Geoelectrical Resistivity and Hydrogeochemical Methods for Groundwater Investigation in the Agriculture Area: A Case Study from Machang - Malaysia

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Abstract

The study area is located in Machang, North Kelantan - Malaysia. The Machang plain is covered with Quaternary fluvial sediments overlying granite bedrock. The drainage system is dendritic with the main river flowing into the South China Sea. Eighteen of geoelectrical resistivity profiling surveys with Wenner configuration was conducted to determine the characteristics of the subsurface and the groundwater within the shallow aquifer. The groundwater sample from twenty existing shallow wells have been analysed to derive their water chemical concentration.

In the southern region, concentration of nitrate is considered to be high (more than 20 mg/l), while the nitrate concentration in the northern region is relatively zero. In the south, the soil properties are all similar. However, the Wenner inverse model shows lower resistivity values (around 10 ohm.m) at the sites with relatively high nitrate concentration in the groundwater (more than 20 mg/l). Conversely, the sites with low nitrate concentration, reveal the resistivity values of Wenner inverse models to be higher (more than 30 ohm.m).

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The basement map of the area is generated from the interpolation of an interpreted Wenner inverse model. The areas that possibly have nitrate-contaminated groundwater have been mapped along with groundwater flow patterns. The northern part of the study area has an east to west groundwater flow pattern, making it impossible for contaminated water from the southern region to enter the northern area, despite the lower elevation of the area.

Keywords: Groundwater,Geoelectrical Resistivity, Hydrogeochemical, Nitrate.

Introduction

Groundwater is among the North Kelantan's most important natural resources. It provides drinking water to urban and rural communities, supports irrigation and industry, sustains the flow of streams and rivers, and maintains riparian and wetland ecosystems. The importance of groundwater for the existence of human society cannot be overemphasized.

Good quality groundwater is one of the great natural resources. Unfortunately it might become contaminated when even seemingly harmless materials and wastes are improperly handled. Contamination may involve different chemicals, excess amounts of nitrogen and phosphorus.

Like other places, in the study area, chemical fertilizers (Yang, et al., 2006) are rigorously used to enhance the agricultural establishment such as for palm oil plantation. Fertilization is conducted every two months using fertilizers of different chemical content. For example, at the beginning of the year, 400 kilograms of Urea with 60% nitrogen is used for a two hectare palm plantation. Two months after that, another fertilizer with 15%

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Nitrogen, 30% Phosphorus, and 55% Potassium (NPK) is applied to further improve the production of palm. This process is repeated in the middle of the same year and continues till the end of the year. All in all, at least 800 kilograms of urea is employed for the fertilization of palm trees in a two hectare area per year.

Other agricultural activities within study area include the cultivation of paddy fields and rubber trees. However, in comparing the intensity of the fertilization process for paddy and rubber trees with that of palm oil, it is much less than that of palm oil. The farmers in study area plant paddy only once a year on average, although some plant paddy up to twice a year over several areas. Paddy fields consume a mere 100 kilograms of urea per two hectare a year. For rubber trees, 200 kilograms of urea is utilized for every two hectare per year.

Contaminant leaching (especially nitrate) from agricultural soils has been widely studied (Almasri and Kaluarachchi, 2004; Saadi and Maslouhi 2003). In this study attention has been focused mainly on nitrate assessment of groundwater within sandy soils in the shallow aquifer. Clay soils are usually not considered to have a high nitrate leaching potential.

Review of Geology Study Area

The total extent of study area covers approximately 98 square kilometers. The southern and northern part of the study area is bounded by Kampung Tok Bok and Kampung Ketereh respectively. Whilst, at the west and east side is bounded by Kelantan River and the high hill (Figure 1). The hill is a part of the Boundary Range Composite Batholith. It consists of two major components, the Machang Batholith which is 100 x 20 km, and the smaller Kerai Batholith situated on the western flank (Cobbing, E.J., Pitfield, P.E.J., 1992). Around the hill, a lot of exposed granite can be found especially at Sungai

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Buluh Quarry. Other exposed granite can also be found in Kampung Pulai Condong around 4 km to the west of Machang Batholith Boundary Range. The study area is covered with Quaternary sediments overlying granite bedrock. It is drained mainly by short rivers and streams which flow into the South China Sea. The thickness of the Quaternary deposits varies from 20 m inland to about 200 m near the coast. The loose quaternary sediments consist of alternating layers of coarse gravels to silts or mixtures of the two (Saim 1999). Figure 1 shows the location map of the research area. The RSO West Malaysia and Kertau 1946 are used as the coordinate system and datum in the map.

Metodology

2D electrical resistivity imaging surveys were performed at the proposed sites using the ABEM SAS4000 resistivity meter and multicore cable to which electrodes were connected at takeouts molded on at predetermined equal intervals. The Wenner arrays were used on eighteen traverse lines of different lengths. The maximum line spreading was 400 m in length, and the minimum spreading was 80 m in length, each line spreading depended on the available space of field. Processing of the data was achieved by a tomographic inversion scheme using the software RES2DINV (Loke, M.H., 2007; Loke, M.H., Barker, R.D., 1996).

A hydrogeochemical method was used to study the groundwater characters in this area. In the study, special emphasis was given to the first aquifer (shallow aquifer) because it is the main source of the water supply for domestic uses. Samples of groundwater were collected from the existing wells, and in-situ parameters such as well depth, water level, total dissolved solid, pH, conductivity, salinity and temperature were measured. Water samples of 500 ml were kept in plastic bottles and maintained at a temperature of 4^0C. This was done for determining their major anion contents analysis in the hydrogeology lab.

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Physical information about water samples were retrieved directly from existing wells or piezometers whereas the physical information about these well, like well location, well depth, depth to water were obtained from the well owner.

Results and Discussion

The amounts of different elements including in-situ water, physical well parameters and hydrogeochemical content have been presented in Table 1.

95% of the groundwater in the shallow aquifer possesses a hydrogen ion concentration (pH) that is moderately acidic (4 - 6.5) whereas the remaining 5% is indicative of a more neutral pH condition (6.5-7.8). Thus it is generally good for some other domestic uses. 30% of the water sample is less than 5 on the pH scale and is considered not good for human consumption if untreated. The fact that the hydrogen ion concentration is more or less neutral affects the aggressiveness of the solution.

The chloride concentration of the groundwater was reported to be relatively low because of the fact that chloride does not show any correlation with the components of pore water derived from mineral breakdown. Also, in sedimentary rocks, the major source of chloride in groundwater is due to evaporate (Egbunike, M.E., 2007). The concentration of rain water by evapotranspiration may be an important source of chloride in the area where it close to the sea. Another common source of chloride in groundwater is the leaching of chloride fertilizing over long periods time. The influence of the fertilizing factor in the chloride content of the groundwater around the southern part of the study area can be found in water sample from the borehole at A006 with chloride concentration of 12.10 mg/l. The chloride concentration in the water samples are within the accepted limits for human consumption.

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The concentration of nitrate in the mapped area is generally good and falls within the accepted limit except in the palm oil field area around surface water termination (A002, A003, A004, S001 and S002). However, out of the exceptional area, the nitrate safe drinking water concentration of 10 mg/l (WHO, 1984). The potential source of nitrate in the area may include fertilizing activities, animal excrement, and probably the atmosphere. Sulphate (SO_4) concentration ranges from 0 - 12.339 mg/l which is considered low and lies within the accepted limit.

Overall, correlation between conductivity and other water chemical content can be calculated statistically using the Pearson product-moment correlation (Till, R., 1974). Based on the data in Table 1, the correlation coefficient between conductivity and TDS is 0.9899, conductivity and chloride is 0.2532, conductivity and nitrate is 0.8024, and conductivity and sulphate is 0.0432. Based on this fact, it is concluded that the amount of nitrate in the groundwater influence total conductivity readings.

The map shown in Figure 2 exhibits the well position for groundwater sampling. It also shows the contour of nitrate concentration from 20 well samples and water levels relative to mean sea level. Relative high concentration of nitrate can be found of wells in the Palm oil field zone. The remaining rubber tree fields and paddy fields exhibit generally low nitrate concentrations.

In the well with sample ID A009, concentration of nitrate is considered to be high (12.58 mg/l) although no palm oil field around the well. Here, there are minor agricultural activities, including corn plantation. For these activities, chemical fertilizer is not utilized. Only organic fertilizers like cow manure are used.

According to Figure 2, zone 1 is the area between the y-coordinate lines 64500 and 65000 which are parallel to the x-axis. The groundwater in the shallow aquifer in this zone

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flows northwest from Boundary Range Hill to kampong Tok Bok. Boundary Range Hill is elevated at more than 250 m above mean sea level whereas Kampung Tok Bok is situated at around 35 m above mean sea level.

The groundwater around the wells S001 and S002 at the zone 1 (Figure 2) flows toward the Kelantan River. The direction is consistent to the groundwater flow of the wells near the eastern boundary of zone 1. It is noted that well S004 of eastern zone is located adjacent to the palm oil field in Kampung Tok Bok.

Thus, generally, groundwater movement within zone 1 is from southeast to northwest. Comparatively, in zone 2 (the area between the Y-coordinate lines 65000 and 65500, which are parallel to the X-axis) the groundwater movement occurs in two directions: southeast-northwest and northeast-southwest flow direction is minor and after calculating the vector resultant for groundwater flow of zones 1 and 2. The general direction of flow is from the southeast to the west, toward the Kelantan River.

It can thus be generalized that the direction of groundwater movement and surface runoff is influenced by elevation, moving from high land areas to lowland areas. It is observed that this mentioned factor may also affect the potential nitrate concentration of an area. Groundwater in lower elevation areas with palm oil field at its borders tend to have higher concentrations of nitrate (S001, S002, A002, A003, and A004) whereas groundwater in higher elevation areas (S003 and S004) have lower concentration of nitrate.

In the zone between 64500 to 655000 of the Y-axis, the groundwater flow within the shallow aquifer in Kampung Merbau Condong (point 3 in Figure 2) is also known to originate from the Boundary Range Hill area. The flow is from an elevation of more than 250 meters above mean sea level at the Boundary Range Hill area to about 30 meters above mean sea level at the Kampung Merbau Condong area.

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At around the A007 well in the north eastern region of Zone 2, groundwater flow is deemed to occur in three directions as a nearest of the well being located at the top of a hill. The three directions of flow are northeast-southwest, east-west, and southeast-northwest, as shown in Figure 2. Nonetheless, all groundwater flows toward the Kelantan River which is elevated at 15 meters above mean sea level.

Zone 3 is located between the Y-coordinate lines 65500 and 66000, which are parallel to the X-axis. The south-eastern part of this zone possesses the lowest groundwater level in the whole area, positioned at a lower elevation than that of the Kelantan River. Thus, groundwater does not flow toward the Kelantan River in this zone. Instead, the groundwater in this zone flows downward into the next aquifer below the first shallow aquifer.

In this paper, selected Wenner inverse model of geoelectrical resistivity survey can be seen in Figure 3. The locations summery of geoelectrical resistivity surveys are as the following; the lines A101, A102, A103, A104 and A105 were conducted within the palm oil field. The lines A109 and A113 were conducted on the preparation of housing and the grass field. Soil and geological condition is considered to be similar for all survey locations. The line A106, A107, A108, A112, A114, A115, A116, A117 and A118 were conducted in the site around paddy field and rubber trees area.

In the Wenner inverse model of lines A101 and line A102 (Figure 3), the lower value of subsurface resistivity (less than 10 ohm.m) can be found at a depth of around 3 meter, although these lines were conducted on the zone with coarse grained size and low moisture content. Around line A101 and line A1002, relative high nitrate concentration in the groundwater was found. Water chemical result from the wells S001 and S002 with a depth of around 5 m informed that nitrate concentration is 24.18 mg/l at the site where line A101 surveyed. The other line which was conducted in the palm oil field is line A103 and

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A104. In the Wenner inverse model of the line A103, at a depth of around 3 m, the possibility of groundwater accumulation can be seen with 52.39 ohm.m of resistivity values (minimum values in the section). While the nitrate concentration found around this area is less than 5 mg/l (S005 and S006).

Generally, within palm oil field, in the zone of relative lower surface elevation, where the possibility of water surface run off will be terminated on it, subsurface and surface resistivity have been found relatively lower than other palaces which the geological condition is considered to be similar. This fact exhibiting that presence of nitrate in the groundwater reduce resistivity value of the medium.

In the Wenner inverse model of line A107 and line A117 (Figure 3), there is an anomaly with high resistivity values (more than 1500 ohm.m) apparent in the section at a depth of 20 m and 25 m respectively. This anomaly also can be found in the other Wenner inverse model which is not shown in this paper. These anomalies are believed to be due to occurrence of basement. Based on the entire Wenner inverse model, the possibility of basement beneath the surface for the whole area has been mapped in Figure 4. From the map, it can be seen that the groundwater at the southern region is blocked by basement at the middle region, making it impossible for contaminated water from the southern region to enter the northern area although lower elevation in the northern region.

Conclusion

The geoelectrical resistivity and hydrogeochemical methods were successful to study groundwater of shallow aquifer characters within the agricultural area. In the area around palm oil field, nitrate concentration is higher compared to the area with no palm oil field. Application of chemical and natural fertilizer is the reason high nitrate concentration

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found in the palm oil field. In the zone with higher nitrate concentration, subsurface geoelectrical resistivity values reveal to be lower, and vice versa.

The groundwater which has high level of nitrate concentration have been mapped along with groundwater flow patterns. The contaminated water from the southern region is impossible to enter the northern area despite the northern area has lower elevation. It is due to the southern and the middle part of the study area has an east to west groundwater flow pattern and also due to in the middle part of the study area, occurrence of basement resist the groundwater flow to the northern area.

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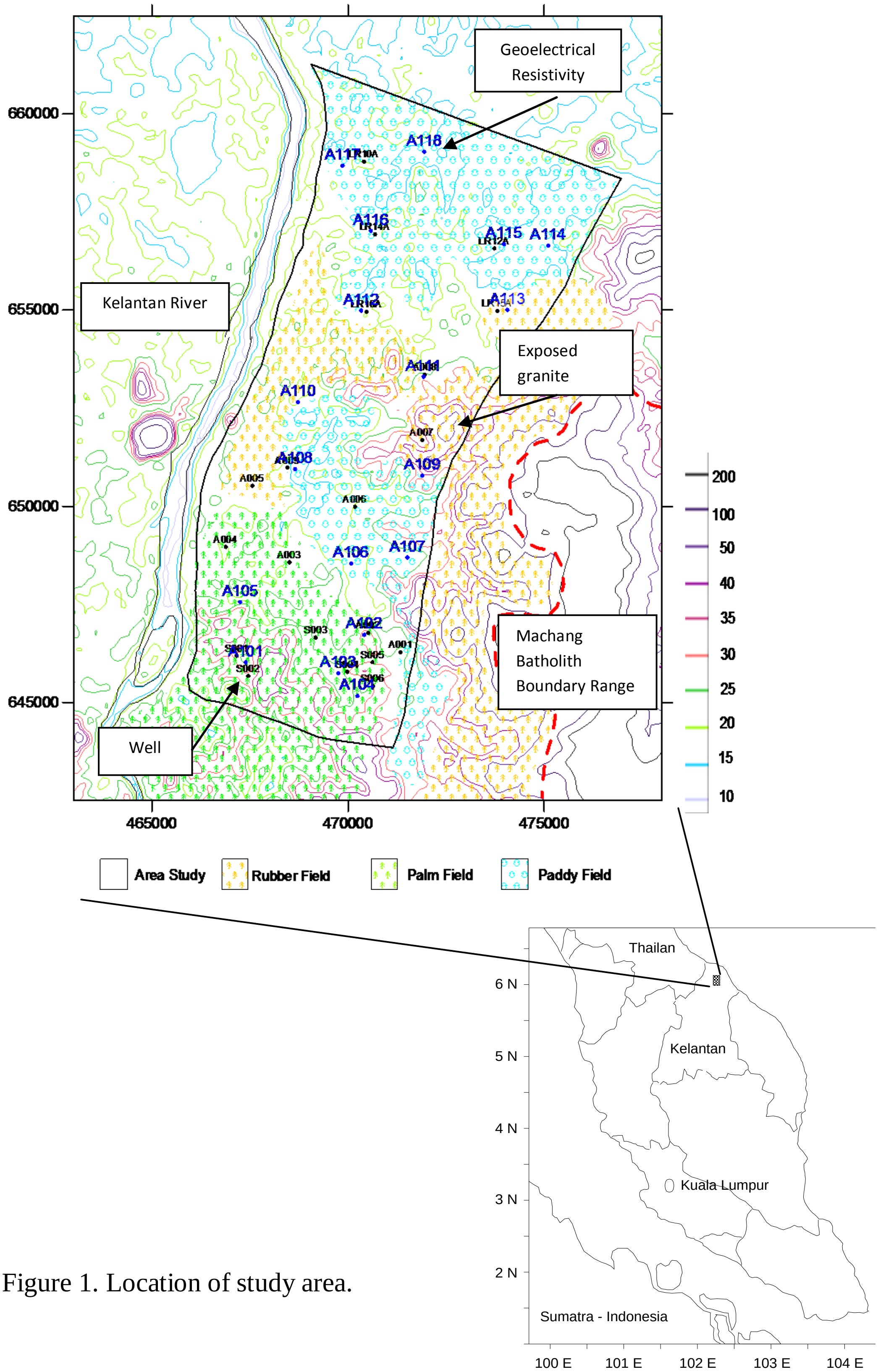

Figure 1. Location of study area.

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Table 1. In-situ parameters and chemical results of groundwater samples within study area. In the bottom row of the table, limit concentration for domestic use by WHO 1992 is displayed.

No	Sample ID	Location X (m)	Location Y (m)	Well Depth (m)	Ground Level (m)	Depth to (m)	Water Level (m) (a.m.s.l)	TDS mg/l	Conduc-tivity µS/cm	Salinity 0/00	T ^{0}C	pH	Chloride mg/l	Nitrate mg/l	Sulfate mg/l	Fluoride mg/l
1	A001	471343	646277	<7	28	2.56	25.44	76	159	0	27.8	4.77	5.86	2.77	5.915	0
2	A002	470511	646770	<7	24	2.1	21.9	323	654	0.1	30.5	5.98	6.66	22.28	1.716	0.058
3	A003	468507	648571	5	22	1.96	20.04	407	830	0	29.4	4.93	7.60	28.79	0.25	0
4	A004	466884	648964	<7	21	0.86	20.14	76	159	0	29.2	4.63	6.75	12.90	0.622	0
5	A005	467562	650522	<7	22	0.98	21.02	78	163	0	29.1	5.72	4.11	3.84	3.544	0.049
6	A006	470178	649987	<7	18	0.67	17.33	151	313	0	27.4	5.75	12.10	4.46	4.154	0
7	A007	471890	651687	<15	40	10.62	29.38	57	120	0	28.5	6.14	2.14	0.00	1.213	0
8	A008	471962	653352	<7	24	1.35	22.65	83	173	0	31.7	4.86	3.51	2.18	1.443	0
9	A009	468452	650985	<7	20	0.91	19.09	50	104	0	34.4	5.72	7.21	12.58	0	0.22
10	LR10A	470404	658785	<7	19	1.02	17.98	183	381	0	42.2	5.77	18.16	0.00	7.953	5.643
11	LR12A	473733	656574	<7	14	0.23	13.77	84	170	0	31.1	6.4	2.43	0.00	0.263	0.032
12	LR14A	470689	656930	5	17	0.65	16.35	89	180	0	25.7	6.42	4.36	0.00	0.212	0.000
13	LR15A	473804	654980	6	28	2.11	25.89	64	130	0	28.7	6.22	1.83	0.00	0.000	0.073
14	LR16A	470475	654957	<7	17	0.61	16.39	106	217	0	27.2	4.11	19.90	0.00	0.663	0.052
15	S001	467159	646187	5	24	1.43	22.57	370	751	0	28.3	6.88	6.28	24.18	0.318	0.000
16	S002	467455	645676	5	26	1.92	24.08	247	501	0	28.3	5.98	8.18	18.93	5.571	0.000
17	S003	469175	646657	3	28	2.38	25.62	49	98	0	30.5	5.09	5.23	6.83	1.605	0.000
18	S004	469982	645778	7	38	2.46	35.54	60	121	0	28.1	4.49	8.15	6.06	12.339	0
19	S005	470622	646025	5	29	1.22	27.78	35	70	0	28.5	6.19	3.65	9.72	1.394	0.000
20	S006	470630	645415	<7	33	2.96	30.04	48	97	0	30.1	6.42	2.11	0.34	0.237	0.000
												6-8	250	10	400	1.5

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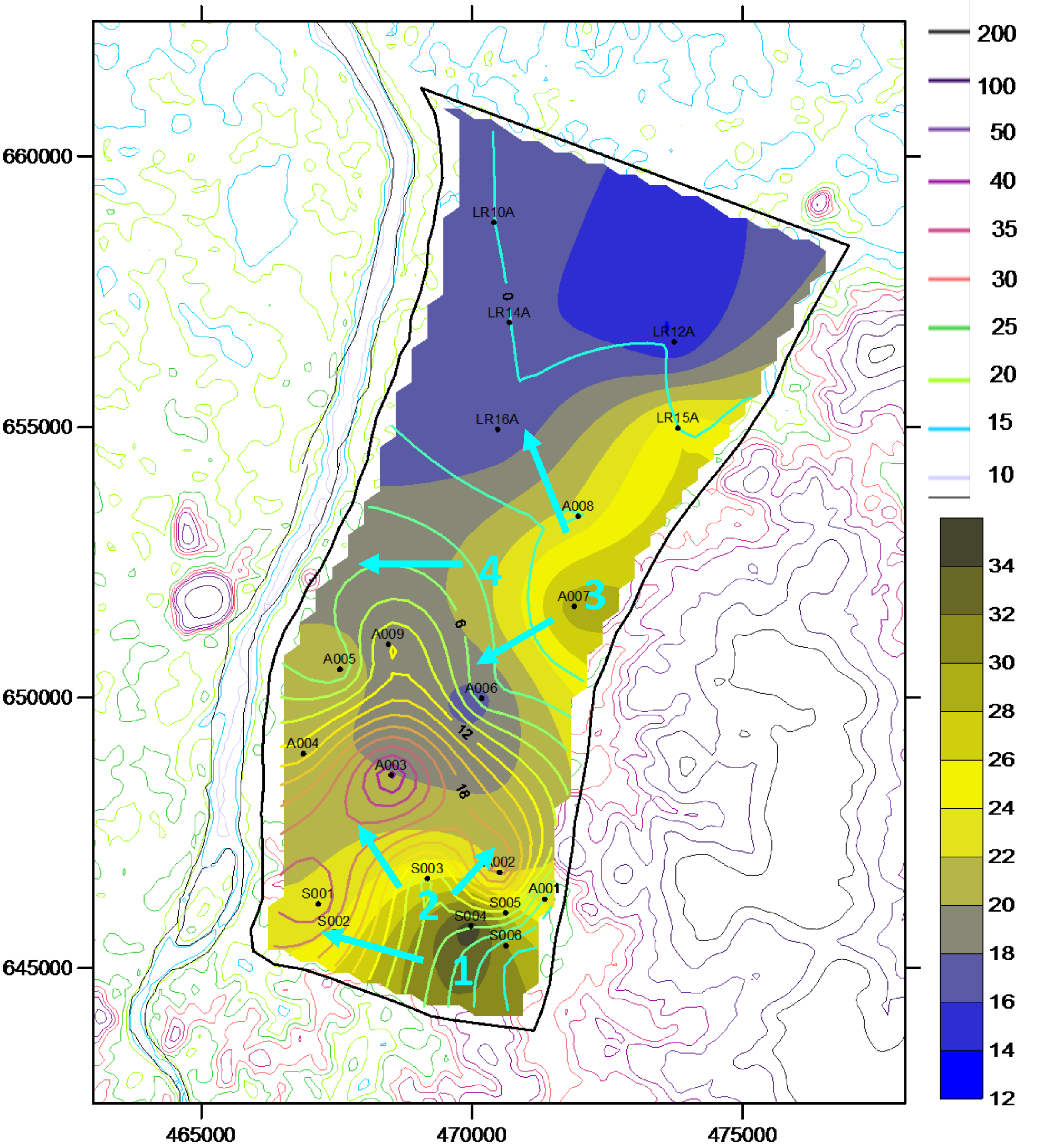

Figure 2. Map of three sets contour data. The solid contour represents water level relative to mean sea level and the line contour above the solid contour is nitrate concentration in shallow aquifer (less than 11 meter deep) with well ID marks. The remaining contour lines reflect surface elevation.

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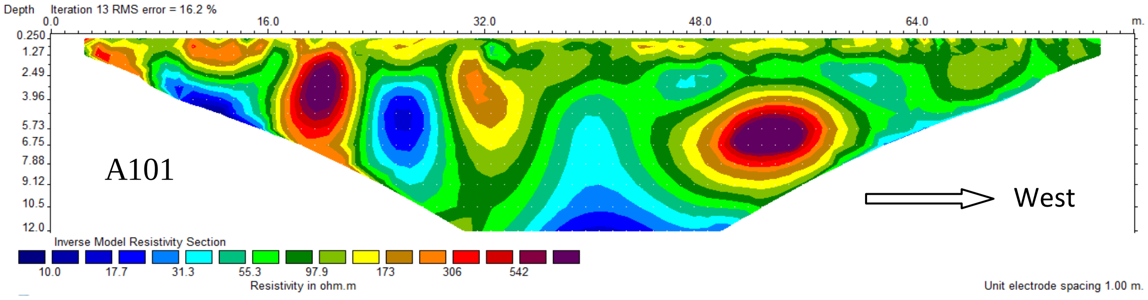

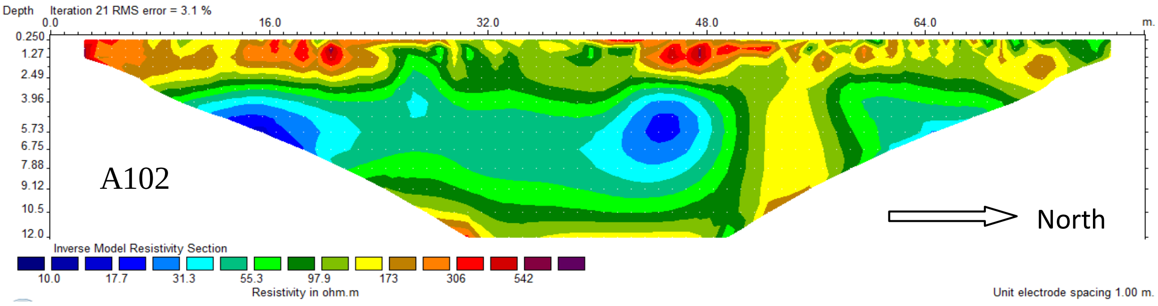

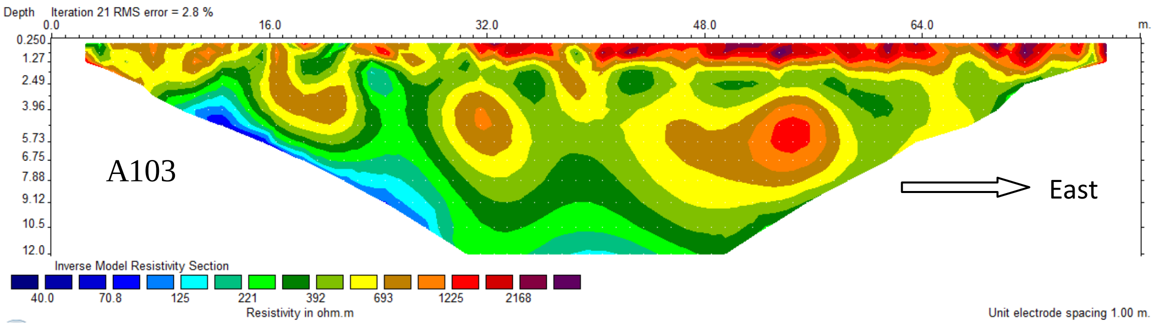

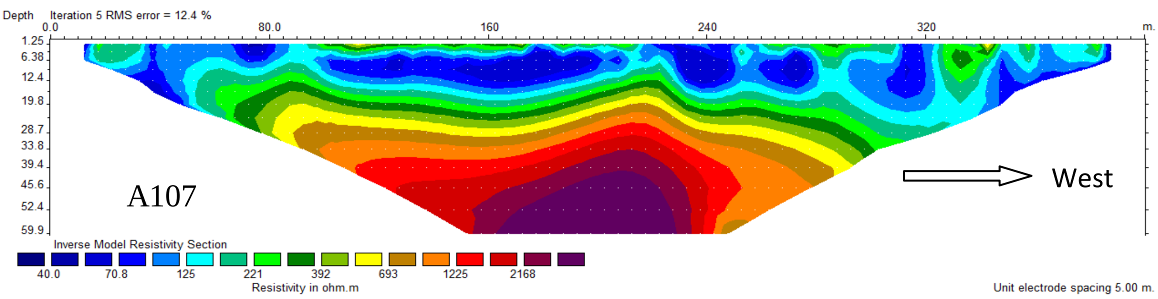

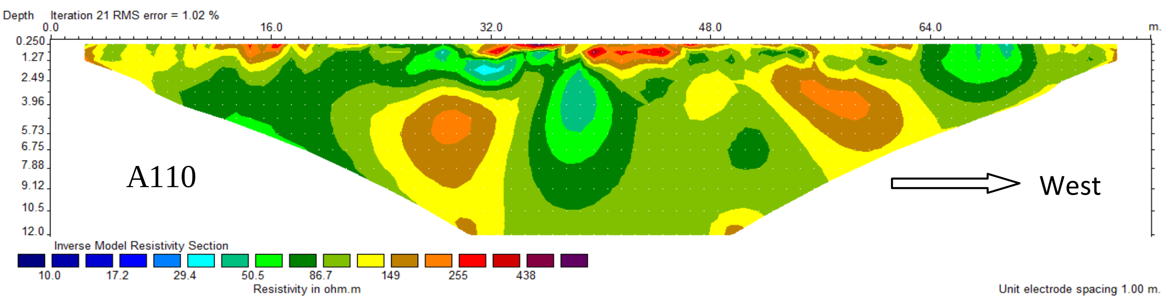

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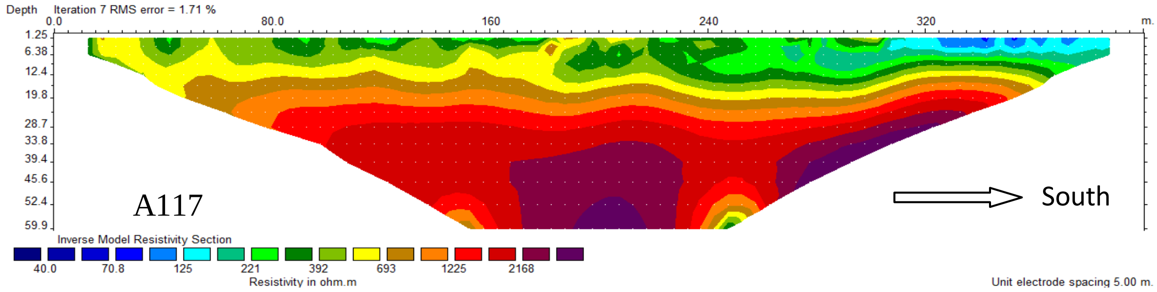

Figure 3. Selected Wenner inverse model.

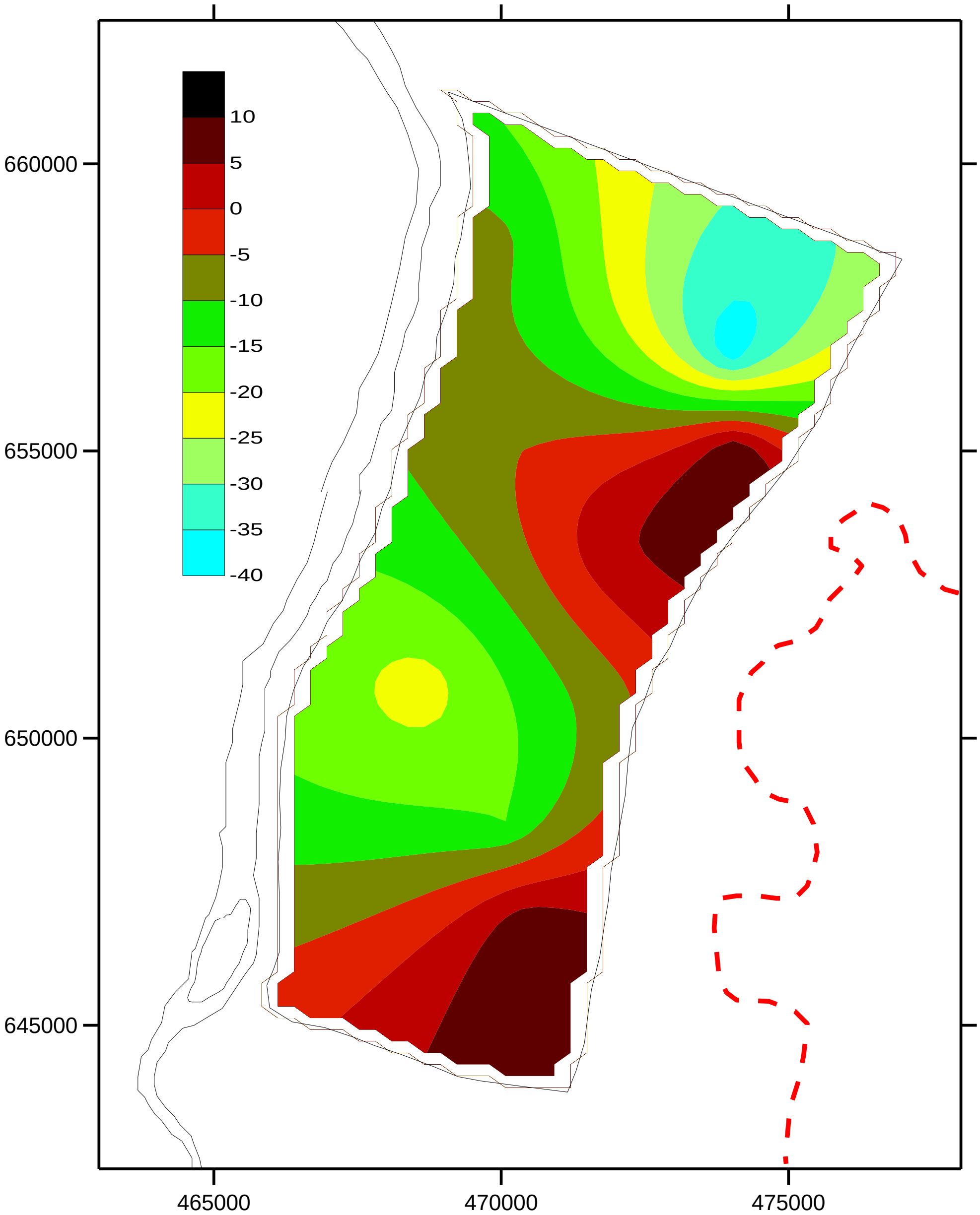

Figure 4. Basement map derived from interpreted Wenner inverse model. Contour values are elevation of basement relative to the mean sea level.

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