5.1.3.2 Groundwater & river water exchange

In order to determine the elevation of groundwater and river water level, nine (9) profiles were designated in the main rivers in the study area, and 12 auger sites and 21 river water level observation sites were selected along the profiles. Fig. 5.13 shows the location of the profiles and other survey points. The results of the survey are shown in Fig. 5.14 to 5.16. The following characteristics for each river basin were inferred from the profiles.

① Huai Hua Mueng River

- Upstream (Profile 1 & 2)

In the southwestern mountain area, groundwater level was higher than the river. The hydraulic gradient slopes toward the river from the mountain, and then from the river towards the northeast. At the old river course, 50 to 80m northeast of the present river course, groundwater level decreases to an extremely low point and then rises towards the eastern mountains. The hydraulic gradient shifts from the northeast to the southwest. However, reddish brown iron sediments in both banks of the river water level survey station at profile 2 indicate that groundwater flowed toward the river from both banks a little prior to the survey..

- Midstream & Downstream

(Profiles 3 & 4 (northern section), profile 6 (northwestern section))

The hydraulic gradient is from both banks toward the river.

② Huai Ron Na River

- Upstream (Profile 5)

While being recharged by groundwater from the mountain on the right bank (southern section), the river replenishes groundwater in the left bank. The lowest point in groundwater level was in the vicinity of the observation hole (Ah-51) about 50m north of the river; and groundwater flow direction then changed from northwards to southwards.

- Midstream & Downstream (Profile 4)

Groundwater flows from both banks toward the river.

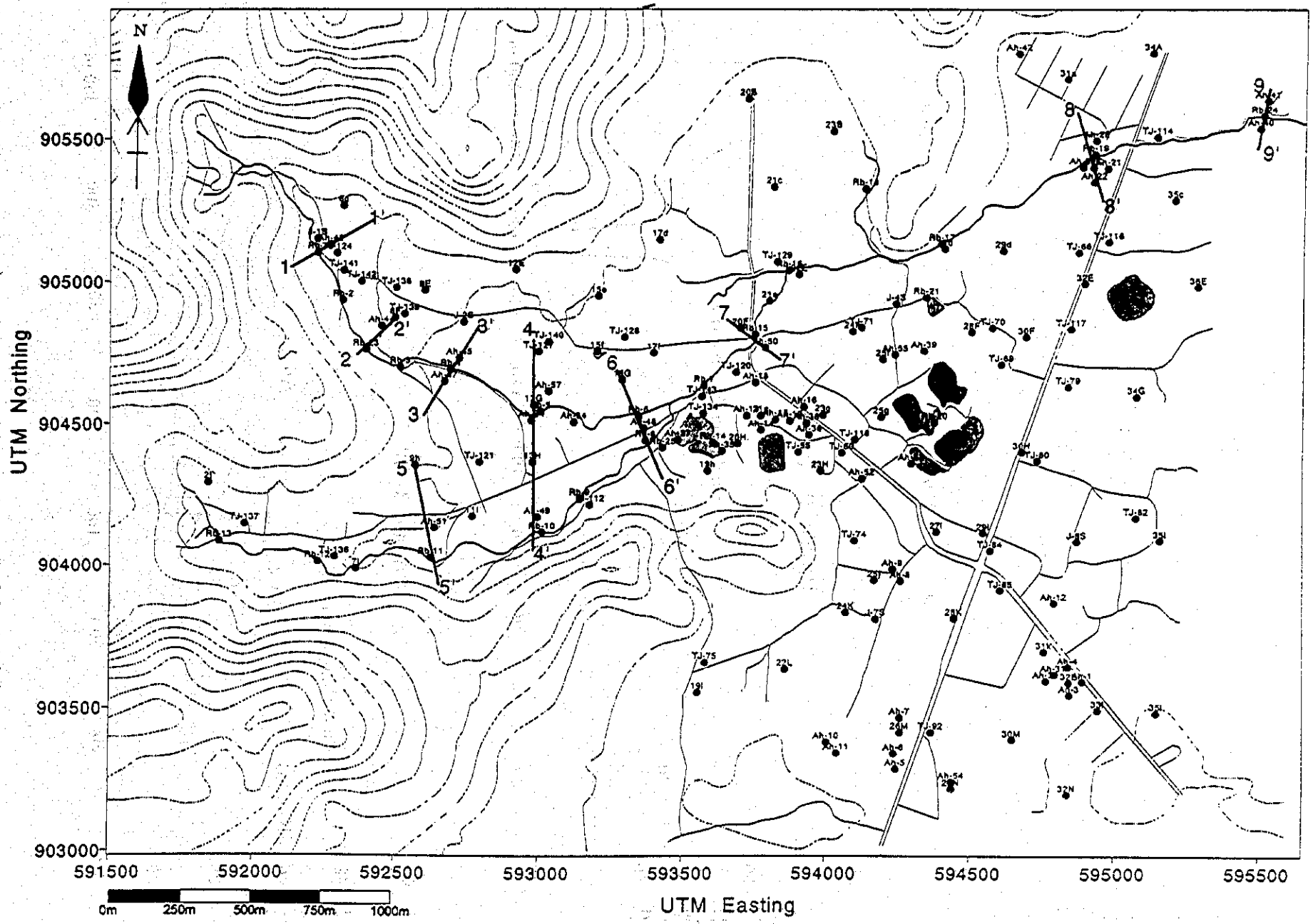

Fig 5.13 Location of Profiles along Rivers

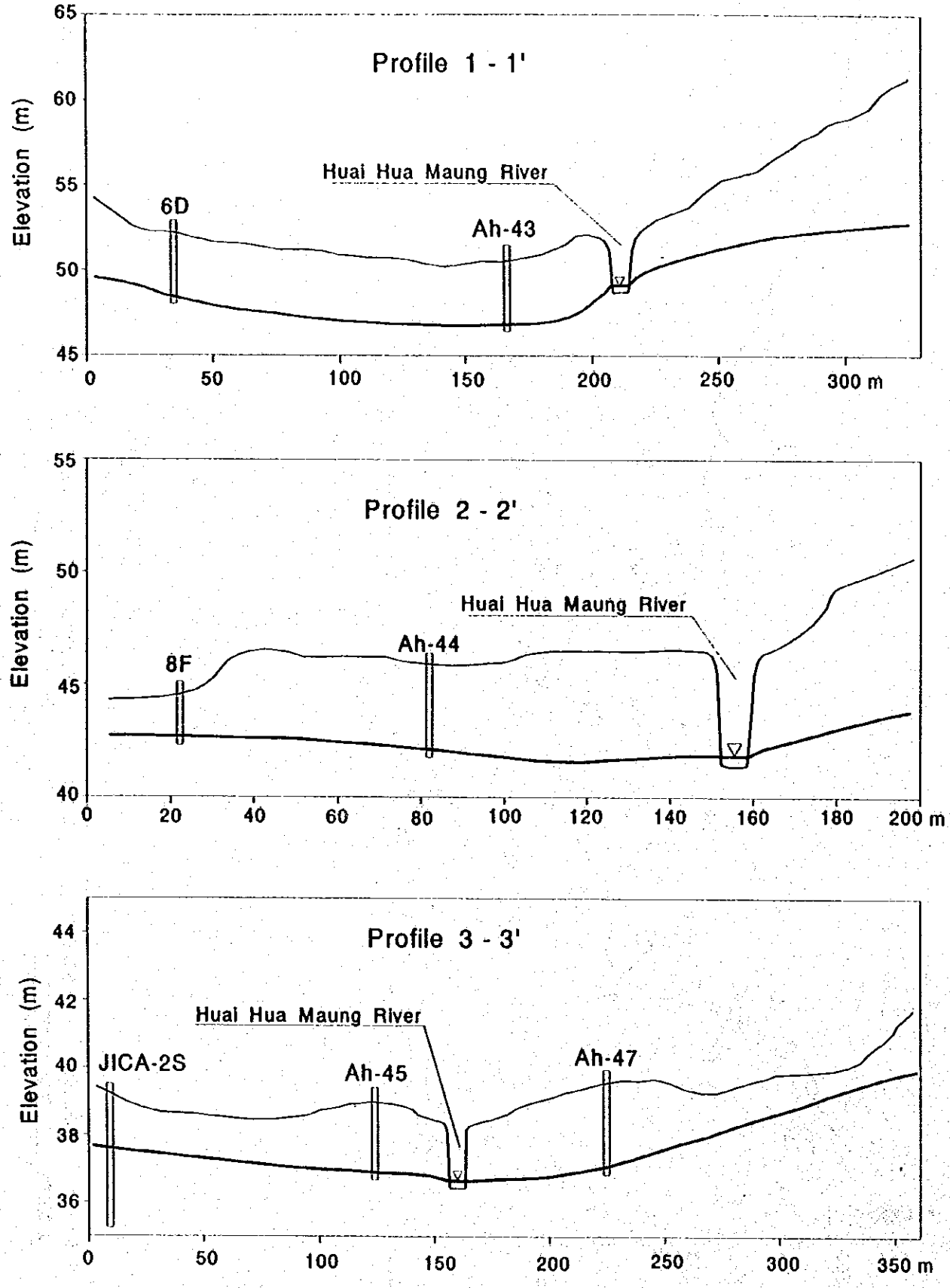

Fig 5.14 Profile 1-1' to 3-3'

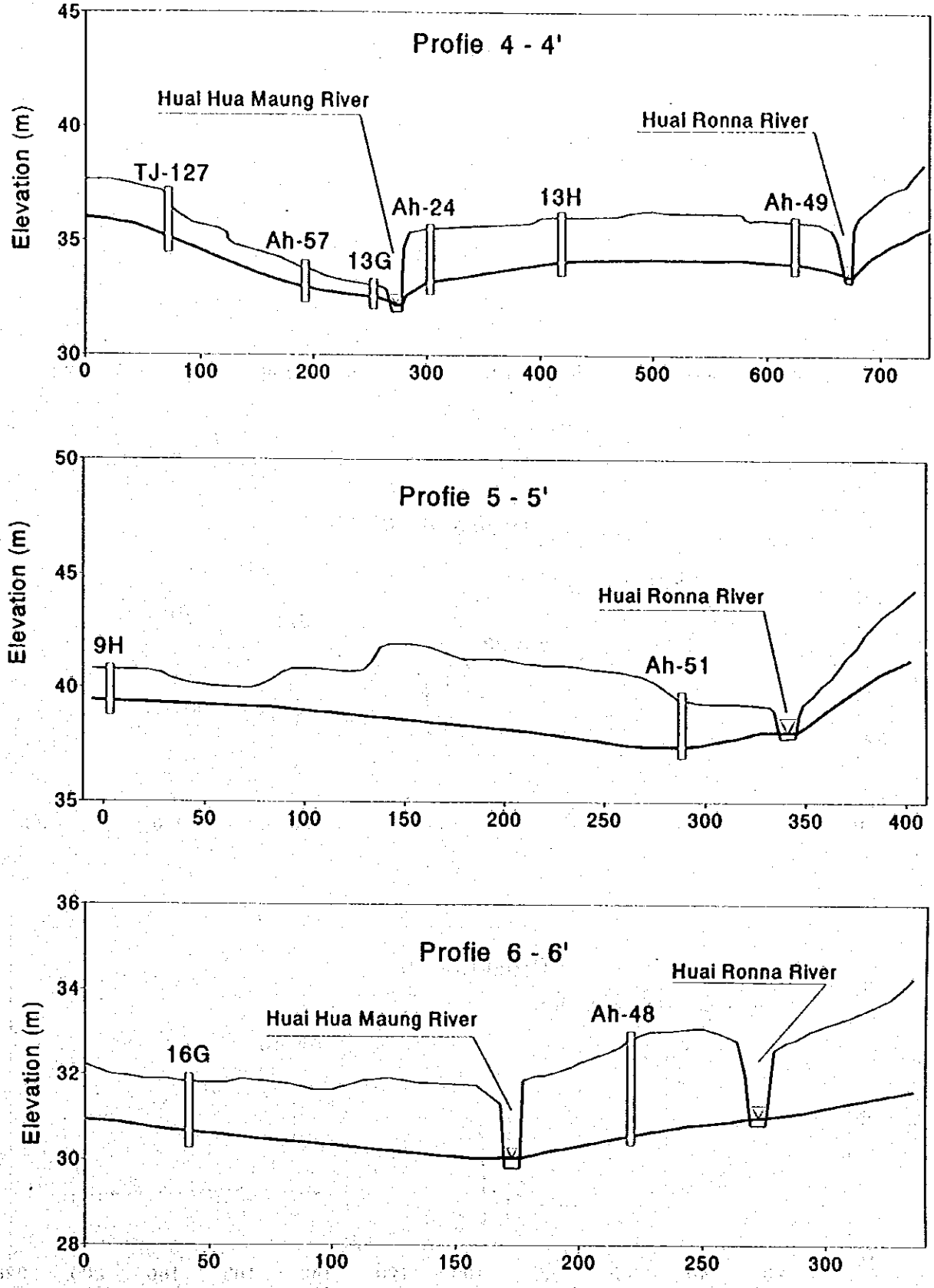

Fig 5.15 Profile 4-4' to 6-6'

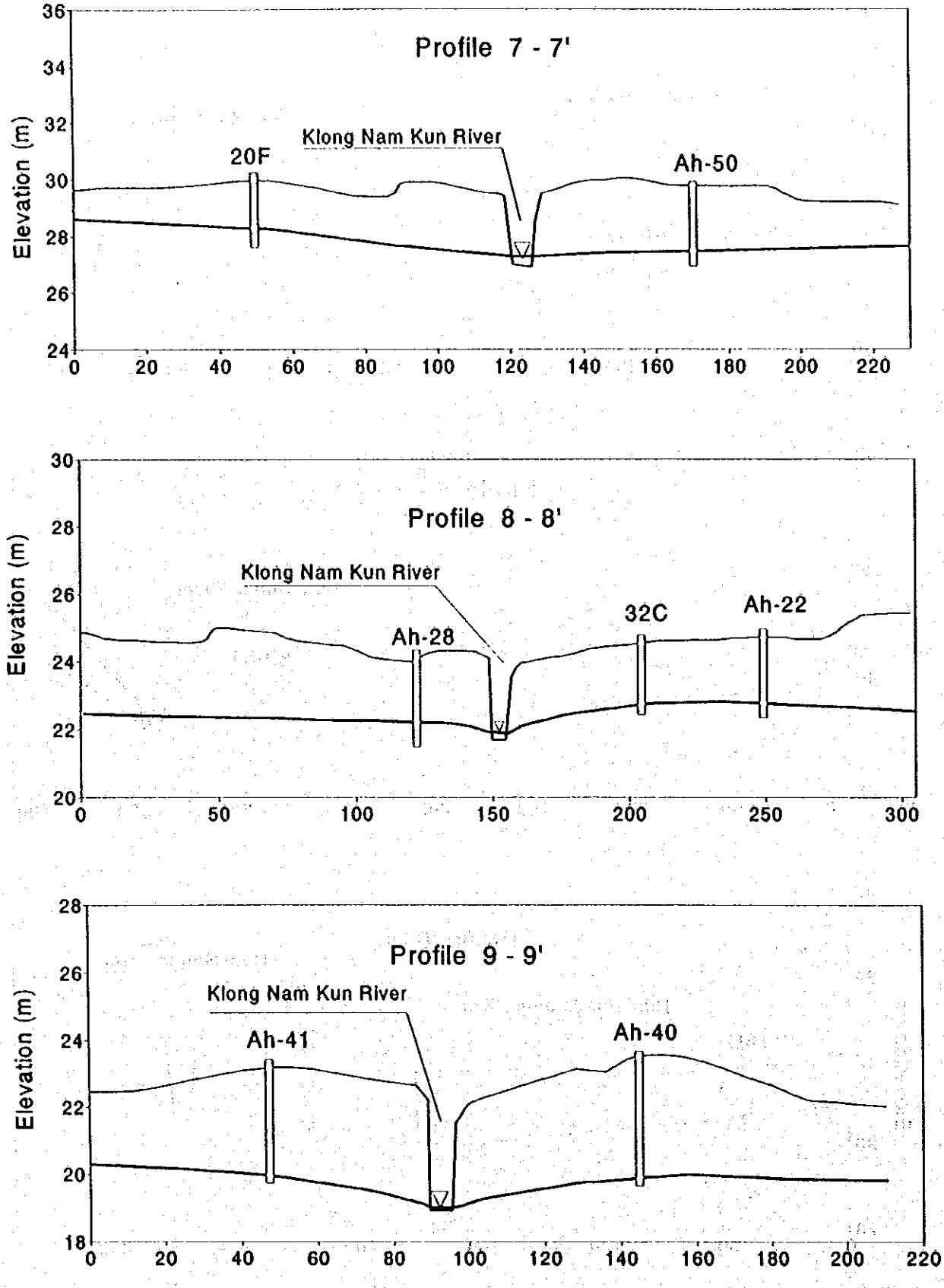

Fig 5.16 Profile 7-7' to 9-9'

・Downstream (Profile 6 (southwest))

While being recharged by groundwater from the right bank (southern section), the river replenishes groundwater in the left bank, which flows toward the Huai Hua Mueng river.

③ Klong Nam Khun River (Profiles 7, 8, 9)

In either profile, groundwater flows into the river from both banks.

The above profiles indicate that although the overall relation between river water and groundwater infers that groundwater mainly recharges river water in Ron Phibun basin, the opposite was observed in several sections. On the other hand, actual groundwater flow has to be illustrated as a three-dimensional vector that flows in the maximum direction of the hydraulic gradient. Therefore, the groundwater level contour map should be referred to when determining the actual groundwater flow direction (Fig. 5.11, 5.12).

5.1.3.3 Water quality classification

Hexa-diagrams distribution map were composed for river, auger, shallow well and deep well water (see Fig. 5.17).

Majority of river samples shows a diamond shape, but the type varies in samples from the upstream sections of Huai Ton I Hong and Huai Hua Mueng rivers. This variation is particularly emphasized in the rainy season as the result of the increase in the ratio of SO4 and Na +K due to the impacts of mine waste and abandoned mine levels along the Huai Ton I Hong river.

The samples extracted from the groundwater in auger holes and shallow wells are also mostly expressed in the shape of a diamond, however, some sections took on a different form. Several shallow wells and auger sites, such as the auger site 32L, which is a reclaimed area, are considered to be significantly affected by man-made activities.

The water quality of deep wells is found to be stable, most of which (more than 90%) form a diamond; and changes in the size of the hexa-diagram are very minimal.

The difference in the size of the hexa-diagrams between each type of water samples is as mentioned in the previous section; the size tends to increase from the

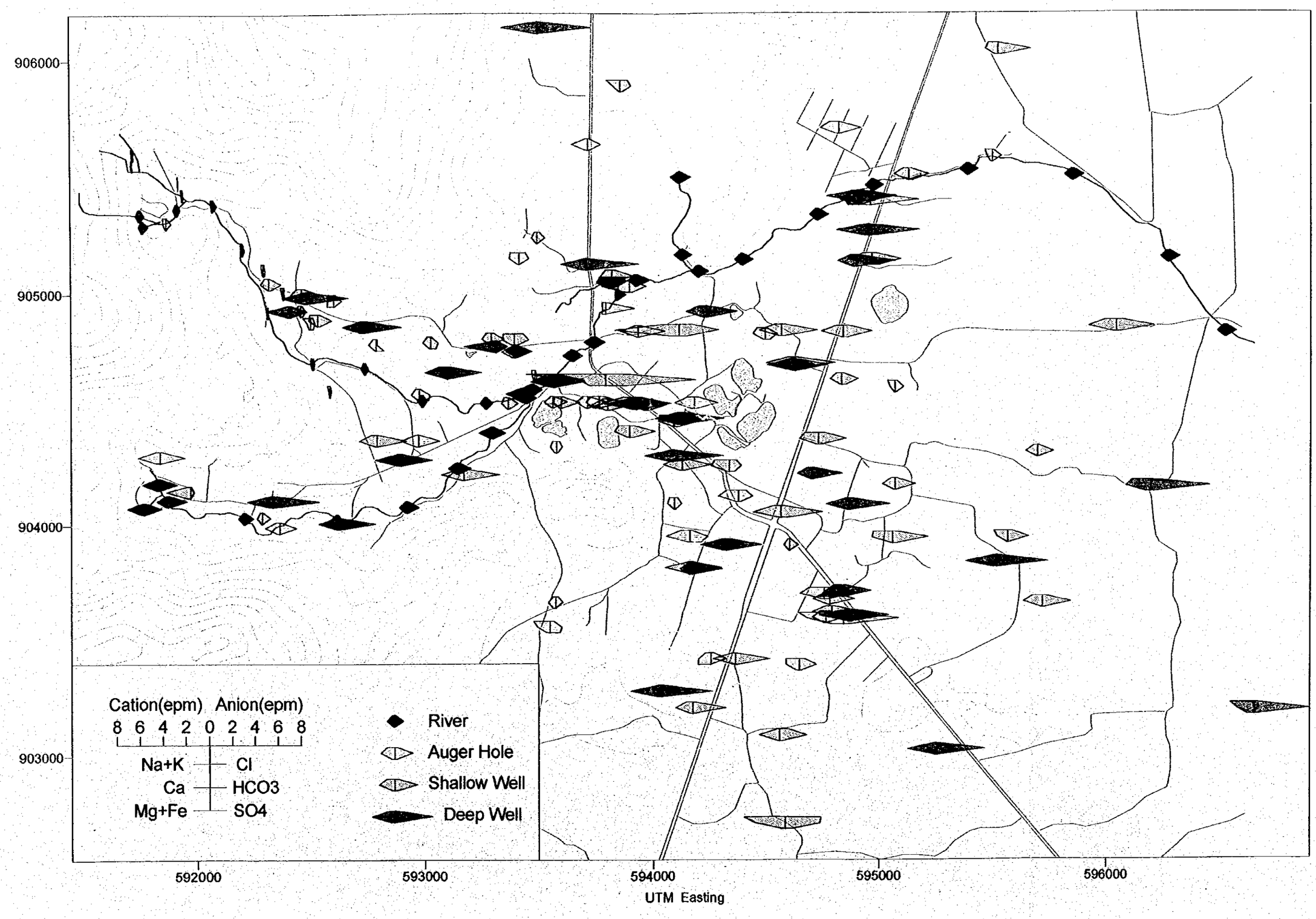

Fig 5.17 Hexa-diagram of River Water and Groundwater (1998-1999)

upstream towards the downstream basin section.

Fig. 5.18 shows the arsenic levels in shallow well water. Contaminated shallow wells are mainly located upstream of the Huai Hua Mueng and Klong Nam Khun river basins, along the highway, and especially from highway 403 towards the western section. Generally, the map is in agreement with that of the auger water analysis. Fig. 5.19 shows the distribution of arsenic within the deep aquifer. Arsenic levels exceeding the drinking water quality standard of Thailand were detected in the Huai Hua Mueng river basin and the central Ron Phibun town. Compared with Fig. 5.18, a strong correlation can be found between the contamination in the deep and shallow aquifers, as the contaminated area of groundwater in deep wells and shallow wells coincided.

5.2 Groundwater flow and contaminant transport modeling

5.2.1 Modeling method

A simulation model was established to simulate the movement of arsenic in groundwater. MODFLOW model developed by the US Geological Survey was used.

Analysis involves the following processes:

① Summarize the results of various studies (topographic and geological studies, groundwater studies, well inventory, etc.) and hydrogeological information; analyze hydrogeological units and groundwater flow mechanism; construct a groundwater flow model, Ron Phibun model to cover the entire study area.

② Simulate groundwater flow using the groundwater flow model

③ Input the information relevant to arsenic contamination obtained from contamination source survey and other surveys to establish the advection / dispersion type transport model for simulation of pollutant movement.

④ Identify the parameters necessary for the transport model based on the results of the survey on the state of contamination.

⑤ Establish the hot spot model based on the identified parameters, in accordance with the characteristics of the contamination source.

⑥ Prediction of future arsenic levels and assessment of countermeasures using Ron Phibun model and the hot spot models.(this part will be discussed in chapter six) .

The MT3D model, which is linked to the MODFLOW model, was used to analyze the contamination mechanism in order to use the velocity components calculated using the MODFLOW model.

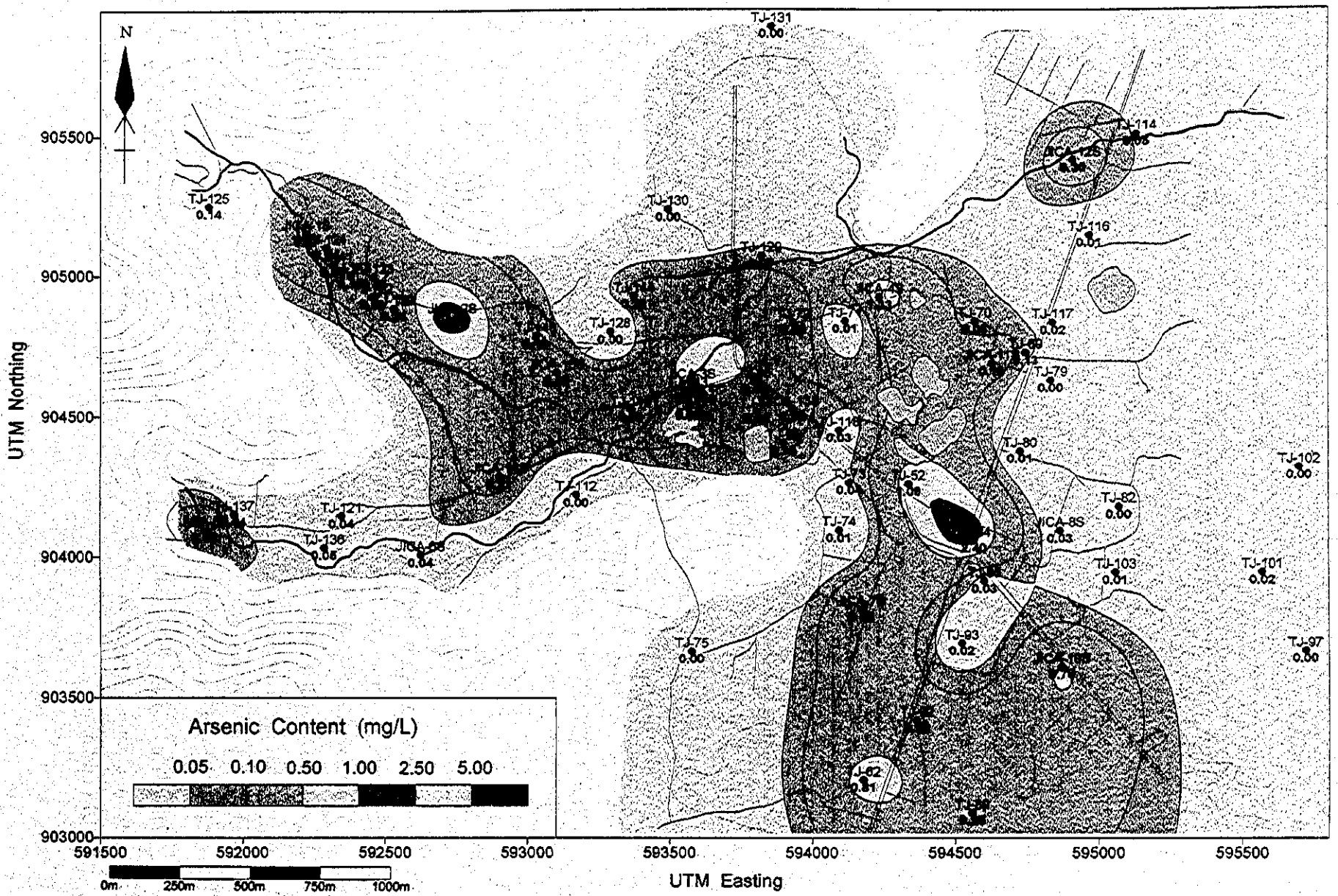

Fig 5.18 Arsenic Content in Shalow Well Water

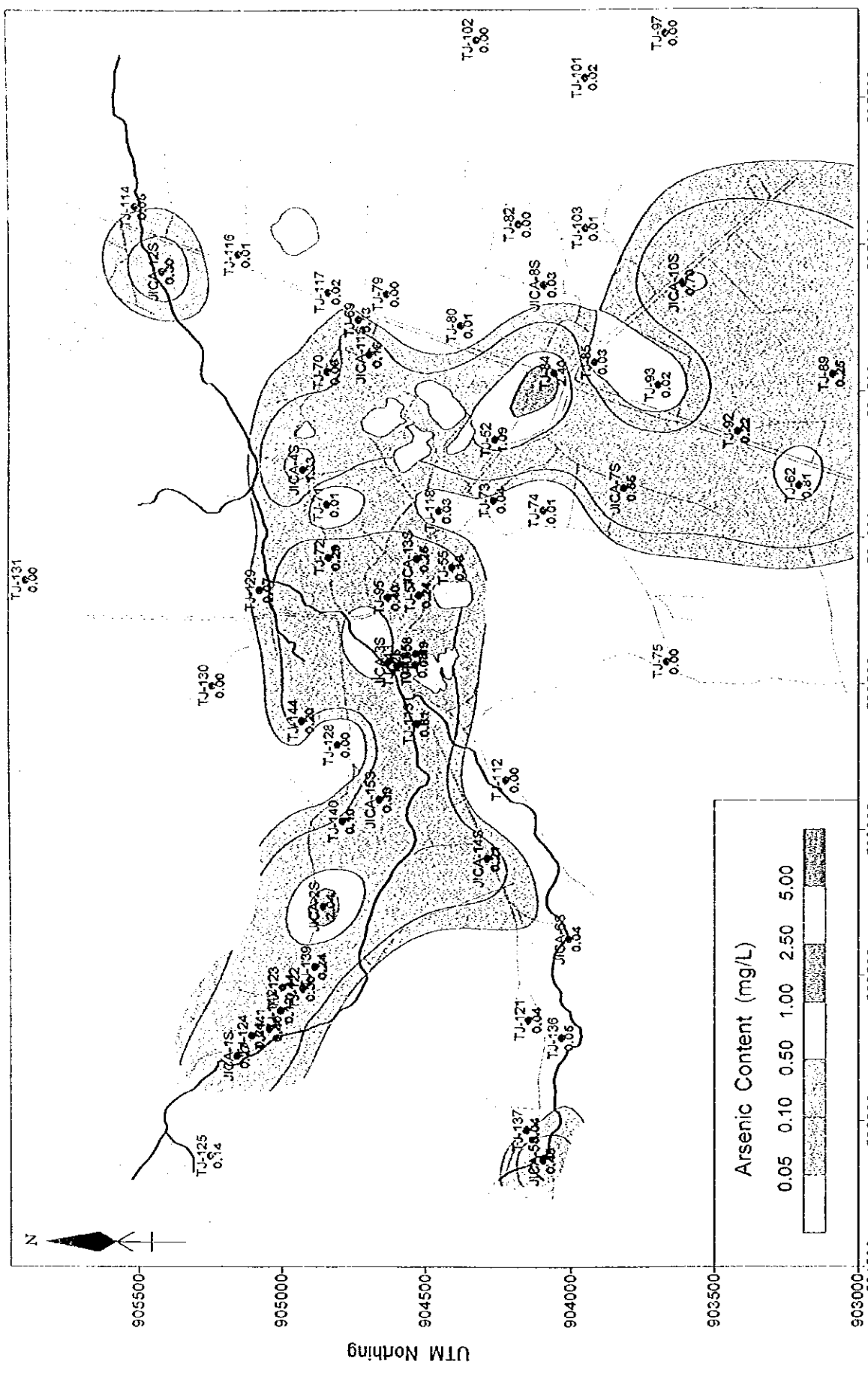

Fig 5.18 Arsenic Content in Shalow Well Water

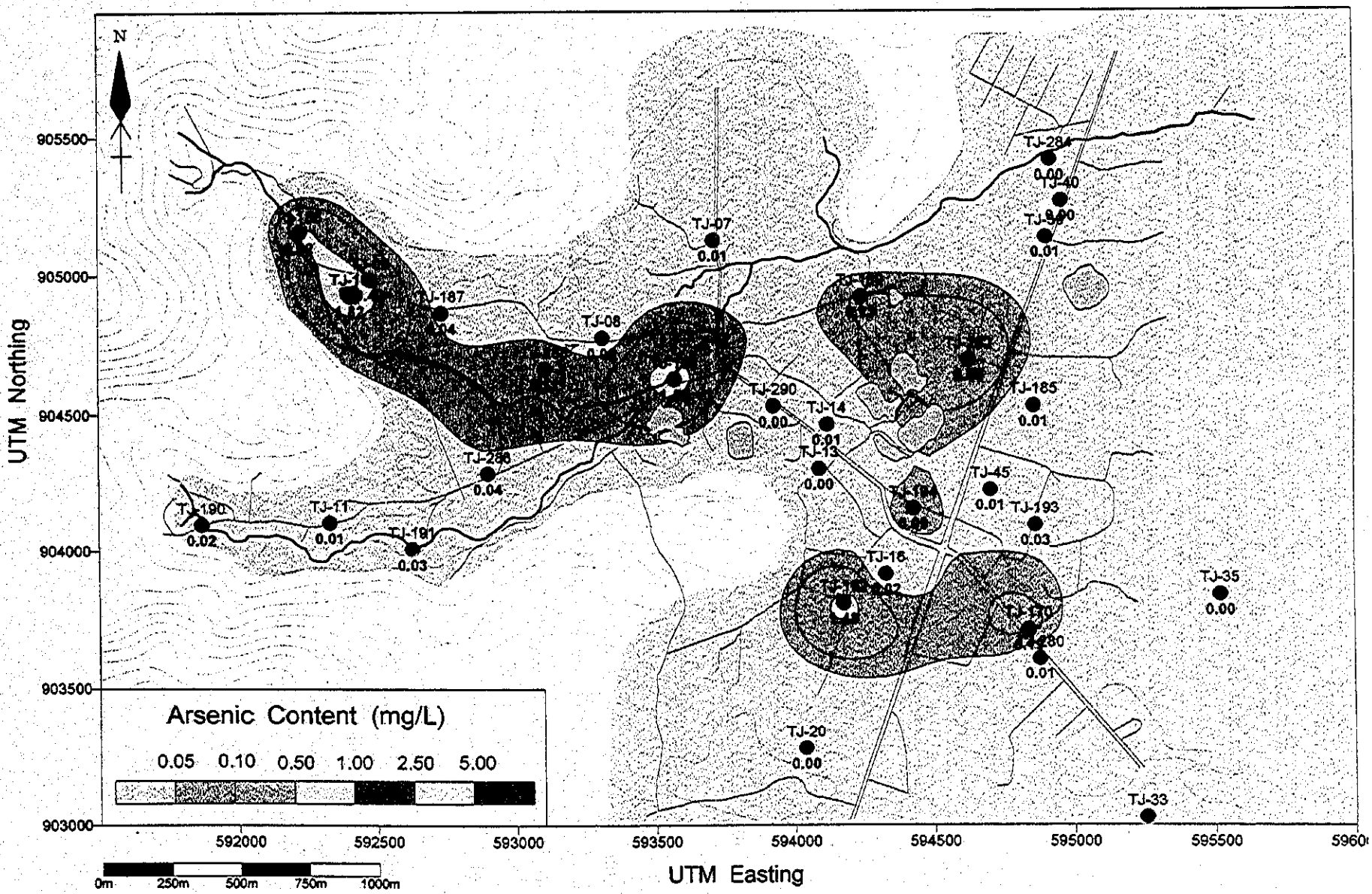

Fig 5.19 Arsenic Content in Deep Well Water

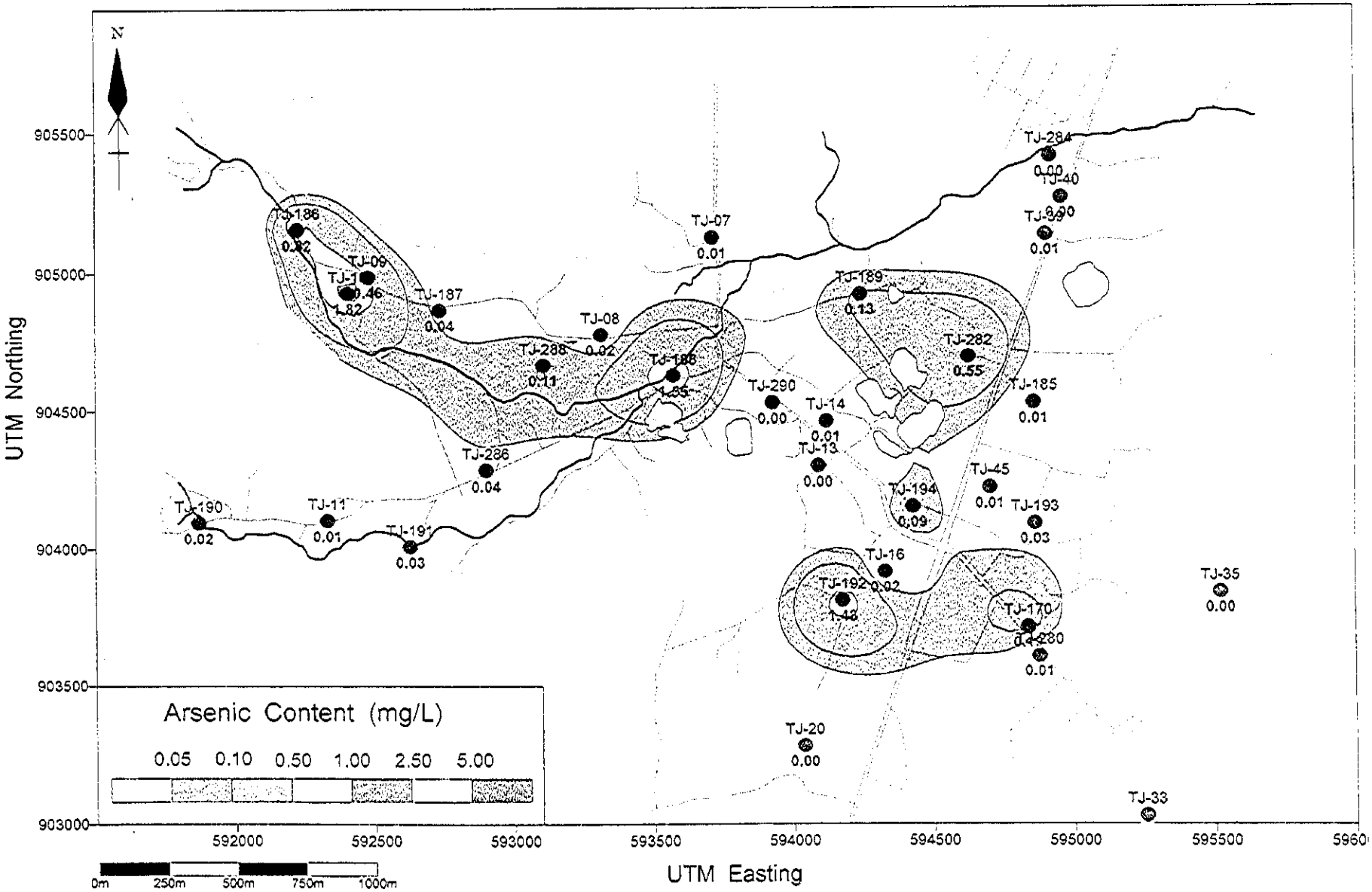

Fig 5.19 Arsenic Content in Deep Well Water

5.2.2 Ron Phibun model

(1) Grid & package

Fig. 5.20 shows the Ron Phibun model structure and the constant concentration cell (contamination source).

The model covers the entire study area defined by the UTM coordinates of 591800 ~595650 East and 903010~905880 North. The four sides (square) of the cell each measures 70m, and the area for simulation is 55 rows x 41 columns.

As indicated in profiles Fig. 5.7 to 5.9, the hydrogeological structure of Ron Phibun basin is vertically divided into 4 layers. Accordingly, the Ron Phibun model is divided into 4 layers, and the hydrogeological unit that corresponds to each layer is as shown below.

Layer1 : shallow aquifers in group 1

Layer2 : Impermeable layer in group 1

Layer3 : deep aquifers in group 1

Layer4 : Basement rock aquifers including all aquifers in groups 3 and 4

Because there are no shallow aquifer in the mountain area, it is specified as an impermeable boundary. Rivers that flow within the basin are simulated by streams package, while ponds were simulated by general head boundary package (GHB). Recharge and evapotranspiration packages were also incorporated in the simulation.

(2) Aquifer coefficient

The values shown in Table 5.5. which were derived from the pumping tests on the JICA test wells. were used to specify the hydraulic conductivity of each layer. However. due to the absence of pumping test data on the clayey layer of layer2. the average of the hydraulic conductivity of the shallow aquifer of layer1 and deep aquifer of layer3 were calculated and then multiplied by 10^{-3} and applied to the clayey layer.

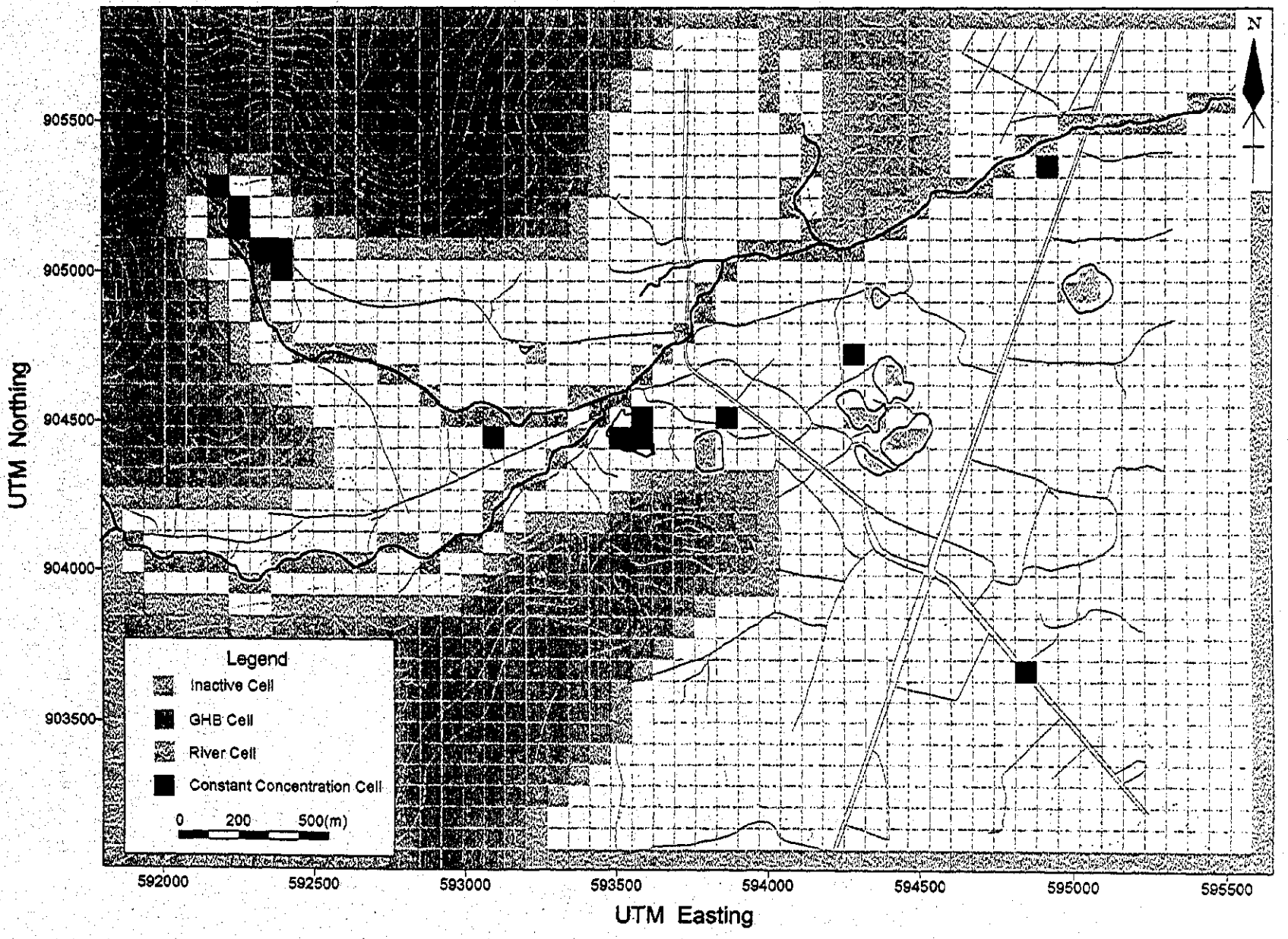

Fig 5.20 Composition of the Ron Phibun Model

Table 5.5 Aquifer coefficient of the Ron Phibun model

Layer	Type	Thickness	Horizontal hydraulic conductivity	Vertical hydraulic conductivity	Storativity
1	Free	7	5×10^{-4}~1×10^{-1}	5×10^{-5}~1×10^{-2}	0.25※
2	Confined	5-15	1×10^{-7}~2×10^{-5}	1×10^{-8}~2×10^{-6}	1×10^{-5}
3	Confined	3-8	3×10^{-4}~2×10^{-2}	3×10^{-5}~2×10^{-3}	5×10^{-3}~1×10^{-1}
4	Confined	15	3×10^{-3}~1×10^{-2}	3×10^{-4}~1×10^{-3}	3×10^{-4}~2×10^{-1}

Note: Hydraulic conductivity is in cm/s

※ : Effect porosity

(3) Conditions

① Rainfall

An average groundwater recharge of 2.5mm/day (912mm/year) was adopted for steady-state simulation. For transient simulation, groundwater recharge by rainfall calculated using the tank model for hydrological analysis was adopted. For rainfall from July to September, the average rainfall in the area was used.

② Evapotranspiration

There are no actual data on evapotranspiration in the study area. On the other hand, simultaneous groundwater measurements and well inventory surveys confirm groundwater exhaustion due to factors, e.g. water use conditions, other than evapotranspiration. The wells used in the study area are located close to each other, making the actual conduct of well package simulation impossible. Accordingly, the value resulting from the addition of the well water consumption volume to the evapotranspiration amount is considered and adopted as the evapotranspiration amount.

③ Simulation period

Steady state simulation does not require a fixed simulation period. For transient simulation, the date (September 1998) when the first simultaneous groundwater leveling was carried out was considered as the start time, and 10 days x 36 periods was divided to complete one (1) year calculation.

④ Initial water level

For steady state simulations, the initial water level was specified higher than the bottom elevation of layer1 taking extra caution as to prevent the occurrence of dry cells. For transient simulation, the groundwater level measured at the start of the calculation was adopted.

(4) Results of groundwater flow simulation

Fig. 5.21 shows the groundwater level in shallow aquifers based on the steady state simulation. In view of the proximity with the actual groundwater level, the reappearance of groundwater flow was considered successful.

Table 5.6 below shows the water balance in the shallow aquifer calculated by this calculation.

Table 5.6 Water balance in shallow aquifer

Items	M^3/day	m^3/year	mm/day
Recharge by rainfall	19,100	6,971,500	2.5
Recharge from rivers	120	43,800	0.02
Evapotranspiration (including by well use)	−17,160	−6,263,400	−2.25
Discharge to rivers	−1810	−660,650	−0.24
Flow to lower layer	−60	−21,900	−0.01
Flow to outside of basin	−190	−69,350	−0.02

Note: Flow to lower layer is the net value of the sum of the outflow and inflow in between the shallow aquifer and the underlying clayey layer.

Fig. 5.22 shows the transient simulation results done to verify groundwater level fluctuation in the study area. As in the results of the steady state simulations, it may be said that the groundwater level fluctuation in the area was successfully simulated.

5.2.3 Transport model

(1) Pollution source cell

The cell for the location of the contamination source confirmed in the contamination source survey was specified as a constant concentration cell (see Fig. 5.20). Consequently, a total of 14 cells for 7 places in the study area were designated as constant concentration cells. These cells are located on the left bank upstream of Huai Hua Mueng river, where contamination has become serious because many pollutant

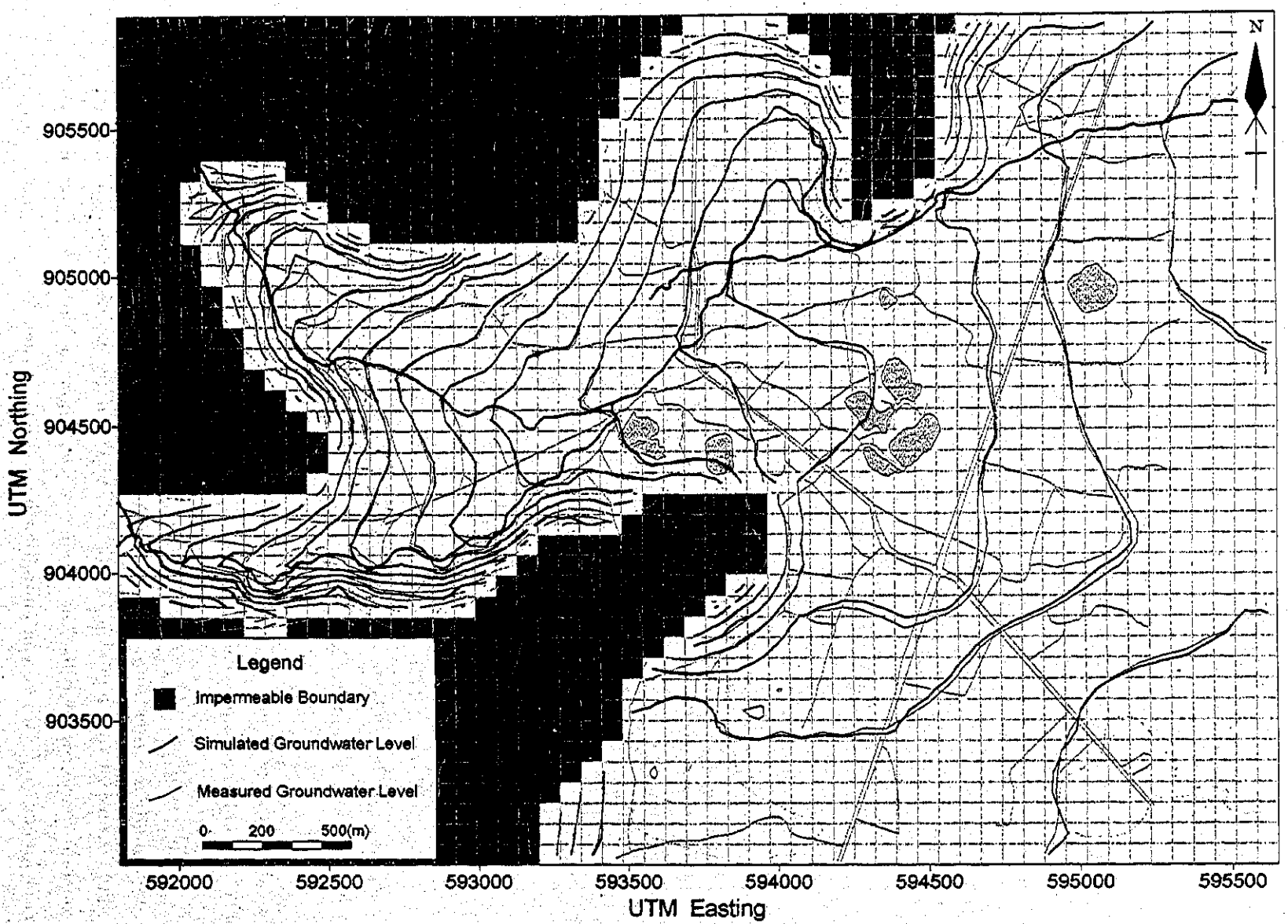

Fig 5.21 Simulated Groundwater Level

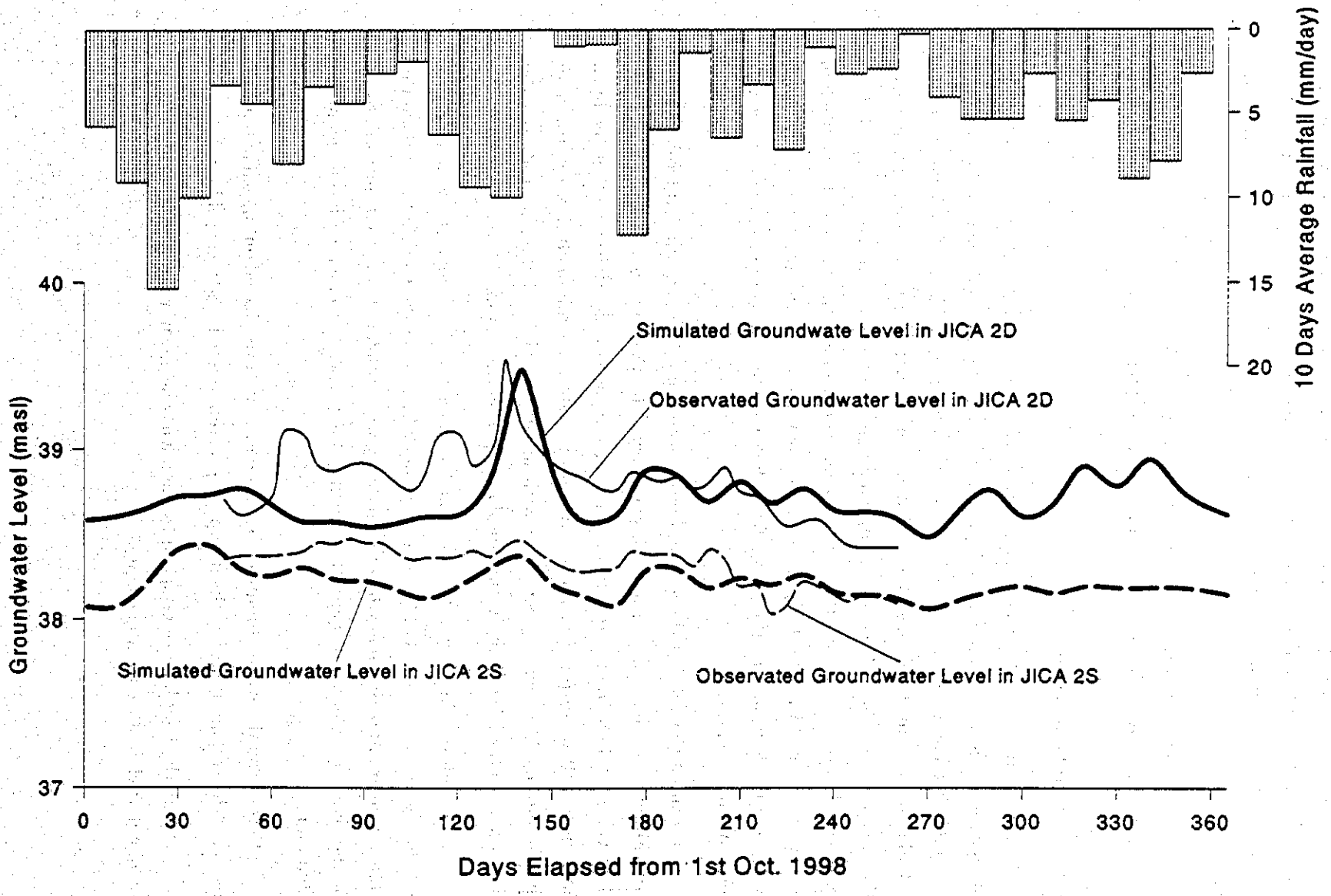

Fig 5.22 Simulated Groundwater Level at Obsrvation Well

such as mine waste transported by river from the foothill concentrator; the waste dump site (old) on the right bank downstream of the same river; the dredging pond; the town concentrator, waste dump site (new) in town, and reclaimed site 32C and 32L along the highway.

The concentration cells were specified an arsenic level of 1mg/l; other cells were considered as active cells and given an initial level of 0.005mg/l.

(2) Simulation period

Generally, when transport simulation is to be carried out, the result of an observation at a certain period is adopted as the initial value and the simulation period is established based on the length of the observation period. Thereafter, changes in the calculations within the observation period and the actual results are compared to verify the model parameter. However, because data on long term arsenic surveys carried out in the study area are scarce, there was no choice but to use the present distribution of arsenic confirmed by this study to verify the parameters of the transport model. This would require determining the period from the time when the contamination source was formed until the present.

It cannot be said that the contamination source on the upstream left bank of Huai Hua Mueng does not contain arsenic transported by the river water from way back. However, past data and the results of interviews at the site clearly reveal that the huge flood in the 1970s resulted in huge volumes of waste from the foothill concentrator in the mountainside being carried along with mudflows. This calamity also altered the river cross section. Accordingly, the simulation period was set for 30 years.

Although the date when the reclaimed area east to the study area was formed is not clearly known, a period of 30 years is assumed based on the fact that it is along the highway, on or after the time when the highway was completed, and that this is a result of the land development activities during high speed economic development in Thailand.

Records on the waste dumpsite are unknown, however, based on the same reasons given for the reclamation site, the dumpsite is estimated to be 30 years old.

Due to the long history attached to the town concentrator and the scouring site in town, a period of 50 years was adopted.

(3) Simulation type

The program MT3D is equipped with functions to separately or jointly simulate the main processes of substance transport, advection / dispersion / sorption in the groundwater. In this work, the transport of arsenic only by the process of advection was dealt with as the basic case, case1. For case 2 simulation, the effects of dispersion were considered also. case 3 took advection / dispersion / sorption into account.

(4) Parameters

Advection/dispersion calculation requires specifying the longitudinal dispersivity (α_L) and the transverse dispersivity (α_r) to serve as chemical parameters of aquifers (to be precise, aquifer and substances for simulation).

α_L and α_r can be determined by laboratory column tests or tracing experiments in the field, and relevant results (reference) are quite plentiful. Longitudinal dispersivity is dependent on the scale as can be seen from the following; 10~110m based on a simulation model for a wide area, 0.01~1cm from the column test results, 0.01 ~ 15m from the intermediate tracing experiments in the field. Transverse dispersivity is mostly within 0.1~0.3 of the longitudinal dispersivity. Accordingly, the parameters were established on a trial and error method, with due reference to results of previous studies.

Sorption simulation requires a parameter relevant to sorption. This arsenic sorption in the soil is non-linear equilibrium. With the Freundlich isotherm sorption line, the distribution coefficient (K_f) fluctuates between 0.8~31 (13 on average) depending on the pH, phosphorous, and Fe levels. when expressing the sorption characteristics of arsenic (V). The exponential constant, a, also fluctuates between 0.18 ~0.93, averaging 0.512. With these results, the parameters of case 4 of type 3 was established and the parameters to reproduce the conditions on a trial and error method were corrected.

Table 5.7 is a summary of the hydro-chemical parameters used for the cases of the established calculation method aforementioned.

Table 5.7 Water quality model parameters

Case No.	α_L(m)	α_r(m)	K_f	a
1	--	--	--	--
2	30	3	--	--
3	30	3	1.3	0.051

(5) Results

With the exclusion of the hotspot model, the simulation periods indicated in the paragraphs and figures are for simulation in 5 areas (excluding the pond and town concentrator); the pond and the town concentrator would require 20 more years.

① Case 1

Fig. 5.23 shows the results of case 1 calculated under a 30-year period.

② Case 2

Fig. 5.24 shows the results of the case2 calculations.

After incorporating the effects of dispersion, pollution coverage was compared with the results of case 1 and expanded. When compared with the actual arsenic distribution (see Fig. 3.7), the result would some favorably bring out the belt-like distribution of arsenic in the shallow aquifer. The simulation of arsenic mechanisms in groundwater in the study area should, therefore, seriously take the impacts of dispersion into consideration.

③ Case 3

Fig. 5.25 shows the results of Case 3 calculations. The calculations do not only specify how contamination from the source spreads out, but also the fact that in comparison with other cases, the results of calculations assuming a 30 year term are very much in sync with current conditions.

5.2.4 Development of hot spot model

The reproduction of current conditions is always a means of verifying the suitability of the model, which is prepared to forecast progress in contamination and assess projects.

In particular, it is advisable to incorporate in detail the features that affect the distribution of every contamination sources as the countermeasures proposed herein target contamination sources individually.

The Ron Phibun model is applied for groundwater analysis in the study area and the reproduction of conditions in a wide area. Although it plays a major role in the coordination of the parameters, it is not advantageous to further subdivide the entire area to form small grids, as this would consume time for calculations due to the lack of basic data relevant to the creation of models.

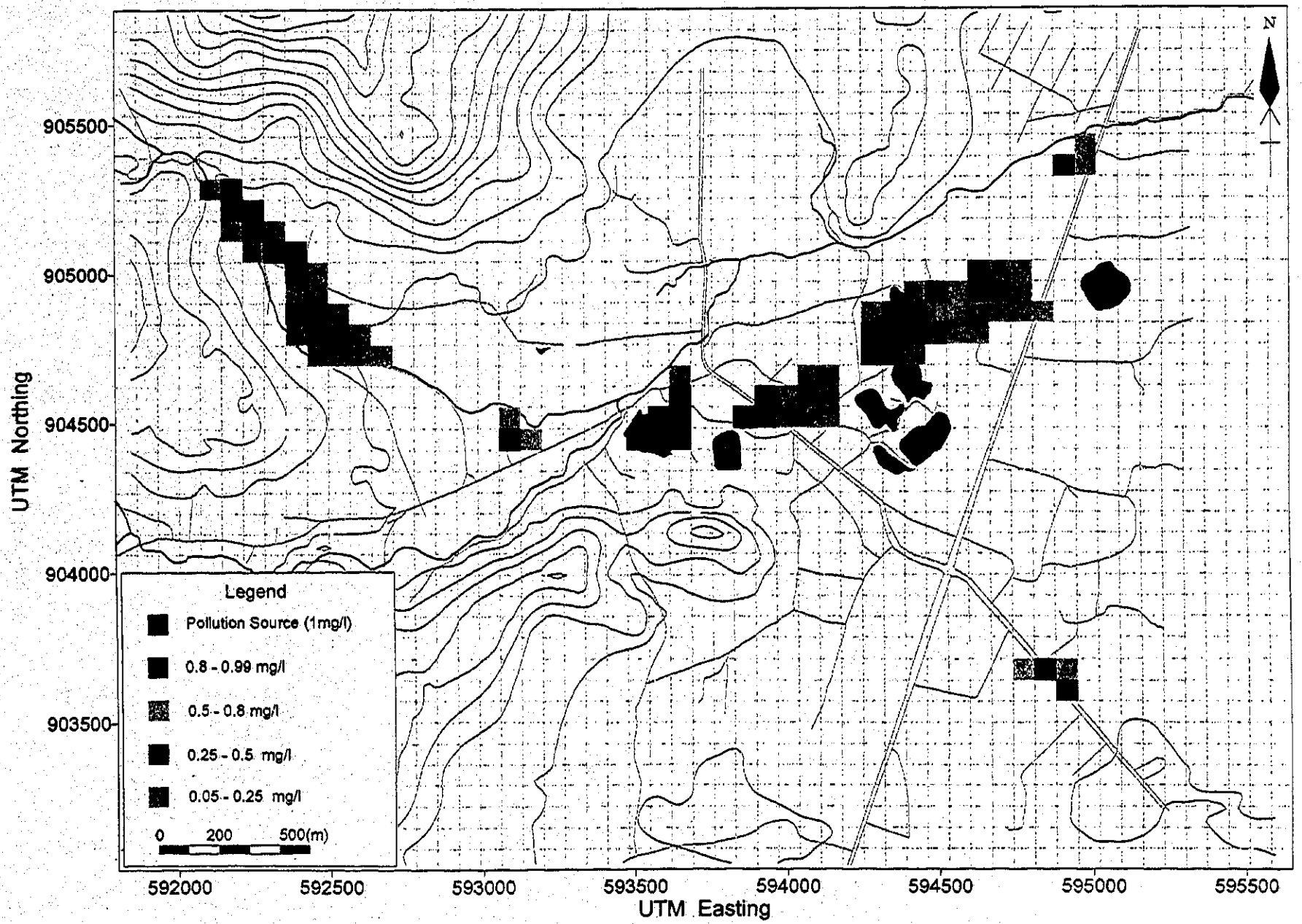

Fig 5.23 Result of Simulation Case 1 (30 years)

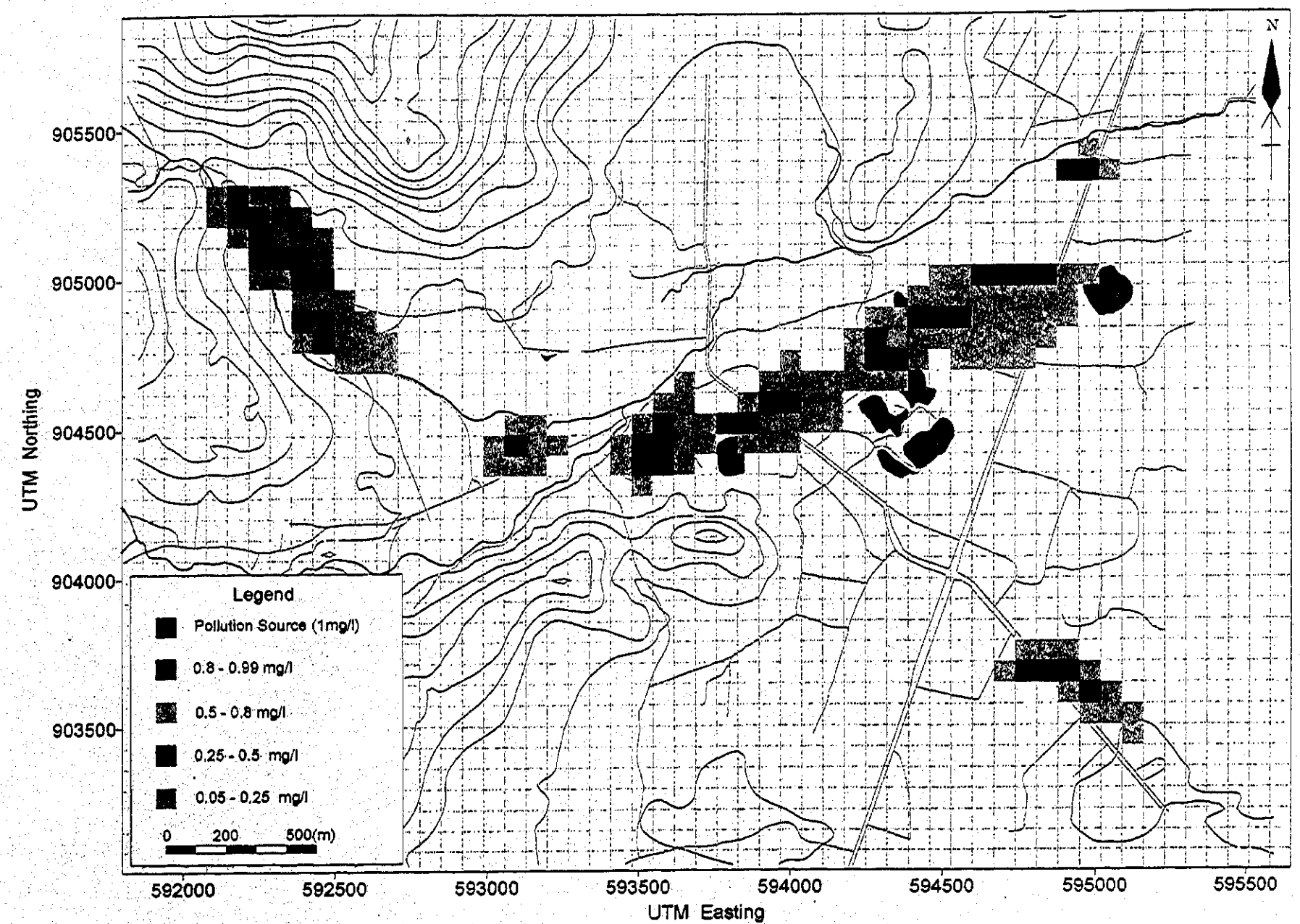

Fig 5.24 Result of Simulation Case 2 (30 years)

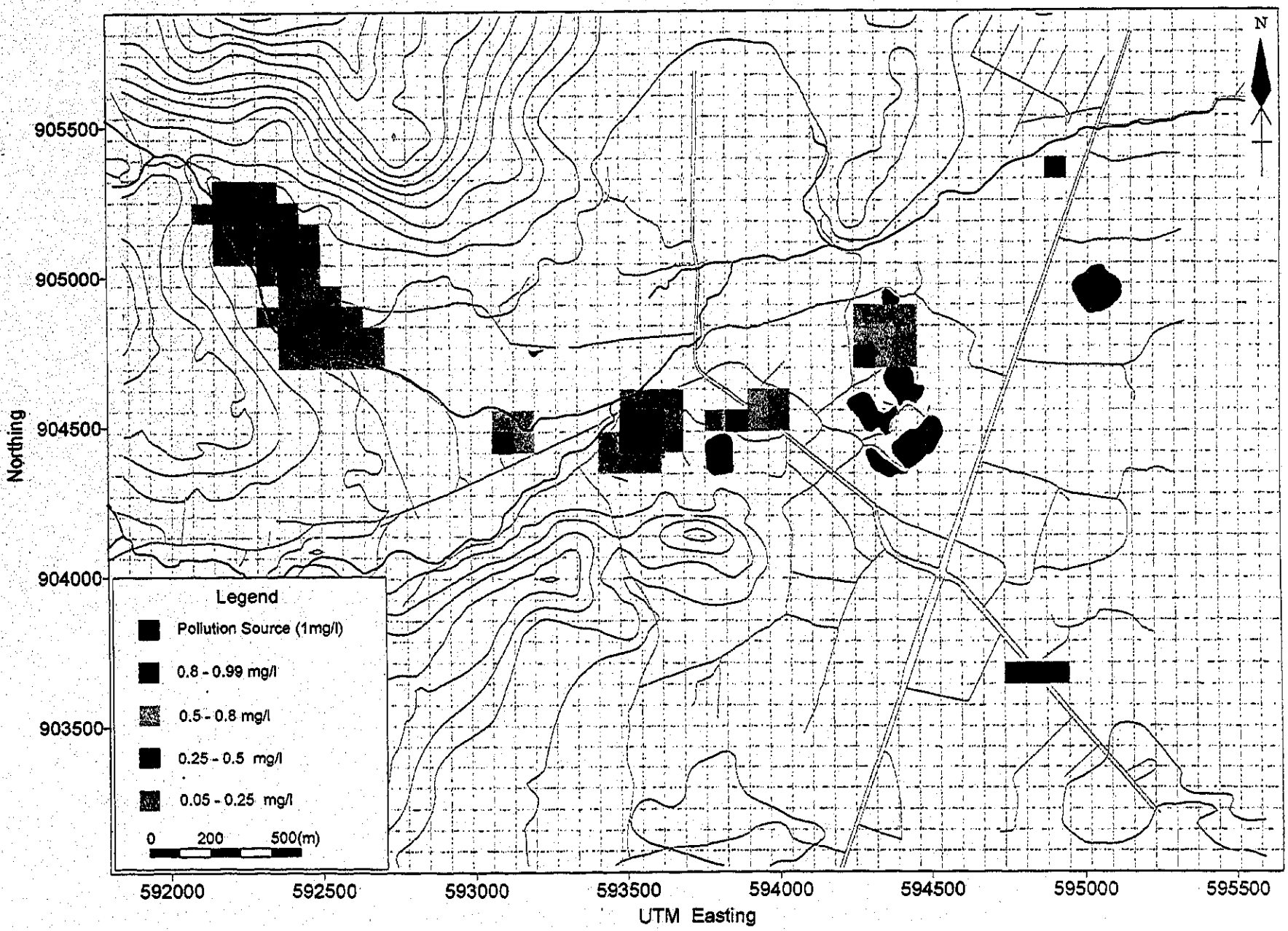

Fig 5.25 Result of Simulation Case 3 (30 years)

On the one hand, as detailed auger surveys and topographic studies were carried out for individual pollution, targeting these individual contamination sources would not require an increase in the number of model cells. This is therefore considered to raise the accuracy of the simulation on a feasible scale.

Consequently, focus was placed on the contamination sources in three places, namely, the dredging pond (including the town concentrator), the auger site 32 C in the reclaimed area, and the auger site 32L, for the creation of the hot spot model.

Either of the three hot spot models are configured with 4 layers, each side measuring 25m and forming a square with a cell of 40 rows x 32 3 lines. The aquifer coefficient of every layer will be the same as the Ron Phibun model. The Case 3 parameters in the Ron Phibun model will be applied as the chemical parameters of dispersion coefficient. Fig. 5.26 shows the positional relationship between the hot spot model and the Ron Phibun model.

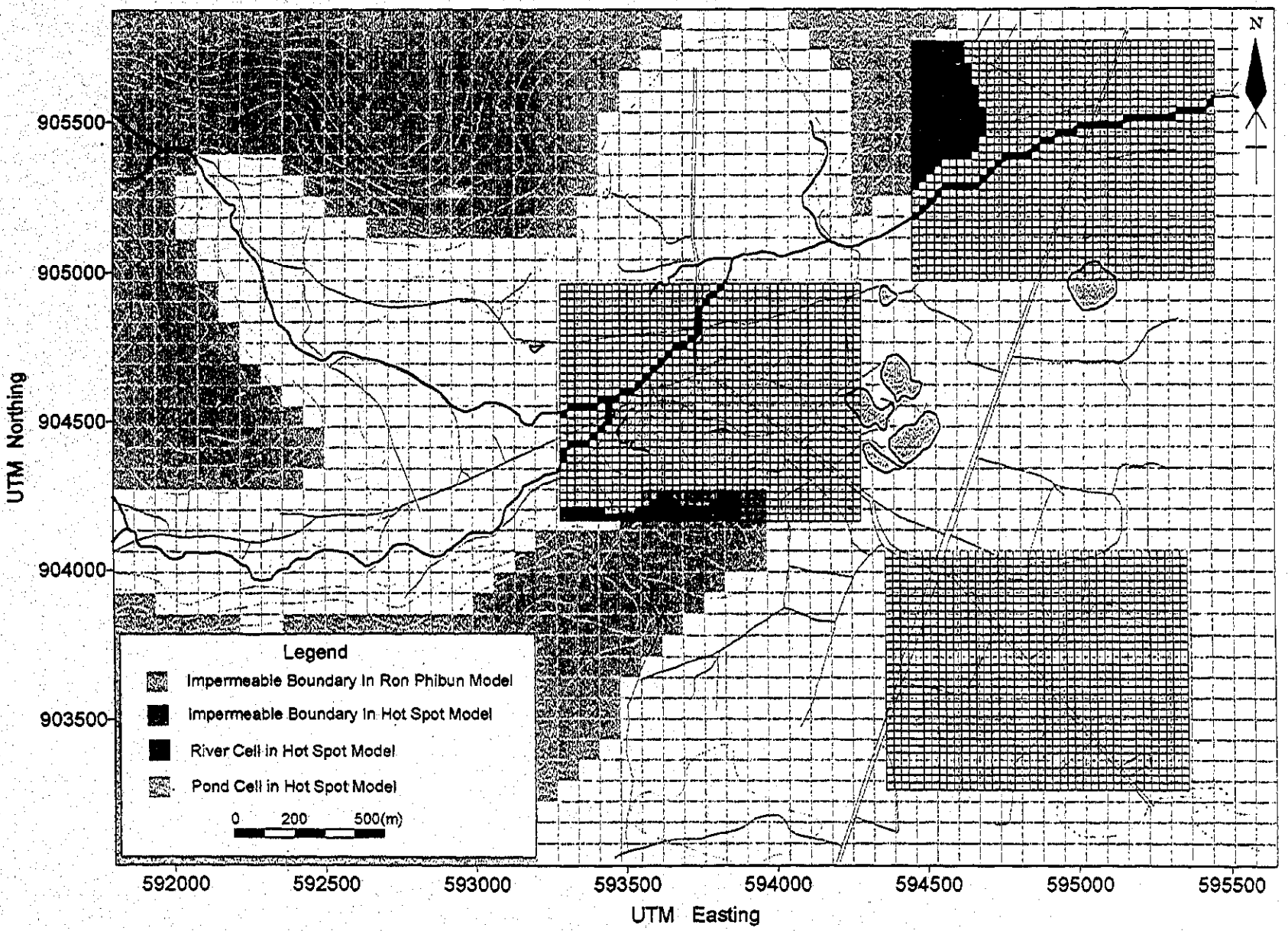

Fig 5.26 Location and Specification of Hot Spot Model

6. Countermeasure

6. Countermeasure

6.1 Present situation

Ron Phibun district is in a basin of the Huai Hua Mueng River flowing eastward, which is downstream of the Huai Ton I Hong River flowing from the Khao Suan Chan Mountain. The Huai Hua Mueng River and Klong Nam Khun River merge and form the Klong Nam Khun River flowing eastward. There are many primary vein and secondary placer tin deposits from the south slope of Khao Suan Chan Mountain to Ron Phibun Town.

Along the south slope of Khao Mak Mountain, which is northeast of the survey area, there are tin deposits. However no arsenic contamination has been found in the area, because no ore roasting has been done.

In the mountains, there are tin deposits with arsenopyrite. Major tin deposits in the mountain are primary veins, but also some secondary placer tin deposits are. Deposits are distributed from the mountain to the plain. In the mountain, tin deposits are high grade and thin veins, but in the plain, deposits are secondary placers.

Mining is already prohibited by DMR in the area but still some placer deposit is mined by sluicing.

Rivers flow from the mountains eastward through Ron Phibun Town and river water stagnates to form swamps and ponds in the plain. The major river flows eastward but groundwater flows south-to southeast ward in the southern part of the survey area. There is old riverbed between them.

A flood was recorded in 1977, but small overflows occured repeatedly in the area. Contaminant may have been transported and spread over the area by the repeated overflows.

Arsenopyrite is rich in the area. so that arsenic content in the area is higher than the average arsenic concentration in the earth crust. 1.8 ppm. Arsenopyrite is a sulfide of iron and arsenic. and is very stable. It is rarely reported in the world that only arsenopyrite causes arsenic contamination in the groundwater and arsenic poisoning. Only when arsenopyrite is changed to sulfate by strong acid. dissolves in water and is deoxidized. it becomes dangerous contaminant.

Concentration processes used in the closed concentrators were mainly simple physical processes. At the mining site. mined ore was selected by sluicing and waste with arsenic minerals was left at the site. The remaining mine waste was transported to a newly constructed sealed waste dump by DMR.

The worst problem in the concentration process is ore roasting done at the foothill concentrator and the town concentrator. By roasting. sulfur can be removed from the

sulfide minerals and roasting process also either gasifies arsenic or changes arsenic to an easily soluble oxide. The remaining arsenic oxide was dissolved in rainwater and became the major contaminant source of the area.

Other concentration waste also contains some arsenic but arsenic in other waste is hardly dissolved in rainwater as in ore. If toxicity created by roasting process was not recognized, roasting waste might have been mixed with other concentration waste and dumped in depressions or ponds or used as landfill material.

We need to discuss arsenic contamination in the area with consideration of the groundwater flow, and absorption and release of arsenic by oxidation-reduction potential.

Highly contaminated areas are at and around 1) the foothill concentrator and its downstream, 2) the old waste dump, 3) the dredging pond, 4) the town concentrator, 5) the new waste dump, 6) the site 32C and 7) the site 32L.

6.1.1 Presumed causes of arsenic contamination

Causes of high arsenic content in groundwater, which is inappropriate for human consumption, are mainly the following two.

1. Soluble arsenite was created during the ore-roasting process at the foothill and the town concentrators, which have already closed down. Produced arsenite was mixed with other concentration waste and concentration waste was transported and dumped. Flooding may have transported some dumped waste. Arsenic content in groundwater became high because of arsenic dissolution in groundwater from arsenite.
2. Iron-hydroxide rich in laterite soil can absorb arsenic well. Absorbed arsenic cannot easily be dissolved in groundwater if soil is kept in oxidation condition. However when soil becomes in reduction condition by covering it with clay filling or organic rich water, arsenic will be dissolved in groundwater with iron-hydroxide.

6.2 Plan of Countermeasure

For preventing new patient of arsenic poisoning, it is very important to avoid consumption and usage of contaminated water. For welfare of existing arsenic chronic patients, medical care is very important.

In order to settle on countermeasure against arsenic contamination in the area, a master plan of the countermeasures must be drafted and the situation must be dealt with in the order of a master plan.

For drafting a master plan, the following must be studied.

- To supply safe potable water to residents who otherwise must use contaminated groundwater. (piped water, rain water, or others)
- To relocate residents from contaminated areas (Relocation may create pollution at new settlement).
- To clean contaminated soil and groundwater by removing contaminated soil and filtering arsenic from contaminated groundwater.
- To monitor arsenic content in groundwater.
- To support treatment and healthcare of patients.

6.2.1 Treatment of contaminant, soil

Extents of contaminated areas are defined by their sizes. Most of them are limited to within one to two meters depth, which can be easily excavated by backhoe. Surface soil can be removed with contaminated groundwater in it.

Before commencing countermeasure, a feasibility study is needed. This report presents the pre-feasibility stage of a countermeasure. Removed contaminated soil must be transported to an insulated waste dump. An insulated waste dump has double-layered insulating sheets at the bottom to collect all contaminated water for treatment.

Volumes of soil to be removed from contaminated areas are shown in Table 6.1.

Table 6.1 Contaminated soil to be removed

Source Area	Location	Area (m^2)	Thickness (m)	Volume (m^3)
1	Foothill Concentrator and Downstream			
	Upstream of Huai Hua Mueng River	12,000	2	24,000
	Midstream of Huai Hua Mueng River	22,100	1.5	33,150
2	Old Waste Dump	10,000	2	20,000
3	Bottom of Dredging Pond	15,000	1	15,000
4	Town Concentrator and Surrounding	2,500	2	5,000
5	New Waste Dump	15,000	1.5	22,500
6	Site 32C	5,000	1	5,000
7	Site 32L	4,000	2	4,000
	Total Amount of Soil Removed	81,600		132,650

Remarks about each contaminated area are as follows:

1. There is contaminated soil around the concentrator and a concentrator waste dump. Floods have transported contaminated soil with mining waste and have spread it at the downstream. This area situates in an important position of the village so that contaminated soil may not completely be removed. It may need to study the possibility of cutting groundwater off from flowing into the villages by constructing

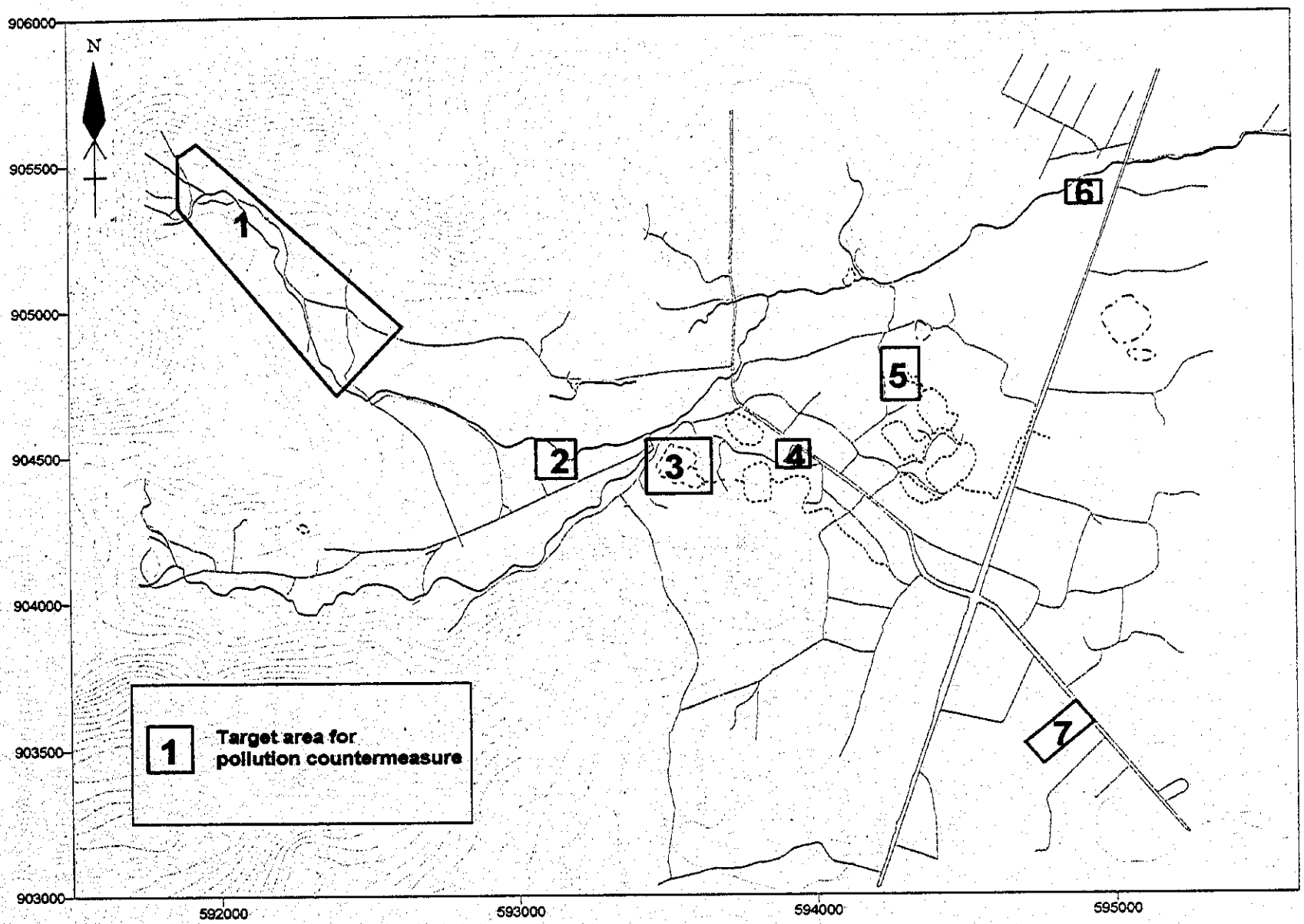

Fig 6.1 Target Area for Pollution Countermeasure

underground dam.

2. There exist possibility of contaminated soil being brought in the dump with domestic waste. The dump needs to be reconstructed along with removal of surface contaminant.
3. The pond was not surveyed in details but it is confirmed that contaminated soil is at the bottom of the pond. The bottom sediment needs to be removed by a grab-bucket or pumped out. Some large rocks at the bottom might prevent from pumping bottom soil out. It is best to remove water in the pond then to dig bottom soil out, but for this process it needs to construct a water treatment plant. It is important to study economics of its construction and operation carefully.
4. There remains contaminated soil around the town concentrator. Because the area is in a populated area, it is necessary to consider the social environment for removing contaminated soil.
5. The new waste dump is similar to "2. Old waste dump". Domestic waste dump needs to be modernized.
6. Landfill material of clay has caused contamination in this area. It is important to refill the land with safe material after the removal of the contamination cause.
7. The area is the same situation as "6. Site 32C".

Among the seven contaminated areas, following areas are most prioritized for removal and isolation of contaminated soil in the viewpoints of land usage and population density.

1. Bottom of Dredging Pond
   - Water at the bottom of the pond is highly arsenic contaminated, 3.2 mg/liter.
   - The pond contains a few tens of thousand tons of contaminated water.
   - The pond is only about 500 m a way from the center of Ron Phibun town and is located its groundwater-upstream.
2. Town Concentrator and Surrounding
   - The town concentrator locates next the Ron Phibun town and is closer to the town than the pond.
   - There was a roasting furnace. Because location of roasting waste has not identified, the area has very high potential of becoming arsenic contamination source.
3. Waste Dump
   - The waste dumps are for domestic waste, but roasting waste may have dumped. The dump has no installations and domestic waste is compiled

without any consideration for environment. Pile of organic waste over laterite soil may have caused laterite to release arsenic because of reduction condition. Mixed hazardous materials with domestic waste may create other type of contamination.

We estimated that total amount of contaminated soil to be removed is about 132,650 m^3. The figure will be corrected after a more precise feasibility study.

6.2.2 Treatment of contaminated water

The most economically feasible method of arsenic-contaminated water treatment is to condense and precipitate arsenic with iron ion. A strong oxidizer must be added to make the tri-valence arsenic to penta-valence and a large amount of flocculant needs to be added. It is economically unfeasible to make the contaminated water to potable water.

We recommend trying to make the contaminated water suitable for domestic use, for laundry or bathing use. It is important to find local materials for contaminated-water treatment.

The general concept of the process is shown in Fig. 6.2. Contaminated water is exposed to air for oxidation process. Flocculant is added to make flocks. Flocks are removed by slope, quick filtration, and filtration by sands. A thickener condenses the precipitates. Precipitates are dumped in an insulated waste dump and clear water is released into the environment.

Thus obtained water is expected to be safe enough to be used for domestic, agricultural and industrial uses. Therefore it can be released into rivers. In order to operate the plant continuously for a long time, usage of solar panels on the roof of the plant may be useful. Many such water treatment plants have been constructed at closed mines in Japan.

In the survey area there are laterite soil which can be used as iron ion additive and oxidizer. Laterite is not a strong oxidizer but it can be used after being pelletized. It is important to use local materials for economical operation of the countermeasure even though the material may not be the most suitable for the technical purpose.

6.2.3 Prevention of arsenic release

It is important to know whether local laterite can be used for landfill material after removing the contaminated soil. It is important for the economical execution of the countermeasure to study the capability of using local laterite as a material for

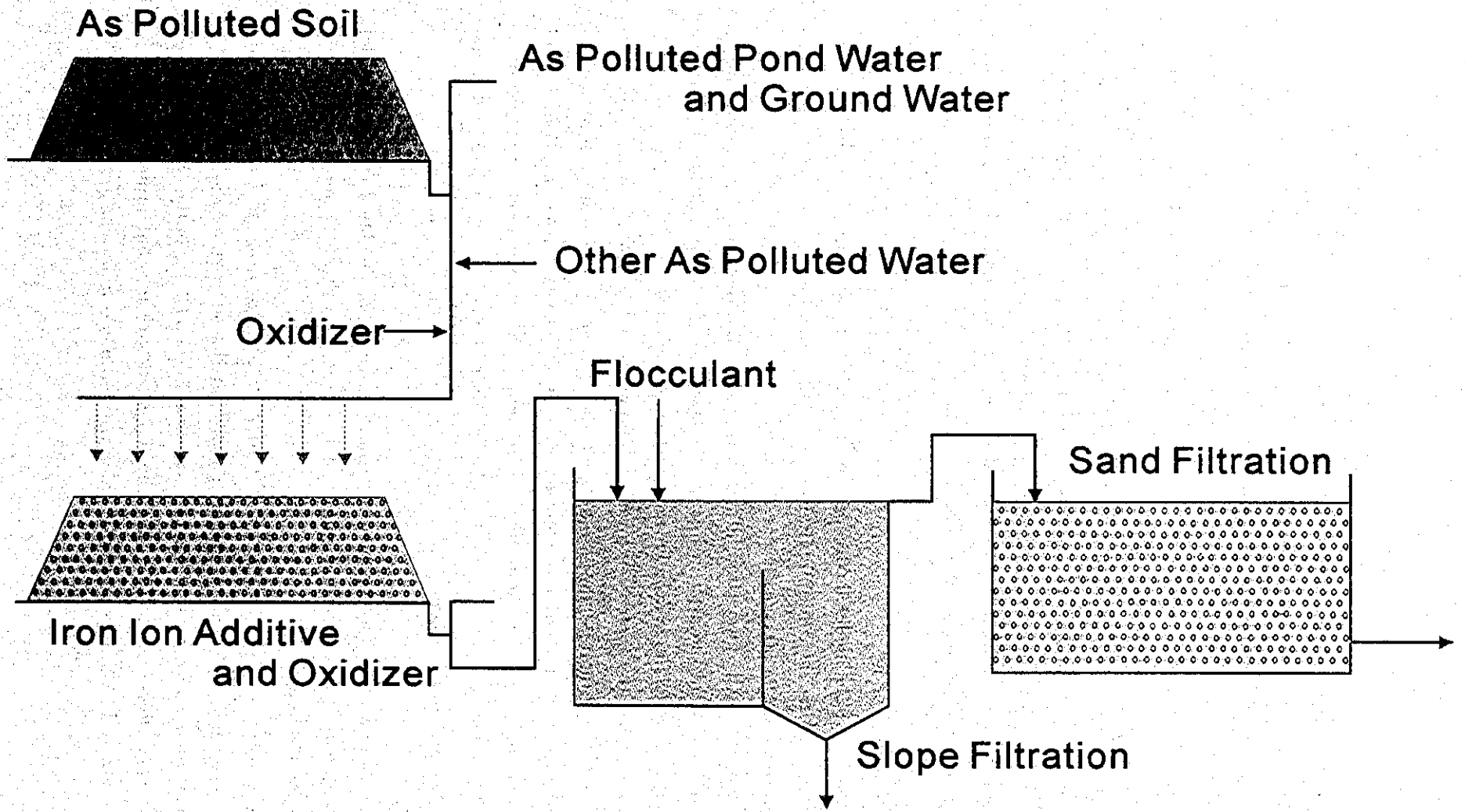

Fig 6.2 Process Flow of Arsenic Removal From Water

preventing arsenic release from the soil.

6.3 Evaluation of countermeasure and monitoring

After the countermeasure will be completed, it is important to evaluate the countermeasure and monitor the existence of arsenic contamination. It is important to keep monitoring arsenic content in groundwater by observation wells. Cleaning of groundwater in the contaminated areas will take long time, in the order of tens of years.

In the previous chapter, 5, we forecasted the change of the contamination of the general survey area. For forecasting, we made a hydrological model of the area from this survey, only one year or one cycle of seasons. It is important to check the validity of our computer model by monitoring the hydrological information.

The following explains the forecasted changes of contamination in three highly contaminated areas with computer model studies.

(1) Dredging Pond

Fig. 6.3 shows the modeled current situation, which is calculated from the computer model assuming the contamination source of the area, the dredging pond, has been in this position for 50 years.

Fig. 6.4 shows the forecasted situation 50 years from now. Because groundwater stagnates around the area in Fig. 5.12. contamination 50 years from now will be transported only 150 m even without any countermeasure.

Fig. 6.5 shows the forecasted arsenic contamination 30 years from now after the removal of contaminated sediments at the bottom of the pond. Movement of groundwater in the area is slow so that even 30 years after the removal of contaminant, some contamination will remain in groundwater. Therefore removal of contaminated groundwater together with soil may be needed for cleaning groundwater in the area.

(2) Site 32C

Fig. 6.6 shows the modeled current situation, which is calculated from the model assuming the contamination source of the area, the site 32C, has been in this position for 30 years.

Fig. 6.7 shows the forecasted situation 50 years from now without any countermeasure. Because permeability around the site 32C is the lowest in the survey area and gradient of head is very small, groundwater in the shallow aquifer flows very slowly at the site 32C. The forecasted arsenic contamination 50 years from now will be transported only 100 m without any countermeasure.

Fig. 6.8 shows the forecasted arsenic contamination 20 years from now after removal of landfill material, clay, from the site 32C. Like the pond, removal of contaminated groundwater and soil may be needed for cleaning the area.

(3) Site 32L

Fig. 6.9 shows the current situation, which is calculated from the model assuming the contamination source, landfill material, of the site 32L has been in this position for 30 years.

Fig. 6.10 shows the forecasted situation 50 years from now without any countermeasure. The forecasted arsenic contamination 50 years from now will be transported 200 m without any countermeasure. even though the source area is smaller than the aforementioned two areas.

Fig. 6.11 shows the forecasted arsenic contamination 20 years from now after removal of landfill material from the site 32L. As the other places, removal of contaminated groundwater and soil may be needed for cleaning the area.

The above three sites have models for removal of contaminant from the area. which is a very important and useful countermeasure against contamination. but we may not be able to remove all the contaminant from the area. Also the model calculation is based on only one year of hydrological record. namely. weather, groundwater movement and river flow record. We recommend continuing monitoring groundwater for several decades.

As a result of this survey, we know the general groundwater flow. We can position a few monitoring wells to monitor effectively the contamination. We can use some wells that were dug for this survey as monitoring wells for the water table and water quality.

Locations of monitoring wells are:

1. east of the contaminated area downstream of the foothill concentrator.
2. near the town concentrator. which is the most populated area in the survey area.
3. downstream of the town concentrator contaminated area and near the highway. and
4. two wells at the old and new waste dumps.

The most important monitoring wells are the above mentioned five wells. Arsenic must be analyzed periodically.

If groundwater quality is not improved, contaminated water may need to be pumped up from those wells and treated before releasing in environment.