Aquifer Simulation Model in Tioman Island

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ABSTRACT

Tioman Island which is situated in the southeast of Pahang State is one of small islands in Malaysia that has been promoted as a tourism destination. Based on previous study, the island requires more than 2000 m^3/day of water for domestic and tourism industry consumption, and the demand is expected to rise due to the increases in population and tourism activities. Study on groundwater of Tekek aquifer indicates a good potential for water resource to meet the demand of the future water-needs in Tioman Island. An intensive study is being carried out to investigate the quantity of water resources in the island. For predicting the amount of groundwater potential that can be extracted, ASM (Aquifer Simulation Model) is used. The paper present the finding of the amount of the groundwater potential that can be extracted in Tekek, Tioman Island.

***Keywords**: groundwater, extract, Aquifer Simulation Model and small island.*

INTRODUCTION

General

Based on the previous study by Nazan Awang and Loganathan (1991), Tioman Island has been investigated for two areas namely, Kampung Tekek and Kampung Juara, which have good potential for exploitation of surface water and groundwater. The current study is focused on Kampung Tekek and to assess the maximum annual yield of groundwater from Tekek aquifer. For this purpose, the available model (ASM) was used to calculate and simulate the hydrological and hydrogeological data.

In hydrological analysis, long-term data is required for any decision. Unfortunately, in the present study such long-term data is not available. Therefore, the present study only uses the data of groundwater level fluctuation of a 10 month-data.

After treating all of the data, the maximum extraction of groundwater can be predicted by using the ASM (Aquifer Simulation Model).

Brief Description of the Study Area

Tioman Island of Pahang is located on the east of Peninsular Malaysia at latitude of 2^0 43' 00" to 2^0 54' 00" N and longitude of 104^0 6' 00" to 104^0 12' 30" E. The area of the island is about 131 km^2, with a maximum width of about 11 km (west to east) and a maximum length of about 20 km (north to south). It is an island among a group of 64 volcanic islands (see Fig. 1).

The coast of Tioman Island is predominantly featured with rocky hills with green flora on the top. On the foothills at the seaside, there are many arrangement of rocks which hold the seashore. In some places there are beautiful sandy beaches and the plains are not large. In these places the following villages are located: Kampung Tekek, Kampung Salang, Kampung Dungun, Kampung Juara, Kampung Asah, Kampung Mukut, Kampung Pasir, Kampung Nipah, Kampung Genting, Kampung Paya and Kampung Lalang. Each of them has a sandy beach as a recreation area which attracts visitors. In general, the island is still in pristine condition with a crystal clear azure sea and it is rich in marine life.

OBJECTIVE OF THE STUDY

The main objective of the study is to assess and to measure the groundwater potential of the Tekek aquifer.

TIOMAN ISLAND

Topography

The terrain of the island is quite steep, rising from 75 m to 1,038 m above mean sea level, resulting in short and steep river profiles. About 12 km^2 of the island's area falls in the range of slope between 0 to 30^0, whilst about 119 km^2 is having slope greater than 30^0 Desa (1999). Approximately 90 % of the land is occupied by slope greater than 30^0.

In hinterland, there are hills, mounts, and plateau, covered by flora of tropical forest, namely Gunung Kajang (1,038 m), Gunung Rombin Tioman (976 m), Gunung Seperak (958 m), and Bukit Nenek Semukut (766 m). There are many small rivers, and the largest river is Sungai Mentawak (about 5.5 km). Ayer Besar River basin lies in Kg.Tekek area. Keliling River basin and Baharu/Air Dalam River basin lie in Kg Juara area. The down stream area of the basins are coastal plains (Daulay et.al, 1999).

Geology and Hydrogeology

Tioman Island is comprised of mainly Triassic granite with Permian volcanic at the eastern part of the island. In low lying areas such as Kampung Tekek, they are generally made up of thin layers of alluvium consisting silt, sand and gravel with some clays and corals. The study area is classified as an unconfined aquifer comprising mainly of about 14 m thick medium to coarse sand with coral along the coast. Geophysical investigation using gravity method showed that the over all coral thickness is most likely within 7 to 20 m (Mohammed Hatta et.all, 1993).

Hydro-geological factors have a major influence on the distribution of groundwater on an island. These factors include the permeability and porosity of the rocks and sediments, and the presence and distribution of karstic features such as small cave systems and solution cavities. Surface water resources prevail only on islands with relatively low permeability. Groundwater resources are most abundant on small islands with moderate to high permeability and porosity. Size, shape and topography of a small island are major influences on the occurrence of both surface and groundwater resources (Falkland, 1997).

The geology of Tioman Island is well described by Bean (1972) . This island is underline mainly by granite rock/hard rocks which mean it has the least groundwater potential, and a thin narrow belt of metamorphosed volcanic and sedimentary rocks along the north and east coast of the island. Meanwhile the alluvium which has a better prospect for groundwater development were found only on the limited areas, patches along coastline at low lying area such as Kampung Tekek, Salang, Juara, Paya, Genting and Mukut. Most of those areas except in Kampung Tekek and Juara, the alluvium was confined to limited area along coastline and it does not form extensive aquifers (Ismail and Mohamad Rais, 2000).

Climate

The study area has a tropical climate characterized by uniformly high temperature and high relative humidity. It can be said that, tropical islands exhibit little variation in temperature (Falkland, 1992) yet, on a regional scale. The most important factors that control the annual variation of tropical convection are the annually varying thermal contrast between land and ocean and the annual cycle of sea surface temperature (Wang, 1994) with mean temperatures in January and July of about 25^0 C compared to 28^0 C during the 1982 Elnino (Desa, 1999).

The highest monthly temperature varying from 30.0^0 C to 38.1^0 C, the lowest monthly temperature ranging from 20.5^0 C to 26.8^0 C, and the mean monthly temperature ranging from24.1^0 C to 31.7^0 C, from September 1998 to August 1999. The mean monthly relative humidity varying between 75 % to 86 % , depending on month from September 1998 to August 1999 (Mohd. Rosaidi, 2000).

The climate of an island influences environment, hydrological cycle and water resources. Among the climatic variables, rainfall contributes significantly to the local hydrology It is the source of supply of all surface and subsurface water. The quantity of available water resources varies daily, monthly and yearly depending on prevailing wind flows which affect the rainfall pattern (Mohamad and Ramli, 2000). The presence of large water body surrounding has great influence on the climate of the island. As Tioman Island is situated within the Asian monsoon regime, monsoon effects modify its climate (Mohd. Rosaidi, 2000).

The rainy season in Tekek from October to January is affected by the northeast monsoon whereas the dry season in Tekek occurs from February to September The dry season coincides with peak season of holidays which makes more demand for water when it is scarce.

WATER RESOURCES OF STUDY AREA

The main factors influencing hydrological processes and the nature of surface and groundwater resources on small tropical islands are physiography, climate and hydrology, geology and hydrogeology, soil and vegetation, and human impacts, including abstraction and pollution from a variety of sources. For low islands and low lying areas of high islands, sea level movements due to tides, pressure changes and longer term influences are also important factors (Falkland, 1997).

Water resources for this study area can be divided into surface water resource and groundwater resource. At present, surface water is used for domestic and tourism industries purposes, as untreated water by direct supply from small collecting dam, which was constructed normally on the hilly terrain at the upstream of the catchment.

Surface Water

Until now surface water is used for water need in Tekek Village, which is obtained mainly from Ayer Besar River.

Groundwater

Tekek Aquifer

Tekek Aquifer has good potential of groundwater resource. The previous study showed that Tekek area can produce water of 1,368 m^3/day (Awang and Loganathan, 1991).

Generally, groundwater on High Island like Tioman Island, occurs in form of elevated (high level) or basal (low-level) aquifer. Basal aquifer, which usually takes form of fresh water lens, is more important as groundwater resource. Assessment of water resources and their sustainable yields are paramount importance for small islands where demands for clean water supply are seasonally fluctuated in nature (Desa, 1999).

Groundwater resources are most abundant on islands with moderate to high permeability and porosity. Generally, the hard rock aquifers do not have very high primary porosity or permeability compared to alluvial aquifers. The water yielding properties in hard rock aquifers are largely dependent on the occurrence of secondary features such as fracture, cavities, joint and fault zones. The hard rock aquifers will only yield limited amount of water compared to alluvial aquifers. Therefore, groundwater from alluvial aquifers is more favored than hard rock aquifers.

The assessment of the yield of a groundwater resource is more difficult and more subjective than the comparable calculation for a surface water resource. This is largely due to the fact that the underground reservoir or catchment is invisible from the ground surface and so the determination of its lateral and vertical dimensions must be accomplished by indirect means such as geophysical investigation or borehole exploration, interpolation and guesswork. Once aquifers have been located and their physical properties assessed, the data may be presented in the form of maps. Typically, maps would be prepared showing the variation of the coefficients of storage and transmissivity in the study area. These factors partly determine the ease with which water can flow to a well, hence, such maps are useful in helping to locate potential well sites. Because of the problems inherent in determining the characteristics of an aquifer, it is inevitable that estimates of groundwater yield will be subjective and approximations to the real values (Hamil and Bell, 1986).

Aquifer Simulation Model

With known maximum extraction from the Tekek aquifer, the ASM model (Aquifer Simulation Model) is used by giving the certain amount of pumping capacity and in a certain time that causes the groundwater level to be same with or little higher than mean sea level. This is done in order to protect intrusion of saline.

The Model and Size

1) Mesh Size

Number of Columns : 20 Size of Columns : 145 m
Number of Rows : 20 Size of Rows : 102 m
Scale on map : west to east : 2909 m and north to south : 2045

After Refining of Mesh, Number of Columns are 84, Number of Rows are 100, and Number of Elements are : 8400

2) Unconfined. Anisotropy Factor-1 for homogenous Tx = Ty , kx = ky

3) Boundary Condition

Fixed Head : South China Sea, Sg. Air Besar, Sg. Air Hantu and Sg. Air Sabut.

Variable Head : Other cells
No Flow : Granite

4) Elevation of Aquifer

Aquifer Top is 4.01 m and Aquifer Bottom is -12.00 m

5) Initial Hydraulic Heads

The initial hydraulic heads are the observed data of the hydraulic heads of Tekek Aquifer as shown in the Table 1. There are only 10 months data available, and only 9 months in the year of 1999. From the 10 months data average hydraulic heads were calculated for each investigated bore-hole, namely:

TK1 = 1.49 m,	TK2 = 1.35 m	TK3 = 1.40 m	TK4 = 1.79 m
TK6 = 1.09 m	TK7 = 1.33 m	TK8 = 1.07 m	TK9 = 0.91 m
TK10 = 2.58 m	TK11 = 3.44 m	TK12 = 1.82 m	TK13 = 2.05 m

These values were used to calibrate the model and to simulate the pumping test from the aquifer through a well.

Table 1 Groundwater Level Data of Tekek Aquifer, Tioman Island.

Date	Groundwater Level (m below ground level)											
	TK1	TK2	TK3	TK4	TK6	TK7	TK8	TK9	TK10	TK11	TK12	TK13
Sep-98	1.25	1.17	1.11	0.76	0.39	0.60	2.55	0.79	1.12	1.57	0.86	1.79
Mar-99	1.18	1.08	0.95	0.62	0.34	0.51	2.42	0.63	1.24	1.06	1.84	1.88
Apr-99	1.00	1.05	0.92	0.46	0.17	0.27	2.47	0.65	0.91	1.00	0.75	1.76
May-99	1.16	1.01	0.90	0.58	0.39	0.53	2.60	0.68	1.16	1.02	0.64	1.64
Jun-99	1.23	1.02	1.05	0.74	0.44	0.59	2.55	0.76	1.53	1.35	0.90	1.60
Jul-99	1.23	1.10	0.99	0.74	0.47	0.56	2.44	0.57	1.64	1.52	0.96	1.75
Aug-99	1.33	1.28	1.19	0.89	0.49	0.64	2.67	0.80	1.78	1.84	1.08	1.81
Sep-99	1.28	1.17	1.09	0.73	0.46	0.82	2.60	0.82	1.54	1.44	0.90	1.73
Oct-99	1.23	1.13	1.00	0.74	0.38	0.48	2.45	0.54	1.53	1.67	0.86	1.38
.Des-99	0.94	0.81	0.62	0.06	0.27	0.37	2.31	0.43	0.51	0.75	0.35	1.69
Min	0.94	0.81	0.62	0.06	0.17	0.27	2.31	0.43	0.51	0.75	0.35	1.38
Max	1.33	1.28	1.19	0.89	0.49	0.64	2.67	0.82	1.78	1.84	1.84	1.88
Avr	1.18	1.08	0.98	0.63	0.38	0.52	2.51	0.67	1.30	1.32	0.91	1.70

Date	Groundwater Level (meter above mean sea level)											
	TK1	TK2	TK3	TK4	TK6	TK7	TK8	TK9	TK10	Tk11	TK12	TK13
Sep-98	1.42	1.26	1.27	1.66	1.08	1.25	1.03	0.79	2.76	3.19	1.87	1.96
Mar-99	1.49	1.35	1.43	1.80	1.13	1.34	1.16	0.95	2.64	3.70	0.89	1.87
Apr-99	1.67	1.38	1.46	1.96	1.30	1.58	1.11	0.93	2.97	3.76	1.98	1.99
May-99	1.51	1.42	1.48	1.84	1.08	1.32	0.98	0.90	2.72	3.74	2.09	2.11
Jun-99	1.44	1.41	1.33	1.68	1.03	1.26	1.03	0.82	2.35	3.41	1.83	2.15
Jul-99	1.44	1.33	1.39	1.68	1.00	1.29	1.14	1.01	2.24	3.24	1.77	2.00
Aug-99	1.34	1.15	1.19	1.53	0.98	1.21	0.91	0.78	2.10	2.92	1.65	1.94
Sep-99	1.39	1.26	1.29	1.69	1.01	1.23	0.98	0.76	2.34	3.32	1.83	2.02
Oct-99	1.44	1.30	1.38	1.68	1.09	1.37	1.13	1.04	2.35	3.09	1.87	2.37
Dec-99	2.67	1.62	1.76	2.36	1.20	1.48	1.27	1.15	3.37	4.01	2.38	2.06
Min	1.34	1.15	1.19	1.53	0.98	1.21	0.91	0.76	2.10	2.92	0.89	1.87
Max	2.67	1.52	1.76	2.36	1.30	1.58	1.27	1.15	3.37	4.01	2.38	2.37
Avr	1.58	1.35	1.40	1.79	1.09	1.33	1.07	0.91	2.58	3.44	1.82	2.05

Source: (Mohamad and Ramli, M.R 2000)

Hydraulic Conductivity

Hydraulic conductivity can be gained from the automatic calibration. In ASM WIN the hydraulic conductivity in a steady state flow model can be adjusted by automatic calibration module (ASMOPTI). To demonstrate the use of this module, we assume that the hydraulic conductivity of the entire model is homogeneous but its value is unknown. We want to calibrate this value. There are 12 observation bore-holes with the coordinates and the observed hydraulic heads listed below.

Table 2 Observation points.

No.	Name	X	Y	Observed Head
1	TK1	1441	906	1.49
2	TK2	1383	869	1.35
3	TK3	1352	807	1.40
4	TK4	1501	991	1.79
5	TK6	1379	945	1.09
6	TK7	1323	948	1.33
7	TK8	1298	1010	1.07
8	TK9	976	563	0.91
9	TK10	1613	1115	2.58
10	TK11	1646	1254	3.44
11	TK12	1468	1215	1.82
12	TK13	1501	1437	2.05

Effective Porosity for Tekek aquifer is used 0.15

Automatic Calibration

Three steps are required for an automatic calibration.

1. Assign the zonal structure of each parameter.
   Automatic calibration requires a subdivision of the model domain into a small number of reasonable zones of equal parameter values. The zonal structure is given by assigning to each zone a parameter number in the Data Editor.
2. Specify the starting values for each parameter.
3. Specify the observation points and the measured hydraulic heads [9].

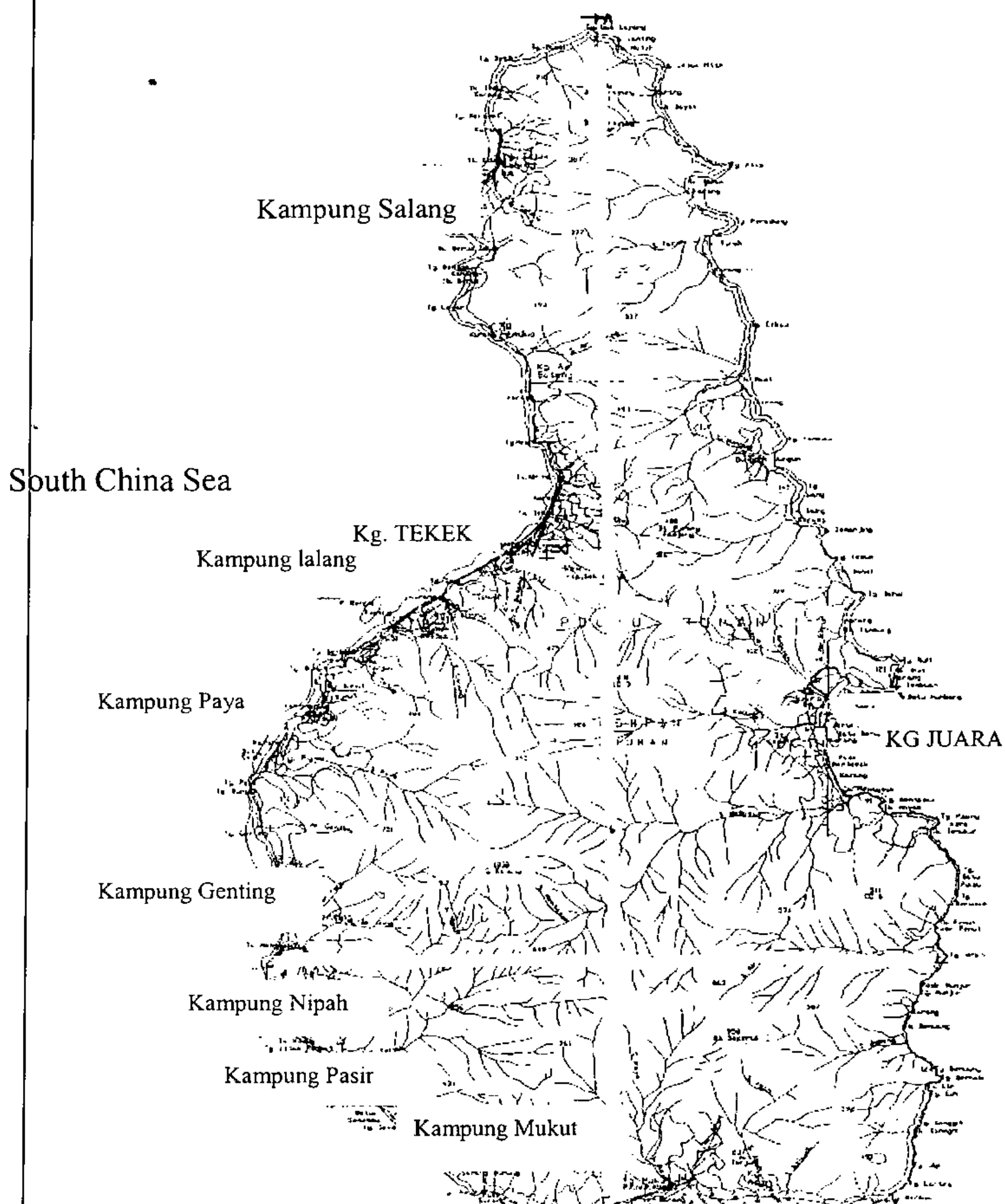

Figure 1 Tioman Island Map.

In this case the domain was divided into four zones with four hydraulic conductivity values k1, k2, k3, k4, (Figure 2).

After specifying the starting values (initial, lower bound and upper bound values), the automatic calibration can be run. Automatic calibrations have been run more than 400 times in more than 3 months time, that gave results of hydraulic conductivity results for each zones, as below:

Zone 1:	for TK9,	k1	= 0.00143
Zone 2:	for TK11, TK12,	k3	= 0.00138
Zone 3:	for TK13,	k4	= 0.00173
Zone 4:	for TK1, TK2, TK3, TK4, TK6, TK7, TK8, TK10,	k2	= 0.00163

These results were used for the model to run the pumping test, by specifying the initial pumping rate. The pumping test was repeated by changing the pumping rate, until one met the suitable rate that made the groundwater surface draw-down to the mean sea level or little higher. This rate is the maximum pumping rate that will be allowed to extract the groundwater from the aquifer.

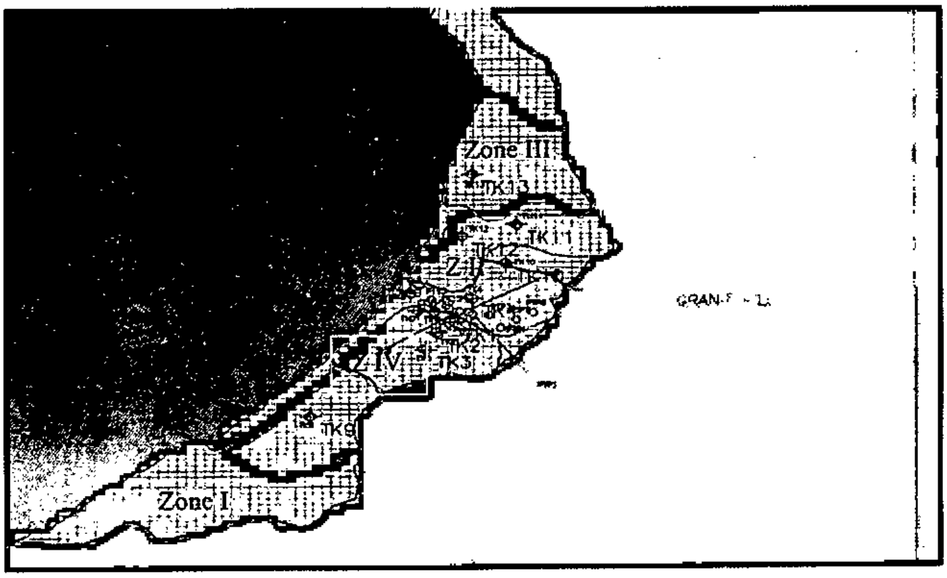

Figure 2 The Tekek Aquifer Zones, Tioman Island.

SIMULATIONS OF PUMPING TEST

This paper only reports the pumping test which uses the initial hydraulic heads of the average values. The average values of the initial hydraulic heads are the average values of the monthly groundwater levels for 10 months of each bore-holes. as showed in Table 1. After filling all parameter values and packages (pumping well rate) into the model, one can run the model for the pumping test in some periods with the certain period length.

Period length was defined in 24 hours (86400 second) for all pumping test. And the pumping rate regarding to the draw-down of the groundwater that be allowed. In this case the pumping rate specified as below:

Pumping I	2000 m^3/day (0.02315000 m^3/second)
Pumping II	2500 m^3/day (0.02894000 m^3/second)
Pumping III :	3000 m^3/day (0.03472000 m^3/second)
Pumping IV	3500 m^3/day (0.04050900 m^3/second)
Pumping V	4000 m^3/day (0.04629630 m^3/second)
Pumping VI	4500 m^3/day (0.05208300 m^3/second)
Pumping VII	5000 m^3/day (0.05787040 m^3/second)
Pumping VIII	5500 m^3/day (0.06365741 m^3/second)
Pumping IX	6000 m^3/day (0.69444000 m^3/second)

Initial hydraulic head in the pumping well (PTP3), can be found by running the model in 24 hours with pumping rate of 0.00 m^3/second, and the result showed that initial hydraulic head, h = 2.30 m. The pumping results are shown in Table 3. The ninth pumping test caused the hydraulic head downed to be –2.505 m and draw down as much as 4.805 m, but the sea water still does not enter to the well. The hydraulic head contours and flow directions of groundwater of the ninth pumping are shown in Figure 3.

Table 3 The results of pumping test simulation from the PTP3 Well (54,55).

No.	Extraction by Pump	Initial Hydraulic Head in the Well (m)	Hydraulic Head after Pumping (m)	Draw down (m)
1.	Pumping I (0.02315 m^3/sec = 2,000 m^3/day)	2.30	- 0.174	2.474
2.	Pumping II (0.02894 m^3/sec = 2,500 m^3/day)	2.30	-0.487	2.787
3.	Pumping III (0.03472 m^3/sec = 3.000 m^3/day)	2.30	-0.752	3.052
4.	Pumping IV (0.040509 m^3/sec = 3.500 m^3/day)	2.30	-1.025	3.325
5.	Pumping V (0.0462963 m^3/sec = 4.000 m^3/day)	2.30	-1.304	3.604
6.	Pumping VI (0.052083 m^3/sec = 4500 m^3/day)	2.30	-1.591	3.891
7.	Pumping VII (0.0578704 m^3/sec. = 5000 m^3'day)	2.30	-1.886	4/186
8.	Pumping VIII (0.06365741 m^3/sec. = 5500 m^3/day)	2.30	-2.193	4.493
9.	Pumping IX (0.069444 m^3/sec. = 6000 m^3/day)	2.30	-2.505	4.805

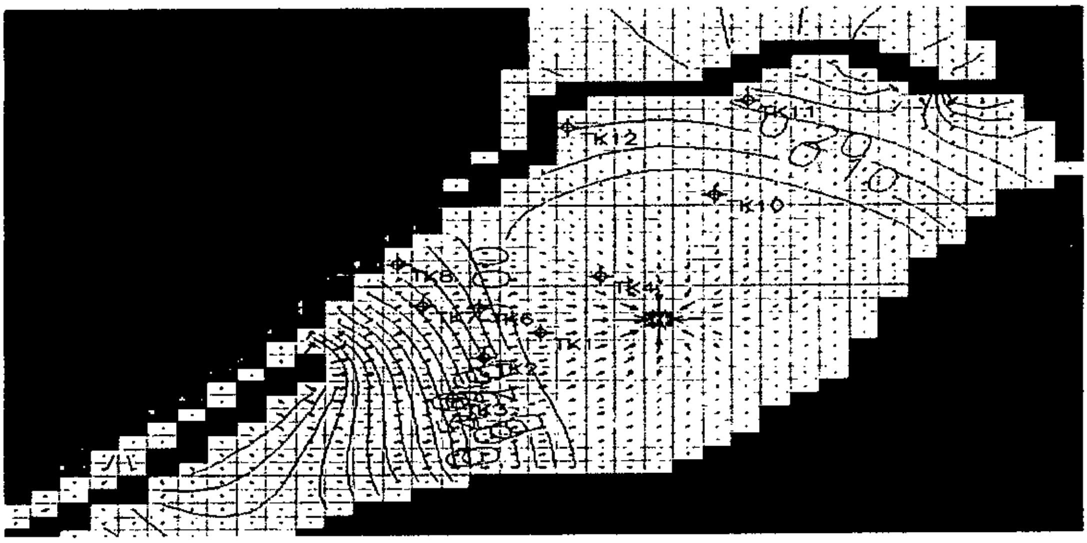

Figure 3 The hydraulic head contours of the ninth pumping for hydraulic head average of Tekek Aquifer, Tioman Island.

According to the hydraulic head contours of the ninth pumping for hydraulic head average of the Tekek Aquifer, the suitable result of the maximum extraction from Tekek Aquifer in 1999 is the fifth pumping as much as 6000 m^3/day, because sea water still does not enter to the aquifer, and hydraulic head in the well (-2.505 m) is higher than aquifer bottom (- 12.00 m).

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1) Tioman Island has a good potential for groundwater resource. From this study, by using ASM to simulate the groundwater extraction with hydraulic head average in 1999, it produces water as much as 6000 m^3/day.

2) The groundwater of Tekek Aquifer can be exploited by maximum pumping rate of 6000 m^3/day.

Recommendations

1) Further study on groundwater of Tekek Aquifer to meet the optimum daily yield needs to be carried out.

2) This groundwater source must be properly managed and operated to fulfil water demand for the future water need in Tioman Island.

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