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TEN YEAR GROUNDWATER SIMULATION IN MERAPI AQUIFER, SLEMAN, DIY, INDONESIA

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ABSTRACT

Simulation of groundwater withdrawal has been conducted with a groundwater modeling system (GMS) version 3.1 software at a regional scale. The simulation was conducted from ten year groundwater withdrawal data in Merapi Aquifer, DIY, Indonesia, for two assumed scenarios, with an emphasis in Sleman area. The result for the ten year groundwater simulation was conducted spatially distributed in the Merapi Aquifer after the steady state simulation was reached. With two different types of transient simulations, the total withdrawal of 28,968 m^3/day for the whole Merapi Aquifer is still acceptable with caution, as long as the recharge is not decreasing. However, less withdrawal as the existing withdrawal condition is recommended until local site investigation is sufficient to avoid the danger of overdraft.

Key words: groundwater withdrawal, GMS version 3.1. software; transient simulations

INTRODUCTION

Water is one of the basic human needs that is very important to be fulfilled. Water is the elixir of life; without it life is not possible [*Fetter*, 1988]. Groundwater in Merapi Aquifer, Special Province of Yogyakarta (DIY), Indonesia, is one of the best source of potable water in DIY. Most groundwater comes from infiltrated rainfall which has reached the aquifer and flow as groundwater [*Hofkes*, 1983]. Aquifer is a geological formation which contains saturated permeable material, so it can yield enough water to be used as a source of water supply [*Walton*, 1970; *Todd*, 1980; *Kruseman et al.*, 1991]. Walton [1970] also stated that aquifer functions both as a transmission conduit and a storage reservoir. Hem [1970] stated that most groundwater was found in a depth less than 2 km below land surface (which in the model is quoted as ground level). At this part, sedimentary rock is more common than igneous rock. Sedimentary rocks which are most common are shale, siltstone, sandstone, limestone, and glacial till, and these sedimentary rocks yield groundwater [*U.S. Environmental Protection Agency*, 1990]. However, the yield of groundwater is smaller in shale and slitstone (hydraulic conductivities are less than 0.5 m/day) compared to sandstone, limestone, glacial till (hydraulic conductivities are usually more than 1 m/day). Valdiya [1987] stated that permeability and geological formation are main factors which affect the ability of water movement. Therefore, good recharge areas are places where there are fault structures, and also pyroclastic materials, especially in the upstream area. Weathered rocks and volcanic areas, especially in volcanic cone and volcanic slope are also a good groundwater recharge area. Alluvial area which is dominated by alluvium is also a good groundwater source [*MacDonalds & Partners*, 1984]. Alluvium is any stream-laid sediment deposit found in a stream channel and in low parts of a stream valley subject to flooding [*Strahler & Strahler*, 1997].

There has already been several research about groundwater distribution in Indonesia, such as research on the landunit as the analysis of groudwater classification in Baturagung [*Hartono*, 1996]; also hydrological and geological survey in DIY by MacDonalds & Partners [1984]. There also have been several research around the world which has emphasis on groundwater studies, which are discussed as below. Longterm statistical analysis of groundwater depth and withdrawal has been studied by Kovalevsky [1992], to understand more about the cyclicity series of wet or dry years, with periods of 2-3 years, 5-6 years, and 21-22 years. Study of overexploitation of groundwater use in Jordan [*Dottridge & Jaber*, 1999] has also been conducted to assess the safe yield and the groundwater management in Jordan. Another groundwater modeling was the modeling of groundwater fluctuation to evaluate landslides and water distribution in Manizales [*Terlien*, 1996].

The paper of ten year groundwater simulation here is conducted to find a local-regional scale acceptable groundwater withdrawal in Merapi aquifer, DIY, with an emphasis in Sleman area. The term of the acceptable withdrawal will be discussed in a special section after this introduction part. This paper is different from other papers which has been done, in two terms: the geographic location of the research, and the first kind of simulation in Merapi Aquifer System using GMS version 3.1. Software, as an expansion of the previous steady state withdrawal simulation [*Asriningtyas et al.*, 2004]. In the previous research, steady state simulation using Groundwater Modeling System (GMS) version 3.1. software had been undertaken to give a depiction of the maximum groundwater withdrawal which can be conducted, spatially distributed with 39 simulation wells in the Merapi aquifer at a certain time. To prove whether the steady state simulation is acceptable for use at a regional scale assessment (total area more than 500 sq km), in this paper, longterm (10 years) groundwater withdrawal is being simulated. Ten year transient simulations (from 1992 to 2001) were conducted to better understand the sustainability of groundwater in Merapi aquifer, especially in Sleman area, DIY, Indonesia.

Yogyakarta has a homogen lithology which comes from Young Merapi eruption material, in the form of sand and volcanic ash [*Sudarmadji*, 1991]. Sudarmadji [1994] also stated that the south slope of Merapi active mountain is functioned as an aquifer system, which is the Sleman-Yogyakarta Formation. Dominant material in the Sleman area, DIY is alluvium [*McDonalds & Partners*, 1984]. Therefore it has high hydraulic conductivity which is a criteria for a high-yielding-aquifer.

Sutikno [1996] stated that there are three spring belts and three groundwater regimes viewed by geomorphological and geological characteristics of Merapi volcano landscape. It can be simplified, that the upper part is the recharge area, the middle part is the storage area, and the lower part is the discharge area. Geomorphologically, the Merapi Aquifer can be distinguished into six geomorphological units [*Suharyadi*, 2001], which are volcanic cone, slope, volcanic foot, hill, volcanic plain, and sand-dunes. However, genetically, hill and sand dunes differ from the others, therefore hill and sand dunes should be seperated from the system if shallow well at site scale is considered. Simoen [2001] stated that Merapi volcano is a strato volcano, with a layered material explosion of efusive (lava flow) and eflata (bom, lapili, tuff, and volcanic ash). With the above descriptions, Merapi aquifer is a complex aquifer. Therefore, other data or descriptions are needed to better model the aquifer.

The Discussion on Acceptable Groundwater Withdrawal

Sustainable use of earth requires human participation in the natural cycles of air, water, organisms, and other systems without degrading or depleting them [*Marsh & Grossa Jr.*, 2002]. One of this cycle is the groundwater, which in DIY, especially in Sleman area plays an important role for the people's water usage. One of the Government Groundwater Agency, which is PDAM Tirtamarta, uses "deep" groundwater withdrawal in Sleman area to be distributed in Yogyakarta. The term "deep" groundwater withdrawal has been somewhat improperly used, because the definition was groundwater pumped from the depth of deeper than 15 m below ground surface. By recent literature in the work of geohydrology and hydrogeology in Merapi aquifer [*Putra*, 2003], it was reconstructed that the aquifer layer is not fully confined in the term of geology, but it is layered with silt and clay lenses. Therefore the term of "deep" groundwater withdrawal is revised with only the term of groundwater withdrawal, in a regional scale basis.

The term of acceptable groundwater discharge or groundwater withdrawal in this research is defined as the amount of total withdrawal in the whole aquifer in the simulation of 10 year withdrawal, which do not make the first layer dried up.

The first layer datum of the simulation is defined at 2/3 of the depth of the whole aquifer. This research is somewhat simpler than Dottridge & Jaber [1999] research which assess the groundwater management, because of the constraint of data available in Merapi aquifer but, this simulation is still meaningful as the first step to regional groundwater simulation in Merapi Aquifer. It will be useful to inform the government that careful care of groundwater withdrawal in Sleman area (upstream) should be taken, because it will affect the Bantul area (downstream), of the same aquifer.

The Objective of The Sudy

With the above descriptions, the objective of this study is to discover a total acceptable groundwater withdrawal in Sleman area of Yogyakarta Special Province (DIY), Indonesia, with ten year simulation using GMS version 3.1. software, at local to regional scale.

The Study Area

The research took place in Merapi Aquifer, DIY, Indonesia, with an emphasis on Sleman area as shown in Fig.1. Sleman area is an area which is bordered by contour of around 500 m above sea level at the north, and contour of around 150 m above sea level at the south. Westward is bordered by one of Progo river branch (Kali Krasak), and eastward by Opak River. This area (Sleman) is still in the recharge and storage area defined by geomorphologist, but deep groundwater withdrawals are commonly used by PDAM (Perusahaan Daerah Air Minum or translated as Governmental Drinking Water Agency). Actually, the term of deep groundwater withdrawal is not being used anymore [*Putra*, 2003] because the Merapi Aquifer stratigraphy is a homogenous aquifer in a local-regional scale with some layered lens, which is not fully impermeable at each layer. This research [*Putra*, 2003] answers the simplification (but not oversimplified) the complex layered Merapi Aquifer system from the interpretation of borehole data at local-regional scale.

Therefore, the simulation of groundwater withdrawal in this area is important to assess acceptable discharge of groundwater which, in this paper, is conducted with mostly secondary data from 1992 to 2001 (using report from Putra, 2003 and PDAM Tirtamarta, 2000]. Due to limitation of borehole data, groundwater simulation is assessed in a local to regional scale, to give an acceptable assessment for geography, and in terms of total discharge assessment only, for the whole Merapi Aquifer, with the emphasis of Sleman area.

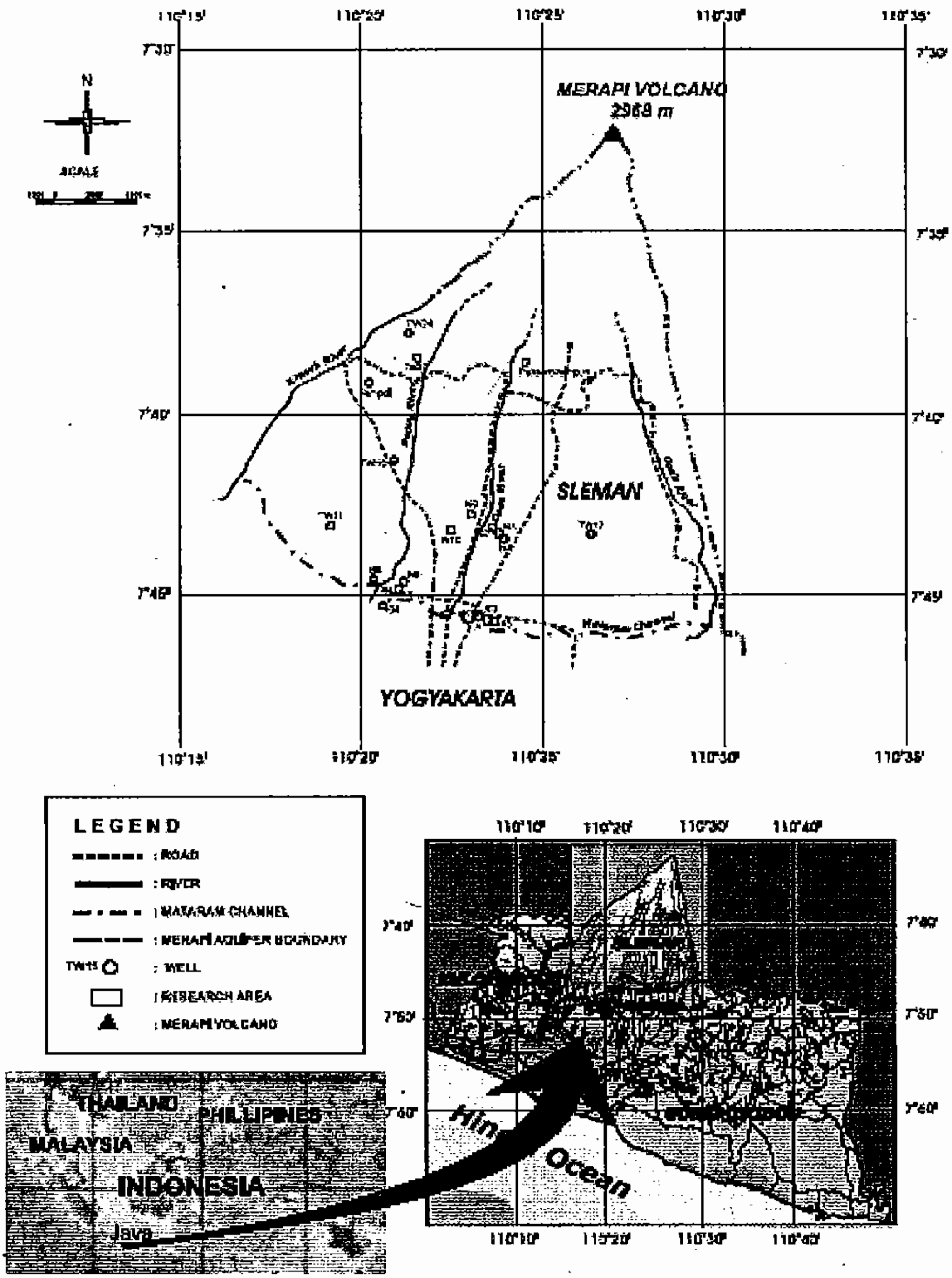

Figure 1. Location of Sleman Area

THE METHODS

The knowledge of aquifer condition and the parameters are needed to study quantitative groundwater resources [*Halasi-Kun*, 1980]. Storage and flow in the aquifer can be governed by natural science law. This law can be written to quantify groundwater characteristics in a specified hydrogeologic term [*Nielsen*, 1991]. The method used for the groundwater simulation in this paper is by using the MODFLOW window-interface of GMS version 3.1. software. The underlying formula are Darcy's formula [*Todd*, 1980] and mass conservation formula [*Domenico & Schwartz*, 1990]. The above equations are solved numerically using the GMS version 3.1. software [*EMRL*, 1999] by MacDonald & Harbaugh [1988] and Hill [1990]. This paper is not assessing the above formulas, as it is going to assess in the view of physical geography, by using the software to run the data taken from the field and interpret the outcome of the simulation.

Data are mostly gathered from PDAM boreholes from 1992 to 2001 and Environmental Geology Laboratory of Gadjah Mada University, Yogyakarta. Other secondary data are collected from *Balai Progo-Opak-Oya* and *Sub Dinas Pengairan DIY* (Governmental Progo-Opak-Oya Irrigation Agency). Field observation is taken to estimate the conductance of the river, river heads, and condition of "deep" wells or actually PDAM borehole wells in the study area. The aquifer is devided into two layers, which corresponds to the Yogyakarta and Sleman Formaton as a one aquifer system.

The compiled data were then used to be an input of the groundwater flow simulation with MODFLOW window-interface in GMS version 3.1. software. Simulation was conducted for steady state condition [*Asriningtyas et al.*, 2004; Asriningtyas, 2003]. After the steady state condition was reached, two assumed flow simulations were performed for the longterm (transient) simulation which lasted from 1992 to 2001 (10 years). The flowchart of the research analysis using GMS version 3.1. software is shown in Fig.2. The two assumed simulations are called Transient Simulation 1 and Transient Simulation 2. Transient Simulation 1 is a transient (10 years period) simulation., with the total recharge which correspond to the previous rc3s steady state simulation [*Asriningtyas*, 2003] and withdrawal of the existing condition. Transient Simulation 2 is a transient simulation which correspond to the previous steady state rc3s simulation, both recharge and total withdrawals [*Asriningtyas*, 2003].

Inputs to the MODFLOW window-interface of the True Layer Approach for the transient condition are as follows:

1. hydraulic conductivity,
2. recharge,
3. ground elevation and elevation of the assumed each layer of the aquifer,
4. head of the boundary of the simulated system (including in the river),
5. discharge (withdrawal),
6. specific yield (for layer 1) and specific storage (for layer 2).

Output of the MODFLOW window-interface of the True Layer Approach for the transient condition are head contours in the Sleman area, for example is in Fig. 3.

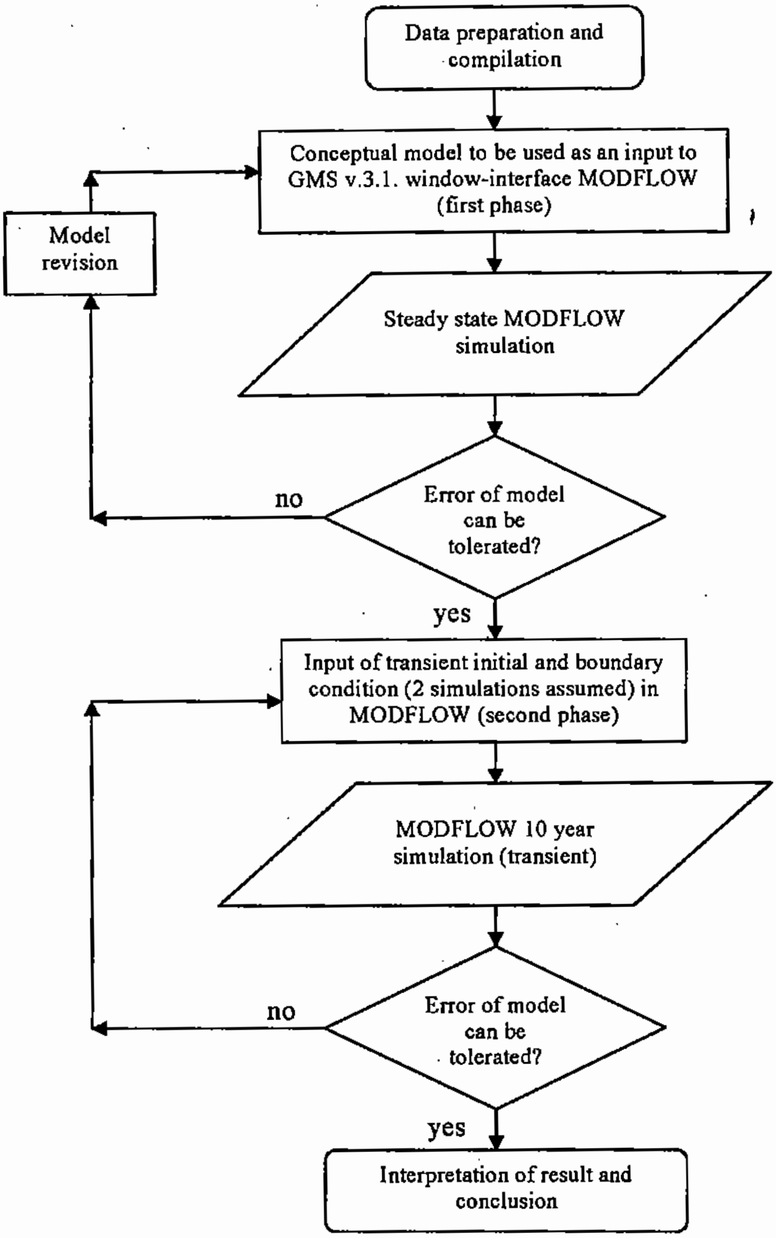

Figure 2. Flowchart of the 10 Year Groundwater Withdrawal in Merapi aquifer with an Emphasis in Sleman area

RESULTS AND DISCUSSION

The result of the steady state simulation has been done in 2003 [*Asriningtyas et al.*, 2004; *Asriningtyas*, 2003], which was concluded that the rc3s scheme of withdrawal is acceptable (total discharge of 28,968 m^3/day in the aquifer). In this paper, the transient simulations are discussed. Two transient simulations are conducted with the first initial existing withdrawal condition taken from Environmental Geology Laboratory [*Putra*, 2003] with the name of Transient Simulation 1 (previously rc3s steady state condition for the recharge and existing well withdrawals). The second simulation is undertaken with the total withdrawal of 28,968 m^3/day (the input of rc3s recharge and withdrawal of the total rc3s recharge divided by 39 simulated wells in Merapi aquifer), by the name of Transient Simulation 2.

The sample result of these 10 years of groundwater withdrawal simulation can be seen in Fig. 3 and Fig. 4. It is revealed that the head contours in Sleman area are not dry (still higher than the second layer top elevation), and similar for both simulations. The head contours for the middle of Sleman area are around 244 to 247 m above sea level for Transient Simulation 1, and around 242 m for Transient Simulation 2, which do not differ much in term of deep well withdrawals. However, from the transient simulations conducted, the southern part of Yogyakarta, Bantul area (still in the Merapi aquifer, but not in Sleman area) shows an appreciable difference as shown in Table 1 for January 1993, 1995, and 2001.

Table 1. Result of Middle Bantul Head Contour

Simulation	Bantul Middle Head-Contour (m msl)		
	January 1993	January 1995	January 2001
Transient Simulation 1	15.89	20.64	20.64
Transient Simulation 2	13.09	10.88	12.90

Actually, it has been discussed in Putra [2003] that in terms of water resources, the Merapi – Yogyakarta basin (Merapi aquifer) faces problem on the effect of landuse changes to the hydrology and hydrogeology regime. Rapid development on northside of Yogyakarta City (Sleman area) has increased the change of forest and agricultural land into dwellings, housing, schools, offices, industries, hotels, etc. According to the Regional Spatial Policy Planning of Yogyakarta Special Province (PERDA No. 23 Tahun 1994 of Spatial Policy Planning of Sleman District), the northside of Yogyakarta City (Sleman area) was defined as protection zone for forestry and water recharge.

Putra [2003] also stated that inconsistency of the implementation of spatial policy planning (regency regulation) by the government caused by the economic factors has made the possibility of urban development to the northside of Yogyakarta. Based on observation, more and more buildings are developed and will develop in the northside of Yogyakarta. Unfortunately, rapid urbanization to

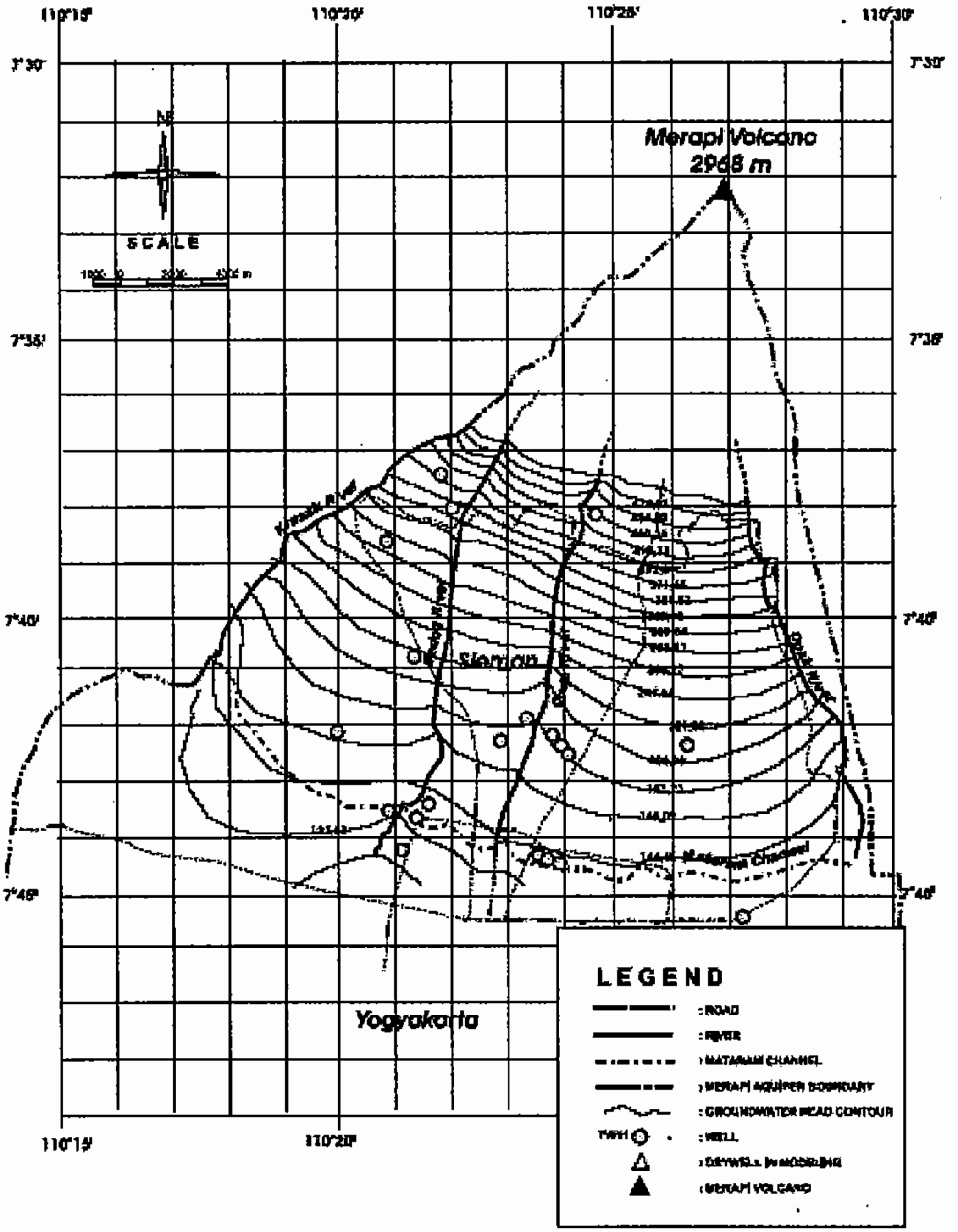

Figure 3. Result of January 2001 Simulation of Transient Simulation 1

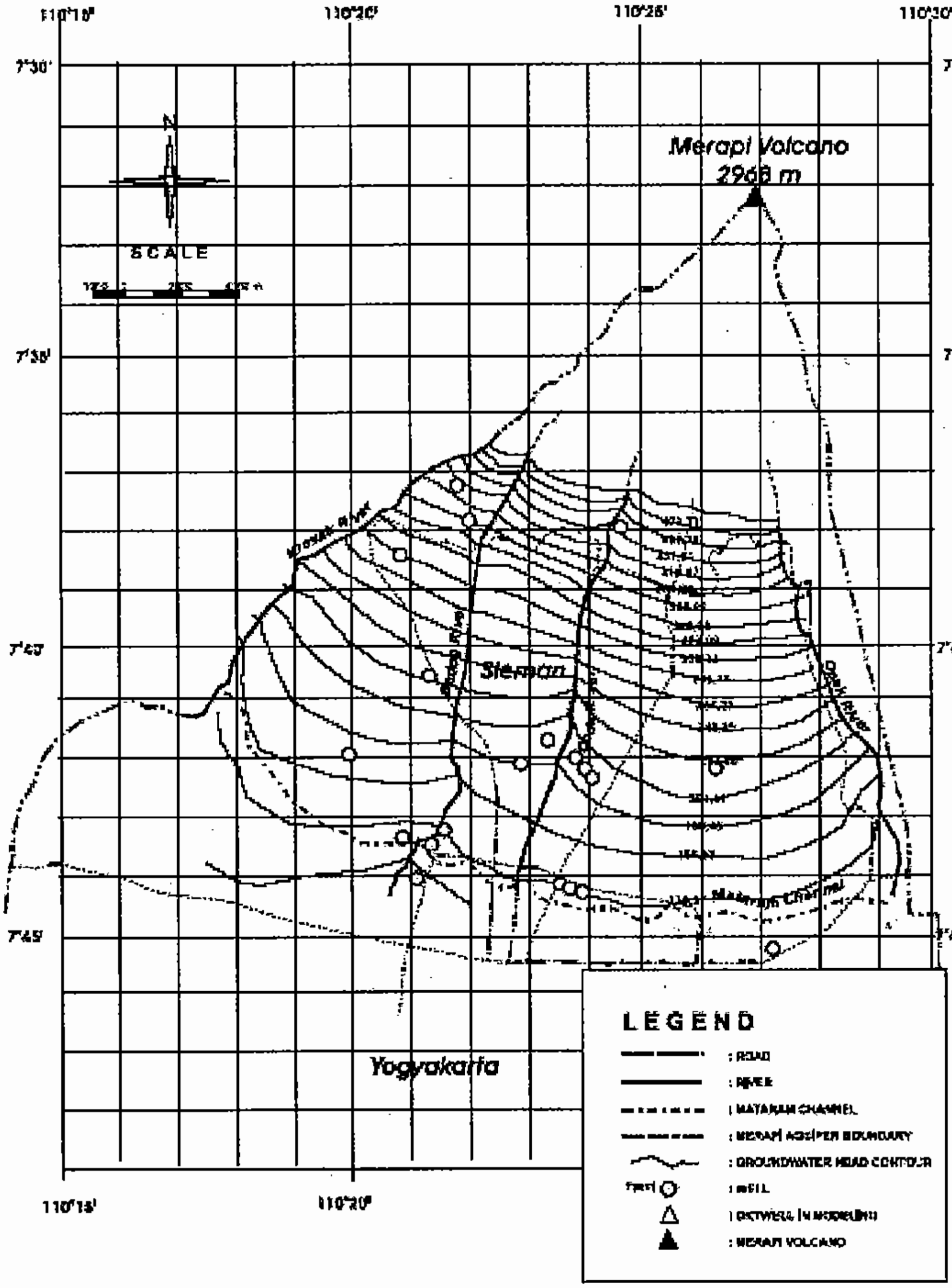

Figure 4. Result of January 2001 Simulation of Transient Simulation 2

the northside is not controlled and followed by good urban infrastructure, and not followed by good implementation of regulation. It should be noted that almost all clean water supply of Yogyakarta City is taken from Sleman Regency (Sleman area defined in this paper) and sources of surface water and groundwater that flow to the Yogyakarta City and Bantul Regency also come from Sleman. Sleman Regency Government has their own regulation of raw water resources protection, but the implementation of this regulation on the field faces many obstacles.

From the result in Table 1, it is discovered that the head contour with Transient Simulation 2 for Bantul is lower than Transient Simulation 1 (ranging from 2 m to 10 m of difference). This is to say that the more withdrawal is conducted in Sleman area, the lower will the head contour be in the southern area (Bantul), although it did not dried up (in a regional scale basis).

With these results of simulations and the above description of the urbanization problem to the north (to Sleman area) Transient Simulation 1 is favorable, although both simulations are acceptable with the conducted simulations until further local site investigation is sufficient. This may involve a multidisciplinary study, such as physical and human geography, in a further and more comprehensive research. Physical geography data includes all the physical data related to groundwater simulation including better on site observations and external sources such as the climatic parameters over a certain time frame. Human geography data will be very helpful in providing population data at certain location and landuse at certain location, both over a certain time frame.

CONCLUSION

The conclusion of this ten year groundwater simulation, which was conducted spatially distributed in the Merapi Aquifer after the steady state simulation was reached is as follows: with two different types of transient longterm simulation (for ten years), the total withdrawal of 28,968 m^3/day for the whole Merapi Aquifer is still acceptable, with caution, as long as the recharge is not decreasing.

However, it is still difficult to assess the appropriate safe-yield withdrawal at an on site scale of the whole Merapi Aquifer because of the data availability restrictions in Merapi Aquifer. Albeit the restriction, this research of the transient groundwater withdrawal simulation at local-regional scale can give a depiction of how the withdrawal in the recharge area defined by geomorphologist (such as Sleman area), in the same aquifer, can effect to the lower part of the aquifer. This will hopefully make the local decision makers of the water resources management aware of the environmental impact of overdraft.

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