GEOMODELS AS A KEY COMPONENT OF ENVIRONMENTAL IMPACT ASSESSMENTS OF MILITARY TRAINING RANGES IN CANADA

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1. ABSTRACT

Military training ranges in Canada often cover extensive areas overlying thick Quaternary stratigraphic sequences containing valuable water resources. Here we present the geomodeling methodologies and tools that have been used and/or developed over the last few years within the framework of environmental assessment studies of some of the largest training ranges across Canada. Essentially, models are built after a substantial data acquisition phase using a discrete modeling approach that provides the needed flexibility not only to meet the requirements of different groundwater flow modeling strategies but also those of aquifer vulnerability and risk to contamination mapping techniques. Tools that improve the interoperability between geologic and hydrogeologic models are presented along with some potential research avenues.

2. INTRODUCTION

The protracted activities (50 to > 100 yrs) on military training ranges including live firing of a large variety of ammunitions are known for their potential impact on groundwater and this situation has highlighted the urgency to improving knowledge of hydrogeologic settings of training ranges. The general objectives of the environmental assessments are to 1) characterize the state of the environment on military training ranges; 2) understand the environmental behavior of energetic materials under various field conditions and; 3) design sustainable training methods. These assessments are also used as a platform to develop standard procedures not only to provide robust field and laboratory techniques for this unique type of investigation but also to allow some degree of comparison between training ranges and to simplify the whole process. The development of geomodels is critical to achieve all of the above objectives and the chosen “standard” approach had to allow for maximum flexibility to meet the requirements of multiple applications. A few models have been completed and others are to be developed as part of this large program. Some are/will be relatively small and detailed to represent a particular setting underlying a small range (e.g. grenade range) and others include an entire training center extending out to the boundary of a sub-regional hydrogeologic model (> 1000 km²). All these models are used mainly as frameworks for flow and transport modeling as well as for mapping aquifer vulnerability and risk to contamination (Parent et al. 2007). This kind of versatility is considered as key to the success of a 3D mapping program (Ross et al. 2005). Here, we present the general geomodeling approach as well as some tools that were developed to improve the interoperability between geologic models and the three main applications: Flow and transport modeling, aquifer vulnerability mapping and risk analysis.

3. FIELD DATA ACQUISITION

Due to access constraints, these areas generally lack archival geoscience data and information and thus require extensive field data acquisition before any geomodeling effort can be undertaken. This includes the production of a geologic map and a detailed study of the stratigraphy from available sections as well as from borehole samples from the well drilling/installation programs. Near-surface geophysical data are limited to well-maintained roads because of the widespread occurrence of metal pieces at or near the ground surface or, in the case of shallow seismic, because of the risk of detonation of buried unexploded ordnance (UXO). Even within the context of an official assessment, access to some of the ranges is very limited complicating field surveys. Nevertheless, significant amount of data can be obtained and used to build 3D geomodels.

4. THE GEOMODELING APPROACH

The software gOcad was chosen to construct the various geomodels following the same methodological steps as those proposed by Ross et al. (2005). Using gOcad, discrete triangulated surfaces are first built by interpolating points, lines, open and closed curves. Surfaces are modified by applying the Discrete Smooth Interpolation (DSI) algorithm (Mallet 2002) which minimizes a roughness criterion while honoring a wide
range of linear hard and soft constraints. At this stage, 3D models consist of a series of interlocking discontinuous surfaces representing the framework boundaries of geological objects (Fig. 1a). The space between boundaries can then be consistently partitioned to describe and represent the geological objects and their properties (Fig. 1b-d). Script commands have been developed to streamline the discretization process. One of the main benefits of using this approach is that it can provide consistent definition of the stratigraphic architecture without depending on any specific high resolution 3D grid (Caumon et al. 2004; Ross et al. 2005). This is a critical point since a detailed geometric definition of the stratigraphy can be used without any internal mesh for visualization purposes or as the backbone for further discretization whose type and resolution are adapted to fit the specific needs of most applications (geostatistics, groundwater flow simulation, etc.) (e.g. Mello and Cavalcanti 2003; Ross et al. 2005). In the context of environmental assessments of military training ranges, two types of discretizations have been used: regular grids with cubic cells or voxels (Fig. 1c), curvilinear stratigraphic grids with hexahedral cells (Fig. 1d) and semi-regular grids with prismatic cells (cf. Fig. 2b). In gOcad, the functionalities are much more extended for the first two types of grids which are used for various geological analyses and for visualization. However, the third type of grids allows better interactions with many flow simulators (e.g. Feflow, HydroGeoSphere) that are based on the finite element approach.

Figure 1: The gOcad geomodeling approach. A framework model (a) consisting of interlocked discontinuous surfaces representing the stratigraphic boundaries is used as a common frame for generating a 3d representation (b) and various grids (c, d). The grids are necessary to model the internal properties of geologic units (Modified from Ross, 2004).

5. INTEROPERABILITY WITH GROUNDWATER FLOW MODELS

Geologic and hydrogeologic models are still generally weakly linked. Geologic models often contain geometric complexities that have to be simplified or removed for the purpose of hydrogeologic modeling unless the models were built just for that purpose; but then they lack the stratigraphic details that might be crucial for other applications. In addition, the structure of the geologic model may not be appropriate or compatible with the adopted numerical modeling strategy. For instance, a geologic survey may release a geologic model with a regular grid discretization, whereas a subsequent hydrogeologic modeling project may require a semi-regular grid structure with different model boundaries. In fact, most of the time grids are built to fit very specific needs that changes over time (e.g. densification of the mesh structure around a new well field). Geologic models have to allow for this flexibility. We have worked on this issue by improving the linkages between geologic models and hydrogeologic models. The goal was to develop a procedure or a tool that would allow a common framework model (Fig. 1a) to be efficiently partitioned and transferred to a specific groundwater flow modeling package. The challenge is to transfer information from a geologic model not only to various regular grids but also to semi-regular grids. A research plug-in (GridLab) developed by the Gocad Research Group (Grosse et al. 2003) was used to test one interoperability approach. A semi-regular 3D grid was generated by extruding 2D triangular meshes along a field of pillars oriented in the
vertical dimension to generate columns of 3D prismatic cells (Fig. 2b). The resulting grid was a replica (later referred to as the “twin” grid) of the grid to be used by the flow simulator (HydroGeoSphere). The latter will be referred to as the “original” grid and was built using GMS, a pre-processor for groundwater flow modeling. To generate the “twin” grid, triangulated surfaces were first provided with the same horizontal mesh structure as the original grid. At this stage, software interplay was facilitated due to similarities between GMS and gOcad file formats for triangulated surfaces. Stratigraphic information in 2.5D can indeed be quickly transferred back and forth between gOcad and GMS. However, the data structure of the “twin” grid is different from the data structure of the original grid complicating the transfer of 3D information. Unfortunately, import/export filters do not yet allow direct translation of these particular data structures. A solution was first developed using the software Access (Microsoft). The data structures of the different grids were partitioned into different tables and cell or element correspondences were determined from one grid to the other through database queries. In the end, a table was created which provided a list of GMS element numbers and corresponding property value. That allowed for correct property transfer from the gOcad grid to the GMS grid in just a few steps (Ross et al. 2005). In a second attempt, an interface (GOGMS) was developed to streamline the process (Fig. 3). The results are very promising but the interface works only in combination with gOcad PGrids which are not available in the regular commercial package.

Figure 2: (a) A geomodel discretized into a curvilinear grid representing the near-surface geology of the Wainwright Area Training Center, AB. (b) The first layer of the semi-regular grid with the transferred facies information.

6. AQUIFER VULNERABILITY AND RISK ANALYSIS

The method that has been chosen to map aquifer vulnerability to contamination over the military training ranges can be applied directly to the 3D geologic models. The method described in more details in Ross et al. (2004a, 2004b) relates vulnerability to the downward advective time (DAT) of transport of dissolved and persistent contaminants. Risk maps are also produced to take into account the various activities that take place on training ranges. A classification index was developed to evaluate the potential risk of contamination of surface and groundwater according to parameters such as quantity, toxicity, solubility and environmental persistence of the possible contaminants released for each activity (Parent et al. 2007). We are currently developing a management tool that would fully integrate the groundwater hazard analysis and the vulnerability assessment. Maps showing the risk to aquifer contamination associated to current land-use will
be drawn combining the risk-classification index and the vulnerability map defined with the DAT approach. This management tool will be useful to evaluate whether the current land-use of the training ranges has a potential to contaminate groundwater. If so, it will be used to help determine what changes should be made to reduce this risk.

7. CONCLUSION

The potential contamination of groundwater by energetic materials and heavy metals can potentially threatens the sustainability of military training ranges. A large environmental assessment program is underway in Canada to evaluate the current state of the environment over several military training ranges and to develop tools and standard procedures to improve the assessment methods and better understand the behavior of energetic materials and related compounds in soil as well as in surface and ground waters. This includes developing approaches and tools to build geomodels that can be readily used for multiple hydrogeological applications including groundwater flow and contaminant transport modeling as well as aquifer vulnerability and risk to contamination mapping. Furthermore, tools and techniques have been developed to allow interoperability with the most important applications in a flexible and efficient way. However, a number of stumbling blocks still lie along the way and new development needs to be made to ensure that the achieved level of interoperability with hydrogeological applications is not going to be lost because of e.g. software upgrades.

Figure 3: The GOGMS interface used to automatically transfer the properties of the gOcad “twin” grid to the “original” GMS grid. The transfer is achieved one grid layer at a time. The whole transfer takes a few seconds to a few minutes depending on the size of the files and the capacity of the computer.

8. REFERENCES


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