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POSSIBILITIES FOR GROUNDWATER DEVELOPMENT FOR THE CITY OF JAKARTA, INDONESIA

G. Schmidt, B. Soefner
Federal Institute for Geosciences and Natural Resources, Hannover,
Federal Republic of Germany

P. Soekardi
Directorate of Environmental Geology, Bandung,
Republic of Indonesia

ABSTRACT

Groundwater resources for the water supply of the city of Jakarta are limited with respect to quantity and quality. In response to the present over-exploitation of the deeper parts of the aquifer system, piezometric heads regionally have dropped below sea level. Sea-water intrusion and land subsidence have been recorded as a consequence of the drop in head in the northern and central city districts. Shallow groundwater is exposed to many sources of contamination. On the basis of recent hydrogeological investigations and available data on groundwater exploitation in Jakarta, a three-dimensional numerical groundwater model was developed to simulate the present situation and the possible future development of the groundwater resources in the area. It is forecast that the present abstraction of 47 mln m^3/year from the deep aquifer system can be maintained and that the velocity of sea-water encroachment can be reduced if the present centres of abstraction are shifted away from the coast and further inland to the south.

INTRODUCTION

Within the scope of an Indonesian/Federal German co-operation programme between the Directorate of Environmental Geology, Bandung, and the Federal Institute for Geosciences and Natural Resources, Hannover, the groundwater situation in the area around the Indonesian capital Jakarta was thoroughly studied between 1983 and 1985 in order to attain more information on possible contributions from groundwater to the water supply of the city.

In pace with the rapid demographic and industrial development of the city, the water demand has increased from about 10 M m^3/year in 1950 to more than 500 M m^3/year in 1985 and is expected to reach about 1 200 M m^3/year in 2005 (JICA, 1985). The central water supply of the city, mainly derived from the treated surface water, serves only about 25% of the present population; 75% still have to rely on untreated surface water and above all on groundwater.

GROUNDWATER USE AND ENVIRONMENTAL SIDE EFFECTS UNTIL 1985

At present groundwater contributes about 250 M m^3/year to the water supply of Jakarta. More than 200 M m^3/year are abstracted from unregistered shallow wells and about 47 M m^3/year is pumped from deep water wells tapping confined aquifer layers between 40 and 200 m below the land surface.

Groundwater abstraction until 1945 was less than 10 M m^3/year and water from the confined aquifer system (about 3 M m^3/year) was only produced from a limited number of deep wells in the central and northern parts of the city. Head levels of the confined groundwater in Northern Jakarta, which initially were artesian, dropped by about 0.2 m/year between 1900 and 1950, indicating an already slight overexploitation of the water resources in the deeper part of the aquifer system. As Figure 1 demonstrates, a rapid decline of head levels started in the early 1970's when the commercial and industrial development of the city was intensified and groundwater abstraction from deep aquifers increased from about 10 M m^3/year in 1950 to more than 20 M m^3/year beyond 1970.

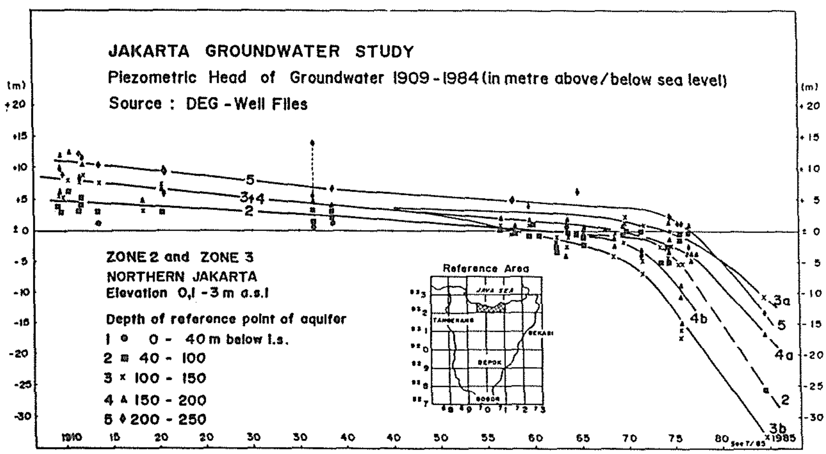


Figure 1. Observed groundwater heads in Northern Jakarta, 1909-1985.

A drop in head during this time period is also evident in Eastern Jakarta (Pulogadung), Western Jakarta (Cengkareng) and Southern Central Jakarta as a consequence of the sudden increase in groundwater production, following expansion of the city into these formerly nearly unaffected areas. At present, the piezometric groundwater surface of confined aquifers tapped between 40 m and 200 m depth is generally below sea level (locally about 30 m) in an area stretching from the coast as far as 10 to 15 km to the south

(Figure 2). Groundwater production from the deep aquifer system in 1985 is estimated to be 47 M m^3/year. Deterioration of groundwater quality in deep wells in the coastal area also became evident after 1970 especially at depths between 0 and 100 m and below 200 m. Visible effects of land subsidence in central Jakarta were first reported in the mid-seventies.

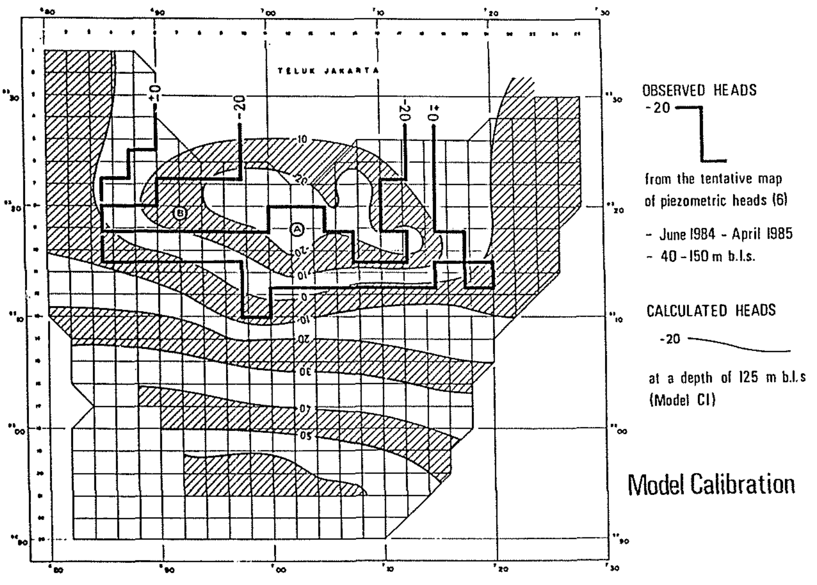


Figure 2. Isolines of observed and calculated piezometric heads, 1984/85, aquifer depths 40-150 m.

The shallow unconfined aquifer is still fully replenished from rainfall and surface water during years of normal rainfall distribution. In terms of quantity aspects only, even the present demand of 200 M m^3/year could be abstracted without major difficulties. Quantitative restrictions exist only during extremely dry periods in an area similar to that underlain by the main cone of depressions in the deep aquifer system. Therefore, a hydraulic connection between the shallow part and the deep part of the aquifer system must be present. With regard to the quality of the shallow groundwater, besides areas affected by sea-water encroachment near the coast, the total salinity of groundwater inside the city boundaries is generally above levels found in areas still unaffected by the expansion of the city. There are many indications of man-made contamination of the shallow groundwater, but detailed studies on dangerous chemical compounds have not yet been made.

THE AQUIFER SYSTEM

The present shape of the regional cone of depression in the confined aquifer system is a consequence of low aquifer permeabilities in the sedimentary basin fill. On the basis of hydraulic tests, the overall horizontal co-efficient of conductivity for the entire confined aquifer system is estimated to be 1.3 m/day. Regionally the system is considered to be rather homogeneous, but highly anisotropic. This is also confirmed by the regional distribution pattern of hydrochemical and isotopic groundwater types. Analysis of the regional hydrogeology gave estimates of horizontal groundwater inflow to the discharge area of 15 M m^3/year, only one-third of the water currently exploited from the confined aquifer system. Recharge by vertical downward leakage is very limited owing to the system's extremely low vertical permeability that is, as model simulations have confirmed, only 1/5 000 of the horizontal permeability. Recharge to the confined part of the system occurs mainly in the hilly area south of Jakarta. Figure 3 shows the principal features of groundwater flow under past and present head conditions.

Various models were used to describe the aquifer system in detail. The objective was to determine the boundaries of the area of interest (the Jakarta area) and to study the reaction of the system to changes in the hydraulic parameters. The regional flow model (Figure 4) extends from the Salak volcano to the Java Sea and includes the deep groundwater in the Tertiary sediments. It reflects the main hydraulic situation and simulates the influence of a fault. Discharge from the system occurs chiefly on the slopes of the volcano and little water reaches the Quaternary sediments of the Jakarta basin. Calculated mean residence times are in the same range as the ages determined by isotopic studies.

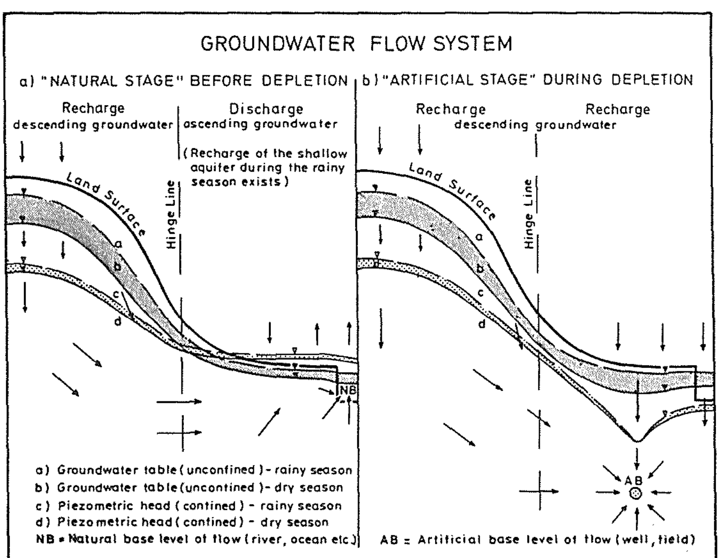


Figure 3. Principles of groundwater flow in the Jakarta area before and during over-exploitation.

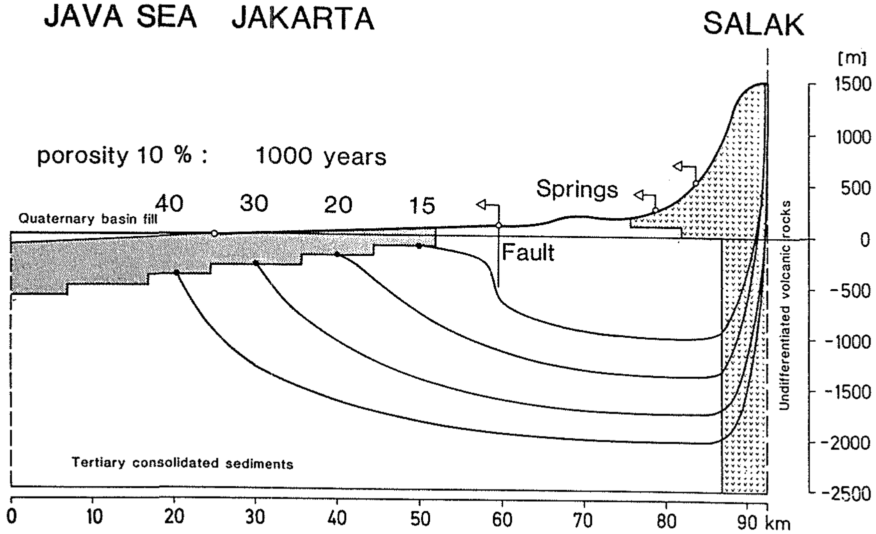


Figure 4. Regional flow model.

A second model covering a smaller area (Figure 5) simulates the main hydraulic components of the upper aquifer systems of the Quaternary basin fill. The results of the model calculations are used as the boundary conditions for a three-dimensional groundwater flow model for simulation of the aquifer system in the greater Jakarta area. This model provides a basis for water management plans.

AVAILABLE GROUNDWATER QUANTITIES AND POSSIBILITIES OF FUTURE GROUNDWATER UTILIZATION

As already stated quantitative restrictions on the groundwater abstraction from the shallow unconfined aquifer depend mainly on quality problems or on an occasional abnormal distribution of recharge from precipitation. Provided that careful quality protection of the shallow groundwater can be implemented, the future drinking water supply from these resources in the residential suburbs of Jakarta outside the area of coastal influence can be saved if certain restrictions can be accepted during the periods of reduced recharge.

For the deep confined aquifer system simulations using a three-dimensional groundwater model developed on the basis of the available aquifer parameters and abstraction data indicated that the continuous abstraction of 47 M m^3/year, adhering to the present

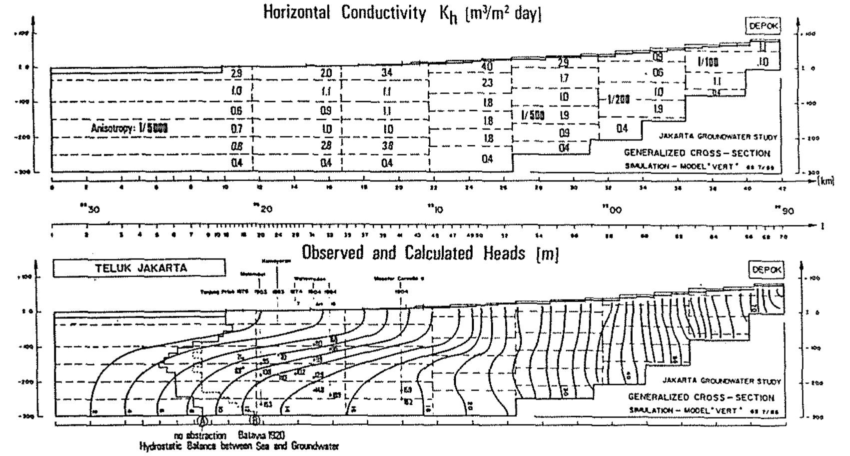


Figure 5. Two-dimensional vertical groundwater flow model of the Greater Jakarta area.

abstraction pattern, will regionally keep head levels near the coast between 20 and 30 m below sea level. As a consequence sea water will continue to intrude fresh water aquifers, its velocity depending on the permeability and on the slope between the sea level and the head level in the cone of depression. This development can only be avoided if groundwater abstraction from the deep aquifer system near to the coast can be reduced or even be stopped in the most affected areas. The model also indicates that the abstraction quantity of 47 M m^3/year for the water supply of Jakarta can be maintained if the main groundwater production is shifted to the south.

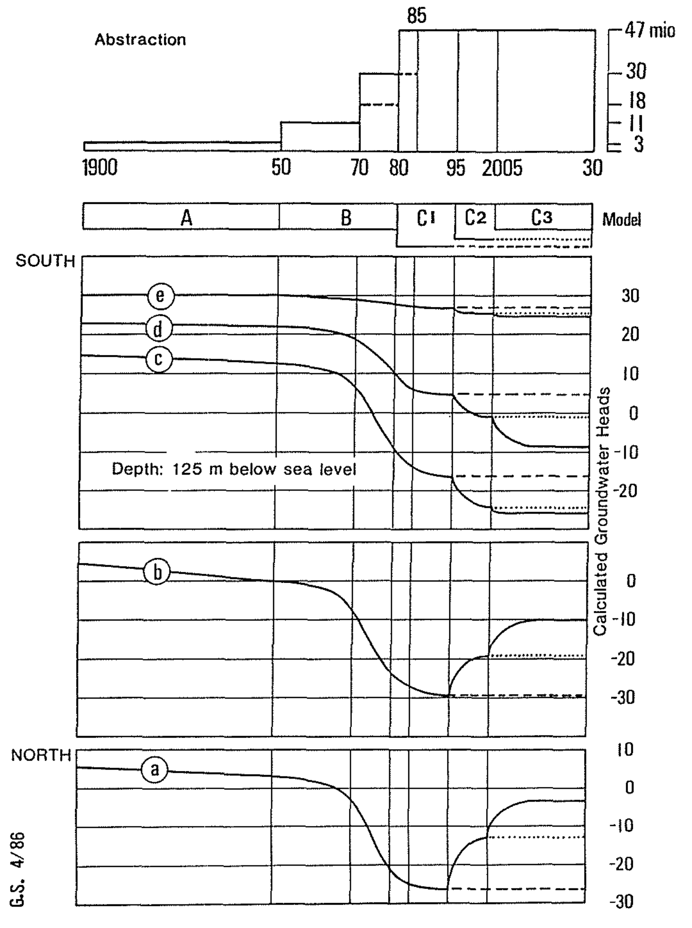
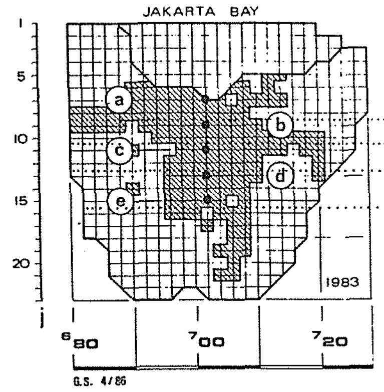


Figure 6. Development of piezometric heads at selected reference nodes of the model for the abstraction configurations A, B and C1, C2, C3; aquifer depth 125 m.

Figure 6 summarizes modelling results for the development of groundwater heads at different distances from the coast and for different abstraction configurations at an aquifer depth of 125 m. The left part of the figure (columns A, B) demonstrates the reliability of the model, reflecting the historical development of head levels in Jakarta between 1900 and 1980 (compare head levels a, b and head level 3 in Figure 1). The right part of the figure presents the result of three simulation runs assuming the different abstraction configurations C1, C2 and C3 of Figure 7.



MODEL C

ZONE	C1 1985	C2 1995	C3 2005
I	26	10	0
II	34	20	10
III	16	40	45
IV	15	20	35
V	9	10	10
	100	100	100

[%]

Total Abstraction

$Q = 47 \cdot 10^6$ m^3/year

Figure 7. Tentative configurations of groundwater abstraction in Jakarta 1985-2005.

With continued pumping of 47 M m^3/year until 2030 (C1) the head decline becomes nearly steady after about 1990 with a maximum drawdown at the model nodes a and b nearest to the coast.

The alternatives C2 and C3 visualize that reducing the groundwater abstraction in zones I and II in 1995 to 10% and 20% respectively, of the total abstraction and a further reduction in 2005 to 9% and 10% respectively, causes a stepwise rise in head levels of 20 to 25 m at the reference nodes a and b by 2015. A simultaneous stepwise increase in the zones III and IV to finally 80% of the total amount of the assumed groundwater production in Jakarta causes an additional head drop of only 2 to 10 m at reference nodes c, d, and e during the same period. Since the centre of the regional depression cone is shifted to the south by about 5 km and the regional gradient between the sea level and the groundwater head level at node b is reduced by two-thirds to 0.25%, the velocity of sea-water intrusion is minimized.

This effect is also demonstrated by a water balance calculated for the model nodes marking the boundary between the confined aquifer system and the open sea (Figure 8). Until 1970 1.3 to 1.8 M m^3 of fresh groundwater passed annually into Jakarta Bay. The effluent situation started to reverse after 1970 and more than 2 M m^3 of sea water will annually move into the aquifer system if the present abstraction pattern of model C1 is maintained. But shifting the centre of abstraction to the south, as in the model configurations C2 and C3, nearly stops the intrusion.

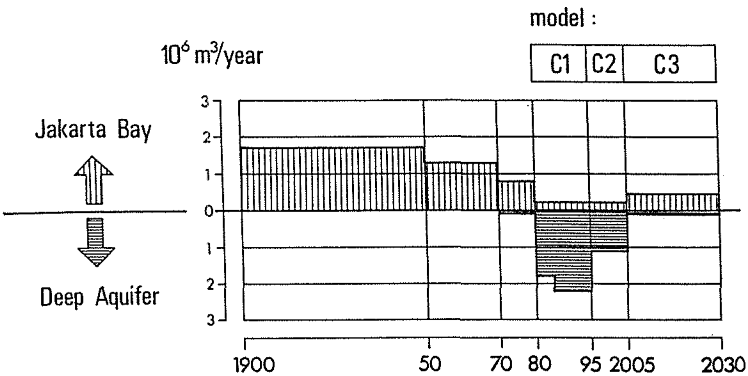


Figure 8. Groundwater balance between the deep aquifer system and the open sea along the Jakarta Bay.

CONCLUSION

The foregoing statements on the availability of groundwater for Jakarta and on the possibilities of its conservation may illustrate the importance of sound groundwater management, to be implemented by the local authorities. Regardless of the decisions eventually taken, careful monitoring of groundwater abstraction and a continued monitoring of the future development of head levels and water quality in both the shallow aquifer and the deep confined aquifer system are necessary in order to supply the information needed to safeguard both the groundwater quantity and quality in the Jakarta area.

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