Evaluation of the Effects of Surface Slope in Discretization of Groundwater Models

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Abstract. A robust representation of hydrogeological properties of the examined study area in discretization step is essential in groundwater modelling to improve the accuracy and efficiency of the model. A number of studies have investigated the effect of grid cell size in model discretization using comparison of performances of different models representing different cell sizes. However, although grid size refinement effect on model performances was calculated, the impact of mean slope was not conclusively discussed. In this study, five models distinguished by five 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 constructed. Using PEST, hydraulic conductivity and specific yield values over a selection of pilot points were estimated. The effect of surface slope is discussed in order to recommend the most appropriate location for observation well placement in terms of topographical characteristic. It is confirmed that the deterioration of model performance is controlled by mean slope of the surface. Results reveal that model performance increases substantially for areas of low slope (< 3 %) and medium slope (3 ~ 10 %) for smaller a grid cell size. Therefore, to improve model performance, it is recommended that the observations wells are placed in areas of low and medium slopes.

1. Introduction
Discretization is one way to spatially and temporally assign physical properties of the real world to the model. Optimal choice of size and number of cells in discretization step would principally enhance the efficiency and accuracy of the model as well as reducing the complexity of model [1]. Spatial discretization comprises of spatially dividing model area into a finite number of cells to which model properties are characterised. In classic numerical methods, such as finite difference method, the nodes which are located in the centre of the cell represent the input components, such as precipitation and hydraulic conductivity. The node is also the place to which the numerical equation is solved to yield the output of the model, such as hydraulic head and discharge. Figure 1 shows that the grid refinement progressively from 1-cell grid towards 16-cell grid resulting in smaller distance between node and observation well (dn). This obviously reduces the head disparity (∆hn) between simulated head (hn) and observed head (ho), which statistically improves model performance. 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. Grid refinement is important in enhancing model performances and to some extent poor representation of the catchment surface attributed by coarser grid results in deterioration of
model performance [2]. The aim of the study is to confirm that by assessing the effect of grid cell properties on model calibration we are able to efficiently select most appropriate cell size during the discretization step of model development; and identify the most suitable location for observation well placement in terms of topographical characteristic. Hence, a guideline to select observation well based on the effect of grid cell properties (size and distance between centre of grid cell and observation well) and the representation of topography is provided in this study.

![Figure 1. Horizontal conceptualization of three examples of model grid representing observed head (h_o), simulated head (h_s), head disparity (Δh_n) and distance between node and observation well (d_n). The shadowed cells are the observed grid cells. Here, the denser grid represented by bigger cell number yields smaller distance (d_3<d_2<d_1) and smaller head disparity (Δh_3<Δh_2<Δh_1). In modeling Δh_n is assigned as statistics criterion](image)

### 2. Materials and Methodology

#### 2.1. Study Area

This experimental area 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, the Oemau spring is located around 3 km from Ba’a, the capital of the Rote Island [3].

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) [4]. 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 classified as eogenetic karst [5]-[10].

#### 2.2. Groundwater Model

This study utilised MODFLOW [11] developed by USGS operated in groundwater modeling system (GMS) user interface [12] to simulate the hydro-geological processes in the catchment. 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 porosity was set as a constant value of 0.3 to represent the typical nature of the recharge area [13]. The drains were simulated using Drain (DRN) package [14] to model the surface drainage network of the recharge area.
The water balance method [15] was used to quantify the recharge. Using SCS-CN method [16], 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. Grouping of Slope Cluster

The recharge area is dominated with a highly undulated topography with elevation ranging between 97.55 m and 339.55 m above sea level. Areas with mild slope are generally found in the middle of the catchment where rice farms are situated; and steeper slopes dominate the upper and lower areas of the catchment. Using ArcGIS the surface of the area studied was clustered into three slope groups (Figure 2). The clustering is intended to categorise the area into distinct slope distribution and to explain the influence of each mean area slope to the performance of the model, in relation to different grid sizes.

![Figure 2. Distribution of areas according to assigned slope cluster](image)

The clustering shows that the catchment is dominated by areas with low and medium clusters; 47.51 % and 41.44 % respectively, while high slope areas share only 11.04 % of the total area. Four wells (OW5, OW6, OW13 and OW15), which are mainly located near the rice farm areas, fall in low slope cluster; while other two wells (OW2 and OW9) fall into medium slope cluster. Well OW17, situated in the hilly area upstream of the catchment, is categorised to rest in high slope cluster.

3.2. Effects of Surface Slope of the Grid

Figure 3 presents the model performance at each observation well with respect to mean slope of the surface area. In general, the increase of slope in each well as a result of modification of grid cell size results in deterioration of model performance represented by increased RMSEh values. The performance decrease due to increased slope differs variably, with the most notable decrease appears at wells, OW6, OW9, OW13 and OW15 (between around 1250 and 2040 %) which are located in low and medium slope areas. In contrast, OW17 representing high slope area responds moderately by around 250% decrease to the increased slope. Meanwhile, the performance change is barely seen in OW2 and OW5, with only around 25 % and 40 % respectively, conceivably owing to their position which are adjacent to almost steady surface water elevation of a pool downstream the spring.
Therefore, it can be concluded that generally in area of smooth topography the possibility of significantly enhancing model performance using grid refinement method is greater than that in high slope areas. The rationale behind this is that grid size coarsening resulting in higher mean slope gradients consequently generates smaller modelled recharge volumes. This at the end would decrease simulated head. The relationship between slope augmentation and simulated head confirms that the higher slopes contribute to lowered simulated head ($h_s$) and increased of $ME_h$ values. The effect of grid cell slope shows that the selection of observation wells locations, with regard to their topographical gradient, to be included into a model is critical because it significantly contributes to the effectiveness of the model to achieve a better statistical performance while keeping a less computation time to do so.

4. Conclusions

In this study the effect of mean slope in discretization of groundwater models is obvious. It is found that generally model performance increases most significantly for areas of low slope ($\leq 3\%$) and medium slope ($3 \sim 10\%$). In these two areas, $RMSE_h$ greatly increases from approximately 7 to 19 times for smaller grid sizes. However, in high slope areas ($>10\%$), model performance increases only a maximum of four times. Another important finding is that the model performance is controlled by the change in grid cell surface geometry represented by the mean slope of the respective cell. Steeper slope would generate smaller flux into the cell thus it decreases simulated head, which results in decreased model performance represented by higher $RMSE_h$.

The results obtained from the simulation of the five models assist us to improve our understanding of how they impact the model performance. This henceforth provides an improved insight and rationale of not only efficient grid cell selection but also the preference for selecting or placing observation well(s). The most optimal model performance was obtained in the low and medium slope areas given the cell size and slope are reduced. Hence, it is recommended to place observation wells within low and medium slope areas to help improving model performance.

5. References
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