WDA TECHNICAL NOTE 1

Application of 2D – Vertical Groundwater Flow Models to the Interpretation of Measured Field Data from the Athabasca Oil Sands: Groundwater flow through underlying Devonian karst systems.

December 2006 (sources added May 2011)

A number of mathematical models for groundwater flow have previously been calculated in the area of the Athabasca Oil Sands based on the assumption that sizeable groundwater flow is essentially limited to the Quaternary and Cretaceous layers. The Basal Sands of the oil sands are usually assumed to be the regional aquifer transmitting groundwater laterally. The Basal Sands are not continuous when considered at the scale of leases. The karst in the Devonian limestone has usually been ignored during field investigations and in the setup and calculation of mathematical models. In many places this karst lies directly under the Athabasca Oil Sands.

The presence of karst immediately below the Cretaceous layers would provide effective pathways for groundwater flow and pressure changes between injection and depressurization wells and, possibly, flow towards the Athabasca River. In addition, the presence of permeable karst also affects the SAGD operation as pressure losses will occur into the Devonian karst. Therefore higher pressures likely need to be applied and the danger of surface escapes of steam is thus increased. Operating costs will increase as well.

Hence it is of some importance to provide proof of the widespread downward flow through the oil sands into the karstic limestone and lateral flow towards the regional discharge area Athabasca River. The proof can be supplied through an evaluation of field measurements of water levels in piezometers and the associated equipotential lines (Figures 1[1] and 2[1]). The Cross-section [1] in both figures was provided in recent applications for SAGD and mining prospects. Cross-section [1] irrefutably shows the downward flow of groundwater from the surface recharge towards the bottom of the Oil Sands. The question now is whether the flow continues laterally within the discontinuous sand layer of the Basal Sands or whether it progresses into the karstic Devonian limestone layers.

In answer to this question, two 2D-vertical groundwater flow models have been calculated by WDA. In Case 1 (Figure 1), flow has been limited to the layers

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above the Devonian limestone (limestone assumed to be impermeable). In Case 2 (Figure 2), groundwater flow is allowed to flow into the karstic limestone. The applied model code is based on the work of the University of Waterloo and has been successfully applied in many projects worldwide.

For Case 1 (limestone impermeable), the results of calculations are shown in Figure 1. Profile [1] shows the lateral extension of the equipotential lines as measured in the field (Millennium EMS Solutions Ltd, Feb 2005. Joslyn SAGD Project, Phase IIIA Expansion, Hydrogeology, Figure 5), while Profile [2] shows the extent of the corresponding finite element mesh of the model. Profile [3] depicts the distribution of equipotential lines as they were calculated in the model. Obviously the resultant equipotential lines are subvertical and therefore fundamentally different from the lateral extension of equipotential lines as measured in the field (Profile [1]). The responding flow lines are shown in Profile [4]. The discontinuous Basal Sands concentrate the groundwater flow in the areas where they occur. Between the occurrences of Basal Sands, groundwater flow is quasi-lateral through the oil sands. In general groundwater flow would be strongly impeded due to the low permeability of the oil sands in combination with the distance travelled within them.

Case 2 (permeable, karstic limestone), however, replicates the lateral extension of equipotential lines within the oil sands and the layers above them (Profile [3]). The model calculation has been extended into the karstic limestone (Profile [2]). The assumed relative permeabilities are shown in Profiles [3] and [4]. Assigning relative permeabilities is sufficient to calculate the direction of groundwater flow. Profile [4] depicts the corresponding groundwater flow from the surface recharge downwards into the karstic limestone and laterally through the karstic limestone towards the regional discharge areas Athabasca River and a site river.

The similarity of the equipotential lines as measured in the field and calculated in Figure 2 shows that, in recharge areas, groundwater flows downward through the Athabasca Oil Sands into the karstic limestone and then laterally towards the regional discharge areas.

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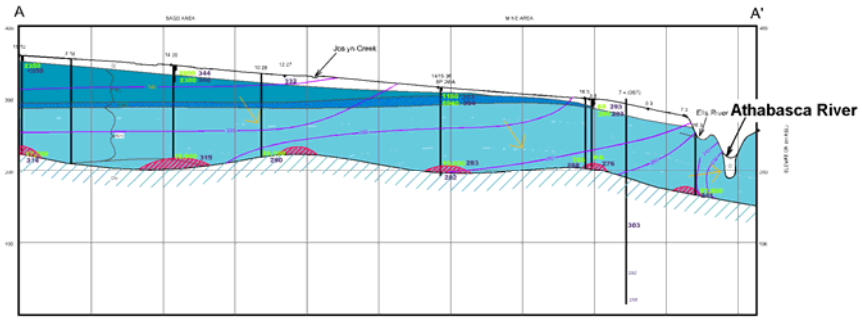
Field measurements contained in an EIA (after Fig 5, Millennium, 2005)

[1]



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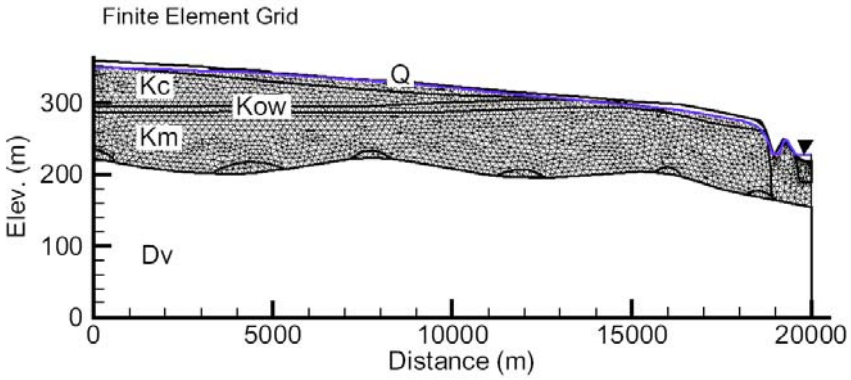
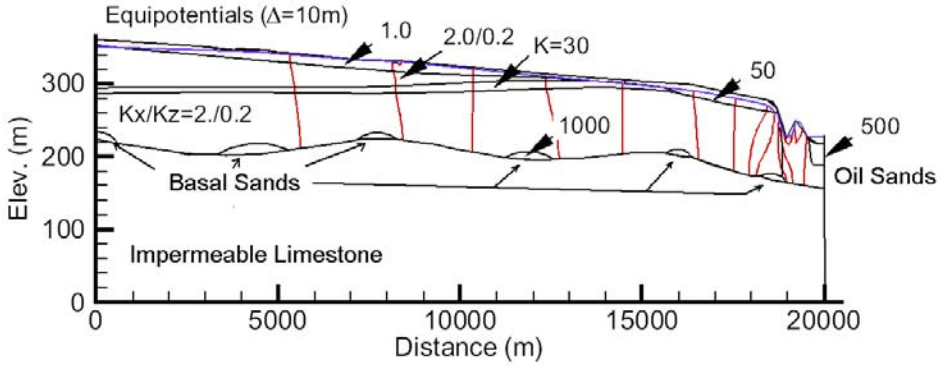


[3]



[4]

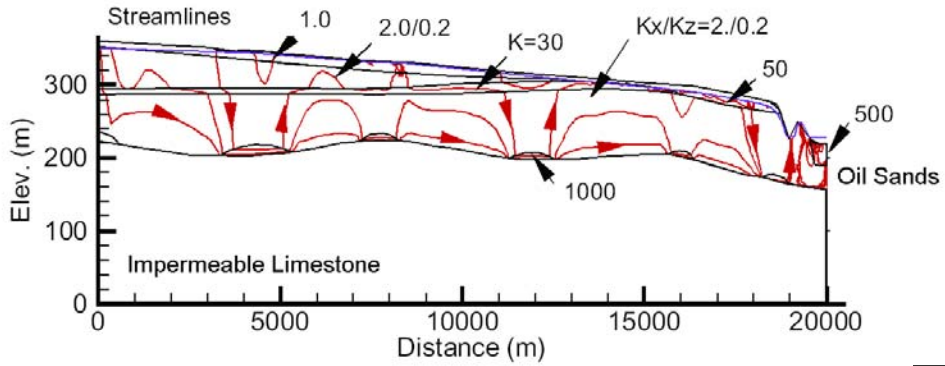
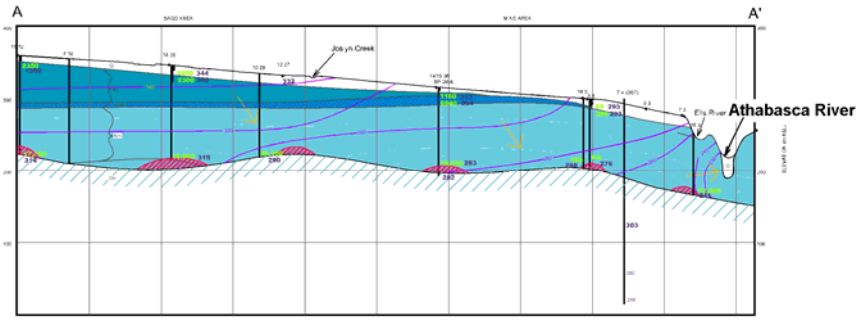


Figure 1

Field measurements contained in an EIA (after Fig 5, Millennium, 2005)

[1]



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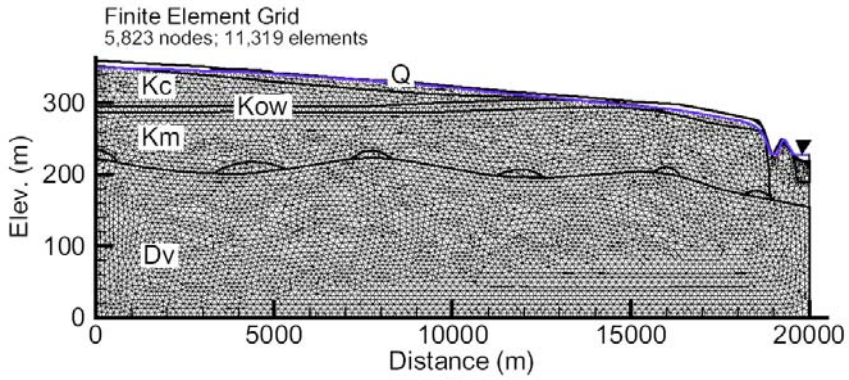

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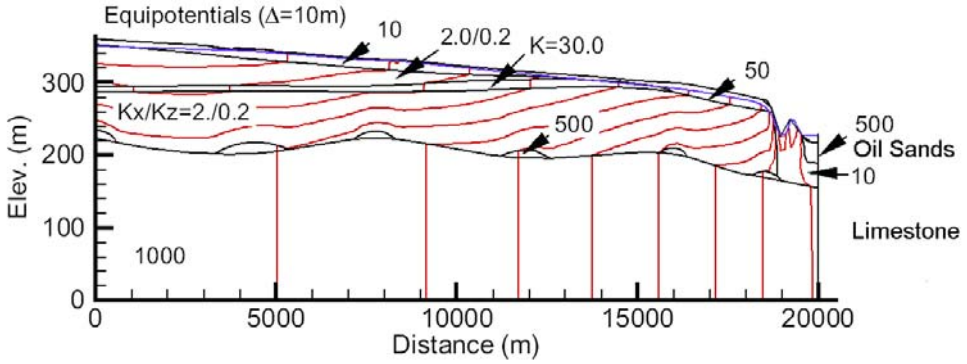

[4]

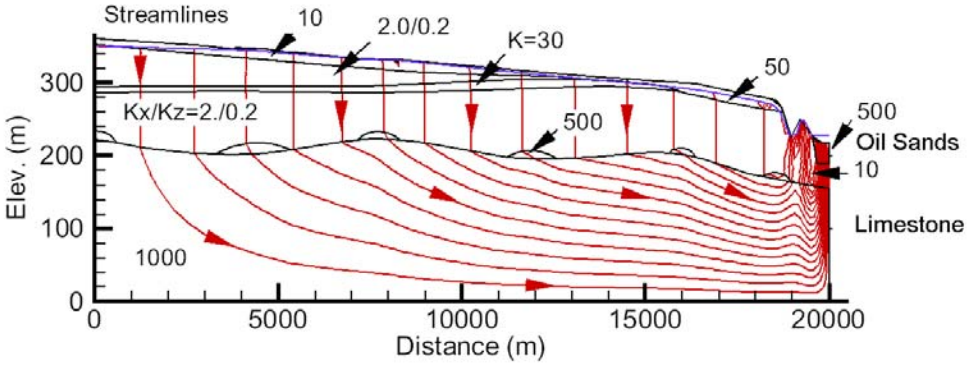

Figure 2