97-135

Environment Canada

Water Science and Technology Directorate

Direction générale des sciences et de la technologie, eau

Environnement Canada

Visualization of the hydrostratigraphy of the cold Lake Region, Alberta, Canada

By:

A. Crowe, A. Piggott, L. Andriashek...

97-136

Management Perspective

Title: Visualization of the Hydrostratigraphy of the Cold Lake Region, Alberta , Canada.

Authors and affiliations:

Allan Crowe[1], Andrew Piggott[1], Laurence Andriashek[2], and Duane McNaughton[3]

[1] Groundwater Remediation Project, National Water Research Institute, Environment Canada, Canada Centre for Inland Waters, Burlington, Ontario L7R 4A6.

[1] Alberta Geological Survey, Alberta Energy and Utilities Board, Edmonton, Alberta, T5K 2G6.

[1] Environment Canada, Environmental Protection, Prairie & Northern Region, Edmonton, Alberta, T6B 2X3.

NWRI Contribution Number: 97-135

Citation: Conference Proceedings; 50th Conference of the Canadian Geotechnical Society.

EC Priority/Issue:

This project contributes to Environment Canada's Issue of "Partnership for Sustainable Development". Specifically, the results of the 3-D visualization exercise provides regulatory personnel and environmental managers with a means of assessing the sustainability of groundwater resources of the Cold Lake region, Alberta, in conjunction with massive groundwater withdrawals required for extraction of heavy oil. This project was undertaken through collaboration with the Alberta Geological Survey and the Environmental Protection Branch (Prairie and Northern Region)

Current status:

Massive quantities of groundwater may be required for the extraction of heavy oil from the Cold Lake Heavy Oil Sands region of Alberta. This may create potential conflicts for the groundwater resources among the heavy oil operators, municipalities, and rural residents, as well as potentially having detrimental impacts on the regions lakes and rivers. Although a vast array of hydrogeological data has been accumulated, it is difficult to correlate, manipulate and display this data for a particular requirement. This paper discusses the development and application of a three-dimensional visualization technique for display the hydrostratigraphy of the Cold Lake aquifer system. This method of data depiction is highly beneficial for those managing the groundwater resources in the Cold Lake Heavy Oil Sands region.

Next steps:

Continuing activities will be directed towards finalization of the three-dimensional visualization of the Cold Lake hydrostratigraphy, and improvements to the visualization technology.

VISUALIZATION OF THE HYDRO-STRATIGRAPHY OF THE COLD LAKE REGION, ALBERTA, CANADA

Allan Crowe[1], Andrew Piggott[1], Laurence Andriashek[2] and Duane McNaughton[3]
[1]*National Water Research Institute, Burlington, Ontario*
[2]*Alberta Geological Survey, Edmonton, Alberta*
[3]*Environment Canada, Edmonton, Alberta*

ABSTRACT

Efforts to determine the impact of groundwater consumption in conjunction with heavy oil production in the Cold Lake region of Alberta have resulted in an extensive accumulation of hydro-stratigraphic data. Three-dimensional visualization is a method of depicting this data that extends standard methods of subsurface mapping by allowing the areal and vertical distributions of a number of geologic units to be represented simultaneously. The approach developed in this paper transforms contour maps indicating the extent and elevation of each geologic unit into raster data using a method that precisely retains the positioning of the contours. This ensures that the geologic expertise expressed in the contour maps is propagated into the visualization results.

RÉSUMÉ

Les efforts à déterminer l'impact de la consommation des eaux souterraines en conjonction avec la production d`huile lourde dans la région de Cold Lake, Alberta, ont créé une accumulation considérable d'information hydro-stratigraphique. La visualisation en trois dimensions est une méthode qui permet, grâce à une représentation simultanée des distributions horizontales et verticales du unités géologique, d`étendre l`utilisation des méthodes standard de cartographie souterraine. L`approche qui est développée dans cette article prend les cartes hypsométriques, en montrant l`étendue et la profondeur de chaque unité géologique et les transforme en matrices de donneés en utilisant une méthode qui retient précisement les positions des contours. Celui-ci assure que l`expertise qui est exprimée dans les cartes hypsométriques est propagée dans les résultats des visualisations.

INTRODUCTION

The Cold Lake region of Alberta, Canada, is an important centre for hydrocarbon production from heavy oil sands deposits. The oil bearing sands of the Cold Lake Oil Sands area are located at depths of 300 to 600 m and therefore steam injection is required in order to mobilize and extract the oil. This process consumes vast quantities of water, a portion of which is derived from groundwater sources. As a result, it is imperative that sustainable levels of groundwater consumption for heavy oil production be estimated, that the impacts of these levels of consumption on agricultural, rural, and municipal users be defined, and that the relation of heavy oil production to groundwater quality be determined.

Efforts to determine the impact of groundwater withdrawals for heavy oil production have been ongoing for over 20 years. A vast array of data describing the stratigraphy, hydrogeology, and performance of the aquifers has been collected and numerous reports and models have been prepared. Unfortunately, access to vast quantities of data does not always lead to a better understanding and improved management of groundwater resources. For example, it can be prohibitively difficult to manually retrieve, correlate, and manipulate the data. Advances in computing technology allow these tasks to be performed more efficiently using methods of database management, geographic information systems, and three-dimensional visualization.

Visualization of geologic data uses a combination of computer graphics and geometric analysis to depict the data in three dimensions, and often with respect to time. Most applications of visualization in groundwater studies focus on small scale contamination problems. A study of the Grand River watershed in southern Ontario (Boyd et al. 1996) has shown that multi-dimensional visualization is a useful basis for the development of a conceptual model of the groundwater resources of the watershed. The objective of this paper is to present visualization results for the Cold Lake Oil Sands region that are determined using a procedure that precisely replicates an expert interpretation of the hydro-stratigraphy of the region.

BACKGROUND

The Cold Lake Oil Sands are located in north-eastern Alberta and cover an area of approximately 9,000 km^2. The region addressed in this study is much smaller, extending from Townships 61 to 69, and Ranges 1 to 10 West of the 4th Meridian; that is, from longitude 110.00 to 111.52° West and from latitude 54.24 to 54.59° North. The topography of the region is rolling to hilly. The major surface drainage systems are the Sand and Beaver Rivers, both of which have formed deeply eroded valleys. Numerous lakes are also located across the region and many of these lakes, although small in area, are very deep.

The uppermost bedrock is comprised of shale and siltstone of the Cretaceous Lea Park Formation. The dominant features of the bedrock surface are preglacial and glacial channels which are deeply eroded into the bedrock surface (Yoon and Vander Pluym 1974, Gold et al. 1983). These channels are filled with a series of pre-glacial and glacial sediments with thicknesses of up to 200 m. The main sedimentary units are listed and described in Table 1.

Within the buried channels are several laterally extensive deposits of sand and gravel separated by till. These outwash deposits are important sources of groundwater for agriculture, rural residents, municipalities, and the heavy oil sands operators.

Table 1. Description of hydro-stratigraphic units (Andriashek and Fenton 1989).

FORMATION	DESCRIPTION
recent deposits	Stratified clay, silt, sand, and gravel of undifferentiated origin
Grand Centre	Glacial sediment, clayey-till to sandy-till; very coarse sand fraction
Sand River	Stratified sand and gravel, minor silt and clay, glacio-lacustrine origin
Marie Creek	Till, clayey-till to sandy-till; very coarse sand fraction
Ethel Lake	Stratified silt and clay, minor sand and gravel; glacio-lacustrine origin
Bonnyville	Till; very coarse sand fraction
Unit 2	Till; very sandy in eastern 2/3 of the Sand River map area, less sandy in the west
Unit 1	Till, sand and clay dominant sections; overlain by stratified sediment in some places
Muriel Lake	Stratified sand and gravel of glacio-fluvial origin
Bronson Lake	Clayey-till mixed with clay of undetermined origin
Empress	Stratified sediment overlying bedrock and underlying lowermost till
Unit 3	Stratified sand and gravel; glacio-fluvial origin
Unit 2	Stratified silt and clay; undifferentiated fluvial or lacustrine origin
Unit 1	Stratified sand and gravel; pre-glacial fluvial origin

The geology and groundwater resources of the Cold Lake area have been extensively studied. A considerable volume of information is available from borehole logs and geophysical logs drilled by Alberta Environment, the Alberta Geological Survey, and the heavy oil operators to study the hydro-stratigraphy of the region. Geological information for the region has been compiled by the Alberta Geological Survey as part of a program to characterize the Quaternary stratigraphy and surficial mapping of the Sand River map sheet (NTS 73L), and is reported by Andriashek and Fenton (1989). This information has been recently updated as part of the present study.

VISUALIZATION OF THE HYDRO-STRATIGRAPHY

Various software are available for the visualization of hydro-stratigraphic data. Our preference was to select from public domain software; that is, software that is freely available and accessible using the Internet. Further, our preference was to implement a surface visualization approach based on a raster model. The volumetric models that will be required for calculation of groundwater flow within the study region may be readily calculated from surface visualization results. The Geographic Resources Analysis Support System (GRASS) developed by the United States Army Construction Engineering Research Laboratory (USACERL 1993) was selected based on these criteria and on the popularity and broad functionality of the system.

The GRASS principally operates on raster data; that is, a rectangular array of pixels with a known attribute value. The data for the Cold Lake region was obtained in vector format as linear features with a known attribute value, elevation in the case of the contour data. Digital contour maps of the extent and elevation of each of the hydro-stratigraphic units were generated using MCadContour© and saved as PICT files. Figure 1 shows a map of the Muriel Lake Formation. The PICT files were then converted into EPS files to obtain the coordinates for the features. During the construction of these maps, the insight and expertise of the geologist was used to alter contour lines to more closely represent facies changes and structures. Each of the stratigraphic units were rendered in raster format prior to entry into the GRASS. Two rasters represent a unit. The first raster indicates the presence of each unit at the midpoint of each pixel and was computed from outlines drawn around the limits of each unit and around discontinuities in the units. The map of the Muriel Lake Formation shown in Figure 1 indicates the limits of the unit and a number of discontinuities that are the result of the erosion of the unit. In one case, a portion of the Muriel Lake Formation persists within an otherwise eroded portion of the unit. An algorithm was developed to perform the required vector to raster transformation. This algorithm uses computational geometry to determine the number of outline segments intersected by a ray drawn from the midpoint of the pixel. An odd number of intersections indicates that the pixel is inside the boundaries of the unit, an even number indicates that the pixel is either outside the limits of the unit or is located within an eroded portion of the unit. Figure 2a shows the raster that represents the spatial continuity of the Muriel Lake Formation.

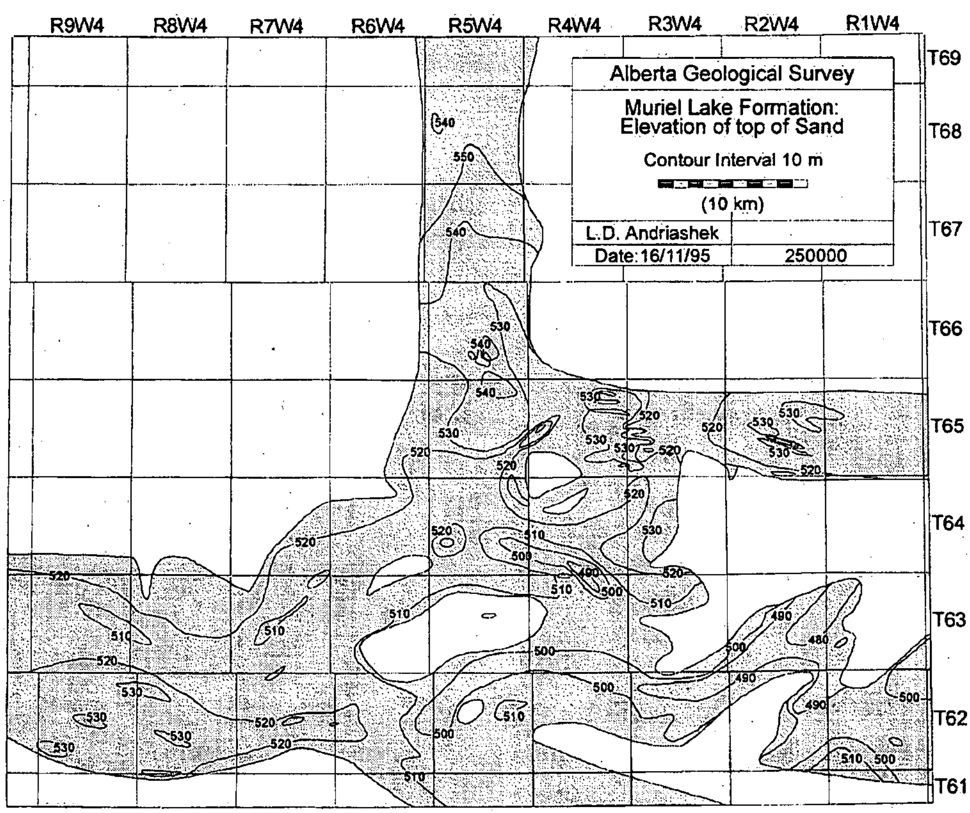
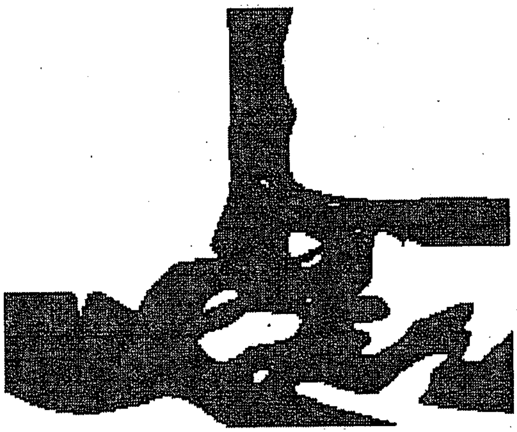


FIGURE 1. Map of the Muriel Lake Formation.



(a)

(b)

FIGURE 2. Outline (a) and elevation (b) rasters for the Muriel Lake Formation

The second raster indicates the elevation of the upper limit of each unit and was computed from the contour lines extracted from the geologic maps. Various methods of spatial interpolation are available for the calculation of a uniform array of data from irregularly distributed data. In contrast, very few approaches for the interpolation of contour data are documented in the literature. Contour data must be interpolated in a manner that reflects the constraints applied by the contours. Specifically, the elevation estimated for a point located between two contour lines is bounded by the elevations of the two contour lines. A goal of this study is to precisely transfer the expertise expressed in the geologic maps into the visualization results. It is therefore necessary that the elevation estimated at a point located on a contour line is equal to the elevation of the contour line. The algorithm applied to the contour data satisfies the requirement that elevation estimates are bounded by the adjacent contours and precisely match the elevation of contours for points that occur on the contour. Again, the algorithm applies methods of computational geometry in locating the most proximal contour line along each of a number of rays drawn from the midpoint of the pixel. In this application, 16 rays spanning 360 degrees were used. The algorithm estimates the elevation of the pixel from the elevation of, z_i, and distance to, r_i, the closest contour lines encountered along each ray using

$$z = \sum_i \frac{z_i}{r_i} \Big/ \sum_i \frac{1}{r_i} \qquad [1]$$

and following an adaptive approach that adjusts the number of rays in the event that no contour lines are detected. Figure 2b shows the raster that represents the elevation of the top of the Muriel Lake Formation. The outline data used to form Figure 2a is also plotted in Figure 2b. Erratic patterns are evident in the elevation raster for regions that are beyond the limits of the unit.

A total of 13 sets of rasters were calculated using this approach, one set for the bedrock surface and one set for each of the 12 overburden formations. These rasters were then imported into the GRASS and edited to mask the regions that are beyond the limits of each of the units. Masking was performed by calculating the product of the outline and elevation rasters. The entries of the outline raster are zero for points that are beyond the limits of the unit, or located in eroded portions of the unit, and unity for points within the non-eroded portions of the unit. The GRASS optionally disregards pixel values of zero and therefore the masked portions of the units do not appear in the visualization results. Figure 3 shows a three-dimensional rendering of the Muriel Lake Formation where the surface is shaded to indicate the topography of the unit.

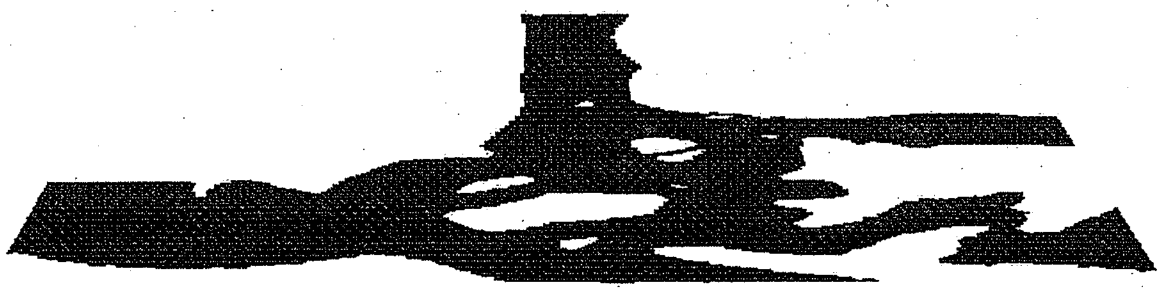


FIGURE 3. Three-dimensional rendering of the Muriel Lake Formation

Figure 4 is a mosaic of each of the units listed in Table 1. The distributions and elevations of the geologic units are consistent across the units and therefore it is possible to construct three-dimensional views of arbitrary arrangements of the various units. Figure 5 compares the Muriel Lake Formation to the bedrock surface. The relation between the topography of the bedrock surface and the deposition of the Muriel Lake Formation is clearly indicated. Cross-sections can also be cut through the units and each of the units can be scaled, translated, and shaded.

CONCLUSIONS

The method of visualization developed in this paper takes vector data, in the form of contour maps indicating the distribution and elevation of geologic formations, and transforms these into raster data that are input into the GRASS for additional processing and display. This approach ensures that the results reflect the considerable geologic expertise entrained in the maps.

Visualization of the hydro-stratigraphy of the Cold Lake region allows the geometry of the various overburden formations to be depicted in a manner that is visually intuitive and sensibly represents the relations between the units. Rendering of the hydro-stratigraphic data in raster format allows calculations to be performed between the units. This capacity will prove to be useful in preparing a numerical model of the region for the simulation of three-dimensional groundwater flow. It is also possible to use this capacity to test the accuracy of the interpretation of the data. For example, areas where units overlap can be more easily located and the interpretation of the corresponding units can be refined accordingly.

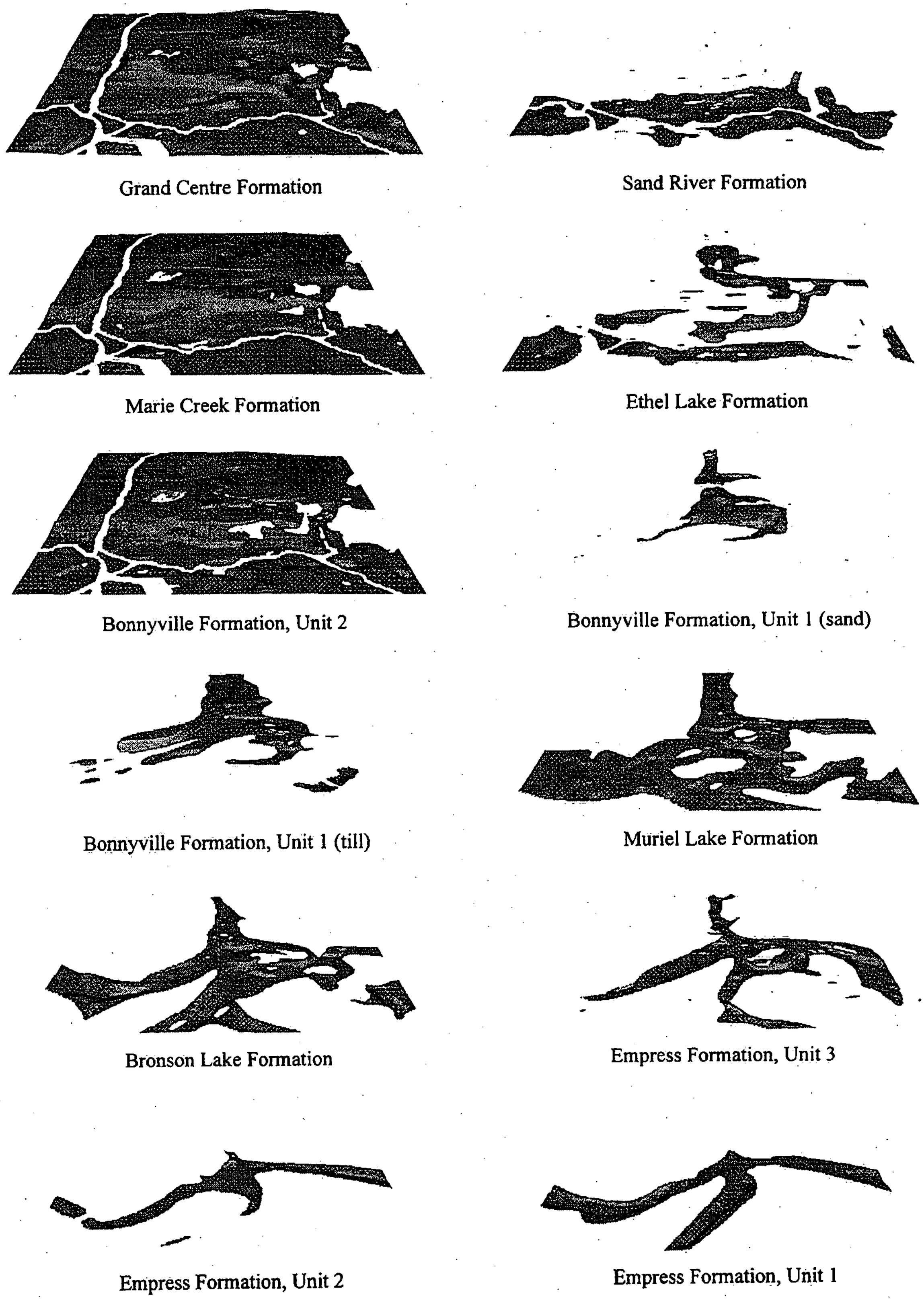


FIGURE 4. Three-dimensional renderings of the formations listed in Table 1.

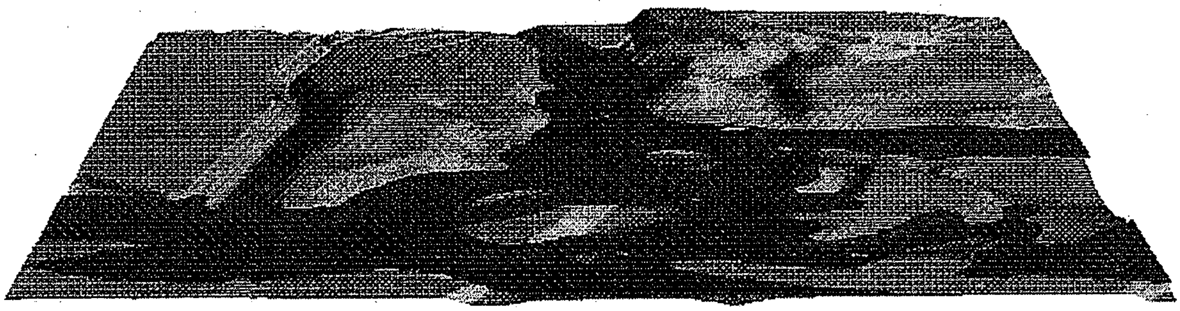


FIGURE 5. Three-dimensional rendering of the bedrock surface and the Muriel Lake Formation

Several extensions and revisions to the results presented in this paper are required. For example, the algorithm used to interpolate the contour data is not optimal. An obvious deficiency of the algorithm is the generation of discontinuous topography across each of the contour lines. This may be rectified by implementing a higher order interpolation scheme that extends beyond the most proximal contours. Also, the data introduced in this paper are referenced to an arbitrary coordinate system and fixed map projection. It is necessary to reference the hydro-stratigraphic data relative to a standard coordinate system and projection (e.g., a UTM-based system) in order to combine the data with additional information such as terrain and land use data.

REFERENCES

ANDRIASHEK, L.D. AND FENTON, M.M. (1989). "Quaternary stratigraphy and surficial geology of the Sand River Area 73L", Bulletin No. 57, Alberta Geological Survey, Alberta Energy and Utilities Board, Edmonton, Alberta.

BOYD, D., PIGGOTT, A.R., BLACKPORT, B. AND MOIN, S. (1996). "Regional characterization of groundwater conditions within the Grand River watershed", Proceedings of the Watershed Management Symposium, pp. 165-169, Canadian Water Resources Association, Cambridge, Ontario

GOLD, C.M., ANDRIASHEK, L.D. AND FENTON, M.M. (1983). "Bedrock topography of the Sand River Map Area, NTS 73L, Alberta", 1:250,00 scale map, Alberta Geological Survey, Edmonton, Alberta.

USACERL (1993). "GRASS 4.1 User's reference manual", United States Army Corps of Engineers Construction Engineering Research Laboratories, Champaign, Illinois.

YOON, T.N. AND VANDER PLUYM, H. (1974). "Buried channels in the Edmonton - Lac La Biche - Cold Lake area, Alberta", Alberta Environment, Earth Sciences Division Report, Edmonton, Alberta.

Environment Canada   Environnement Canada

Canada

Canada Centre for Inland Waters
P.O. Box 5050
867 Lakeshore Road
Burlington, Ontario
L7R 4A6 Canada

National Hydrology Research Centre
11 Innovation Boulevard
Saskatoon, Saskatchewan
S7N 3H5 Canada

St. Lawrence Centre
105 McGill Street
Montreal, Quebec
H2Y 2E7 Canada

Place Vincent Massey
351 St. Joseph Boulevard
Gatineau, Quebec
K1A 0H3 Canada

Centre canadien des eaux intérieures
Case postale 5050
867, chemin Lakeshore
Burlington (Ontario)
L7R 4A6 Canada

Centre national de recherche en hydrologie
11, boul. Innovation
Saskatoon (Saskatchewan)
S7N 3H5 Canada

Centre Saint-Laurent
105, rue McGill
Montréal (Québec)
H2Y 2E7 Canada

Place Vincent-Massey
351 boul. St-Joseph
Gatineau (Québec)
K1A 0H3 Canada