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Managing Saltwater Intrusion in The Pioneer Valley, Northern Queensland, Australia: Modelling Strategies, Preliminary Results and Future Challenges.

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EXTENDED ABSTRACT

The Department of Natural Resources and Mines (NR&M) have documented increasing groundwater salinity in the Pioneer Valley associated with saltwater intrusion (Queensland Government, 2002). The landward encroachment of the fresh water-saltwater interface is contributed to excessive groundwater extractions, primarily for the purpose of sugar cane irrigation. The inland movement of saline groundwater in the coastal fringe is exacerbated by the lateral intrusion of saline plumes from macro-tidal estuaries, primarily Sandy and Bakers Creeks. Numerical modelling of the saltwater intrusion in the Pioneer Valley will assist managers to best allocate the groundwater resources from a regional standpoint.

In order to better understand the contribution of estuaries to saltwater intrusion in the Pioneer Valley, a preliminary study was carried out that culminated in a two-dimensional section model of estuarine-aquifer salt exchange at a local scale (1400m in length). The primary objectives of the modelling study were to reproduce observed groundwater salinities (i.e. *calibrate* the model) and make assertions regarding the impact of future management decisions; and to examine the role of both density-dependent flow and aquifer heterogeneities on predicted salinity distributions. The code 2DFEMFAT (Yeh, et al., 1994) was employed. The model adopted time-invariant hydrologic stresses and a simplified representation of the aquifer heterogeneities.

The model successfully reproduced observed groundwater salinities after a limited calibration effort. Predictions made with the calibrated model indicated that an inland hydraulic head of at least 1m above sea level was required 1400m from the estuary to halt the advance of the estuarine-based saltwater intrusion. Both density-dependent groundwater flow and an approximation of aquifer heterogeneities were necessary to achieve a reasonable match between observed and predicted salinities. In particular, the steep concentration gradient in the vertical direction could only be achieved by emulating the highly conductive sand and gravel deposit encountered at the base of the alluvial aquifer.

NR&M are constructing a three-dimensional saltwater intrusion model of the Pioneer Valley using the code MODHMS (HydroGeologic, Inc., 2002), a descendent of MODFLOW-SURFACT (HydroGeologic, Inc., 1996). It was originally anticipated that this 3D saltwater intrusion model could be developed through manipulation and refinement of the single-layer (unconfined) regional groundwater flow model (MODFLOW, McDonald and Harbaugh, 1988), which is near completion. The two graphical user-interfaces PMWIN Version 6.0.0 (Chiang and Kinzelbach, 2001) and Groundwater Vistas Version 3 (Environmental Simulations Inc., 2002) have facilities for mesh refinement (of a MODFLOW model) and importation of MODFLOW files for the purpose of building a 3D MODHMS model. However, the early stages of this work have identified a number of obstacles in the transformation of the single-layer MODFLOW model to a multi-layer MODHMS model. Three main problems are outlined here - 1. Which model layer type (i.e. confined/unconfined, variably-saturated) should be adopted to represent the Pioneer alluvium and to promote numerical convergence? 2. How might the recharge estimates and the calibration results of the

MODFLOW model be applied to the MODHMS model? 3. What is the best method of vertical discretization (i.e. variable or horizontal layering)?

Firstly, in order to represent the preferential flow paths of saline plumes in the Pioneer alluvium, the regional model must utilise a multi-layered grid. As time-variant recharge and pumping induces large variations in water table heights, the classical "confined-unconfined" layer approach of MODFLOW is not possible due to the difficulties of cell drying and re-wetting. Hence, it is proposed to utilise the variably-saturated approach of MODHMS. Unfortunately, the conversion to a variably-saturated model prevents the application of previous recharge estimates (from a 1D lumped-parameter, soil moisture model), which account for rainfall, evaporation, crop and soil parameters, irrigation losses and surface runoff.

Secondly, the calibrated hydraulic conductivities from the regional groundwater flow model were expected to be utilised in the saltwater intrusion model, limiting the expenditure of additional calibration effort and producing matching simulated water levels in both the groundwater flow and saltwater intrusion models. However, the above issue with adopting previous recharge estimates, along with the representation of aquifer heterogeneities in the saltwater intrusion model limits the application of previously calibrated hydraulic conductivity values.

Initially, the finite-difference grid for the saltwater intrusion model was extracted from the groundwater flow model by telescopic mesh refinement and layer subdivision. The single-layer used in the MODFLOW model was subdivided into 10 MODHMS layers of thickness proportional to the spatially-variant thickness of the MODFLOW single-layer. Unfortunately, this process lead to adjacent model cells which were disconnected (i.e. the top of one model cell was lower than the bottom of a neighbouring cell). While MODHMS may have produced groundwater and solute predictions using a model grid with these characteristics, the representation of the groundwater system was considered non-physical. Hence, the saltwater intrusion model grid was redesigned using horizontal model layers. The number of horizontal layers increased to 20 and model cells were inactivated where the elevation of the aquifer basement exceeded the layer top or where the natural surface elevation was below the layer bottom.

The issues raised here are primarily associated with the conversion of a single-layer groundwater flow model (MODFLOW) to a multi-layer saltwater intrusion model (MODHMS). Preliminary attempts indicate that this conversion is not a plausible option and that a saltwater intrusion model will need to be developed independently of the groundwater flow model.

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