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Assessing the impact of grid cell properties in spatial discretization of groundwater model

DKSY Klaas¹,²,³, M A Imteaz¹, A Arulrajah¹, I Sudiayem³, EME Klaas³ and ECM Klaas⁵

¹ Department of Civil & Construction Engineering, Swinburne University of Technology, Melbourne, VIC, Australia. dklaas@swin.edu.au
² Department of Civil Engineering, Politeknik Negeri Kupang, Indonesia.
³ Department of Health, Science and Technology, Klinik Garuda, Malang, Indonesia

Abstract. In groundwater modelling the validity of both calibration and validation processes depends on how well the hydrogeological properties of the investigated area are conceptually, spatially and temporally represented in the model. A good discretization represented by optimal choice of size and number of cells would essentially improve the accuracy and efficiency of the model while reducing the complexity of model through lesser time and cost consumption. In this study, models with five different spatial discretization schemes; 10 x 10 m, 20 x 20 m, 30 x 30 m, 40 x 40 m and 50 x 50 m were developed. The trends of the performances were calculated at each observation well and compared with grid cell size and distance between centre of grid and observation well. It is confirmed that the deterioration of model performance is mainly controlled by the increase of distance between well and centre of the cell, and the cell size.

1. Introduction
In groundwater modelling a good discretization represented by optimal choice of size and number of cells would essentially improve the accuracy and efficiency of the model while reducing the complexity of model through lesser time and cost consumption [1,2]. It is well acknowledged that, the finer the grid size is, the better the node represents the output. However, on the other hand due to the additional computational tasks as a result of increased grid numbers due to grid refinement, time consumption would exponentially increase. In some cases, very finer grid may only provide an insignificant model improvement at the huge expense of computational time.

Several studies [3,4] have discussed the effect of grid cell size in model discretization using comparison of performances of different models representing different cell sizes and highlighted the importance of grid refinement principle in enhancing model performances. However, little is known about the influence of cell properties on model performance. Therefore, the aim of the study is to assess the impact of grid discretization properties in the calibration and validation performances of a groundwater model. The results are evaluated using standard statistical criteria i.e. Root Mean Square Error (RMSEₜ) using the observed and simulated heads. The study exercises a natural real small-scale catchment of a karst spring for the advantage of reducing parameter uncertainty due to better representation of hydrogeological properties and thus increasing model accuracy.
2. Materials and methodology

2.1. Study area

This study is located in Rote island, Indonesia, geographically located between latitudes 10°46’42.17"S ~ 10° 43’36.91"S and longitudes 123° 3’14.84"E ~ 123° 9’17.64"E. Having a topographically bounded surface-drainage basin area of 20.11 km² (Figure 1a), the Oemau spring is located around 3 km from Ba’a, the capital of the Rote Island [5].

![Figure 1](image1.png)

The area experiences an average annual rainfall between 1000 and 2300 mm, having two distinct seasons; dry (April-November) and rainy (December – March). In the rainy season, monthly rainfall amount reaches around 400 mm in February, while its intensity then usually decreases in subsequent months and may reach to only 4 mm/month in the dry season (August) [6]. The humidity increases during wet months (December – February) to around 92 %; and subsequently drops in the dry season in November to as low as 75 %. Geomorphologically characterised by low karstification degree and typified by the absence of preferential flow paths and conduits and, the area is grouped as an eogenetic karst [7,8].

2.2. Groundwater model

MODFLOW (McDonald and Harbaugh, 1988) developed by USGS operated in groundwater modeling system (GMS) user interface [9] was employed to simulate the hydro-geological processes in the catchment. The model was simulated under steady-state and transient conditions. Under the steady-state and transient simulations, a no-flow boundary is used along the catchment boundary of the spring outlet assuming no flux flowing through the boundary. Specified head boundary was set for the small stream downstream the spring using Time-Variant Specified-Head (CHD) package provided in GMS MODFLOW. The conceptual model consists of one horizontal layer which assumes the continuum representation of unconfined carbonate aquifer in the study area. The model was constructed using Layer Property Flow (LPF) package. Prior information of hydraulic conductivity and specific yield values were used and determined using Boulton method which analysed pumping test data at 3 locations in the catchment area. The porosity was set as a constant value of 0.3 to represent the typical nature of the recharge area [10]. The drains were simulated using Drain (DRN) package [11] to model the surface drainage network of the recharge area. Surface drain conductance assigned at the streams was set between 2,700 and 8,125 m/d. The values are dependent on the dimension of the drain and $K_h$ values which are derived from local pumping test analysis. The input into the model is the recharge
mainly characterised by surface (i.e. land use type) and atmospheric stresses (i.e. precipitation and evapotranspiration). The land use types used in the model represent the four main land use types in the recharge area (i.e. savanna grass/bush, plantation, rain-fed farm and settlement). The water balance method [12] was used to quantify the recharge. Using SCS-CN method [13], each land use was assigned the run-off value as the input for the recharge. The calibration and validation processes used the daily observed groundwater heads for a 16-month period collected from 7 dug wells scattered in the recharge area. The model was then spatially discretised by a grid system comprising of a finite difference mesh of cells. The grid cell of the model domain was homogenously discretised to 5 different sizes, i.e. 10 x 10 m, 20 x 20 m, 30 x 30 m, 40 x 40 m and 50 x 50 m, to assess the impact of spatial discretization properties (cell size and distance between observation well and centre of grid cell).

3. Results and discussion

3.1. Model calibration and validation

Overall, the performance of the five models in the calibration and validation steps are considered acceptable in regards to RMSE$_h$ values (between 0.22 m and 0.57 m), confirming that all models are capable of reproducing hydraulic heads to a satisfactory level.

3.2. Effect of discretization of grid size

The results of the calibration of the five models show that the increase of grid cell size significantly reduces model performance as represented by RMSE$_h$ (Figure 2). The effect of coarsening in weakening model performance becomes more visible for models bigger than 30 x 30 m grid characterised by an exponential increase of RMSE$_h$. As expected, the simulation time logarithmically reduced as the effect of grid coarsening.

![Figure 2. Model performance (RMSE$_h$) vs. grid cell size](image)

$y = 1.74e-01 e^{0.98-0.2x}$

$R^2 = 8.57e-01$

3.3. Effect of distance between centre of grid cell and observation well

The grid coarsening results in widening of the length between observation well and the centre of the cell, where the well is positioned in the model. Similar with the extent of RMSE$_h$ reduction as a result of grid cell expansion in wells, OW6, OW9, OW13 and OW15, the drops of model performances due to increased distance implicated by cell size coarsening at those wells are up to approximately 23 times poorer (Figure 3). As such due to the expansion of grid cell size, the increase of distance between well and the centre of the cell has parallel effect on the model performance. This confirms that the more distant an observation point is positioned due to grid cell enlargement the poorer the model perform.
Figure 3. RMSE<sub>h</sub> results vs. distance between centre of grid cell and observation well.

4. Conclusions
Overall, it is concluded from this study that the accuracy of models depends on how well the spatial resolution of grid cell is predefined. As expected, the model simulation results using smaller cell size demonstrate a significant improvement to those of bigger cell sizes. The study confirms that the increase of distance between well and centre of the cell as a result of the coarsening of grid cell results in deterioration of model performance. Thus, the better representation of model surface area would improve simulation of hydrological processes (i.e. such as run-off and recharge) related with topographic slope.

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