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Groundwater modelling of Nenasi, Pekan, Pahang

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Abstract: One of the most valuable and practical tools the groundwater manager can use is the computer model. Any professional working in the field of hydrogeology should adapt to and use groundwater models to be truly efficient. The conceptual model of the groundwater system in Nenasi, Pekan Pahang was proposed and translated into a numerical model. Groundwater flow model, MODFLOW was used to simulate the steady state hydrogeological conditions for the area. Good agreement was obtained between the simulated and observed groundwater levels. The calibrated model was used to study the environmental impacts on groundwater caused by over abstraction in Nenasi. The present model boundary conditions and modelling results suggested that over abstraction would lower down the groundwater level, dry up the shallow aquifer and induce saltwater intrusion.

Abstrak: Salah satu alatan yang berguna dan praktikal yang boleh digunakan oleh pihak pengurusan air tanah ialah pemodelan air tanah berkomputer. Para professional di dalam bidang hidrogeologi sepatutnya mengadaptasi dan menggunakan model air tanah untuk menguruskan air tanah dengan lebih efisen. Model konsepsi sistem akuifer di kawasan Nenasi, Pekan, Pahang telah dicadangkan dan diterjemahkan ke dalam model numerasi. Model aliran air tanah, MODFLOW telah digunakan untuk mengsimulasi keadaan hidrogeologi tunak bagi kawasan tersebut. Persetujuan yang baik diperolehi daripada perbandingan aras air tanah yang diukur dilapangan dengan aras air model simulasi. Model yang telah ditentukurkan telah digunakan untuk mengkaji kesan alam sekitar yang diakibatkan oleh pengepaman air tanah secara berlebihan di kawasan Nenasi. Hasil pemodelan akuifer ini dengan berdasarkan keadaan sempadan model yang dibina buat masa ini telah mencadangkan bahawa pengepaman berlebihan air tanah akan menyebabkan kejatuhan aras air tanah, mengeringkan akuifer cetek dan menggalakkan intrusi air laut.

INTRODUCTION

This paper describes how the groundwater flow system in the coastal area of Nenasi, Pekan, Pahang was simulated using the MODFLOW groundwater flow model. In the Nenasi area that is close to the South China sea, excessive groundwater pumping for aquaculture activities may result in higher risk of salt water intrusion and other groundwater problems such as lowering water levels and ground subsidence. It was reported that there was a continuos fall of groundwater levels and an elevated chloride concentration in the groundwater within the area (Ismail C. Mohamad & Ang, 1996). An aquaculture activity (eel aquaculture) at Tanjung Batu, Nenasi that extracted water from the deepest aquifer since 1980's might be the major cause of the problems. Beginning from 1997, due to the shortage of eel supply and other reasons, the aquaculturist had shifted to the production of tiger prawn and has pumped sea water into the ponds.

Groundwater model is a valuable tool to study the problem and could highlight any future threat to the groundwater resource. The groundwater modelling processes involve several steps including development of the conceptual model for the aquifer based on geological, hydrogeological and current climatic conditions. It also involves aquifer recharge estimation and model calibration.

Under the present study, the flow of work involved interpretation of the geology and hydrogeology of the area using published and unpublished investigation reports. Thirteen groundwater boreholes were installed to assist on the hydrogeological interpretation and eased the development of the conceptual model of the aquifer systems. The conceptual model was translated into MODFLOW with simplification of physical and hydraulic data input. The model calibration was done to match the observed field data and the simulated groundwater level. The model sensitivity analysis was carried out on the calibrated model.

GEOLOGY AND HYDROGEOLOGY

The area towards the coast is covered by unconsolidated Quaternary alluvium which is underlain by Permian metasedimentary and volcanic bedrock. The alluvium consists of clay, sand and gravel of probably fluvatile origin. The alluvium plain is characterised by sandy ridges towards the sea which alternate with swampy swales.

The Permian metasedimentary bedrock consists mainly of phyllite, slate and schist. A small hill near Tanjung Batu is made up of volcanic pyroclastic rock. The depth to the bedrock from the drilled boreholes at the Nenasi Waterworks is between 95 -110 m.

From the aspect of hydrogeology, there are three sand aquifer layers in the area that are separated by alternating clay layers. The sand consists of fine to coarse sand with some gravel. The first sand aquifer that also forms the ridge along the coastal area is an unconfined aquifer. The water table could be found at 1-3 m depth from the surface. The rest of the sand aquifers are confined aquifer with clay as the confining layer. Some leaky condition could exist between the second and the third aquifer layers according to the physical extent and the thickness of the clay layers.

CONCEPTUAL MODEL

A conceptual model is a pictoral representation of the groundwater flow system, frequently in the form of a block diagram or a cross section (Anderson& Woessner, 1992). A conceptual model for Nenasi was developed based on the geological cross section and report reviewed as shown in Figure 2. The conceptual model of the aquifer system consists of five (5) layers. There are three aquifer layers of fine to coarse sand that are separated by the clay layers. The clay is assumed to hydrogeologically provide some leakage (recharge) to the underlying sand aquifer. The aquifer's hydraulic conductivity values were obtained from grains size analysis and from previous pumping test results. However, the hydraulic conductivity for the clay layers was ascertained from published data. All the model parameters are described beolw.

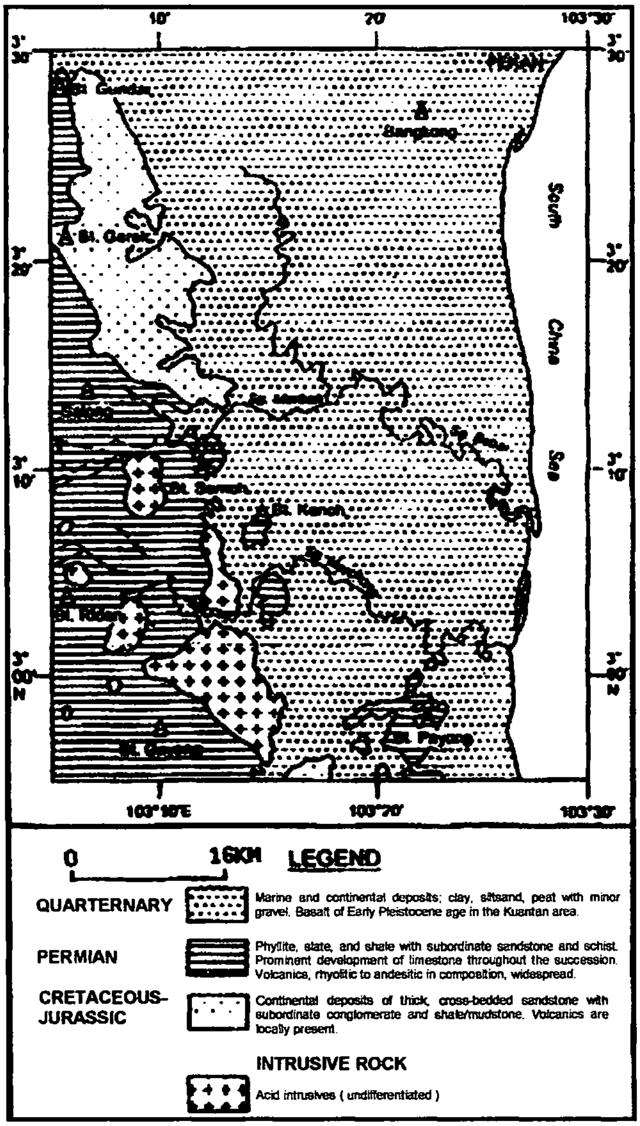

Figure 1. Geology of Nenasi-Kuantan area.

Model boundaries

Model boundaries were identified physically and by using hydraulic assumptions. The boundaries for the east, west, north and south of the first layer aquifer of the model were decided as given in Table 1.

All the other layer boundaries were modelled as no flow boundary. The abstraction is considered taking place only from the third aquifer. The small abstraction from the local well is negligable. All the model boundaries especially the north and west boundary were adjusted according to the result of the sensitivity analysis that was performed during the model calibration process.

Model layers

A five layer model with three (3) layers of aquifer was proposed. The confining clay layers that separate the aquifers were modelled as the continous layer with a reasonable value of hydraulic conductivity (i.e published data) as required by MODFLOW. The thickness and bottom elevation for each aquifer layer that had been assigned are given in Table 2.

River bed sediment

In order to acquire the physical and hydraulic properties of the main river in the area; Sg. Nenasi, fieldwork was carried out by travelling along Sg. Nenasi. At certain distances, the river bed sediment was taken using the grab-sampler. Another interest from this fieldwork was the river bed elevation of Sg. Nenasi. The estimation of the river bed hydraulic conductivity was done using the Hazen's method. The value is between 18-78 m/day.

Hydraulic conductivity

Since the hydraulic data on the aquifer layers within the study area is quite limited, all the available data on the

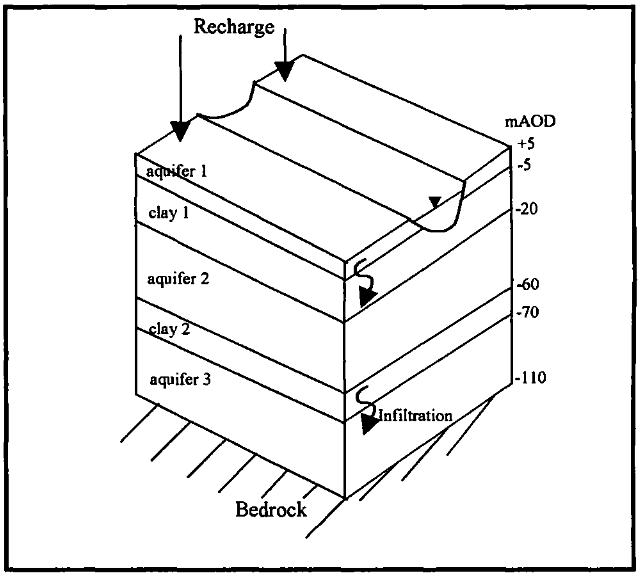

Figure 2. Aquifer conceptual model for Nenasi. Note: mOAD is meter above ordinary datum.

hydraulic conductivity was considered as the initial input data in the groundwater model. The initial hydraulic conductivity values for the groundwater model are tabulated in Table 3. The vertical hydraulic conductivity was assumed to be betweeen 1-10% of the horizontal values (Yusoff, 2000).

Groundwater recharge

The groundwater recharge calculation was performed by using the average monthly precipitation and potential evapotranspiration (PE) data for the year 1990 to 1999. The recharge value of 3.73×10^{-3} m/day was used as the initial recharge input in the groundwater model. The recharge was only assigned to the uppermost layer (Layer 1). The leakage was considered to be taking place into the deeper layer which is controlled by vertical hydraulic conductivity and groundwater head of the upper layer.

Groundwater abstraction

There were about 336 tube wells installed for aquaculture activities before 1997 (Ismail 1993). Unfortunately, the abstraction record was not available. The estimated groundwater abstraction at the farm during the full operation was about 22,500 m^3/day. From a field test that was conducted in the farm, it was found that the well average discharge value was approximately 0.0341 m^3/s. To proceed with the groundwater modelling, it was decided that the initial groundwater abstraction value for the model is 10% of the estimated value by Ismail (1993). The current estimation was based on personal communication with Song Cheng's officer. The model sensitivity on the prescribed abstraction value had been performed during model calibration.

For public groundwater supply, Ismail (1993) reported that the total discharge value from the pump house was about 175 m^3/day. There is an increase in discharge value at present due to the increase in groundwater demand in the area. It was estimated that the current water abstraction value is about 500 m^3/day based on the size of the elevated storage tank and the duration of the pumping. The abstraction was considered taking place only from the third layer aquifer (Song Cheng's farm and pump house). A relatively small abstraction from the local well (first aquifer) was negligible.

NUMERICAL MODELLING

The conceptual model was translated into a groundwater model with a total area of 1296 km^2 by using a commercial preprocessor known as Groundwater Vistas (developed by Environmental Simulation Inc., UK). The model domain was discretized into grid dimensions of 1 x 1 km, 1 x 0.5 km, 0.5 x 0.5 km, 0.5 x 0.25 km and 0.25 x 0.25 square cells, with the smaller cell size assigned to the active model area where rivers and abstractions were simulated. There are 59748 cells in total, with 47412 active cells for the five layer model. There are 3536 constant head cells representing the river and ocean and 242 well cells. The model discretization and boundary conditions for all the model layers are shown in Figure 3. The second and third layers are the clay layers while the fifth layer is underlain by the bedrock. In this modelling study, the performance of an initial model was carried out prior to the model calibration.

Table 1. First layer aquifer model boundary conditions.

Boundary	Description
East	Basically follows the coast line, modelled as the prescribed head boundary; h = 0 mAOD(metre above ordinary datum)
West	Boundary between impermeable hardrock formation and alluvium deposit; modelled as no flow boundary
North	Follows the imaginary impermeable flow line that is from west to east; modelled as no flow boundary
South	Basically follows the allignment of Sg. Nenasi; modelled as constant head boundary, head values obtained from the river survey

Table 2. Thickness and bottom elevation for each aquifer.

Layer No.	Thickness (m)	Bottom Elevation mAOD
Layer 1(First aquifer)	7	-3
Layer 2(Second aquifer)	41	-71
Layer 3(Third aquifer)	27	-110

Table 3. Initial hydraulic conductivity for each model layer.

Model Layer	Initial Horizontal K (x,y) m/day	Initial Vertical K (z) m/day
1	100	1
3	50	0.5
5	50	0.5
Clay (2 & 4)	8.64×10^{-5}	8.64×10^{-7}

Model Calibration

The purpose of the calibration is to establish a model that could reproduce field-measured heads and flows (Anderson and Woessner, 1992). These measured heads and flows are known as calibration targets. The calibration was accomplished by finding a set of parameters, boundary conditions and stresses that could produce simulated heads and fluxes that match observed values with an acceptable degree of error. A calibration strategy was developed to assist the model calibration process.

To calibrate the present model, more than 50 model simulations were run during the calibration process. The results of simulation NN11je was eventually chosen as a calibrated steady-state model. The selected model is considered calibrated based on the reported errors in simulated groundwater levels with limited time. The model is able to represent the field conditions and could be used for the purpose of the study. The full model results are given in Table 4. The comparison between the observed and modelled solutions (simulated) of water levels is shown in Figure 4.

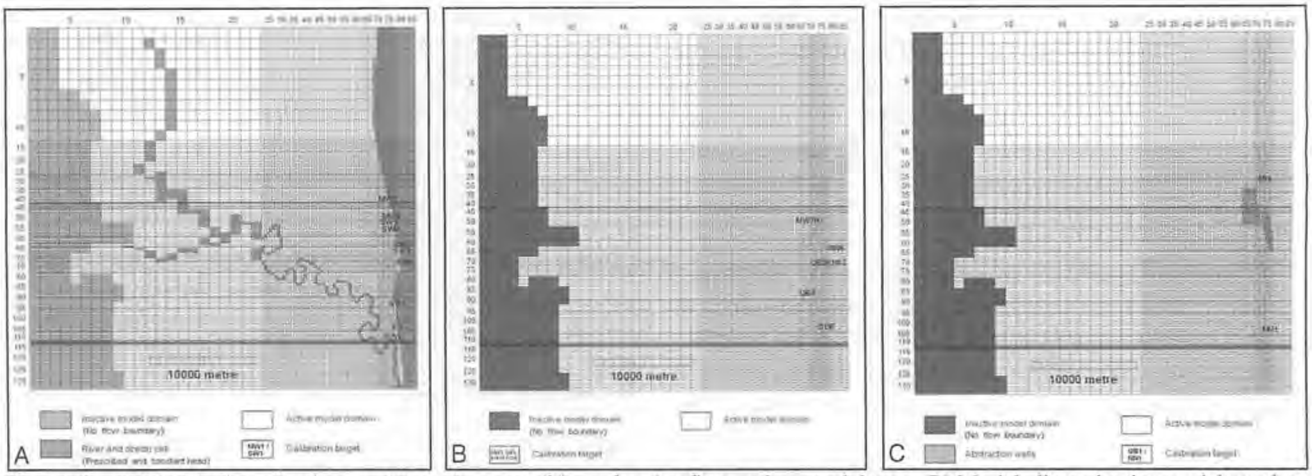

Figure 3. A) Model discretization and boundary conditions for the first and second layers. B) Model discretization and boundary conditions for the third and fourth layers. C) Model discretization and boundary conditions for the fifth layer.

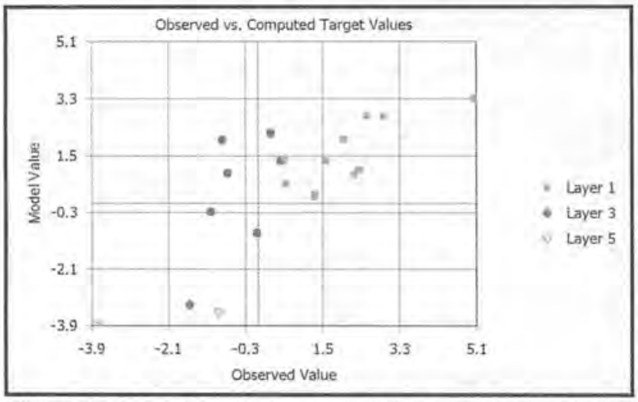

Figure 4. Comparison between modelled and observed values of groundwater levels for the calibrated model.

Sensitivity Analysis

The calibrated groundwater model (i.e NNj11e model) was used to study the sensitivity of the model to change due to internal and external stresses. The main objectives of the analysis was to determine the effect of groundwater abstraction in Song Cheng's farm area and the surrounding area. The details of the sensitivity study or so called "scenario analysis" are outlined below and the results are shown in Table 5.

Scenario 0: The model was assigned to simulate the pre-abstraction period with no groundwater abstraction taking place in the area. This scenario represents the natural condition of the groundwater basin.

Scenario 1: The model is the result of the calibrated groundwater model (i.e NN11je) and is considered representing the present day condition of the groundwater basin with groundwater abstraction in Song Cheng's farm and the public water works area. The total abstraction rate is 3000 m^3/day.

Scenario 2: The model is assigned to simulate the maximum (i.e maximum production of Song Cheng's existing wells) groundwater abstraction in the area. The model represents the condition of the aquifer system in the area under the worst condition.

The groundwater level contour for the first, third and fifth model layer of Scenario 2 are shown in Figure 5. It is clearly seen in Figure 5 that the maximum well capacity abstraction in Song Cheng's farm would create a larger cone of depression up to 12 km in land thus drying up not only the shallow wells but eventually the peat swamp too. The results also shows that over-abstraction would induce the saltwater intrusion. Any increase in groundwater abstraction in the public water works area would not cause any environmental impacts.

CONCLUSION

The results of the present study of geology, hydrogeology and groundwater modelling in Nenasi, Pekan area could be concluded as follows:

1. The geology of the area is covered with alluvium of alternate layers of sand and clay that is underlain by Permian bedrock. The thickness of the alluvium could reach more than 100 m close to the sea.
2. At least, 3 layers of sand aquifers exist. The aquifer layers are hydraulically connected with less permeable clays that act as the confining layers. The main river in the area is also hydraulically connected with the first aquifer and the first clay layer. The groundwater recharge to the first aquifer comes directly from the surface while the deeper aquifer is receiving recharge from the infiltrated water through the clay layers.
3. The modelling study demonstrated how a numerical groundwater flow model could be used as an aid in interpreting the field data and for hypothesis testing. In addition, the model developed could assist in explaining the anomalous field data and is very cost effective. This tool is valuable and practical for the groundwater manager.
4. The present model boundary conditions suggest that over abstraction would clearly lower down the groundwater level, dry up shallow aquifers and the

Table 4. Results of the groundwater level calibration.

Simulation File	Model Error			
	Residual mean RM (m)	Residual sum squared RSS (m^2)	Absolute residual mean ARM (m)	Water balance (%)
NNj11e (Scenario 0)	0.25	38.8	1.1	2.0

Table 5. Model descriptions and results of the scenario analysis with calibrated model.

Model File	Description	Water table / Piezometric level (mAOD)							
		MW4	SW3	SW8	MW2	MW6	DoE	NN1	OB1
Scenario 0	Natural condition, without abstraction	4.15	2.45	0.6	6.05	2.10	1.55	1.58	3.81
Scenario 1	Present day condition (abstraction rate 3000 m^3/day)	2.76	2.01	0.6	-0.28	-0.96	1.35	-3.9	-3.47
Scenario 2	Abstraction at Song Cheng 3500 m^3/well/day (872,000 m^3/day)	-5	-3.19	0.58	-120.46	-46.49	-0.03	-31.7	-94.2

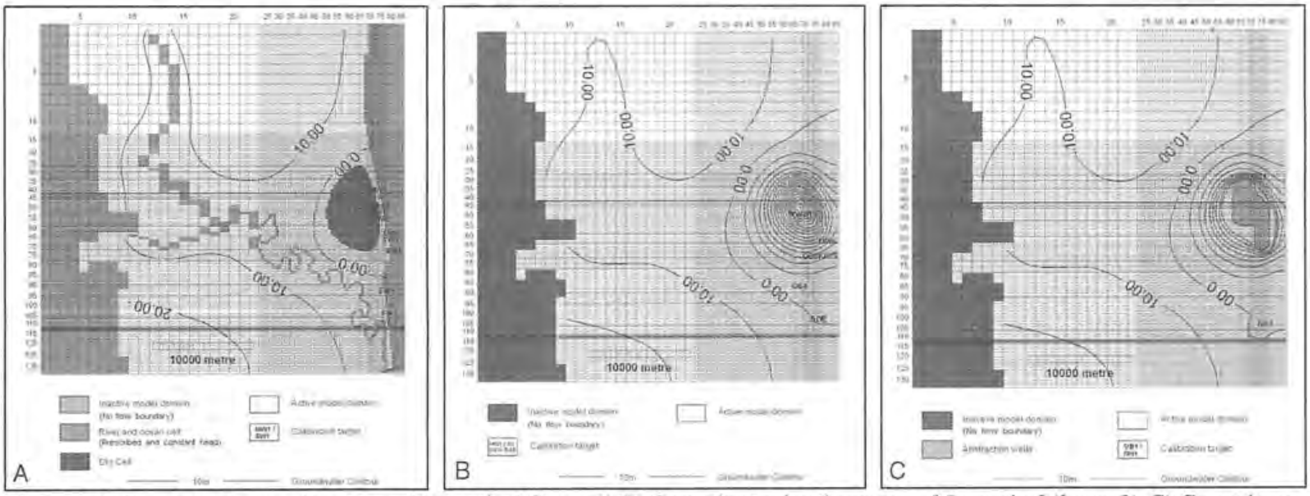

Figure 5. A) Groundwater level contour of Scenario 2 (Layer 1). B) Groundwater level contour of Scenario 2 (Layer 3). C) Groundwater level contour of Scenario 2 (Layer 5).

peat swamp and induce saltwater intrusion. The results should also be analyzed with a survey of ground subsidence status.

5. Continuous monitoring should be carried out so that geological and hydrogeological information could be updated in order to improve the model prediction.

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