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MONITORING THE SEAWATER INTRUSION INTO COASTAL-AQUIFER USING GEO-ELECTRICAL SOUNDING
A case study of the Northern-coastal area of Central Java, Indonesia

By:
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ABSTRACT

The aims of this study are : (1) to investigate whether there is seawater intrusion into the coastal-aquifer of the northern-coast of Central Java, (2) to study the seawater intrusion movement along the corresponding coastal area, particularly from the district of Brebes to the district of Kendal.

To achieve the above goals, geo-electrical sounding technique was applied, hence by producing cross-sections of resistivity values which are perpendicular to the coast-line. The measurements were conducted in 1989 and 1996, each of wich included eleven locations which were at the same spot. Resistivity shown in the cross-section is the resistivity of the rock composition and the water in the aquifer. In this case, saline water has resistivity less than 1 ohm meter.

The result shows that in 1989, among the eleven measured locations, there was only one location indicated interface between fresh water and saline seawater. This was at the cross section number 5 obtained in Pemalang. In 1996, there were 6 locations indicated the occurrence of interface. Connate saline water was detected at every cross section with various depth.

INTRODUCTION

Coastal aquifer comes in contact with ocean at or seaward of the coastline and here, under natural conditions, fresh groundwater is discharged into the ocean. With increased demand for groundwater in many coastal areas, however, the seaward flow of groundwater has been decreased or even reserved, causing sea water to enter and to penetrote inland in aquifer. This phenomenon is refered to sea water intrusion (Todd, 1959, pp.277).

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An interface is able to move toward the land when the hydrostatic pressure of the fresh water decreases. The decreased hydrostatic pressure of the fresh water is caused by the reduced amount of the groundwater resulting from several reasons. It can be due to the increase use of groundwater by people or due to lessening recharge of the aquifer caused by increase of area covered by an impervious structure over the recharge area of the corresponding aquifer.

The depth of an interface can be estimated by two approaches, i.e. by applying the Ghyben-Herzberg formula and by conducting the geo-electrical sounding survey. The Ghyben-Herzberg formula is written as:

$$h_s = 40 \times h_f \qquad \text{(Wannielista, 1997)} \qquad (1)$$

where h_s is the height difference between the sea surface level and the interface while h_f is the height difference between the fresh water level and the seawater level (see Figure 1). The value of 40 was obtained by calculating the density of seawater and the density of the fresh water written as:

$$h_s = \frac{\rho_f}{\rho_s - \rho_f} h_f \qquad \text{(Wannielista, 1997)} \qquad (2)$$

where ρ_f is the density of the fresh water (=1000) while ρ_f is the density of the seawater (=1025). The values were obtained by measuring the samples of the fresh water and seawater in laboratory.

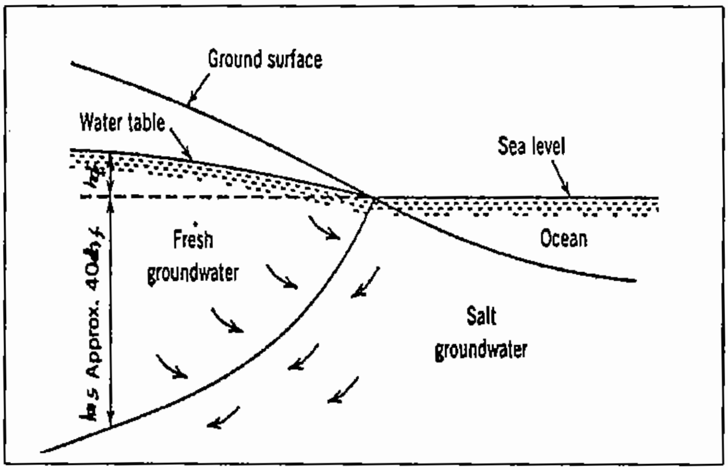


Figure 1. Illustration of saltwater intrusion (Wannielista, 1997)

Using the geo-electrical sounding technique, one may identify the stratigraphy of the resistivity of the rock composing the aquifer and the water inside. As an illustration, a rock containing water shows resistivity value less than the rock which has no water contain. Another example is a rock containing saline water which shows resistivity value far less than that of the rock containing fresh water.

People often find saline groundwater in certain place and certain depth over this area, thus it is interesting and important to study the seawater intrusion phenomenon over the northern coastal area of the Central Java as. Klosterman (1989) found that the saline groundwater in this area is partly due to the existence of connate water or fossil water. Connate water is seawater which was trapped during the formation of aquifer in the past.

Because of expansion of residential area, there has been increasing activity of groundwater pumping for domestic use. In addition, many fish/shrimp ponds, which are built over the above- mentioned coastal area, have been pumping the groundwater extensively in order to supply the need of fresh water for their fish ponds. It is important to study whether the interface has any relationship with these pumping activities.

These facts stimulate a thought that the more groundwater over this area being pumped the higher possibility of intrusion will be. Likewise, the intrusion will be propagating further toward the land indicated by the shallower interface.

RATIONALES FOR THE STUDY

The increasing use of groundwater by fish/shrimp ponds located over the northern coastal area of Central Java may cause further propagation of seawater intrusion toward the land. It is, therefore, important to monitor the movement of the interface toward the land.

The geo-electrical sounding technique can be used to estimate the interface and to detect the locations of layers containing connate water. If the measurements were conducted in a certain period, then the movement of the intrusion can be detected.

AIMS OF THE STUDY

The aims of the study are as follow:

1. to investigate whether the saline groundwater in the northern coastal area of Central Java is caused by the seawater intrusion or connate water occurrence.
2. to study whether the interface over this area is steady or moves from time to time.

THEORETICAL BACKGROUND

Hydrostatic pressure of the groundwater prevents the saline seawater for coming inland. This is the case when the hydrostatic pressure of the groundwater is higher than that of the seawater. When the hydrostatic pressure of the groundwater is getting lower, the seawater can move further inland (Todd, 1959).

The decline of such hydrostatic pressure is commonly due to the intensifying use of the groundwater. The groundwater uses increase because of several reasons such as the increase of domestic use and industrial one as well. The intensification of groundwater pumping activity in many fish ponds, in particular, has been thought to cause the occurrence of seawater intrusion.

An aquifer containing saline water has resistivity value which is smaller than the resitivity of an aquifer containing fresh water. Zohdy's (1980) study in the coast of California, showed that a saturated aquifer has resistivity varies according to the type of material composition. The resistivity of sand and gravel saturated with fresh water ranges from about 15 to 600 ohm meter. Field experience indicates the values ranging from 15 to 20 ohm meter are characteristic of aquifer in the South Western United-States, whereas for certain areas in California the resistivity of fresh water bearing sands generally ranges from 100 to 250 ohm meter. In parts of Maryland, resistivities have been found ranging from 300 and 600 ohm meter. In California, it was found that the resistivity of an aquifer containing saline water was 10 ohm meter.

A study conducted in Cilacap coastal area by Simoen et al. ,(1976), indicated that the layer containing saline water has a resistivity of less than 2 ohm meter. It was also found that the fresh water in Cilacap area lied on top of the interface of the Penyu bay and the interface of the Donan River on the other side of Peninsula of Cilacap.

Simoen (1996) conducted a groundwater study in the Pasir District of East Kalimantan Province. The aquifer over this area is composed by quartz-sand material. It was found that the saturated aquifer containing fresh water has resistivity ranging from 500 to 600 ohm meter while the unsaturated aquifer has resistivity of more than 1500 ohm meter.

Based on the theory and the results of several studies previously mentioned, it can be inferred that the geo-electrical sounding technique is useful in determining the depth of saline groundwater and in detecting any occurrence of interface in a given location.

HYPOTHESIS

Considering the theory mentioned earlier, there are two hypothesis can be made, i.e.:

1. The geo-electrical sounding can be applied for determining the cause of saline groundwater in the northern coastal area of Central Java. Hence, whether it is caused by seawater intrusion or it is caused by the existence of connate water.
2. The movement of sea water intrusion toward the land is related to the pumping activities conducted by fish/shrimp ponds.

METHODS

The geo-electrical sounding technique applied in this study was the Schlumberger method. The alternating current (AC) was obtained from a 500 watt Honda generator which was then transformed into a direct current (DC) with a potential of 220 - 440 Volt. This electrical current was introduced into the ground via two current electrodes (A and B). The change in potential induced by the electrical current was measured using two potential electrodes (M and N) after passing a compensator. This compensator was necessary for eliminating spontaneous potential from the ground. The electrical current (I) and the potential difference (□V) were measured using two digital multimeters.

The array of the electrodes in Schlumberger method is as follows: L/2 (half A-B) is always the same or higher than 5 x $\frac{a}{2}$ (half M-N). In another words, AB ≥ 5MN. The extent of the current electrodes (L/2) was 250 meters, thus the depth that can be estimated was L/2 (meters).

The resistivity is calculated using the formula written as:

$$\rho_a = C\frac{\Delta V}{I} \qquad \text{(Zohdy, 1980)} \qquad (3)$$

where

ρ_a = apparent resistivity (in ohm meter)

C = a constant which depends on the extent and the array of the electrodes. Here,

$$C = 2\pi\left(\frac{1}{\overline{AN} - \overline{AM} - \overline{BN} - \overline{BM}}\right) \qquad (4)$$

ΔV = potential difference (millivolt)

I = electrical current which was introduced to the ground (milliampere).

The array of the electrodes in the Schlumberger method is illustrated in Figure 2.

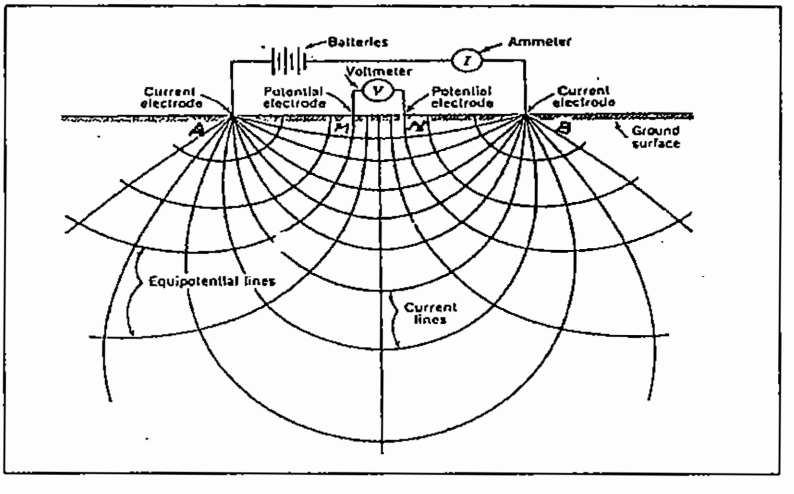
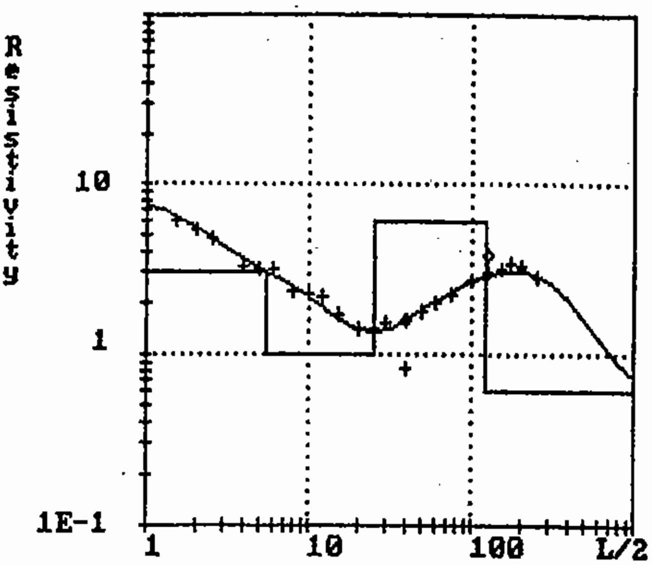


Figure 2. Geo-electrical sounding with a Schlumberger array (after Todd, 1980)



Data (File) name	PU 01-01 .	Data	18.10.1996
Project name	1 Brebes	Direction lay out	TMA .9 m
Code name	Losari kidul	Remarks	DHL 4690 um/cm
Coordinates	9241656/258568	Schlumberger	O'Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.5	6.0	15.0	1.7	100.0	2.7
2.0	5.5	20.0	1.4	125.0	3.0
2.5	4.8	25.0	1.4	125.0	3.9
4.0	3.3	30.0	1.5	150.0	3.1
5.0	3.2	40.0	0.8	175.0	3.4
6.0	3.2	40.0	1.6	200.0	3.3
8.0	2.3	50.0	1.8	250.0	2.8
10.0	2.3	60.0	2.0		
12.0	2.2	70.0	2.3		

Resistivity (Ohm.m)	Depth (m)
8.0	1.0
3.0	5.5
1.0	25.0
6.0	120.0
0.6	

Figure 3. An example of interpretation using the Schlumberger O'Neill program. The interpretation shows the resistivity and the depth of each layer

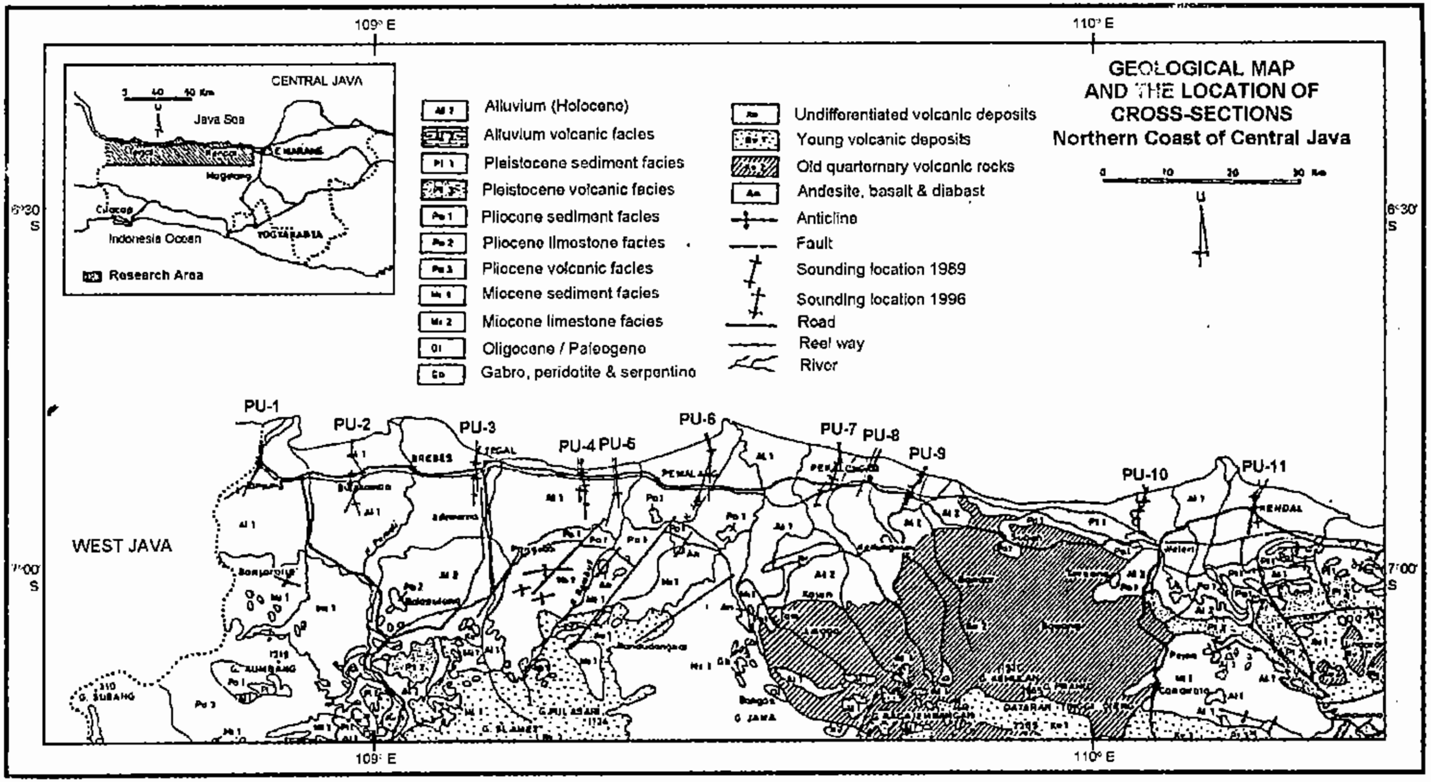


Figure 4. Geological Map and the Location of Geo-electric Cross-sections at Northern Coast of Central Java (From Brebes Residency to Kendal Residency)

The geo-electrical sounding data, i.e. L/2 and resistivity ρ_a, obtained from the field were put into a Schlumberger O'neill computer program. Interpretation was then conducted to obtain resistivity values (namely ρ_1, ρ_2, ρ_3 and so on) as well as the depth of each layer. An example of the interpretation result is provided in Figure 3.

In Figure 3. the Y-axis is the resistivity while the X-axis is the depth. Symbol (+) shows the measured resistivity value while symbol (---) shows the applied standard curve. The solid line indicate the result of the interpretation. In order to obtain resistivity profile of the coast toward the land, the soundings were performed in two to three points. In doing so, a cross-section is produced by interpolating one to another point.

The fieldwork was conducted in 1989 and in 1996. According to the former plan, monitoring will be conducted in the year of 2001, but until May 2001 there is no sponsor yet. There is also a plan of a student of the Faculty who will take this matter for his thesis.

Both the 1989 and 1996 field works were conducted over the northern coastal area of the Central Java Province, i.e. from Brebes to Rembang. In the future, the monitoring will only be performed in the area covering Brebes to Kendal.

In this paper, the focus is placed upon the result of geo-electrical sounding over Brebes to Kendal (see Fig.4). There are 11 cross-sections to be discussed (see Appendix). If a resistivity of less than 1 ohm meter is found in the cross-section, while this cross-section is separated from sea-salt water, then the ground-salt water is not brought in by the sea water intrusion but is caused by the connate water. It also can be informed that ground water samples taken from these areas by the students of the Faculty of Geography, Gadjah Mada University and the students of the Free University, Amsterdam, show that the water is entrapped in the rock for such a long time (Kloosterman. 1989).

RESULTS

Initially, both the 1989 and 1996 field works were not specifically conducted for seawater intrusion monitoring purposes. Actually there were more than 20 sounding points with different locations that they cannot be used for monitoring purposes.

Among them, eleven points were chosen for monitoring purposes due to the fact that they were located at the same locations (or relatively close) both in the 1989 and 1996 sounding. Hereinafter the cross-sections is called cross-section PU1, PU2, ..., PU11 where PU is an abbreviation of *Pantai Utara* meaning a northern coast. The file name is PU 01-01, PU 01-02 and so on. The location, including the name of the village and the UTM grid of each sounding is provided in Table 1.

Table 1. Detail information about the locations where geo-electrical sounding was performed as well as the depth of the interface in 1989 and 1996.

Cross Section	1996			1989			District
	Name of Kampong	UTM grid South-East (m)	Depth of interface	Name of Kampong	UTM grid South-East	Depth of interface (m)	
PU1	Losari kidul Kedungdeng	92417-2585 92389-2565	120 -	Losari Kedungmeneng Babakan	92419-2582 92392-2568 92379-2549	- - -	Brebes
PU2	Pulanggadung Pakijangan Bulusari	92428-2731 92404-2747 92376-2734	95 - -	Bulakamba Bulusari Rancawuluh	92402-2728 92385-2724 92357-2731	- - -	Brebes
PU3	Kraton Lor Debong	92413-2924 92387-2927	- -	Tegalsari Debong Pagongan	92413-2922 92388-2922 92360-2922	- - -	Brebes
PU4	Surodadi Bulakbanteng	92391-3095 92369-3092	- -	Surodadi Bulakan Pondokjali	92392-3093 92368-3099 92346-3090	- - -	Tegal
PU5	Badur Banjaranyar	92388-3147 92363-3148	150 160	Badur Banjaranyar Kandayaan	92389-3145 92362-3144 92329-3136	160 - -	Pemalang
PU6	Klarean Bulu	92429-3301 92388-3296	80 -	Klarean Bulu Sitemu	92428-3302 92391-3291 92351-3278	- - -	Pemalang
PU7	Randuwotan Pakuncen	92400-3490 92385-3485	110 -	Api-api Mejayu Kampil	92405-3490 92386-3480 92367-3462	- - -	Pekalongan
PU8	Krpyak lor Kranding	92404-3540 92399-3520	- -	Ranca Panjangkulon Tegalrejo	92406-3534 92396-3531 92368-3518	- - -	Pekalongan
PU9	Karangsari Batang	92390-3610 92373-3594	- -	Karangsari Pejangkaran Singosari	92381-3610 92374-3596 92353-3583	- - -	Batang
PU10	Sendang Gempolsari	92360-3962 92347-3953	58 -	Sendang Krangkong Rowosari	92381-3957 92348-3953	- - -	Kendal
PU11	Betakmalang Karangsari	92364-4124 92346-4127	- -	Betakmalang Srendeng Sukodono	92360-4129 92353-4126 92323-4119	- - -	Kendal

Cross-section number 1 (PU1)

This cross-section is located in Brebes district. In 1989, there were three locations (Losari, Kedungmeneng, and Babadan) while in 1996 there were only two locations (Losari kidul and Kedungdeng).

In 1989 there was no interface detected. On the contrary, in 1996 in the Losari site there was an interface detected at the depth of 120 meter.

Cross-section number 2 (PU2)

This cross-section is located in Brebes district. In 1989, there were three sounding points (Bulakamba, Bulusari and Rancawuluh) and no interface was detected. In 1996, there were also three measurement points (Pulau Gadung, Pakijangan and no name). At Pulau Gadung which is closed to the Bulakamba, an interface at the depth of 95 meters was observed.

Cross-section number 3 (PU3)

This cross-section is in Brebes district. In 1989, there were three sounding points (Tegalsari, Debong and Pagongan). At that time, there was no interface detected. In 1996, there were two sounding points (Kraton Lor and Debong) and no interface was detected.

Cross-section number 4 (PU4)

This cross-section is located in Tegal district. In 1989 there were three sounding points, i.e at Surodadi, Bulakan and Pondok Jati. Interface did not exist. In 1996, there were two sounding points, i.e. at Surodadi and Bulakbanteng. Interface was not detected.

Cross-section number 5 (PU5)

This cross-section is in Pemalang district. In 1989, there were three sounding points, i.e. at Badur, Namjaranyar and Kendayaan. Interface was observed at the depth of 160 m. In 1996, there were two sounding points, i.e. at Badur and Banjaranyar. The interface found in Badur and Banjaranyar was at the depth of 150 m and 160 m respectively.

Cross-section number 6 (PU6)

This cross-section is in Pemalang district. In 1989, there were three locations i.e. Klarean, Bulu and Sitemu, there was no interface detected. In 1996, there were two points i.e. at Klarean and Bulu. An interface was detected at Klarean at the depth of 80m.

Cross-section number 7 (PU7)

This cross section is in Pekalongan district. In 1989, there were four locations (Api-api, Mejayu, Kanyil and Kadipaten Kidul), interface had not been detected. In 1996, there were two sounding points i.e. Randuwotan (next to Api-api) and Pakuncen. An interface was detected at Randuwotan at the depth of 110 m.

Cross-section number 8 (PU8)

This cross-section is in Pekalongan district. In 1989 there were three locations i.e. Ranca, Panjang Kulon and Tegalrejo. There was not any interface observed. In 1996, there were two locations (Krapyaklor and Kranding) where there was no interface detected.

Cross-section number 9 (PU9)

This cross-section is in Batang district. In 1989, there were three sounding points (Karangsari, Pejangkaran and Singosari) while in 1996 there were two locations (Karangsari and Batang). In both years, there was no interface observed.

Cross-section number 10 (PU10)

This cross-section is in Kendal district. In 1989, there were two locations (Sedang and Krangkang) and no interface was detected. In 1996, there were two locations i.e. at Sendang and Gempol Sari). An interface was observed at Sendang at the depth of 58 m.

Cross-section number 11 (PU11)

This cross-section is in Kendal district. In 1989, there were three sounding points (Betakmalang, Srendeng and Sukodono) while in 1996 there were two locations (Betakmalang and Karangsari). There was not any interface detected in both years.

DISCUSSIONS

Taking the land use surrounding each cross section into consideration, the discussion of the results of each cross section can be given as follows.

Cross section number 1 (PU1)

This location is an extensive and a wide fish pond area where most of the fish companies pump the groundwater in order to fulfil their fish pond needs. Additionally, this is a developed residential area due to its position which is at the intersection of an alternative road (simpang Losari), i.e. in the direction to Purwokerto.

In Losari (UTM grid of 92417-2585), there was no interface in 1989. On the contrary, in 1996 there was an interface at the depth of 120 located at approximately 3.4 km of the coastline. It is suspected that the rise of such interface was triggered by the extensive pumping of the groundwater by the fish pond industry. This matter requires a further study for studying the relationship between the amount of groundwater being pumped and the increasing of an interface. In addition to the interface, connate water at the depth of up to 20 meters was also found in Losari.

Cross section number 2 (PU2)

Both Bulakamba (UTM grid 92403-2729) in 1989 and Pakijangan (UTM grid 92404-2746) in 1996 showed no interface. At the same time, however, in Pulanggadung (UTM grid 92428-2731), a wide fish pond area, there was an interface observed at the depth of 95 meter at around 500 m from the coastline.

In addition to the interface, connate saline water was also detected at each sounding point, thus at all the cross section and the surrounding area. The depth of the connate water ranges from 5 to 20 meters with a thickness ranging from 15 to 30 meters.

Cross section number 3 (PU3)

This section is located at an urban area and partly crosses the fishpond area. Both soundings performed in 1989 and 1996 showed no interface. In Kraton Lor (UTM grid 924128-2924) the occurrence of connate saline water at the depth ranging from 5 to 20 meters was detected. In Debong (UTM grid 923877-2927) the connate saline water was observed at the depth of 10 to 30 meters.

In this location, there are three rivers running so close to each other, i.e. Watgalik, Gung, and Wadas River. Although no interface is detected, there are connate saline water lens at the depth ranging from 5 to 25 meters.

Cross section number 4 (PU4)

In this location, there is no fish pond and the residential area is relatively small. It is not surprising if there was no interface detected in both 1989 and 1996 field works. Geomrphologically, this location lies on top of the Balapulang aluvial fan so that the fresh groundwater runs from a wide recharge area. In the Sidodadi to Bulakan area, connate saline water was found at depth of 40 meters.

Cross section number 5 (PU5)

In this location, the residential area and fish pond is quite small. The groundwater is not yet pumped to fulfil the need for fish pond. In Badur (UTM grid 92389-3145), in 1986 the interface was found at the depth of 160 meters while in 1996 the interface was getting shallower (i.e. at 150 meters). The connate saline water was also detected in Badur at 10 meters depth.

In Banjar anyar (UTM grid 92363-3296), an interface did not exist in 1989. However, in 1996 an interface was detected at the depth of 160 meters. This is presumably caused by the extensive use of the groundwater.

Cross section number 6 (PU6)

This location is characterized by a big fish pond where ground water is extensively used. In Klarean (UTM grid 92429-3301), no interface was detected in 1989. In 1996, an interface was observed at the depth of 80 meters. Since the groundwater used for residential and industrial areas are relatively zero in this area, such interface must be due to the use of groundwater for the fish pond. In Klarean, there was also connate saline water at the depth of 10 to 40 meters.

Cross section number 7 (PU7)

A large fish pond and a small residential area are the feature of this location. In Randuwetan (UTM grid 92400-3490) no interface was found in 1989. In 1996, an interface was found at 110 meters. The existence of such interface, therefore, is resulted from the extensive pumping of the groundwater for fulfilling the need of the fish pond.

In addition to the interface, connate saline water was also observed at the depth ranging from 5 to 60 meters.

Cross section number 8 (PU8)

There is no fish pond at this location. Likewise, there was no interface detected. Connate saline water lens were observed at the depth ranging from 5 to 25 meters.

Cross section number 9 (PU9)

No interface was detected in both 1989 and 1996. This area, where the city of Batang is located, has no fish pond. Hence, the domestic and industrial uses of the ground water do not largely influence the seawater intrusion. Small connate saline water lens at the depth up to 10 meters were noticed in Karangsari (UTM grid 92390-3610).

Cross section number 10 (PU10)

Although fish pond in this area is small, the company uses the groundwater intensively. In Sendang (UTM grid 92360-3962) there was an interface (58 meters) in 1996 but none in 1989. This interface is presumably not only due to the intensive use of groundwater but also due to the small recharge area (i.e. ± 9 km) from the shoreline. In addition to the seawater intrusion, connate saline water was also observed (10-40 meters) in the area of Sendang to Gempolsari.

Cross section number 11 (PU11)

This location has a large fish pond and it is situated at the tidal flat so that the seawater enters the fish pond easily. There is no need to pump the groundwater for the fish pond. Here, interface was not detected in both 1989 and 1996. In Betakmalang (UTM grid 92364-4124) connate saline water was also observed at the depth between 5 to 50 meters. Its lens was observed up to Sukodono (UTM grid 92323-4119) with the depth of 5 to 20 meters.

CONCLUSIONS

Based on the discussion provided previously, it can be concluded that:

1. connate saline water was detected at every cross section at various depth. This is why some people find that their wells contain saline water.
2. there is a movement of seawater intrusion toward the land. This is marked by the existence of interface which was not observed before or the decreasing depth of the interface in 1996 (compared to the depth in 1989). It is also noticed that the existence of interface associate with the increasing amount of groundwater pumping for fish pond.
3. Interface movement can be monitored using the geo-electrical sounding technique.

SUGGESTIONS

It is important to monitor, at least every 5 years, the intrusion using the geo-electrical sounding technique, particularly over the area where the fish pond pumps the groundwater extensively. It is also important to study the relationship between the amount of groundwater being pumped and the increasing level of the interface.

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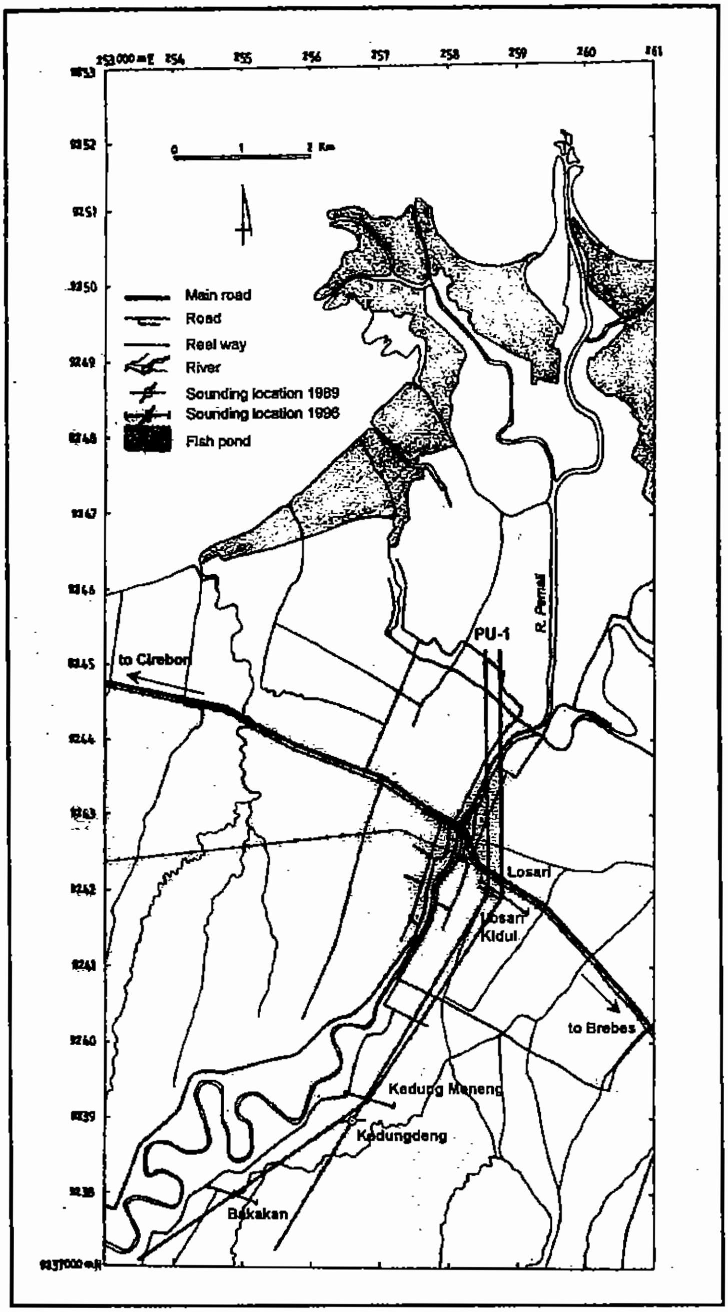
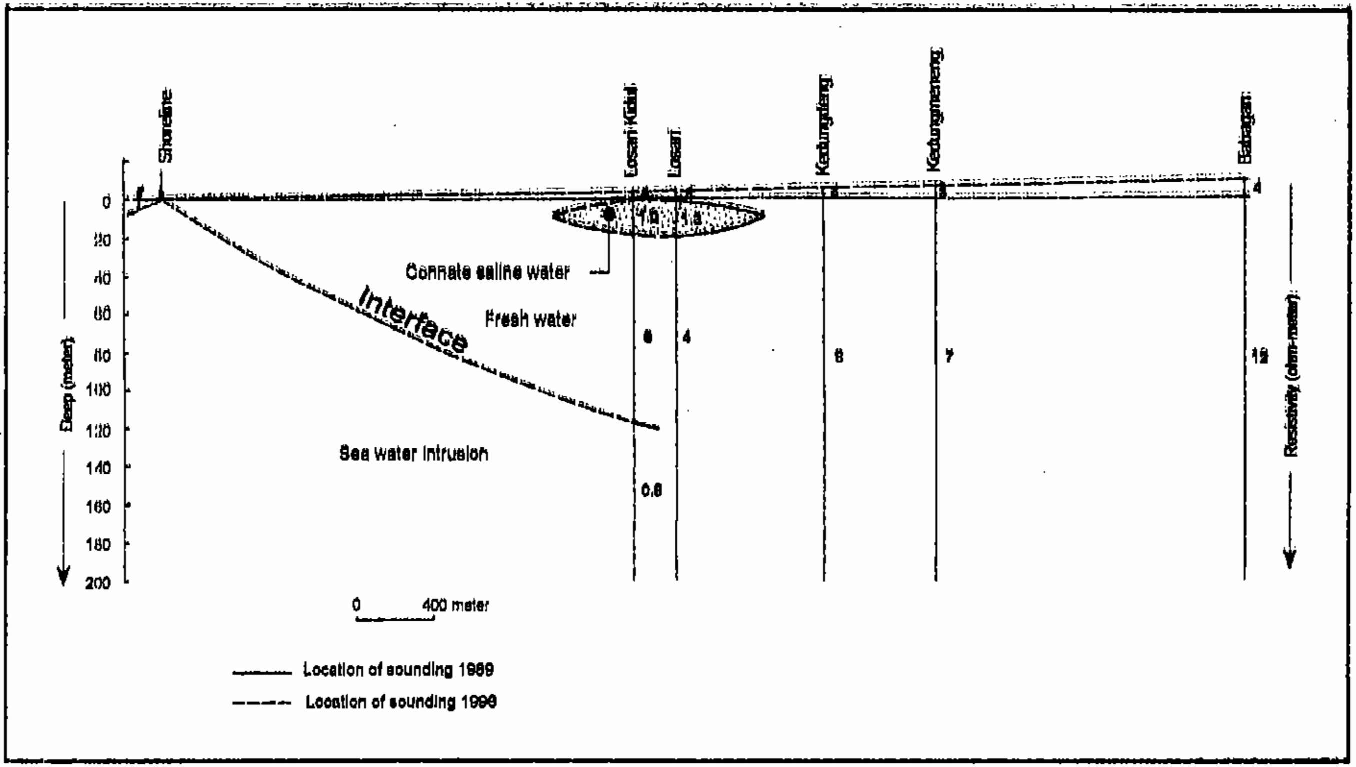
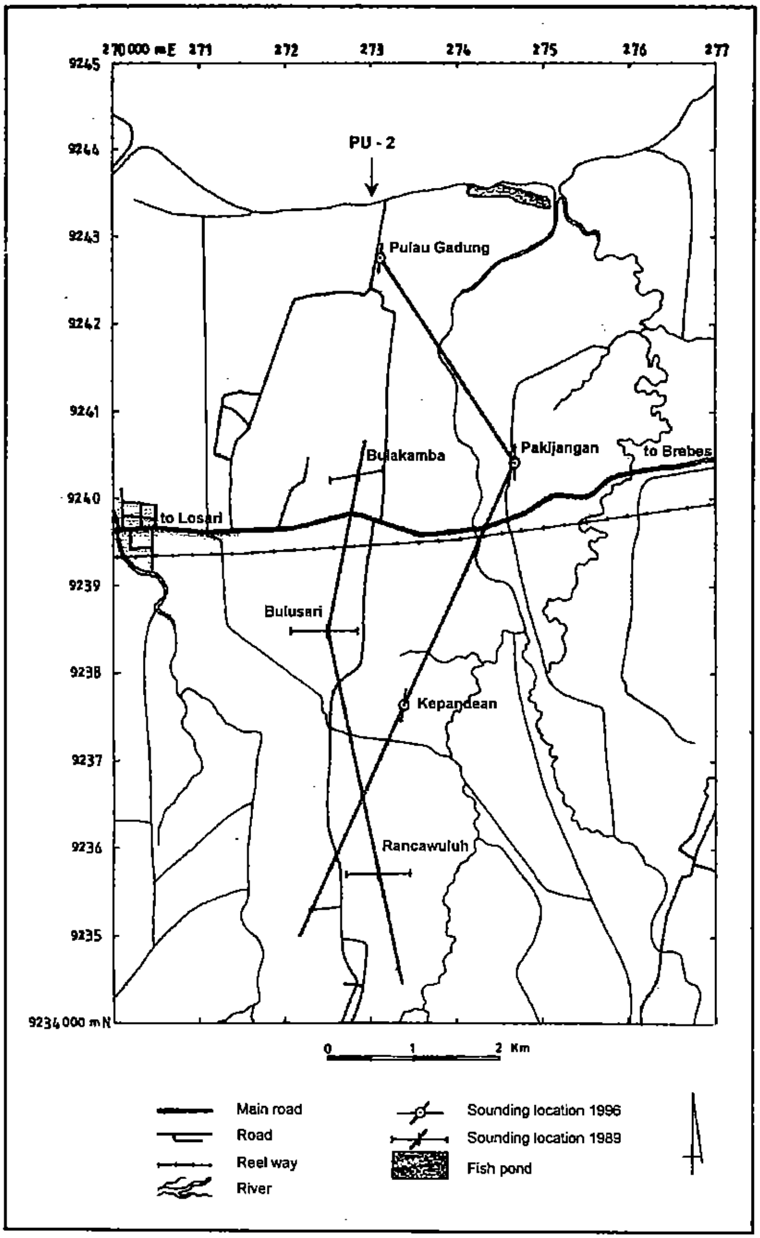


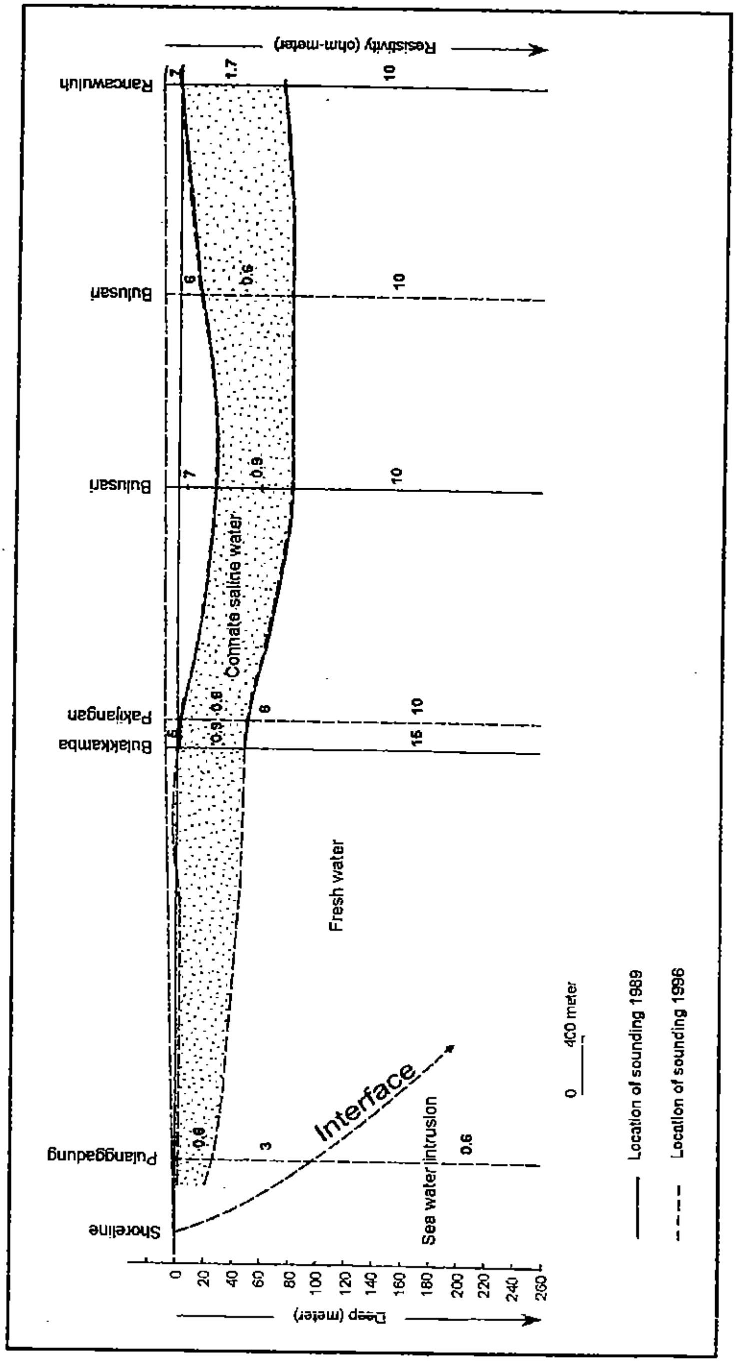
Location of Cross Section PU-1



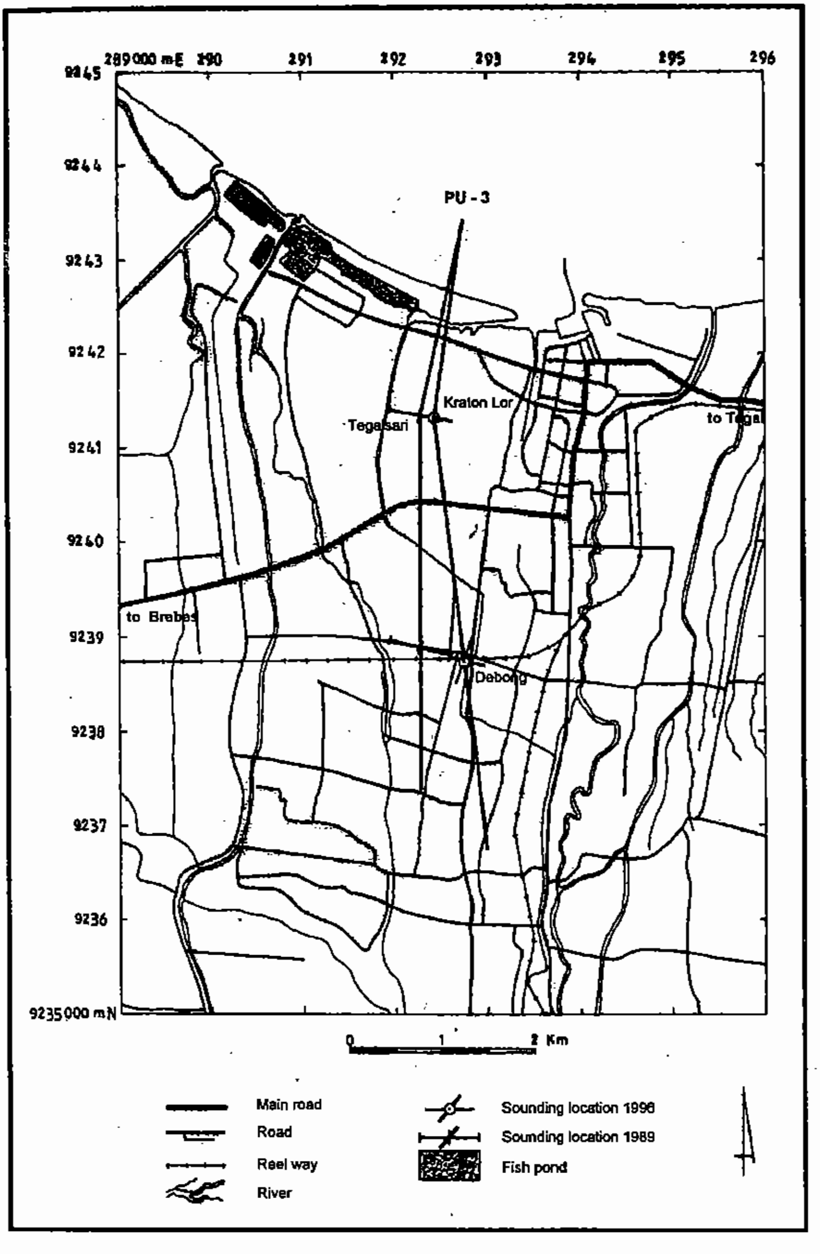
Cross-section of Resistivity PU-1



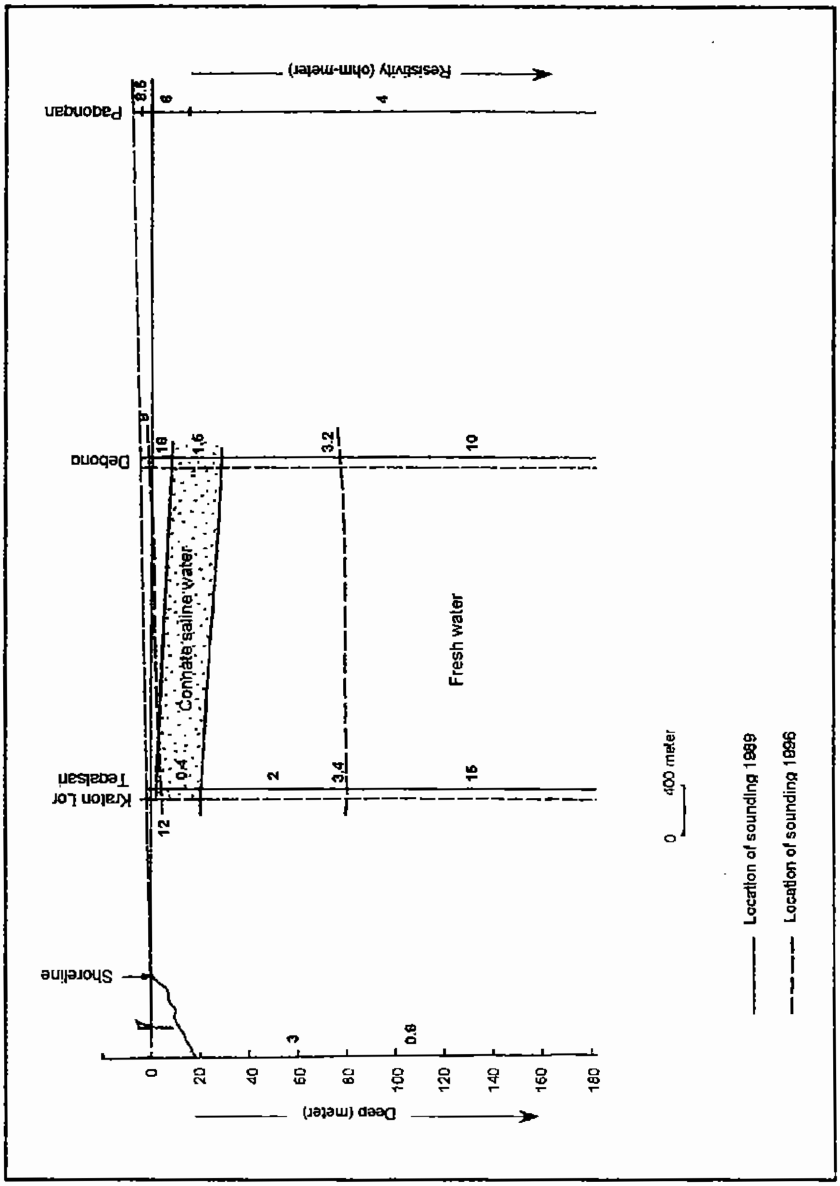
Location of Cross Section PU-2



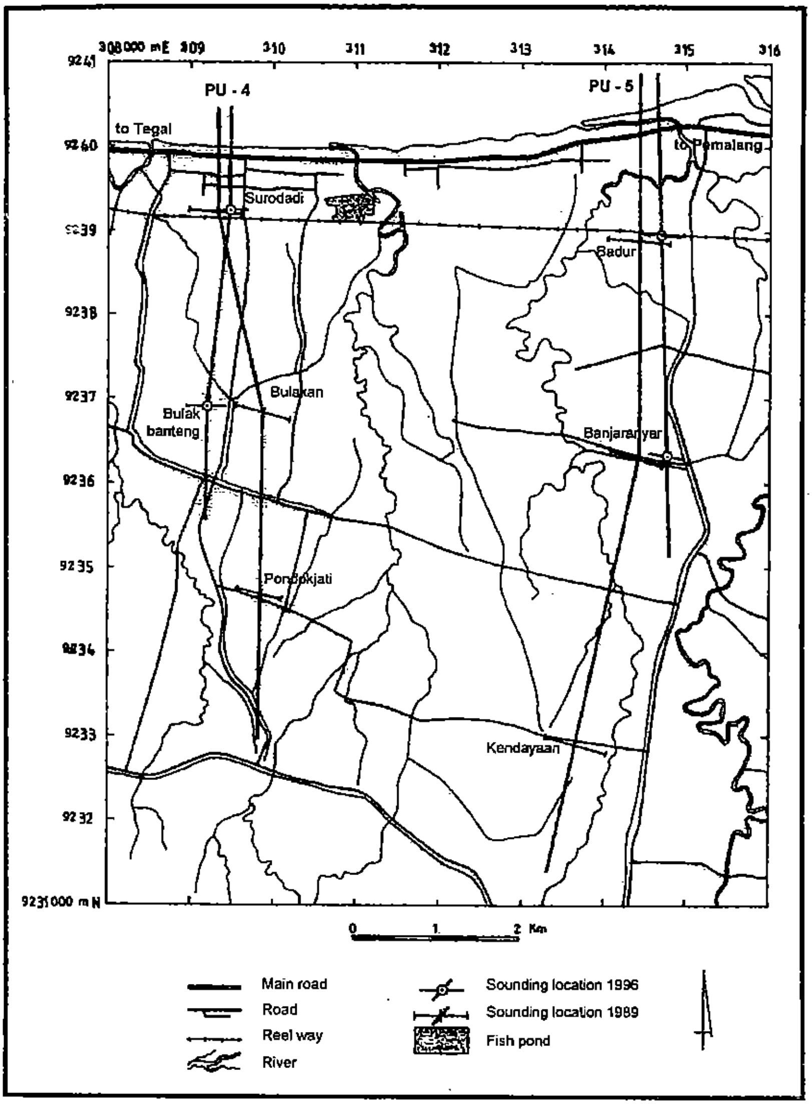
Cross-section of Resistivity PU-2



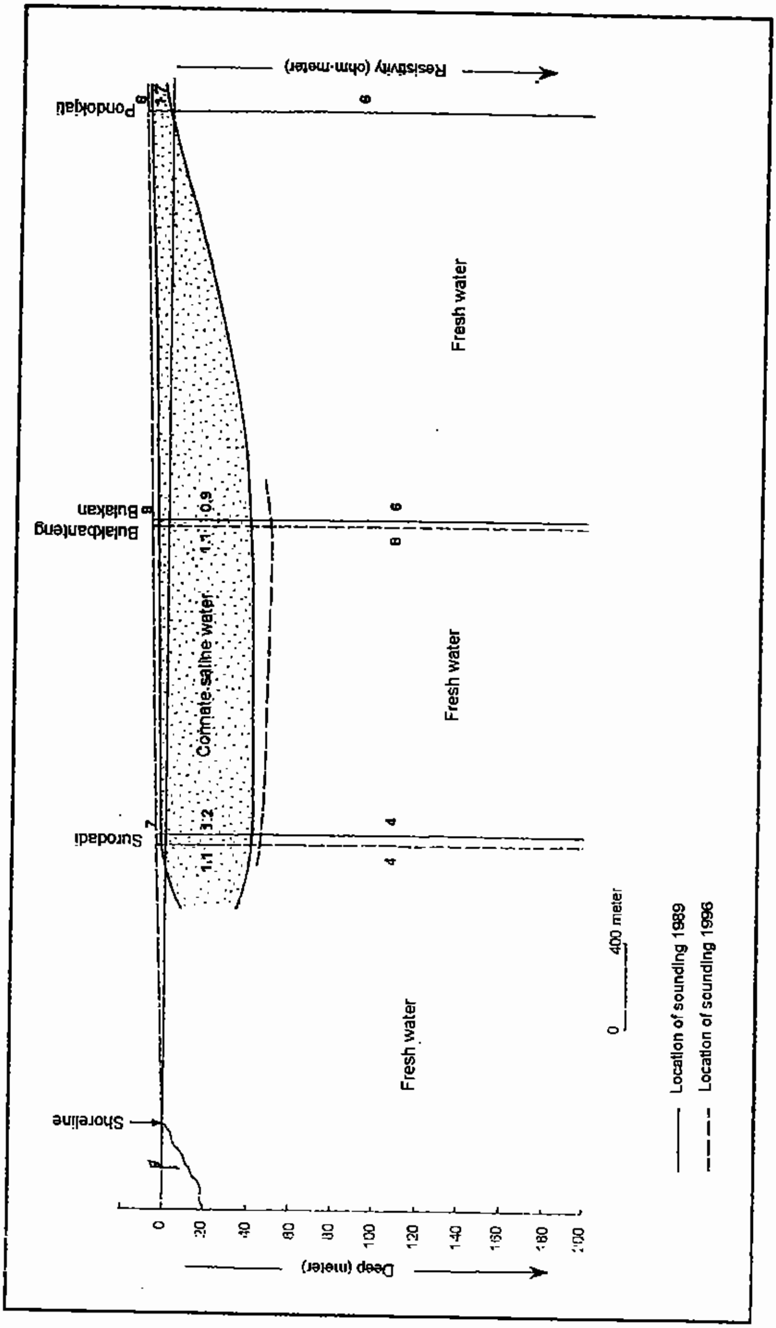
Location of Cross Section PU-3



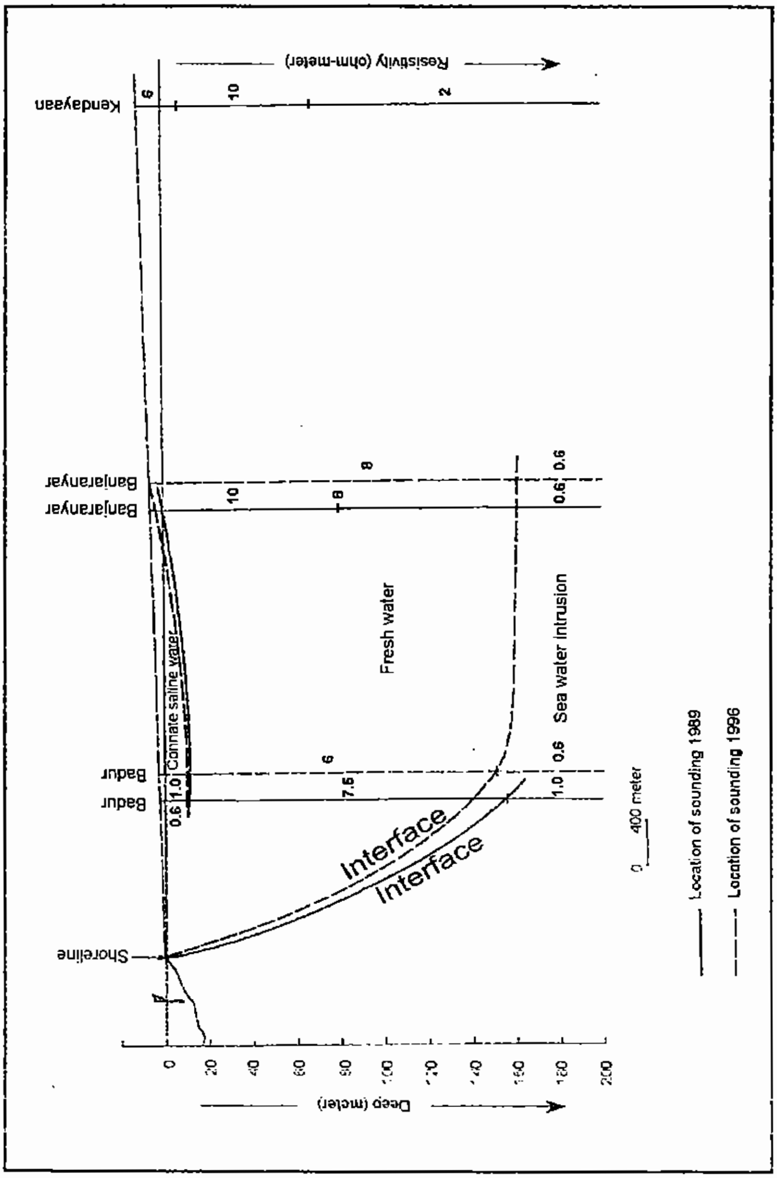
Cross-section of Resistivity PU-3



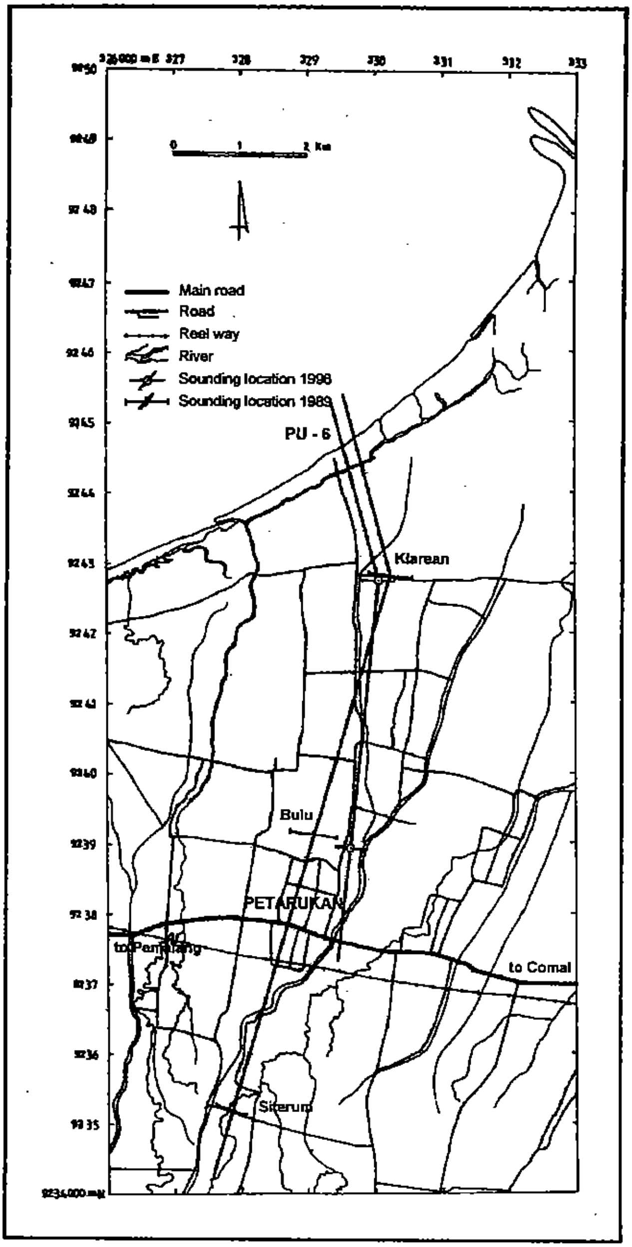
Location of Cross Section PU-4 and PU-5



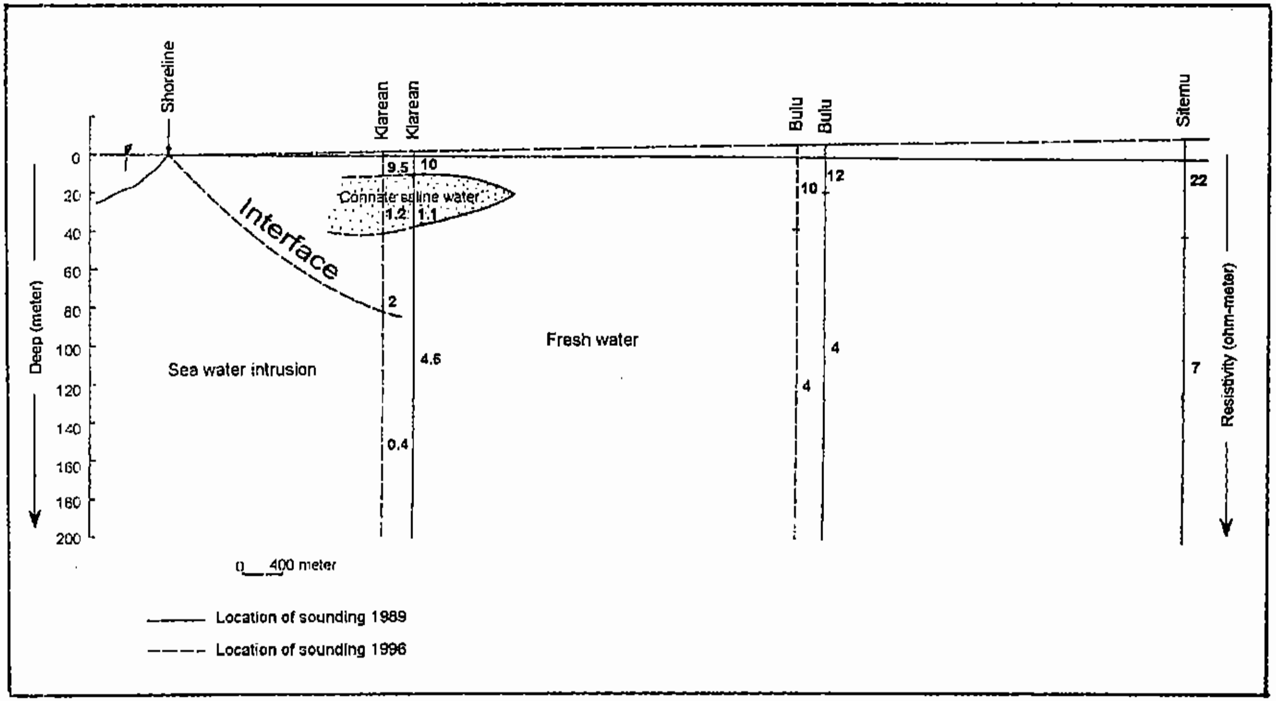
Cross-section of Resistivity PU-4



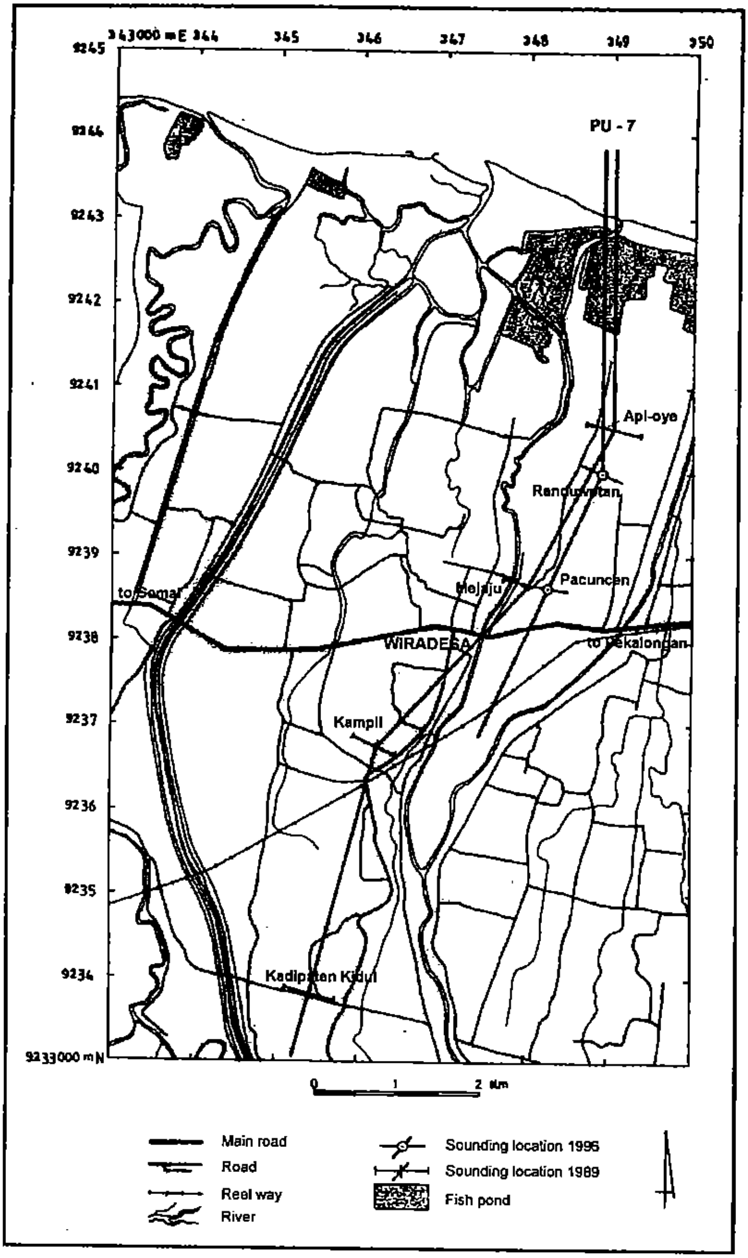
Cross-section of Resistivity PU-5



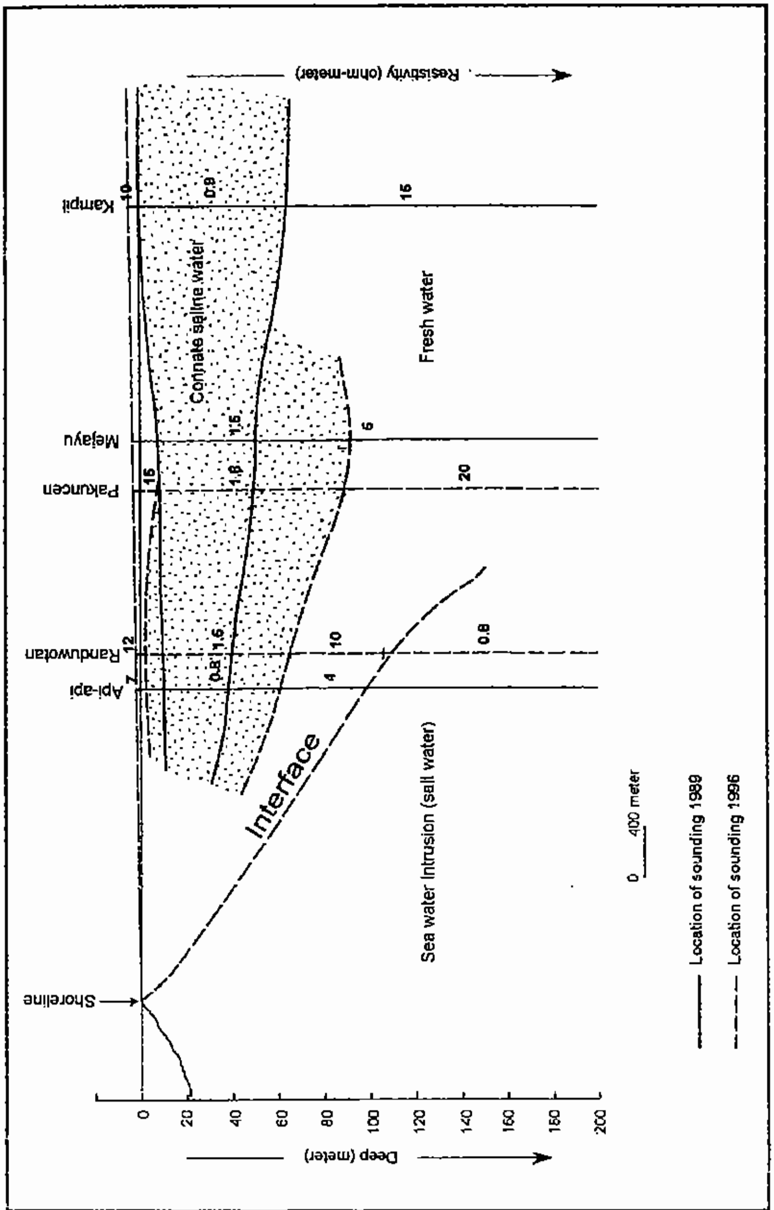
Location of Cross Section PU-6



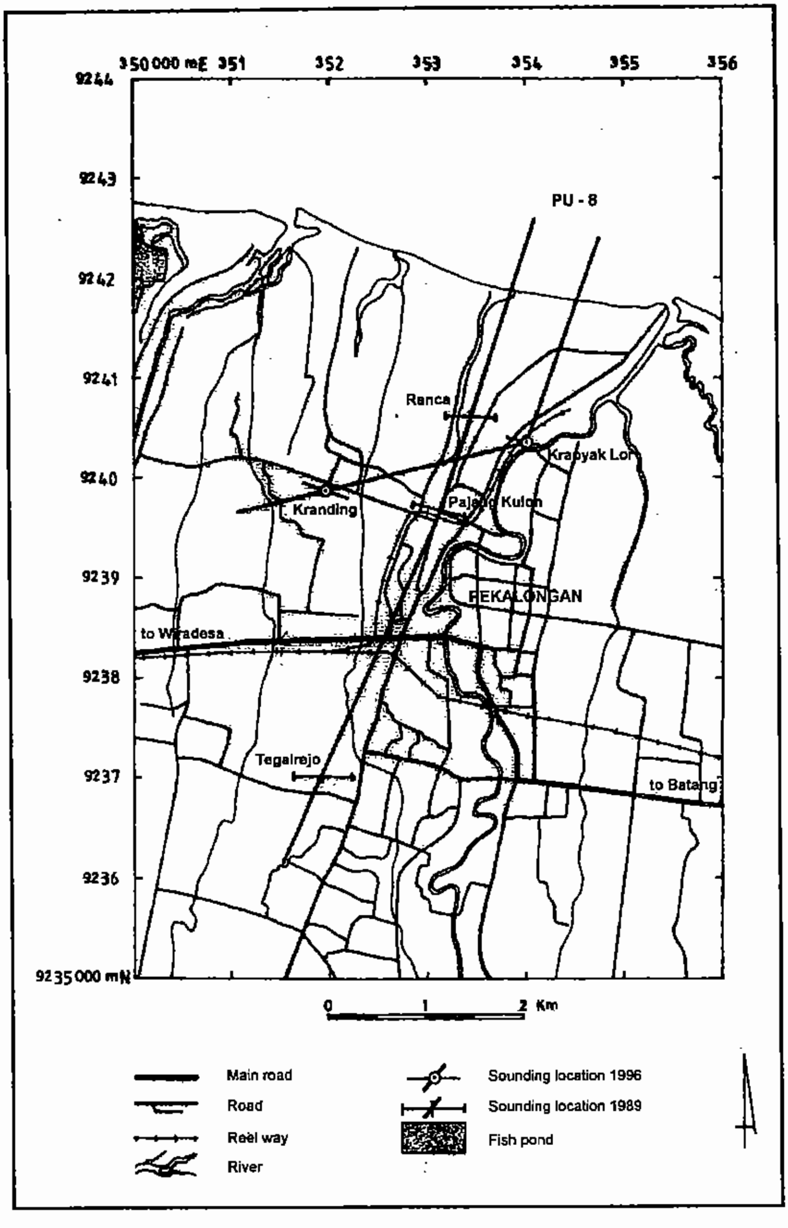
Cross-section of Resistivity PU-6



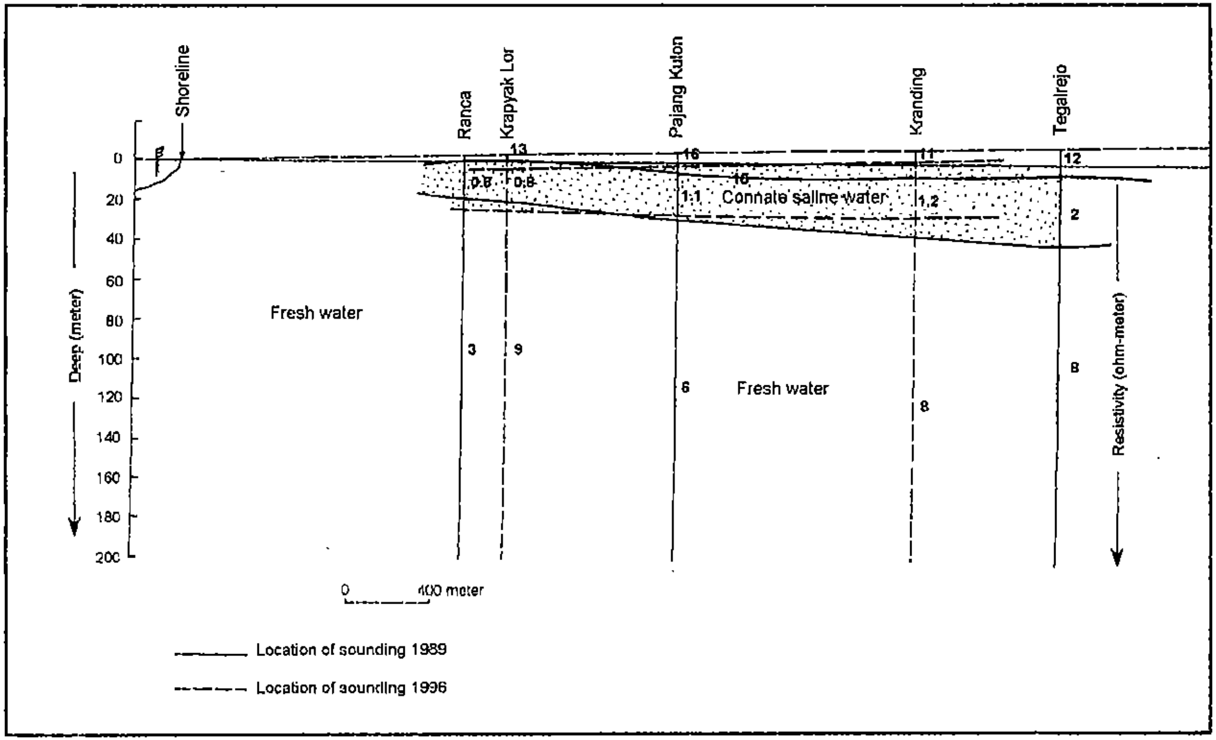
Location of Cross Section PU-7



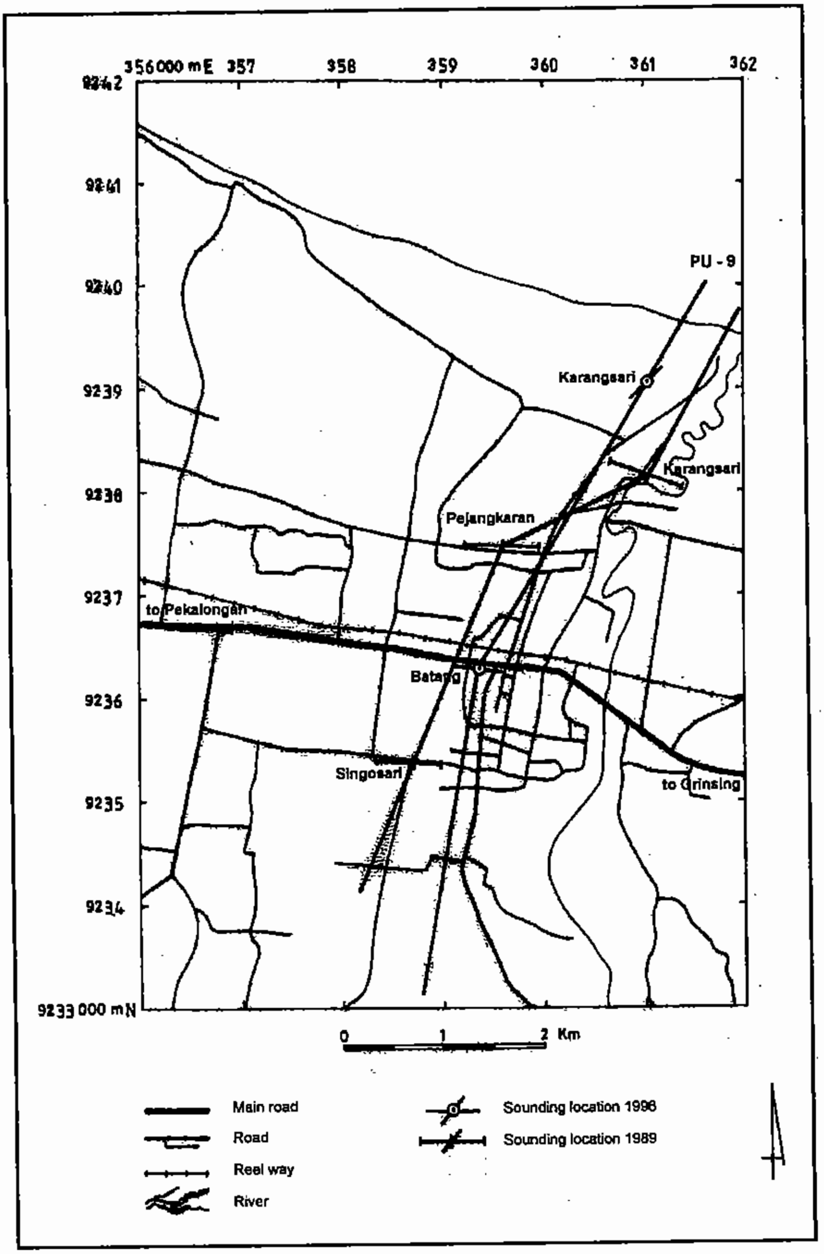
Cross-section of Resistivity PU-7



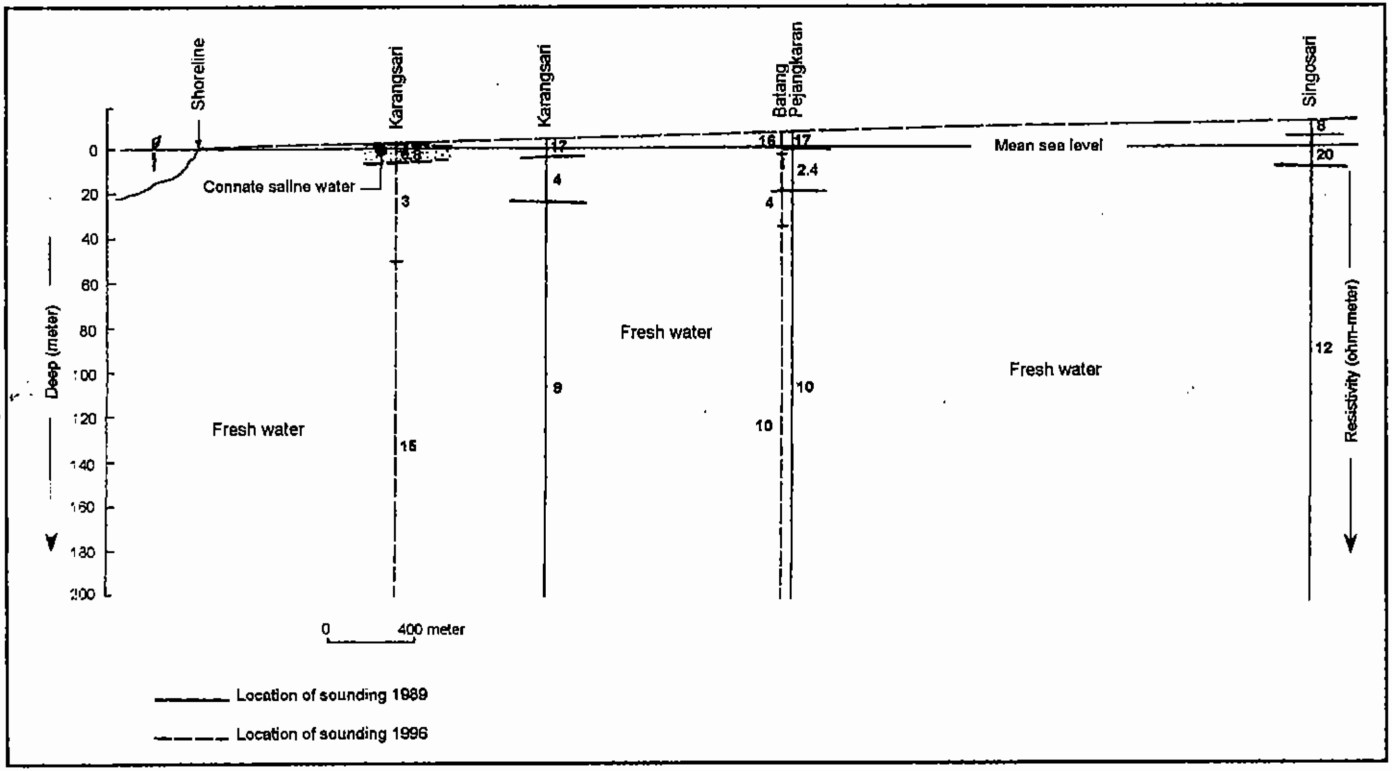
Location of Cross Section PU-8



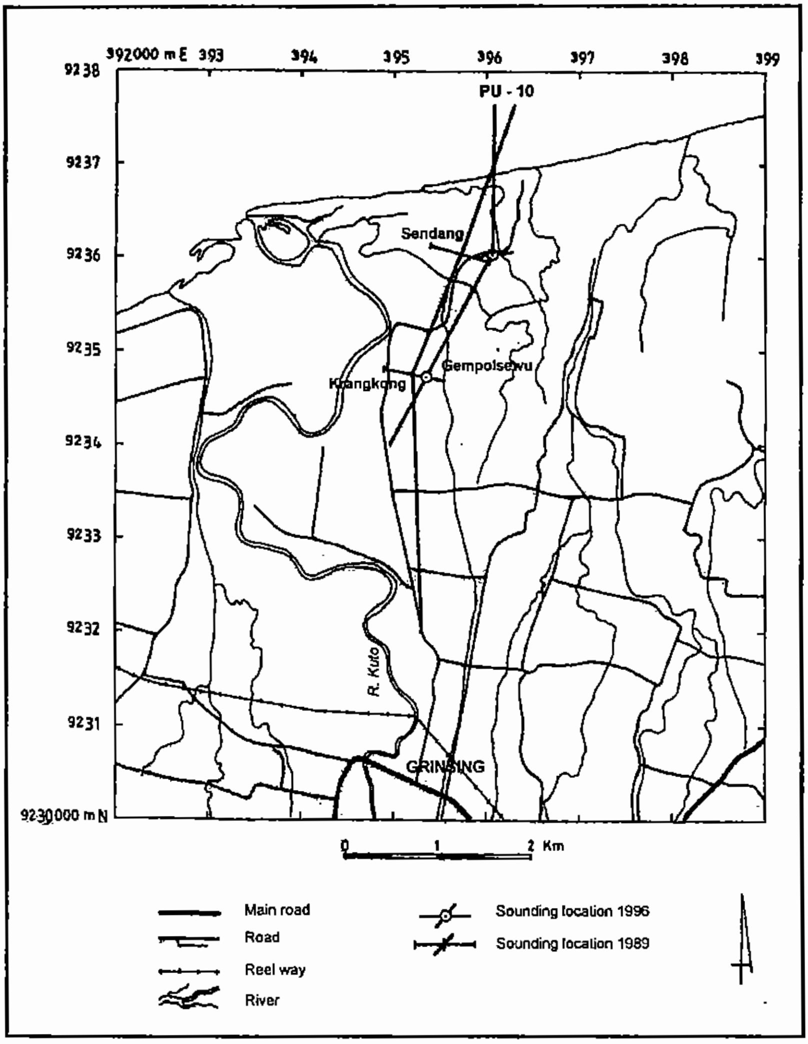
Cross-section of Resistivity PU-8



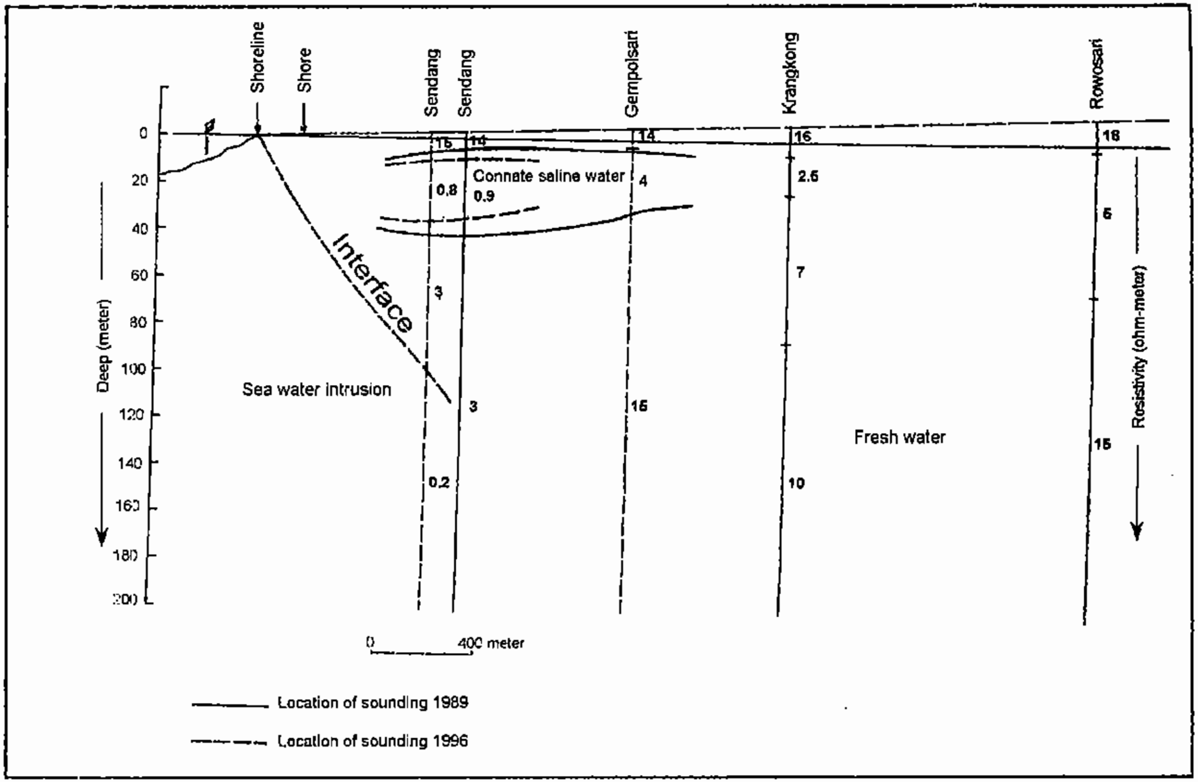
Location of Cross Section PU-9



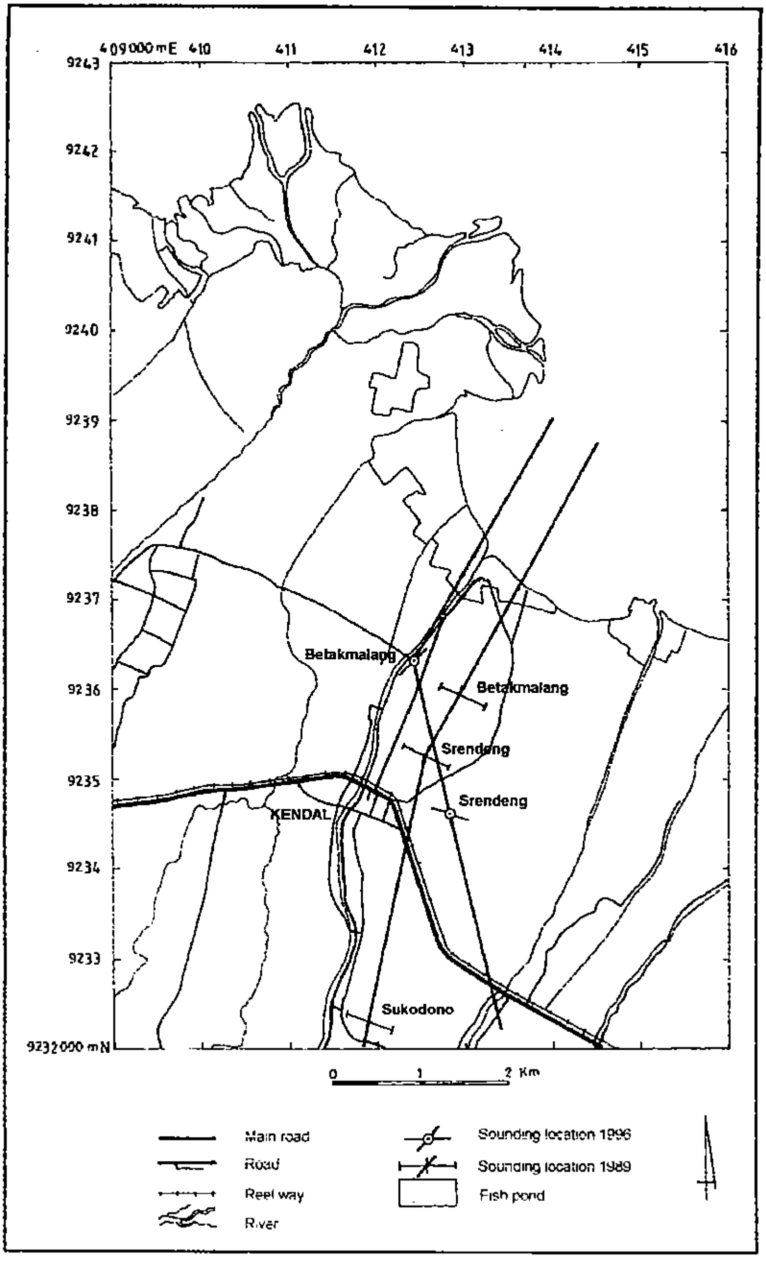
Cross-section of Resistivity PU-9



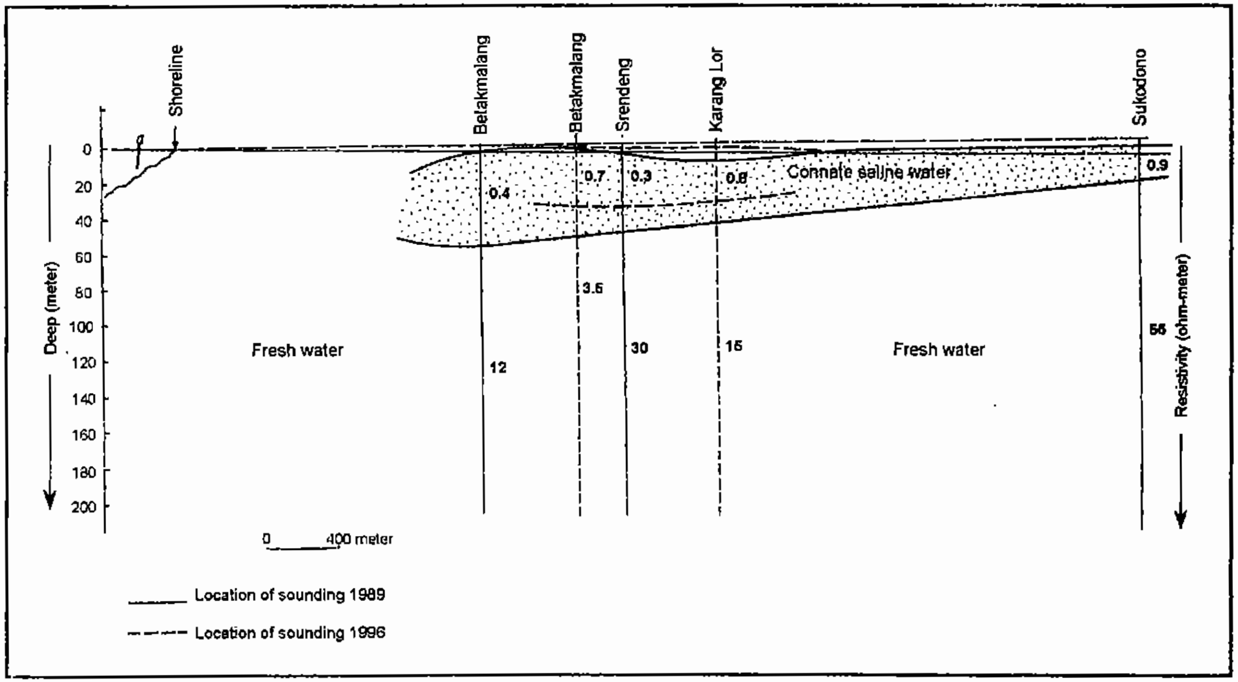
Location of Cross Section PU-10



Cross-section of Resistivity PU-10



Location of Cross Section PU-11



Cross-section of Resistivity PU-11