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# Chemical fractionation of ferrum, manganese, zinc and copper in agricultural soil sample from Ranau, Sabah, Malaysia

(Pemecahan kimia ferum, mangan, zink dan kuprum dalam sampel tanah pertanian dari Ranau, Sabah, Malaysia)

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Key words: micronutrients, sequential extraction, chemical fractions, extractable, 'potentially available', availability

## Abstrak

Kajian ini dijalankan untuk menentukan taburan kimia mikronutrien Fe, Mn, Zn and Cu dalam 12 sampel tanah dari daerah Ranau, Sabah yang amnya digunakan untuk kegiatan pertanian. Taburan tersebut ditentukan dengan kaedah pengekstrakan berturutan menggunakan 0.5 *M* $KNO_3$, 0.5 *M* NaOH, 0.05 *M* EDTA dan 4.0 *M* $HNO_3$. Pengekstrakan yang berasingan menggunakan 0.1 *M HCl* juga dilakukan. Hasil kajian menunjukkan jumlah mikronutrien yang terekstrak berturutan adalah dalam turutan Fe > > > Mn > Zn > Cu. Peratus yang terekstrak oleh 0.5 *M* $KNO_3$ ialah Mn > Cu > Zn > > > Fe manakala 0.5 *M* NaOH ialah Cu > > Zn > Mn > Fe, 0.05 *M* EDTA ialah Mn> Cu > Zn > Fe dan 4.0 *M* $HNO_3$ ialah Fe > > Zn > Cu >Mn. Peratus yang terekstrak oleh 0.1 M HCl pula ialah Mn > Cu > Zn > > Fe.

## Abstract

This study was carried out to determine the chemical distribution of the micronutrients Fe, Mn, Zn and Cu in 12 agricultural soil samples from Ranau district in Sabah. The distribution was determined by sequential extraction using 0.5 *M* $KNO_3$, 0.5 *M* NaOH, 0.05 *M* EDTA and 4.0 *M* $HNO_3$. A separate extraction was also carried out using 0.1 *M* HCl. The results showed that the total amount of micronutrient extracted sequentially was of the order Fe > > > Mn > Zn > Cu. The percentage extracted by 0.5 *M* $KNO_3$ was Mn > Cu > Zn > > Fe while 0.5 *M* NaOH was Cu > > Zn > Mn > Fe, 0.05 *M* EDTA was Mn > Cu > Zn > Fe and 4.0 *M* $HNO_3$ was Fe > > Zn > Cu > Mn. The percentage extracted by 0.1 M HCl was Mn > Cu > Zn > > Fe.

## Introduction

Heavymetals in soils, including cationic micronutrients, exist in several arbitrary chemical fractions:- (i) easily soluble, (ii) easily exchangeable, (iii) complexed with organic matter, (iv) associated with metal oxides and (v) primary minerals (Viets 1962; McLaren and Crawford 1973; Soon and Bates 1982). The first three fractions are believed to be in equilibrium with one another and generally considered to be most 'potentially available' to plants

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particularly within a relatively short period of time (Viets 1962; Cox and Kamprath 1972; Soon and Bates 1980). The various chemical fractions are normally determined by sequential extraction techniques using selected extractants (Lake et al. 1984).

Studies on chemical fractions of heavy metals including certain micronutrients in soils have been concentrated on metal polluted or contaminated soils (Elsokkary and Lag 1978; Alloway et al. 1979; Garicia-miragaya et al. 1981; Emmerich et al. 1982; Soon and Bates 1982; Sposito et al. 1982; Kue et al. 1983). In this particular study the chemical fractions of four micronutrients (Fe, Mn, Zn and Cu) in agricultural soil samples were investigated. The area chosen is Ranau district which is the main vegetable growing area in Sabah. This study would provide further understanding on soil chemistry as well as the availability status of the micronutrients.

## Materials and methods

Twelve top (0–10 cm) soil samples were collected from the Ranau district in Sabah, Malaysia *(Figure 1* dan *Table 1)*.

The soil samples were air-dried and sieved through a 2-mm sieve before analysis. pH was measured in 1:2.5 suspension of distilled water while organic matter content was estimated by loss on ignition technique. The four micronutrients (Fe, Mn, Zn and Cu) were fractionated using a similar sequential extraction procedure as described by Sposito et al. (1982). It consisted of placing 2 g of soil sample in a centrifuge tube and extracting sequentially as outlined in *Table 2*. The samples were equilibrated on an 'end over end' shaker, centrifuged, decanted and filtered through *Whatman no. 42* filter paper after each extraction. Ferrum, Mn, Zn and Cu in the supernatant liquids were analysed by atomic absorption spectrophotometry. The extractants used, namely 0.5 $M$ $KNO_3$, 0.5 $M$ NaOH, 0.05 $M$ $Na_2EDTA$ and 4.0 $M$ $HNO_3$ were regarded to remove metals in easily soluble and exchangeable, complexed with organic matter, associated with oxides and residual (or primary mineral) chemical fractions respectively. A separate extraction was carried out on all soil samples using 0.1 $M$ HCl. This extraction is thought to extract 'available' Zn and Cu (Baker and Amacher 1982) and for comparative purposes was extended to Fe and Mn. All analyses were carried out in duplicate.

## Results and discussion

The soil samples are acidic with pH ranging from 4.4 to 6.5 while its organic matter content ranges from 4.83% to 31.03% *(Table 3)*. There is heterogeneity among soil samples of the same soil association as evident in their pH and organic matter content values. Differences in site location *(Figure 1)* and the degree of agricultural activities could be among the factors contributing to the variation. The total extractable micronutrient, obtained by summing up the amounts extracted by the four extractants used in the sequential extraction, is on average of the order Fe > > > Mn > Zn > Cu. This order is followed strictly in all but three (S3, S4 and S5) of the soil samples. The total extractable Fe in all samples is, however, several orders of magnitude higher compared to the other three micronutrients.

The total content of a micronutrient in soil is generally not well correlated with plant uptake or availability of the micronutrient (Baker and Chesnin 1975; Elsokkary and Lag 1978). Therefore, information on the total content of a micronutrient in soil, such as the amount extracted by concentrated acid or the total amount extracted sequentially (as in this study), is not very useful in describing

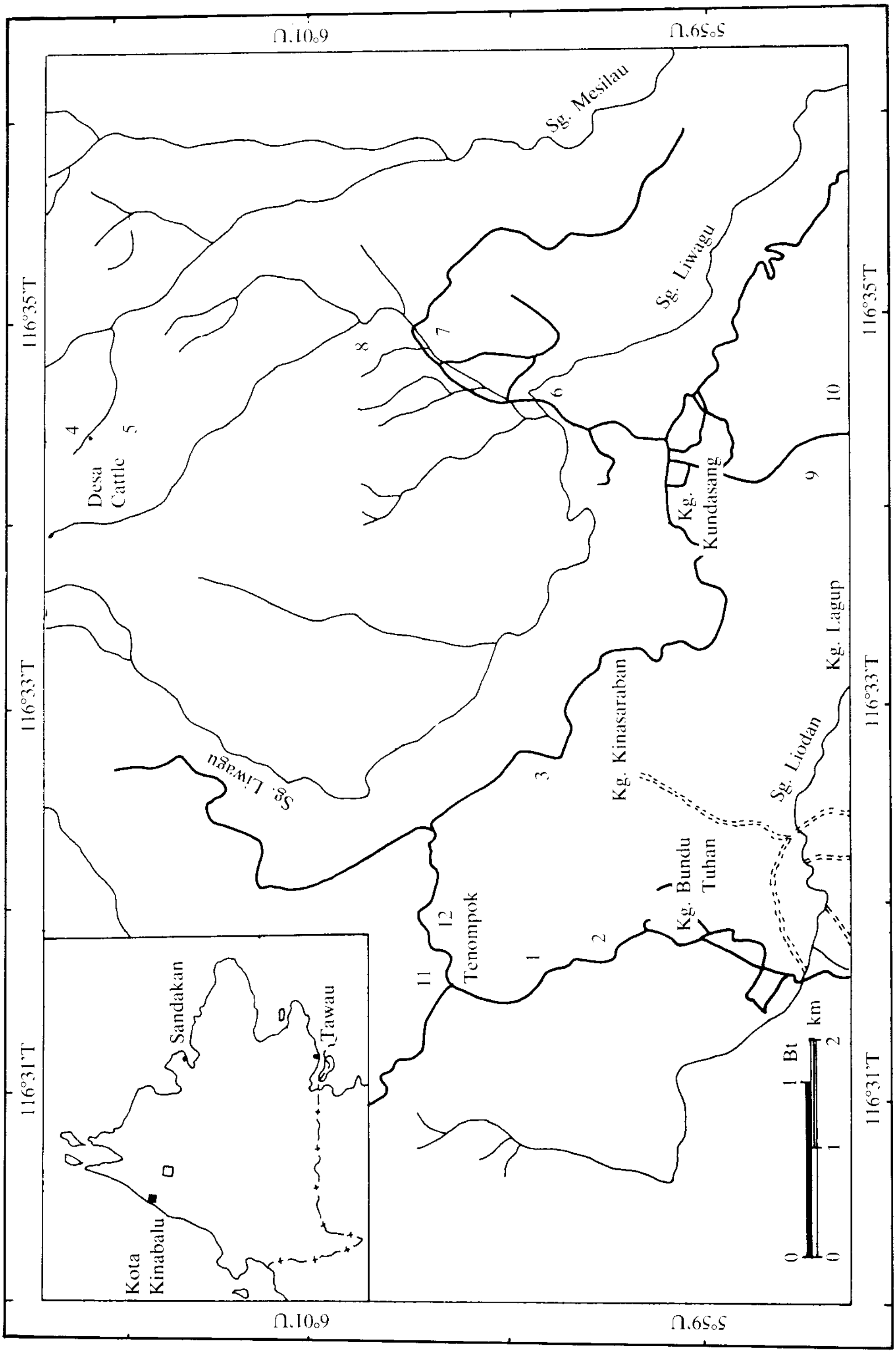

*Figure 1. Sampling sites of the 12 agricultural soil samples*

Table 1. Some physical descriptions of the agricultural soil samples

| Sample | Location | Soil assoc. | Parent material | Soil unit |
|---|---|---|---|---|
| S1 | Bundu Tuhan | Trusmadi | Sandstone & mudstone | Humic acrisol |
| S2 | Bundu Tuhan | Trusmadi | Sandstone & mudstone | Humic acrisol |
| S3 | Kinasaraban | Trusmadi | Sandstone & mudstone | Humic acrisol |
| S4 | Desa Cattle | Pinousuk | Adamellite boulder | Gleyic acrisol |
| S5 | Desa Cattle | Pinousuk | Adamellite boulder | Gleyic acrisol |
| S6 | Lembah Permai | Trusmadi | Sandstone & mudstone | Humic acrisol |
| S7 | Kouluan | Trusmadi | Sandstone & mudstone | Humic acrisol |
| S8 | Kouluan | Trusmadi | Sandstone & mudstone | Humic acrisol |
| S9 | Dumpiring | Crocker | Sandstone & mudstone | Orthic acrisol |
| S10 | Dumpiring | Crocker | Sandstone & mudstone | Orthic acrisol |
| S11 | Tenompok | Trusmadi | Sandstone & mudstone | Humic acrisol |
| S12 | Tenompok | Trusmadi | Sandstone & mudstone | Humic acrisol |

All locations are more than 1 200 m above sea level

Table 2. Sequential extraction procedure

| Extractant | Extraction time (h) |
|---|---|
| 0.5 $M$ $KNO_3$ | 16 |
| 0.5 $M$ NaOH | 16 |
| 0.05 $M$ $Na_2$ EDTA | 6 |
| 4.0 $M$ $HNO_3$ (80 °C) | 16 |

plant uptake or availability of the micronutrient. However, sequential extraction provide other information, including the chemical fractions of the micronutrient in the soil. The chemical distribution of Fe, Mn, Zn and Cu in the soil samples, expressed as a percentage of the total amount extracted sequentially, is presented in *Table 4.* The micronutrients are distributed non-uniformly among the various chemical fractions extracted by the respective extractant. Despite such extractants representing only arbitrary division between the different chemical fractions (Sterrit and Lester 1980), the data do indicate that the four micronutrients, studied in four different chemical fractions. The fractions are generally designated here as $KNO_3$-, NaOH-, EDTA- and $HNO_3$-extractable in preference to the proposed solid phases extracted. The percentage of micronutrient extracted by $KNO_3$ is of the order Mn > Cu > Zn > > Fe; NaOH is Cu > > Zn > Mn > Fe; EDTA is Mn > Cu > Zn > Fe and $HNO_3$ is Fe > > Zn > Cu > Mn. A large proportion of Fe in each soil sample exist as relatively insoluble fraction and therefore needs a more drastic chemical action, in this case extraction with 4.0 $M$ $HNO_3$, in order to be released into the solution phase. Copper has the highest proportion in the NaOH-extractable fraction. Similar result for Cu has been obtained elsewhere for metal polluted soils (Emmerich et al. 1982; Sposito et al. 1982) and relatively unpolluted soils (McLaren and Crawford 1973). Copper forms the most stable complexes with soil organic matter compared to Zn, Mn and Fe (Schnitzer and Khan 1972; Stevenson and Andakani 1972; Stevenson 1982).

It is clearly evident in *Table 4* (as described above) that the four micronutrients differ in proportion in each of the four chemical fractions irrespective of the individual total extractable amounts. Based on the types of extractant used, the four chemical fractions vary in term of solubility. The $KNO_3$-extractable fraction is potentially the most soluble while the $HNO_3$-extractable fraction is the least. The more soluble fractions, namely the easily soluble and exchangeable ($KNO_3$-extractable) and that associated with organic matter (NaOH-extractable) are considered more 'potentially available' to plants (Soon and Bates 1982) because they are relatively more likely to be released from the solid phases into the

Table 3. pH, organic matter content and total micronutrient extracted from the 12 soil samples

| Soil sample | pH | % OM | *Micronutrient (μg/g) | | | |
|---|---|---|---|---|---|---|
| | | | Fe | Mn | Zn | Cu |
| S1 | 4.4 | 13.08 | 16 051.84 | 202.35 | 129.62 | 49.27 |
| S2 | 4.8 | 10.56 | 16 223.53 | 363.46 | 83.99 | 60.51 |
| S3 | 4.6 | 4.83 | 18 687.95 | 63.25 | 100.66 | 57.15 |
| S4 | 5.3 | 31.03 | 11 618.05 | 81.25 | 46.91 | 60.43 |
| S5 | 5.1 | 19.13 | 14 653.87 | 37.76 | 79.55 | 40.03 |
| S6 | 5.7 | 13.74 | 24 057.33 | 837.43 | 111.88 | 58.30 |
| S7 | 6.5 | 7.74 | 27 751.34 | 382.70 | 122.34 | 56.79 |
| S8 | 4.9 | 11.99 | 18 755.27 | 741.93 | 183.09 | 140.26 |
| S9 | 5.0 | 5.98 | 19 925.23 | 410.42 | 111.66 | 49.93 |
| S10 | 5.3 | 10.84 | 11 351.98 | 522.23 | 128.37 | 50.27 |
| S11 | 4.6 | 16.32 | 26 428.04 | 93.13 | 66.57 | 47.86 |
| S12 | 4.7 | 6.95 | 28 014.24 | 258.96 | 162.98 | 56.73 |
| Av. | | | 19 459.89 | 332.90 | 110.63 | 60.63 |

*The total micronutrient extracted was obtained by summing the amounts removed by four extractants through sequential extraction

soil solution. The average amount of 'potentially available' Fe, Mn, Zn and Cu in the soil samples are 54.49, 33.89, 10.34 and 23.12 μg/g soil respectively. In terms of percentage relative to the total amount extracted sequentially, they are 0.28, 10.18, 9.35 and 38.13 respectively. These indicate that only a small proportion of each of the micronutrients is 'potentially available' to plants. The percentage values, however, do not reflect the actual amount 'potentially available'. As shown above, the amount of Fe is relatively higher despite the smaller percentage.

The proportion of HCl-extractable micronutrient, as percentage of the total amount extracted sequentially, is of the order Mn > Cu > Zn > > Fe *(Table 4)*. Their individual amounts are on average 268.54, 84.06, 14.42 and 13.30 μg/g respectively for Fe, Mn, Zn and Cu. A comparison between the amount of 'potentially available' micronutrient and the amount extracted by HCl (termed as 'available') is shown in *Table 5*. All the 'available' Cu seems to reside in the KNO$_3$- and NaOH-extractable fractions or the 'potentially available' fractions. A large proportion of Zn also reside in the two fractions but on contrast a relatively smaller proportion of 'available' Fe and Mn is present. The sum of Fe, Mn, Zn and Cu in the KNO$_3$-, NaOH- and EDTA-extractable fractions is, however, significantly higher than their respective 'available' amount. These suggest that at least one of the chemical fractions identified through sequential extraction contribute towards the 'available' micronutrient. The contribution of each fraction has not been determined quantitatively in this study . However, since the KNO$_3$- and NaOH-extractable fractions are more 'potentially available' because of their relatively higher solubility, these two fractions could be regarded to contribute significantly towards 'available' Cu and Zn (and possibly Fe and Mn) in the agricultural soil samples studied.

## Conclusion

The micronutrients Fe, Mn, Zn and Cu in the agricultural soil samples studied are each distributed unevenly among four different chemical forms identified through sequential extraction. This provides a more meaningful information on plant availability of the individual micronutrient compared to total content. High levels of the relatively more soluble fractions could suggest higher amount

Table 4. Percentage of Fe, Mn, Zn and Cu extracted sequentially and by HCl

| | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 | S11 | S12 | Av. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fe** | | | | | | | | | | | | | |
| $KNO_3$ | 0.06 | 0.04 | 0.03 | 0.08 | 0.06 | 0.03 | 0.02 | 0.03 | 0.04 | 0.06 | 0.03 | 0.03 | 0.04 |
| NaOH | 0.13 | 0.03 | 0.04 | 0.75 | 0.60 | 0.19 | 0.25 | 0.08 | 0.08 | 0.68 | 0.02 | 0.01 | 0.24 |
| EDTA | 8.16 | 13.70 | 1.82 | 19.59 | 19.18 | 2.99 | 2.17 | 8.34 | 4.28 | 12.75 | 6.35 | 3.57 | 8.58 |
| $HNO_3$ | 91.64 | 86.22 | 98.10 | 79.57 | 80.14 | 96.79 | 97.56 | 91.54 | 95.59 | 86.50 | 95.59 | 96.39 | 91.30 |
| HCl | 1.09 | 0.93 | 0.36 | 3.12 | 4.48 | 1.14 | 1.00 | 1.31 | 0.91 | 1.15 | 0.87 | 0.30 | 1.39 |
| **Mn** | | | | | | | | | | | | | |
| $KNO_3$ | 18.26 | 5.38 | 12.79 | 5.89 | 19.83 | 1.15 | 1.01 | 3.15 | 12.38 | 3.17 | 9.93 | 7.80 | 8.40 |
| NaOH | 1.07 | 0.53 | 2.92 | 5.12 | 5.77 | 0.33 | 0.41 | 0.41 | 0.50 | 0.71 | 2.80 | 0.77 | 1.78 |
| EDTA | 40.89 | 66.13 | 32.66 | 62.58 | 31.09 | 39.45 | 51.05 | 51.81 | 53.26 | 61.56 | 41.47 | 56.53 | 49.04 |
| $HNO_3$ | 40.08 | 27.95 | 51.62 | 26.40 | 43.30 | 59.06 | 47.55 | 44.62 | 33.84 | 34.55 | 45.70 | 35.93 | 40.88 |
| HCl | 34.01 | 10.75 | 23.57 | 42.10 | 48.57 | 10.41 | 48.92 | 15.65 | 32.17 | 7.11 | 14.69 | 15.08 | 25.25 |
| **Zn** | | | | | | | | | | | | | |
| $HNO_3$ | 8.18 | 6.73 | 13.43 | 6.48 | 7.05 | 2.41 | 1.27 | 6.55 | 4.41 | 2.37 | 11.70 | 5.49 | 6.34 |
| NaOH | 1.82 | 1.67 | 1.44 | 8.69 | 3.52 | 3.23 | 2.66 | 2.99 | 2.62 | 4.79 | 1.79 | 0.94 | 3.01 |
| EDTA | 10.54 | 13.26 | 17.20 | 24.28 | 20.41 | 13.83 | 7.99 | 17.01 | 8.78 | 12.86 | 10.48 | 11.72 | 14.03 |
| $HNO_3$ | 79.50 | 78.34 | 67.49 | 60.54 | 69.01 | 80.53 | 88.07 | 73.43 | 84.18 | 79.96 | 76.02 | 81.85 | 76.58 |
| HCl | 11.77 | 9.09 | 9.21 | 15.13 | 23.69 | 9.47 | 6.91 | 17.61 | 5.72 | 2.08 | 39.39 | 6.30 | 13.03 |
| **Cu** | | | | | | | | | | | | | |
| $KNO_3$ | 8.24 | 8.08 | 8.75 | 5.72 | 9.72 | 6.50 | 6.07 | 3.38 | 7.09 | 6.98 | 10.19 | 8.74 | 7.46 |
| NaOH | 37.55 | 16.97 | 25.62 | 32.17 | 32.50 | 27.89 | 24.05 | 50.04 | 23.03 | 42.21 | 34.41 | 21.09 | 30.63 |
| EDTA | 15.14 | 13.26 | 14.45 | 16.43 | 17.19 | 12.26 | 13.87 | 19.38 | 10.79 | 15.09 | 13.60 | 16.23 | 14.81 |
| $HNO_3$ | 39.07 | 78.34 | 51.18 | 45.67 | 40.59 | 53.34 | 55.99 | 27.20 | 59.08 | 35.71 | 41.79 | 53.93 | 48.49 |
| HCl | 26.14 | 9.09 | 23.27 | 25.53 | 21.21 | 15.63 | 22.91 | 42.23 | 16.96 | 10.26 | 26.10 | 20.46 | 21.64 |

The percentage of distribution is based on the total micronutrient extracted sequentially

S = soil sample

Table 5. Ratio between the sum of $KNO_3$ and NaOH extractable micronutrient to the amount extracted by HCl

| Soil sample | Micronutrient (μg/g) | | | |
|---|---|---|---|---|
| | Fe | Mn | Zn | Cu |
| S1 | 0.17 | 0.57 | 0.85 | 1.75 |
| S2 | 0.09 | 0.55 | 0.92 | 2.00 |
| S3 | 0.20 | 0.67 | 1.02 | 1.47 |
| S4 | 0.27 | 0.26 | 1.00 | 1.48 |
| S5 | 0.15 | 0.53 | 0.45 | 1.99 |
| S6 | 0.19 | 0.14 | 0.59 | 2.20 |
| S7 | 0.27 | 0.03 | 0.57 | 1.31 |
| S8 | 0.09 | 0.23 | 0.54 | 1.26 |
| S9 | 0.13 | 0.40 | 1.23 | 1.77 |
| S10 | 0.65 | 0.54 | 0.66 | 3.23 |
| S11 | 0.06 | 0.86 | 0.34 | 1.71 |
| S12 | 0.14 | 0.87 | 1.02 | 1.46 |
| Av. | 0.20 | 0.47 | 0.77 | 1.80 |

'potentially available' to plants. Contribution of the other fractions, however, should not be ignored since the characteristics of the different chemical fractions could likely change with soil physicochemical conditions, such as pH and redox potential.

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# Ground water potential for supplemental irrigation for new rice growing areas in Bertam

(Potensi air tanah sebagai pengairan tambahan di kawasan penanaman padi yang baru di Bertam)

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Key words: ground water, irrigation

**Abstrak**

Keupayaan pengeluaran air tanah untuk Stesen MARDI di Bertam telah dinilai melalui kajian ini dan didapati terlalu rendah untuk memenuhi keperluan tambahan tanaman padi.

Hasil air tanah dari telaga-telaga kajian, MB 1A dan MB 2, adalah hanya pada kadar 3–4 L/s dengan keupayaan spesifik 0.2 L/s semeter dan nilai keterusan 20 m$^2$/hari sahaja. Tempoh mengepam air pula tidak boleh melebihi 6 jam sehari.

Telaga-telaga kajian MB 1 dan MB 4 pula terpaksa ditimbus kembali kerana pengeluaran air tanah yang amat rendah, sementara telaga MB 3 terpaksa ditimbus kerana air tanah yang terlalu masin untuk pengairan tanaman.

Walaupun kadar pengeluaran air tanah ini terlalu rendah untuk memenuhi keperluan tanaman padi, tetapi kadar ini masih mampu untuk memenuhi keperluan air bagi tanaman lain seperti buah-buahan dan sayur-sayuran.

**Abstract**

Ground water potential for MARDI Station at Bertam was evaluated in this study and the results of hydrogeological analysis have indicated poor ground water potential.

Yields from wells MB 1A and MB 2 are only about 3–4 L/s with specific capacity of 0.2 L/s per metre and with an average transmissivity of only 20 m$^2$/day. Pumping time to operate these wells was limited not to exceed 6 h/day. Other boreholes, MB 1, MB 3 and MB 4 had to be abandoned because of poor yield or poor ground water quality. Ground water from MB 3 was found to be of high salinity level thus it is unsuitable for crop irrigation.

Eventhough the discharge capacity of the viable wells could not meet the demand for padi irrigation, it can certainly be used to supply water to fruit orchards and vegetable farms.

## Introduction

The MARDI Research Station at Bertam covers approximately 120 ha of former rubber lands. It has a slope of 2–3° with

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an average elevation of about 7 m above mean sea level. It is located to the east of the Butterworth – Sungai Petani road, about 10 km from Kepala Batas.

This study is to determine the potential water resources to meet irrigation water requirements during the time of water shortages. Ground water development was one of the possible ways, besides constructing reservoirs, to meet the water needs. A study was conducted by the Ground water Team of the Department of Irrigation and Drainage with the collaboration of MARDI's staff to evaluate the ground water potential of the station.

## Materials and methods

The study involved surface electrical resistivity survey, inventorying of existing wells in the surrounding areas, drilling of exploratory boreholes, geophysical borehole loggings and finally pump tests to estimate the ground water yield and aquifer parameters. The theory of these operations is referred to Todd (1980) and the exploration procedures are described by Sir MacDonald and Partners (1983), Azuhan (1985a, 1987). All the profiles used a Wenner Configuration of $a = 100\ m$.

The chemical analyses of well water were done by using Hach DR-EL/1 Portable Water Analysis Kit. Electroconductivity was measured using a Radiometer Model CDM 3 conductivity meter at the MARDI Bertam laboratory.

## Results and discussion

The resistivity survey detects differences in electrical resistivity within the earth's crust and it provides indirect indication of ground water potential (Azuhan 1985b). It basically involves resistivity profiling and sounding.

Resistivity sounding involves a single station with a series of resistance readings at different electrode spacings to determine the different buried layers, whereas a profiling involves a constant electrode spacing to interpret changes in aquifer limit and ground water quality within the study area.

### *Resistivity profiling survey*

The outcome of the resistivity profiling survey (step-traverse procedures) produced a set of iso-resistivity contours as shown in *Figure 1*. The lowest resistivity value recorded was 50 ohms-m while the highest was 350 ohms-m with 50 ohms-m interval between contours. The ranges of resistivity values (50–350 ohms-m) may indicate the presence of clay and shale materials (Todd 1980). The patterns of high resistivity ridge (<200 ohms-m) was observed to extend from the east and the north-east to the south of the station *(Figure 1)*. In contrast, zones of low resistivity were recorded to run from the north-west to the south-west of the station.

Areas of high resistivity (low conductivity) in the alluvium, normally would have a better prospect for ground water development. The surface resistivity readings could not provide definitive ground water prospects, however, several deductions can be made from them.

The ridge of high resistivity may represent an area of high resistance bedrock lying close to the ground surface. In contrast, low resistivity area may represent a layer of thick overlying alluvium. The high resistivity readings may also represent areas of alluvium with predominantly sandy materials whereas, the low resistivity area may represent alluvium with clayey composition.

In areas where the depths from the ground surface to the bedrock are uniform and the make up of the alluvial sediments are homogenous, then the high resistivity ridge may represent areas of low salinity ground water and areas with low resistivity readings may represent high salinity ground water. High resistivity

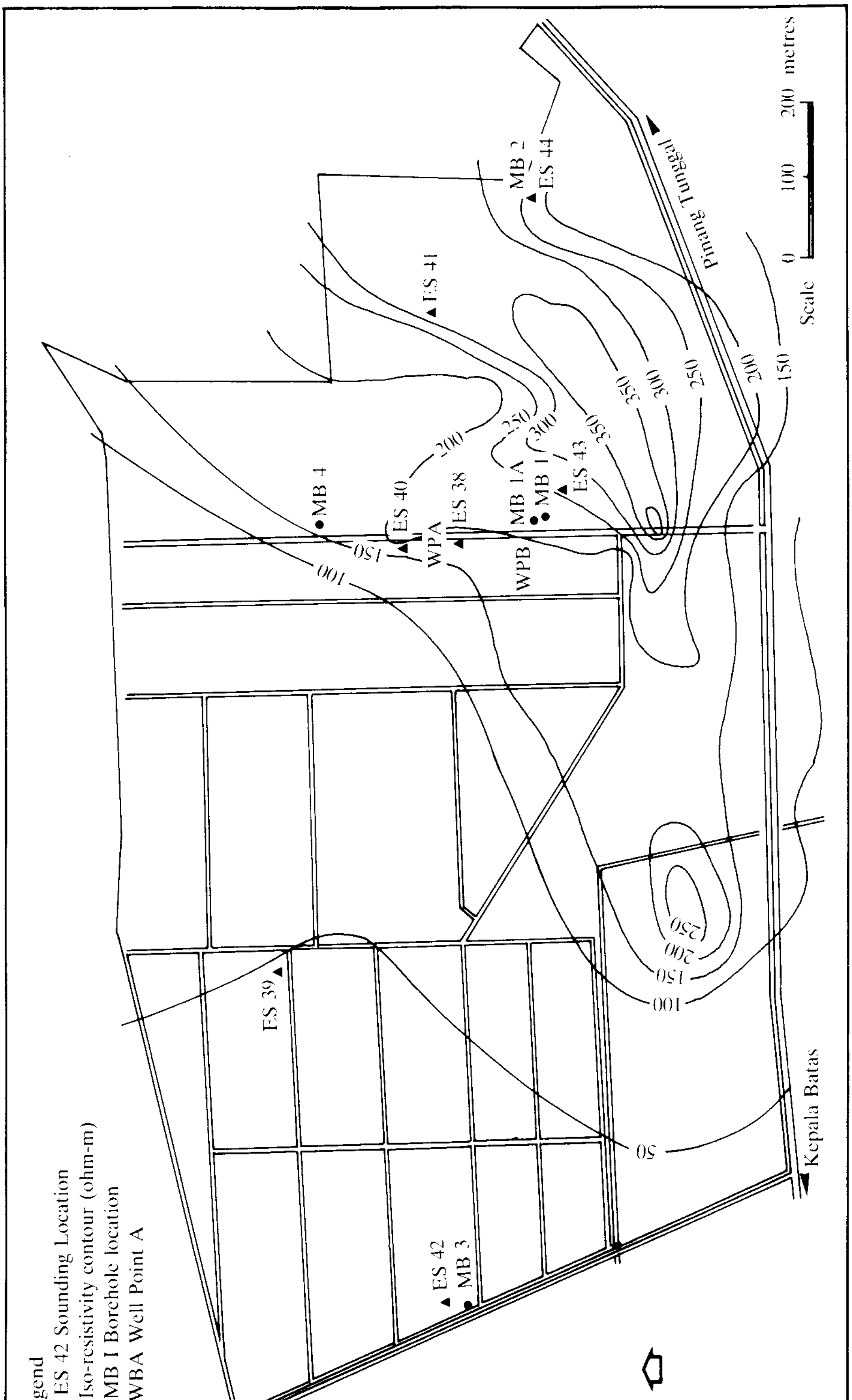

*Figure 1. Iso-resistivity contours of Bertam Station resistivity survey*

reading may also mean a combination of thin, sandy alluvium containing low salinity ground water.

### *Resistivity sounding survey*

Sounding survey may cover interpretation for aquifers, water tables, salinities, impermeable formations and bedrock depths. Soundings enable us to determine the resistivities of buried layers. Sounding results in *Figure 2* clearly matched the resistivity profile values in *Figure 1*. Soundings with high resistivity layer (ES 38, ES 41, ES 43 and ES 44) are located in the high resistivity areas. In contrast, soundings with low resistivity layers (ES 39 and ES 42) are located in the low resistivity zones.

Sounding interpretation by manual curve matching and computerized curve simulation produced the vertical layer interpretation bars in *Figure 2*. Areas of high resistance may represent areas of high resistant geological materials whereas areas of low resistance may comprise wholly of clayey materials. Soundings ES 39 and ES 42 registered resistivity values of 5.4 to 90 ohms-m which may indicate clayey layers. For sounding ES 39, the top 10-m depth is probably made up of silts and clayey sands registering resistivity values of 240 and 300 ohms-m respectively.

Soundings ES 38, ES 41, ES 43 and ES 44, located in the eastern section of the station, were probably made up predominantly of silt, clayey sand, sand, sand and gravels. There was no evidence, however, of the presence of hard impervious bedrock within the 100-m depth from the surface. Therefore, high resistivity ridge detected by the resistivity profiling may be interpreted as layers of sandy facies within the alluvium.

### *Drilling results*

Typically, an argillaceous alluvium between 20-m and 40-m depths was cut *(Table 1)*. The alluvium contained thin beds of coarse sand and gravel up to 4-m thick (MB 1, MB 2 and MB 3), whilst in MB 4, clayey alluvium was encountered. The sand within the alluvium of MB 1 were screened, developed and airlift-tested and the result was disappointing i.e. very low yield. The permeability of the sand within the argillaceous alluvium was much reduced by the interstitial clay content. Comparison of lithologic logs between MB 1 and MB 4 further indicated that the sand and gravel are laterally impersistent (SMMP 1983 and Azuhan 1985a).

Since the overlying alluvium in MB 1 produced a low yield, other exploratory boreholes were extended deeper to test the productivity of the underlying Sungai Petani formation. The Sungai Petani formation yield was unsatisfactory even though the yield was slightly higher than that of the alluvial aquifer.

### *Pumping test*

From the drilling discharges *(Table 2)*, only three bores justified to be airlift-tested (MB 1A, MB 2 and MB 3). However, MB 3 was abandoned due to the high salinity of ground water which was unsuitable for irrigation purposes (Ayers 1977). Pump tests were also conducted on MB 1A and MB 2 and the yields are low. The low yields are

Table 1. Borehole formation depths

| Bore number | Possible depth to base of alluvium (m) | Top of unweathered Sungai Petani formation (m) |
|---|---|---|
| MB 1/1A | 36 | 42 |
| MB 2 | 39 | 56 |
| MB 3 | 20 | 78 |
| MB 4 | 17 | 37 |

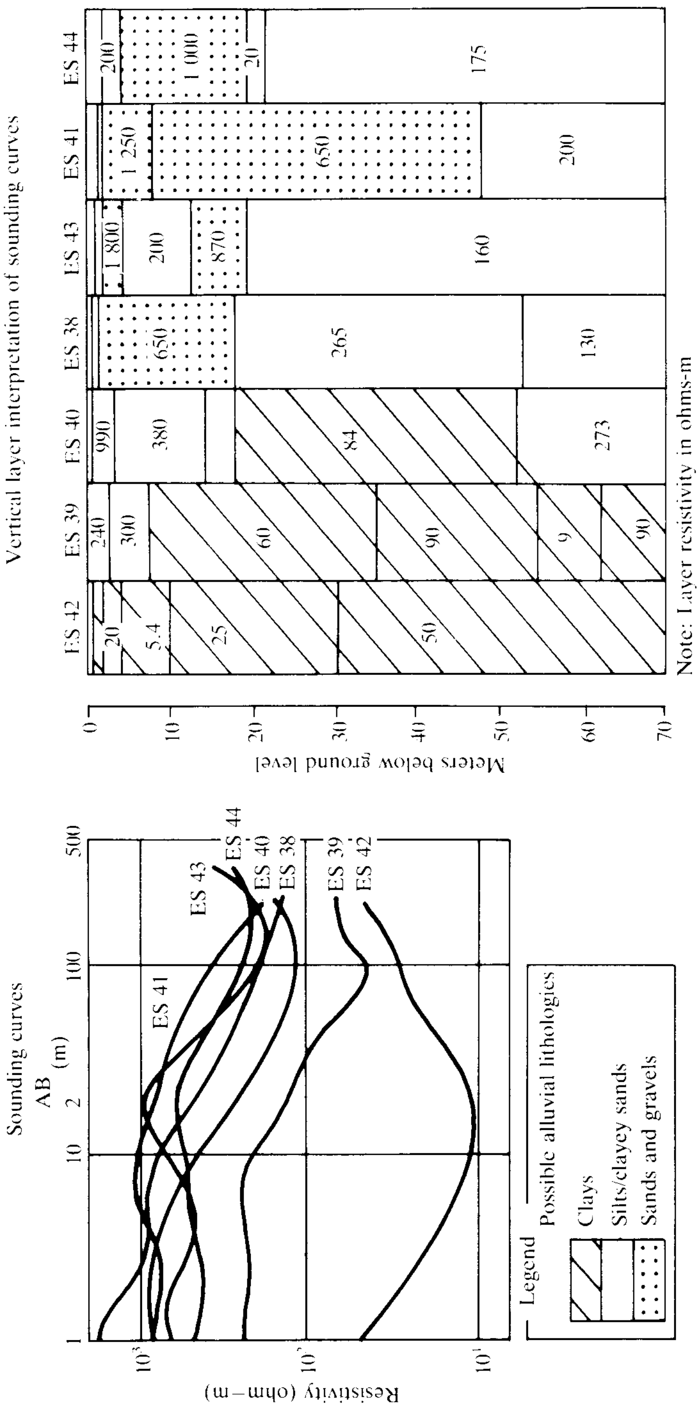

*Figure 2. Resistivity sounding of MARDI Bertam station*

Table 2. Drilling and airlift yield test of borehole for MARDI Bertam

| Informal borehole no. | GSM borehole no. | Total depth (m) | Aquifer target | Static water level (m) | Test date | Discharge (L/s) | Drawdown (m) | Specific capacity (L/s per m) | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| MB 1 | 1136 | 95 | Alluvium | – | – | (1.3) drilling discharge | – | – | Low discharge after development. Screen (21–24 m) and 15 cm casing withdrawn. MB 1A drilled adjacent. |
| MB 1A | 1136 | 85 | Sg. Petani formation | 1.60 | 26.10.82 | (3.0) airlift test<br>(0.4) drilling discharge | 14.4 | 0.2 | Production from joint-cracks in Sg. Petani formation. 15 cm casing 0–38 m EC = 200 micromhos/cm. Later pump tested. |
| MB 2 | 1137 | 84 | Alluvium & Sg. Petani formation | 1.76 | 15.09.82 | (3.25) airlift test.<br>(7.0) drilling discharge | 17.2 | 0.18 | Alluvium 0–39 m. Crack-joint aquifer in Sg. Petani formation. 6" casing 0–60.5 m. EC = 275 micromhos/cm. Later pump tested. |
| MB 3 | 1138 | 79 | Alluvium & Sg. Petani formation | – | – | (5.5) drilling discharge | – | – | Alluvium 0–20 m. Crack joint aquifer in Sg. Petani formation. EC = 8000 micromhos/cm. Bore abandoned |
| MB 4 | 1139 | 100 | Sg. Petani formation | – | – | (0.1) drilling discharge | – | – | Alluvium 0–18 m. Low permeability. Low drilling discharge of Sg. Petani formation EC = 150 micromhos, bore abandoned |

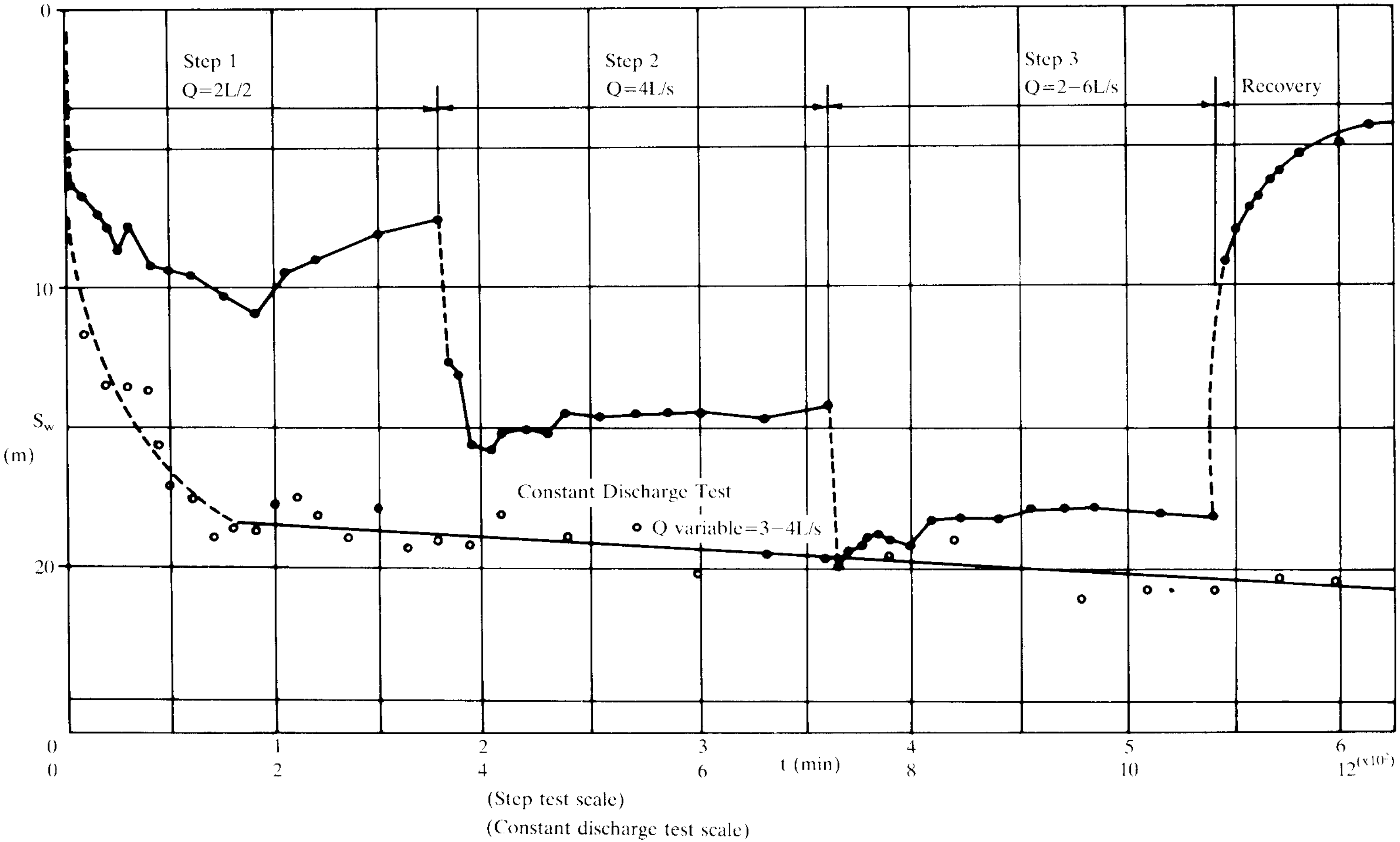

*Figure 3. MB 1A well Pumping Test showing discharge performance*

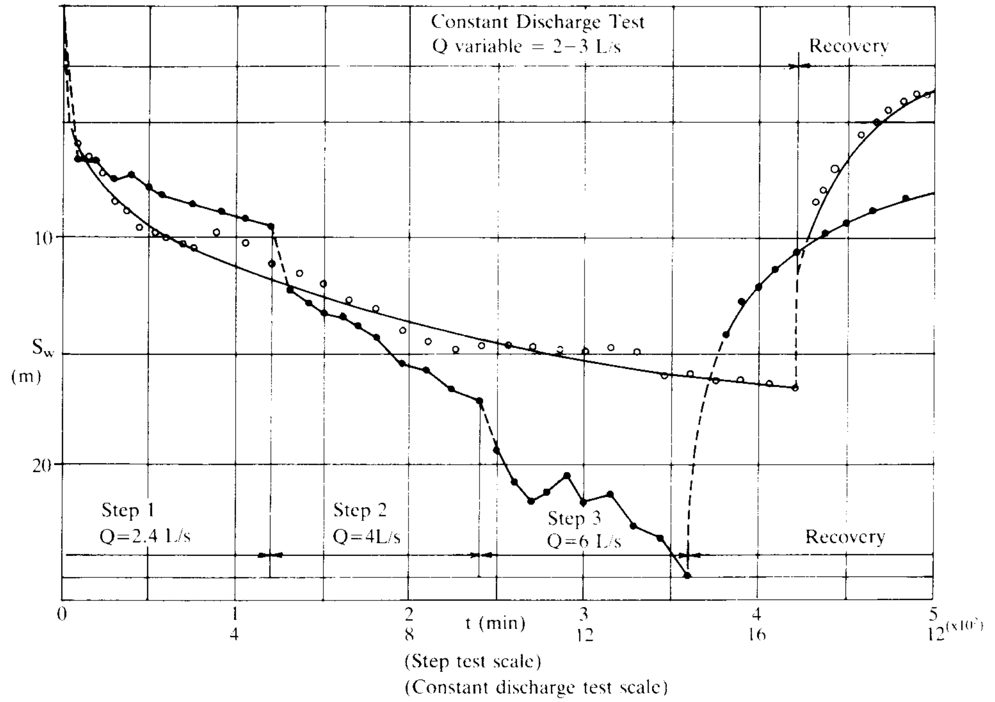

*Figure 4. MB 2 well Pumping Test discharge performance*

inadequate even for supplemental padi irrigation. However, they are sufficient to irrigate less water demanding crops such as nurseries and vegetables. The pumping test results are presented in *Table 3*.

**MB 1A test results** Despite the difficulties in controlling the discharge rates, quasi-equilibrium drawdown was probably reached in the step (Step 3, 18.22 m drawdown and Q = 2–6 L/s) *(Figure 3)*. The constant discharge (CD) test, with Q = 4 L/s, did establish a near equilibrium pumping water level of about 23.8 m below the top (drawdown, $S_w$ = 20.58 m) and this can be used as a safe production level.

A Logan analysis of the CD test data gives the following:

$$\text{Transmissivity (T or Kd)} = \frac{1.22Q}{S_w} = \frac{1.22 \times 4 \times 86.4}{20.58} = 20 \text{ m}^2/\text{day}$$

where Q is the discharge rate (L/s)
$S_w$ is the drawdown (m)

The permeability of the yielding sections could not be determined because it is quite impossible to estimate accurately the total length of that sections.

**MB 2 test results** No near equilibrium drawdown level was attained in the step test *(Figure 4)*, but rather a continuous (and accelerating in Step 3) water level decline which approached pump inlet depth was recorded.

The bore was cased to 61 m but the maximum pump setting was only 30 m. Therefore, the available drawdown is limited to only 26 m. The accelerating

Table 3. Pumping test summary

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **MB 1A** | | | | | | | | | | | | |
| 28.3.83 | TR | 4.4 | 21.4 | 0.21 | 200 | – | – | – | – | – | – | t = 120 min |
| 12.4.83 | S1 | 2 | 7.55 | 0.26 | 220 | – | 7.1 | – | 29 | – | – | t = 180 min steps |
| | S2 | 4 | 14.25 | 0.28 | – | – | – | – | – | – | – | – |
| | S3 | (6)* | 18.22 | (0.33) | 195 | 1.2 | 7.1. | – | 29 | 10 | <5 | 96% recovery after t = 270 min |
| 14.4.84 | CD | (4)* | 20.58 | (0.19) | 193 | 1.35 | 7.4 | – | 29 | 7 | <5 | t = 1 400 min; 96% recovery after t = 330 |
| **MB 2** | | | | | | | | | | | | |
| 21.3.83 | S1 | 2.4 | 9.60 | 0.25 | 220 | 0.4 | 7.0 | 142 | 30 | 10 | – | t = 120 min steps |
| | S2 | 4 | 17.01 | 0.24 | 253 | – | 7.1 | 139 | 29 | 10 | – | – |
| | S3 | 6 | (24.85) | (0.24) | 250 | – | – | – | – | – | – | Accelerating drawdown at the end of test; 85% recovery after; t = 660 min. |
| 22.3.83 | CD | (3)* | 16.46 | (0.18) | 240 | – | – | – | – | – | <5 | t = 1 680 min; recovery after t = 480 min |

Key: (1) Date of test; (2) Type of test; (3) Discharge (L/s); (4) Drawdown (m);
(5) Specific capacity (L/s per m); (6) Electrical conductivity (micromhos/cm at 25 °C);
(7) Total iron (mg/L); (8) pH; (9) Hardness as CaCO3 (mg/L); (10) Water temperature (°C);
(11) Sulphate (mg/L); (12) Chloride (mg/L); (13) Remarks;
TR – Test Run; S – Step Test (1, 2 or 3); CD – Constant Discharge Test;
* – Declining and Fluctuating Discharge

pumping water level decline generated at Q = 6 L/s in Step 3, probably indicate a reduction in transmissivity caused by limited lateral extent of cracks in the aquifer.

The CD test was run at 3 L/s and a quasi-equilibrium drawdown was established. The discharge of 3 L/s probably represents a safe production maximum. A Logan analysis of CD test data gives a transmissivity estimate of 19 $m^2/d$.

**Recommendations** For the operations of MB 1A and MB 2, some limitations are to be observed. The suggested production rates and pump settings are given in *Table 4*.

Because of the proximity to saline water (EC = 8 000 micromhos/cm at MB 3), water levels and EC must be regularly observed. At present, water quality is generally good. However, it is worthwhile to construct piezometers to the west of MB 1A to monitor water levels and water EC changes as MB 1A is pumped.

### *Evaluation of existing wells in the surrounding communities*

Water sample salinity values collected from 66 existing driven/jetted wells are presented as contours in *Figure 5*.

This map provides iso-salinity contours for the station surrounding areas. In the station, salinity values range from 50 $\mu$ mhos/cm in the south to 300 $\mu$ mhos/cm in the northwest. This iso-salinity contour pattern has a similar alignment to the iso-apparent resistivity contour presented earlier in *Figure 1*. The ground water EC range and the resistivity contours identified that the change in resistivity over the station is caused by ground water salinity variation and this is proven by the drilling results.

### Conclusions

The drilling investigation shows that the potential of the hard rock aquifer is better than that of the alluvial aquifer in the study area. The permeability of the alluvial sand, within an argillaceous alluvium, is much reduced by interstitial clay content and it is laterally impersistent.

The pump test results indicate a low permeability and low yield aquifer. The general behaviour was that of declining discharge with increasing drawdowns followed by long water-level recovery periods, all of which indicate a low transmissivity and low storage aquifers. They may further indicate limited lateral extent of transmissive cracks. Specific

Table 4. Suggested production rates and pump settings

| Bore no. | Discharge (L/s)* | Pump setting+ (m) | Remarks |
|---|---|---|---|
| MB 1A | 4 | 35 | Bore water levels and water E.C. are to be regularly monitored |
| MB 2 | 3 | 45 | |

Note: Bore is used for not more than 6 h/day.

The suggested discharge (*) is the maximum permissible for intermittent pumping. It is deliberately conservative because of the deficiencies of the Sg. Petani aquifer and the salinity threat.

The suggested pump setting (+) is very difficult to estimate correctly since the JPT test pump has a total column pipe lengths of 30 m. Therefore, the available drawdown to be tested is limited and the behaviour of the yielding sections could not be fully observed

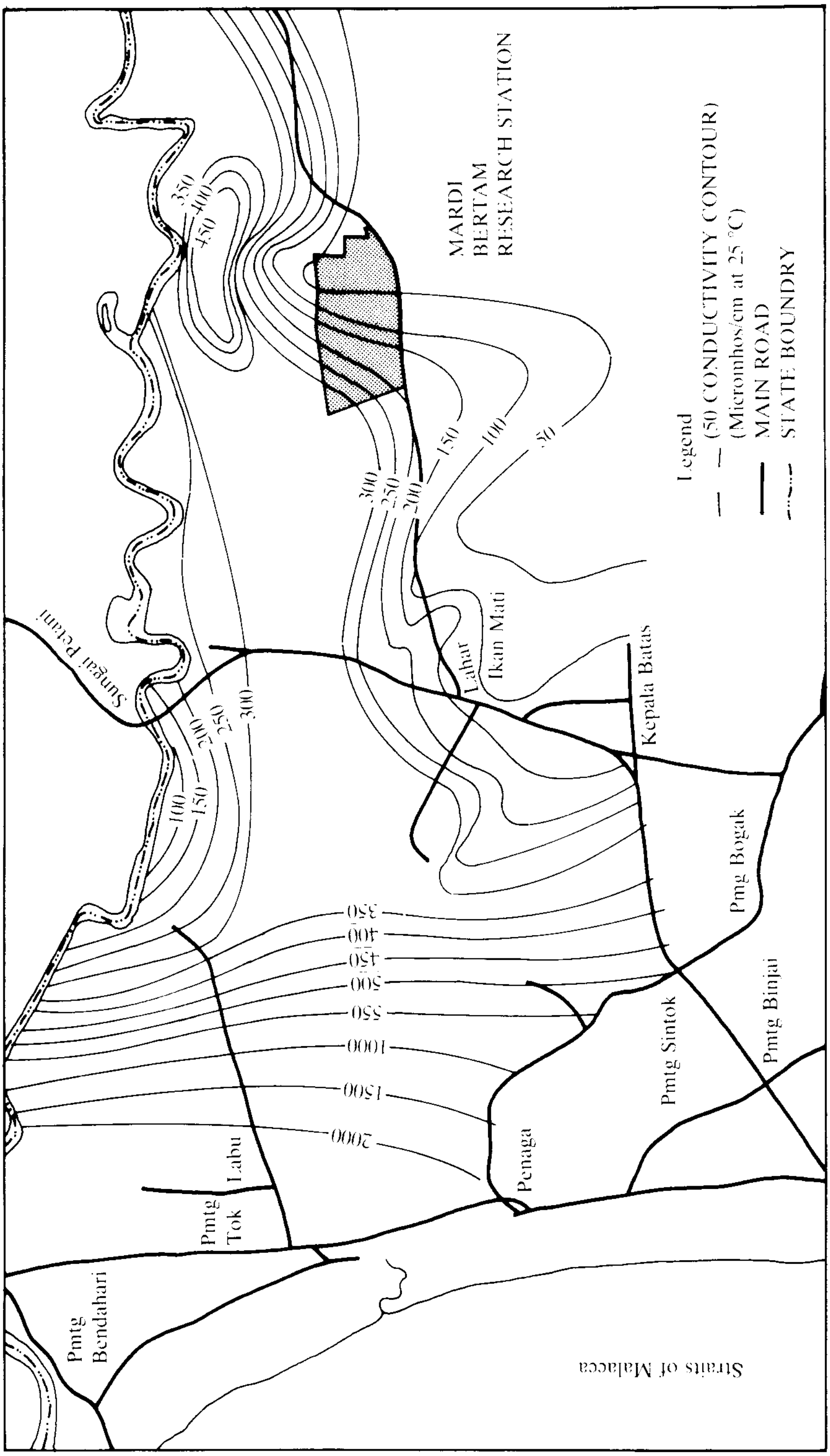

*Figure 5. Ground water iso-salinity distribution of northern Seberang Perai*

capacities of MB 1A and MB 2 are found to be low, about 0.2 L/s per metre with discharge rates of 3–4 L/s. The yield may not be enough for padi irrigation but probably sufficient for orchard and vegetable irrigation requirements.

The quality of water discharged during the pump test is generally good with low salinity values and low chloride content. However, resistivity and drilling (MB 3) results in the west of the station indicate that the Sungai Petani formation is affected by saline water. The iso-apparent resistivity contour map indicate the extent of salinisation. The increase in ground water salinity in the west side of the area is probably because of its proximity to the sea.

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