiteman[6]

[1]Deltares USA, Edwin.Welles@deltares-usa.us, Silver Spring, Maryland
[2]Deltares, Bennie.Minnema@deltares.nl, Delft, Netherlands
[3]Alberta Geological Survey, Dan.Palombi@ercb.ca, Amandeep.Singh@ercb.ca, Edmonton, Alberta
[4]Alberta Ministry of Environment and Sustainable Resource Development, Steve.Wallace@gov.ab.ca
[5]Alberta Energy Resources Conservation Board, Brent.Welsh@ercb.ca, Edmonton, Alberta
[6]Environment Agency, rolf.farrell@environment-agency.gov.uk, mark.whiteman@environment-agency.gov.uk, Leeds, United Kingdom

ABSTRACT

Groundwater regulators in Alberta have identified cumulative effects associated with groundwater pumping, through time and across multiple wells, as an additional impact they need to assess when authorizing groundwater use. These cumulative effects are likely best evaluated by a numerical groundwater flow model with well-defined boundary conditions. Therefore, the responsible agencies are exploring technical and policy requirements to move from pump test based authorizations to an enhanced framework utilizing numerical groundwater models. Through workshops and pilot projects, groundwater modelers at the Alberta Geological Survey (AGS) and model users within Alberta's regulatory agency (Alberta Environment and Sustainable Resource Development [AESRD]) have determined that a successful transition must involve interactive model development. During implementation, model users may identify anomalies when new data becomes available through an application for a groundwater authorization. As a result, the users subsequently provide feedback to the modelers to make updates and improvements to the model. To implement this process, the developers and users need a system or an operational framework which enables updated models to be easily loaded into the user environment (with consistent displays and controls). In this paper we will provide a description of the model development and implementation process which supports easy exchange between the various stakeholders. This framework may be useful for other regulatory agencies considering a similar transition.

INTRODUCTION

As pressure on water resources increases, the need for comprehensive management of available resources increases. The water resource regulators in Alberta have identified this need and have initiated a provincial scale program to address this need for management strategies which addresses both surface and groundwater. One component of the program is to analyze the cumulative effects of groundwater pumping. That is, Alberta groundwater regulators are now developing assessment tools/methods for predicting the long-term impact on the aquifers given all the other pumping authorizations and baseflow requirements for surface water resources.

One of the most effective methods for assessing the cumulative effects, especially when the assessment of the impacts must be made for periods of years or decades into the future, is to use numerical models. Integrating a numerical model into the regulatory process, while conceptually simple, requires establishing a new consistent support infrastructure to develop, test and then provide managers access to these models. This need is not unique to Alberta. The United Kingdom Environment Agency National Groundwater Modelling System offers an example of a mature system which provides managers access to groundwater and surface water models of their region. The developments in Alberta have enhanced the process to make an explicit link between model development and model use.

FROM MODEL DEVELOPMENT TO MODEL USE

Model development and model use are distinct phases of a model life cycle. Often these two phases are mingled. For example, when a developed model is used to analyze conditions at a specific location, or when a particular process within the developed model is under investigation, model use occurs right after model development and it is most efficient for the model developer to also act as the model user. However, these models often do not have long term uses. When the operational life of the model will continue for as long as or longer than the model development phase, mingling the two phases can make the second phase (i.e. the model use) challenging. This mingling becomes more detrimental to model use as the uses become more structured, with increasing user group size, and with bigger complex models. When models are to be used in highly structured frameworks necessary to support regulatory actions, then they must take on a more fixed character than those models which are a part of a study where model improvements are one element of a project. Within a structured environment, model changes must be made more deliberately – albeit to the great frustration of the majority of scientific model developers.

In Alberta, we have started to pilot a model development, use, enhancement, and re-deployment process which we expect can provide the structure needed for a regulatory process and at the same time the quick response capability to which model developers are accustomed.

The requirements for an effective model development environment consist of easy viewing of all model parameters and outputs, and the capability to build and edit model grids and parameter values. The model development environment is an exploratory environment. The model builder needs to make ad hoc queries of the model parameters, states and outputs to diagnose the model behavior. While there is order and structure in the development process, the path forward is not predetermined.

An operational environment focuses on well-ordered analysis resulting in consistent objects and displays. It is easy to imagine the frustration of people applying for groundwater authorizations if each authorization was issued based on a different set of criteria evaluated with different analyses. To support a regulatory process, the criteria and review process must be known at the outset and the final reports summarizing the findings must be the same from applicant to applicant. The requirements for an operational environment are very different from those of the model developer.

As models are used, operators will develop detailed knowledge of the model strengths and flaws. Cooperation between the developers and the users will lead to model improvements which will be re-integrated into the operational setup. This improvement cycle is essential to ensure the models supporting the regulatory process are as accurate as possible. Within the Alberta Groundwater Pilot Project, we have laid a foundation for supporting model development and use based on this iterative cycle of continuous improvement.

ALBERTA GROUNDWATER PILOT PROJECT

It is envisioned that groundwater models will be developed by the Alberta Geological Survey (AGS) and be used by the regulators in Alberta including AESRD. The two groups need different working environments and those two working environments must communicate. Models developed by AGS must drop easily into the operational environment at AESRD.

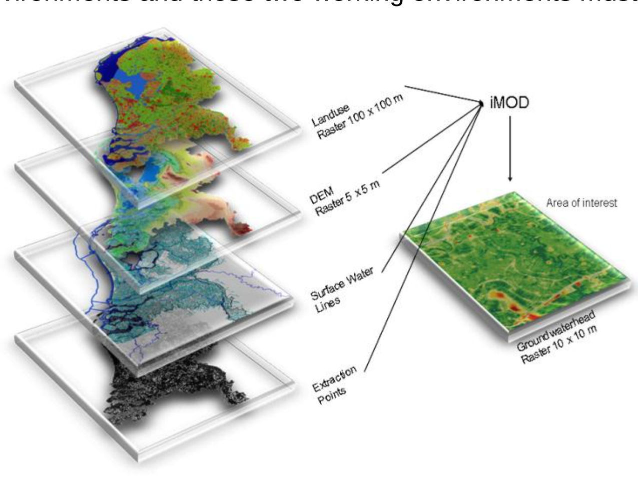

Figure 1: The iMOD-approach: one input data set without clipping to any areas of interest.

The Model Development Environment

Considering the links between development and operations, the model development environment iMOD (Minnema et al, 2013) was introduced to the AGS modeling team. iMOD is a very fast and flexible user interface for building and analyzing MODFLOW models. The approach allows the modeler to interactively generate models of any sub-domain within the area covered by a data set. Regardless of the size of the actual files in the data set, iMOD offers very high performance while processing the data. When priorities change in time (e.g. due to changing political agenda's) the modeler can simply move to that new area of interest, add new or more detailed data or expand the data set for the new area and apply any desired grid resolution.

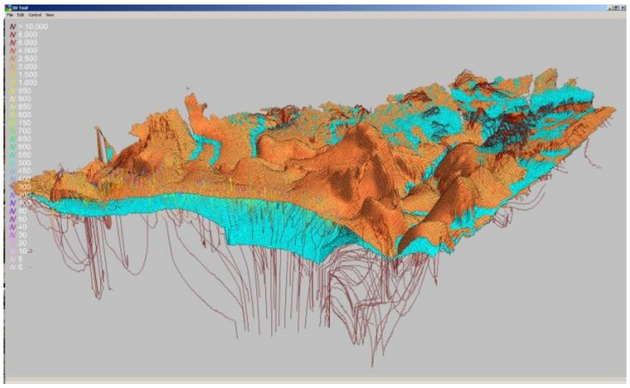

Figure 2: 3D visualization of surface elevation, hydraulic head and flow lines in Southern part of Alberta.

The capability of iMOD to rapidly view and edit model inputs is an essential component of the workflow to build effective models. The rapid and integrated views of the geologic / hydrostratigraphic models as well as dynamic model output is critical for the public, stakeholders and regulators to understand and trust the model as a valid decision support tool (Figure 1). iMOD uses a random accessible data format for 2D grids which facilitates instant visualization or editing subsets of such a large grid file. Also iMOD contains very economical zoom-extent-dependent visualization techniques that allow subsets of grids to be visualized instantaneously both in 2D and 3D (Figure 2). Another feature is that iMOD generates MODFLOW input directly in memory, skipping the time-consuming production of standard MODFLOW input files (generating standard MODFLOW input files in ASCII format for large transient models may take hours to a full working day); this efficiency is especially useful during the model building phase when checking newly processed or imported data.

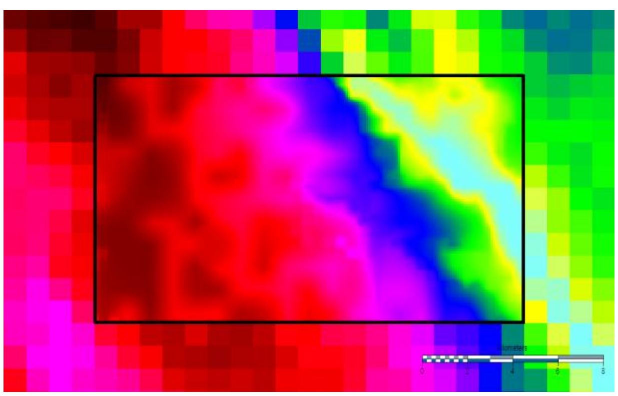

Figure 3: Example of sub-domain model (rectangle) embedded in coarser regional model; both models are based on the same data set, the only difference is the assigned grid-extent and resolution.

The iMOD approach allows gathering the available input data to be stored at its finest available resolution; these data do not have to be clipped to any pre-defined area of interest or pre-processed to any model grid resolution. Resolutions of parameters can differ and the distribution of the resolution of one parameter can also be heterogeneous. In addition, extents of the input parameters do not have to be the same. iMOD will do up- and down scaling (Vermeulen, 2006) whenever the resolution of the simulation is lower or higher than that of the available data.

A major difference, compared to other conventional modeling packages, is the generic geo-referenced data structure that for spatial data may contain files with unequal resolutions and can be used to generate sub-domain models at different scales and resolutions applying up- and down-scaling concepts (Figure 3). This is done internally without creating sub-sets of the original model data. For modelers and stakeholders, this offers high performance, flexibility and transparency.

Utilizing the internal up- and down-scaling techniques ensures that sub-domain models remain consistent with the larger regional model or that the regional model can be updated locally with the details added in the sub-domain model. iMOD facilitates the modeler leaving the era of sequentially building individual models behind while maintaining consistency between all groundwater models based on the extendable data set.

In time the modeler may have gathered so much detailed data that a groundwater model honoring the extent and resolution of the data set would become far too big to fit in any CPU-memory. iMOD facilitates generating sub-domain models with a user-defined resolution depending on how large the available CPU-memory is and how long the modeler permits her/himself to wait for the model calculations to last. To generate a high resolution result for the whole model domain a number of partly overlapping but adjacent sub models are invoked and the result of the non-overlapping parts of the models are assembled to generate the whole picture. The modeler should of course be cautious that the overlap is large enough to avoid edge effects, but this overlap is easily adjustable in iMOD. A big advantage of this approach is that running a number of small models instead of running one large model takes much less computation time. Using this approach means that the modeling workflow is very flexible and not limited anymore by hardware when utilizing iMOD. This enables AGS and AESRD to proceed with building groundwater models in Alberta in any order, region after region or sub regions within larger regions with resolutions that fit the actual needs and still maintain consistency between the different sub models and resolutions.

The Operational Modeling Environment

Each type of user, including forecasters, regulators, and planners, will ask a different set of questions. In the case of AESRD groundwater regulators, they need to know what will happen if a new groundwater authorization is issued. They need to know if the new well will influence the existing wells and surface water resources (i.e. if it will deplete surface water resources and more importantly if the pumping is sustainable for the authorized term). The operational process piloted in a demonstration project consisted of three steps: background data display, modeled scenario comparisons, and transition curve analysis. Following the example of the UK Environment Agency, this process was embedded in the Delft-FEWS (Werner et al., 2013) framework. The background data displays included GIS layers of topography and surface water features, sub-surface formations, well locations and characteristics, the model grid, and political boundaries (see the example in Figure 4).

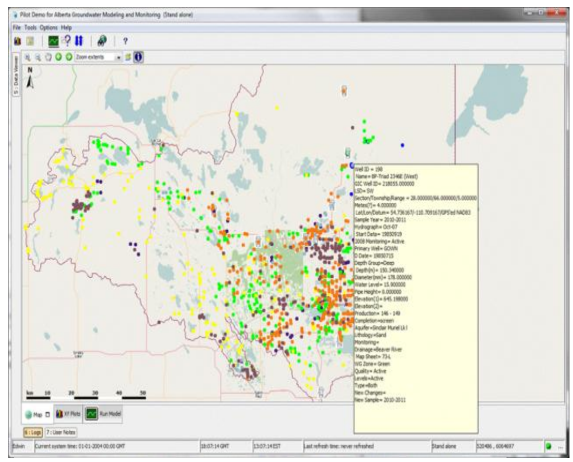

Figure 4: Data display showing well locations and characteristics from the Alberta Groundwater Pilot Project.

If this system becomes operational, then all the relevant data can be displayed via Delft-FEWS to the range of regulators in a consistent manner (even to those not in Edmonton where the data is stored). Providing consistent data access helps to provide consistency in the regulatory process.

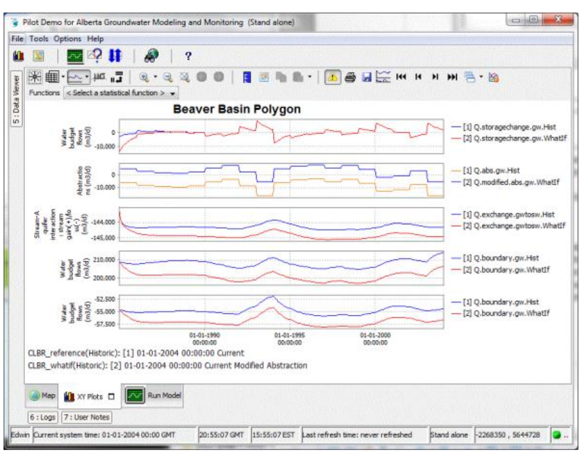

Figure 5: Example comparison of scenarios to assess the impact of pumping on a lake.

Again following the example of the UK Environment Agency, the second phase of the pilot process is to model “what-if” scenarios. The operators can add a well to the model or change pumping rates and then compare the model results for the modified model with the results from a baseline reference case. In Figure 5 there is a comparison of a modeled scenario to that of the reference case within a specific polygon from the Alberta Groundwater Pilot Project. The top plot shows that the change in storage over time within the polygon is the same for the original and new scenarios. The second graph shows the two pumping rates with the newly increased rate in blue. The lower three graphs show the increased surface water losses, reduced exchange across the vertical boundaries of the polygon and increased recharge.

The third phase of the proposed process is conducting transition curve analysis. The transition curve offers a summary of the differences between the baseline and what-if scenario a user has tested. The transition curve shows how the sources of water being pumped from a well transitions from water released from aquifer storage to induced recharge, eventually reaching a new steady state. An example of transition curves is shown in Figure 6.

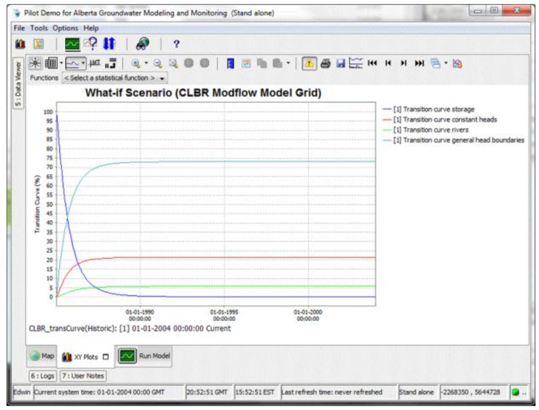

Figure 6: Transition curves.

Enhancing and Re-deploying a Model

Once the operators have become familiar with a model and identify needs for improving the calibration in particular areas, they will ask for changes. When this occurs the model developers can return to their build environment to make the necessary improvements. It is possible to update an existing model in the Delft-FEWS framework simply by uploading new parameters. While it is technically feasible to easily upload new model parameters, a more strategic tiered approach is under development in order to ensure the regulatory process remains. After development is complete, a period of testing will follow to assess the model changes and their impact on the groundwater authorization process. Once approved, the model will be made available to the regulators via simple upload. Though such a process may appear bureaucratic and slow, it ensures the stability of the operational environment.

SUMMARY

In order to make full use of the science developed with models, it is important to make the models available to a broad group of users. Working with the model developers and the regulators in Alberta we have piloted a full cycle of model development and model use supported by a data management and decision-support system that provides easy access to model output for use by a wide range of stakeholders. This process has been designed to support Alberta groundwater regulators as they transition away from managing groundwater withdrawals one well at a time, to managing the cumulative effects associated with several withdrawals and future development scenarios. This process may be of use to others intending a similar transition.

ACKNOWLEDGMENTS

We gratefully acknowledge the funding provided by Alberta Innovates – Energy and Environment Solutions and Agentschap NL, Ministry of Economic Affairs, The Netherlands.

REFERENCES

Minnema, B., Vermeulen, P.T.M., Riddell, J., Palombi, D., Wallace, S., Aimo, N., 2013. Utilization of Interactive MODeling (iMOD) to Facilitate Stakeholder Engagement in Model Development Using a Sustainable Approach with Fast, Flexible and Consistent Sub-Domain Modeling Techniques. In: Proceedings of MODFLOW and More 2013 conference held from June 2-5, 2013 at the Colorado School of Mines campus in Golden, Colorado, USA.

Vermeulen, P.T.M., 2006. Model-Reduced Inverse Modeling. Ph.D. thesis Delft University of Technology - with ref. - with summary in Dutch. ISBN-10: 90-9020536-5. ISBN-13: 978-90-9020536-6.

M. Werner, J. Schellekens, P. Gijsbers, M. van Dijk, O. van den Akker, K. Heynert, The Delft-FEWS flow forecasting system, Environmental Modelling & Software, Volume 40, February 2013, Pages 65-77, ISSN 1364-8152, 10.1016/j.envsoft.2012.07.010. (http://www.sciencedirect.com/science/article/pii/S1364815212002083)