

The Study on Water Resources Management in the Hashemite Kingdom of Jordan

**FINAL REPORT VOLUME V
SUPPORTING REPORT
FOR
PART-A “WATER RESOURCES MANAGEMENT MASTER PLAN”
Chapter 4 Water Quality Conservation**

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ANNEX TO 4.2.5

**GROUNDWATER QUALITY
SIMULATION**

Annex to 4.2.5 Groundwater Quality Simulation

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Explanation of Groundwater Quality Simulation Modeling

1. Modeling System

FEFLOW (Finite Element subsurface FLOW system) have been employed for the groundwater quality simulation analysis in South Amman by the JICA Study Team. FEFLOW is an interactive, graphic-based groundwater modeling system for three-dimensional (3D) and two-dimensional (2D) - areal and cross-sectional (horizontal, vertical or axisymmetric) - , fluid density-coupled, also thermohaline, or uncoupled, variable saturated, transient flow, chemical species and heat transport in subsurface water resources with or without free surfaces.

Databases in form of line-, point-, polygon- and annotation-related formats, such as the ESRI Shape file format and the ASCII format widely used in the Geographical Information Systems (GIS) ARC/INFO and ArcView as well as Raster Database (TIFF) and Hewlett-Packard Graphics Language (HPGL)-formatted data can be imported and applied for purposes of data regionalization and visualization.

2. Steps of the Explanation

Method of the groundwater flow and solute transport modeling in South Amman area and use of the FEFLOW have been explained to the MWI's hydrogeological engineers by the JICA Study Team during the last week of May 2001.

The following steps define the tutorial procedure of the modeling three dimensional flow and transport problems based on real South Amman data.

- Step 1 : Design the basic structure of the groundwater model.
- Step 2 : Develop the model into a 3-Dimensional structure.
- Step 3 : Assigning and editing model parameters
- Step 4 : Run the simulation
- Step 5 : Features analyzing the model results

3. Contents of the Explanation

(1) Step 1 : Design the basic structure of the groundwater model

We generate the supermesh and the finite element mesh at the first step of the simulation.

STEP1-1 DESIGNING THE SUPERELEMENT MESH

To define the outer borders of the finite element model, a superelement mesh must be digitized. The superelement mesh will provide the basic structure of the model. We can define the outside boundary of the model and nodes needed by clicking the left mouse button along the background map.

Next, we import well's points which FEFLOW uses as focal points to create finite element nodes during the mesh generation.

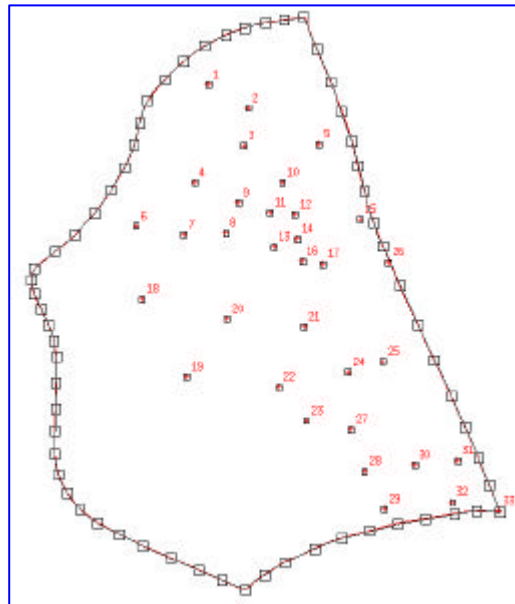


Fig.1 Result of Step 1-1

STEP1-2 GENERATING THE FINITE ELEMENT MESH

The finite element mesh can be automatically generated in the **Mesh generator** menu. Precise meshes are created based on well's points and boundary design.

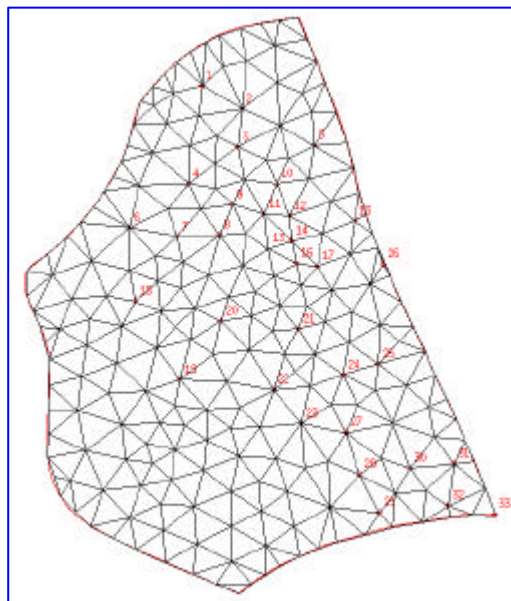


Fig. 2 Result of Step 1-2

STEP 1-3 MODIFICATION OF THE MESH GEOMETRY

For the mass transport simulation, the mesh should be fine in the area where the groundwater quality will be deteriorated. We can refine the mesh using the **Mesh enrichment** function in the **Mesh geometry editor**.

When the shape of the mesh is distorted, the node can be moved using the **Move node** function in the **Mesh geometry editor**.

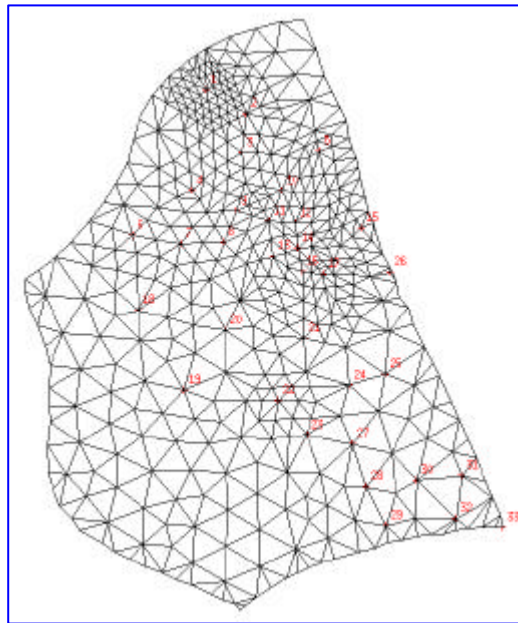


Fig.3 Result of Step 1-3

(2) Step 2 : Develop the model into a 3-Dimensional structure.

STEP 2-1 DESIGNING SLICES AND LAYERS

Until now, we have only designed two-dimensional model. A three-dimensional finite element model is built up by number of nodal plane, called slices. These slices can be regarded as the top or bottom planes of the geological layers. We assign 3 slices and 2 layers .

The topographic data will be imported in the Step 3-3 “3D-slice elevation”.

We can display the model in a 3-D view as shown in the Fig.4.

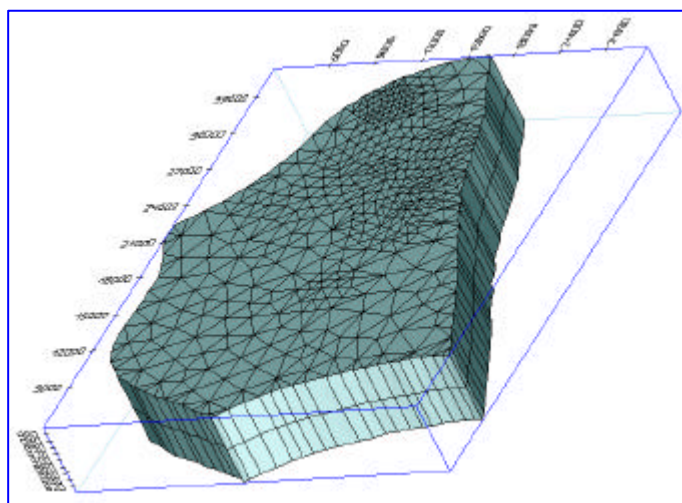


Fig.4 Result of Step 2-1.

(3) Step 3 : Assigning and editing model parameters

We assign the parameters of the model

Assigning flow initials, boundary conditions, material parameters, etc.

Step 3-1 Problem class

In the Problem class menu we define the principle model type of the model. South Amman model is a transient flow with mass transport for unconfined aquifer.

STEP 3-2 TEMPORAL & CONTROL DATA

We set the parameters for the time steps during the simulation run. Also, the error norms and the up winding technique for suppressing numerical oscillations are specified here.

STEP 3-3 3D-SLICE ELEVATION

We set real elevations by assigning the corresponding z-elevations. For avoiding intersection we must consider the order of assigning elevations among slices. We import z-elevations from GIS shape file.

We add two additional layer to increase the accuracy of modeling.

The generated model can be display in a 3-D view as shown in the Fig.5.

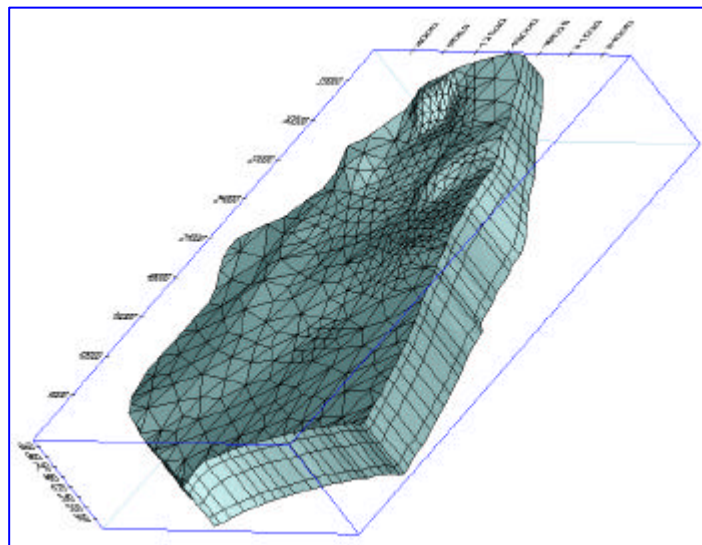


Fig.5 Result of Step 3-3

Step 3-4 Flow data

The **Flow data** section controls all the necessary input parameters for the groundwater flow model. The **Flow data** menu is consists of 3 submenus: the **Flow initials**, the **Flow boundaries** and the **Flow materials** menus.

Flow initials

We assign the groundwater surface for the start of our simulation run. We import flow initials from GIS shape file. We copy the initial values to all the remaining slices. The result can be visualized as shown in the Fig.6.

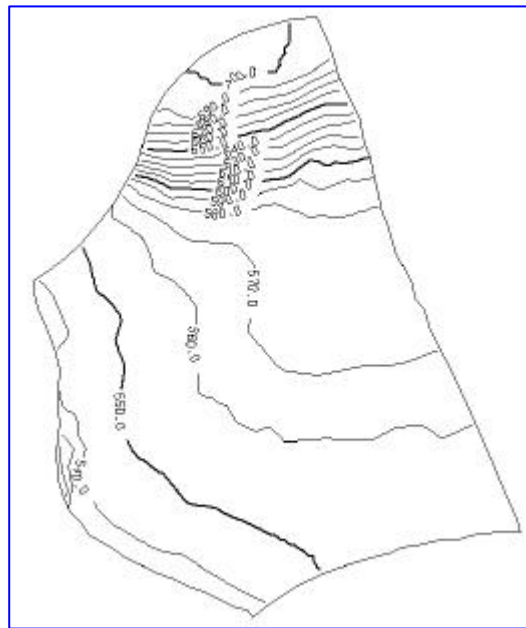


Fig.6 Result of the Flow Initials

FLOW BOUNDARIES

We set the boundary conditions for our model in the **Flow boundaries** menu.

We set a constant hydraulic head of 540m to the southwestern boundary and no flow boundaries to remain three boundaries.

The wells (boundary conditions) should be set as boundary conditions with a discharge rate. We set the 33wells with time-varying discharge rates.

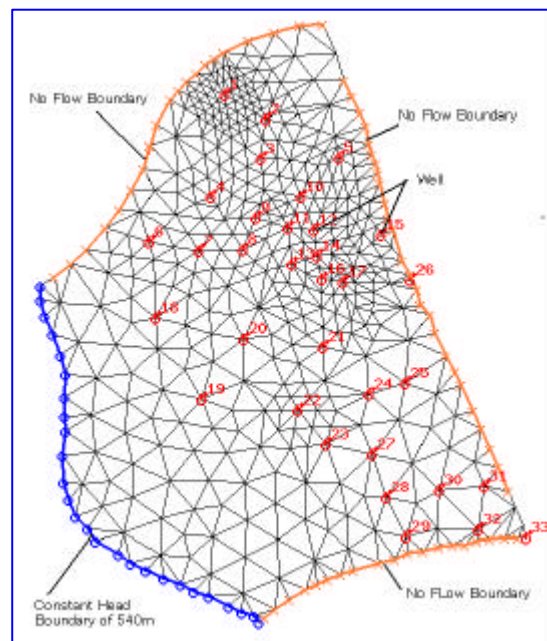


Fig.7 Result of the Flow Boundaries

FLOW MATERIALS

The **Flow materials** menu allows us to edit all material parameters such as conductivity [Kxx, Kyy, Kzz], storativity, compressibility, density ratio and etc.

Groundwater recharge should be assigned using the “**In/out flow on top**”.

The distribution of the assigned Conductivity Kxx value is shown in Fig.8.

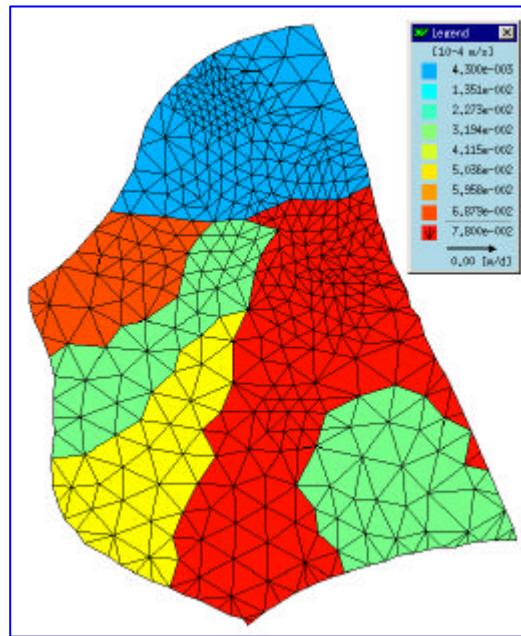


Fig.8 Distribution of the assigned Conductivity Kxx value

STEP 3-5 Transport data

The **Transport data** menu contains all editors for defining mass and heat transport parameters. Its structure is similar to the **Flow Data** menu, i.e. we can set **Mass transport initials** values, **Mass transport boundaries** conditions and **Mass transport materials** parameters.

MASS TRANSPORT INITIALS

We set the initial groundwater salinity concentration for the our groundwater quality model. We import salinity values from GIS shape file. Because we do not have the data concerning vertical distribution of salinity, we copy the initial values to all the remaining slices. The result is shown in the Fig.9.

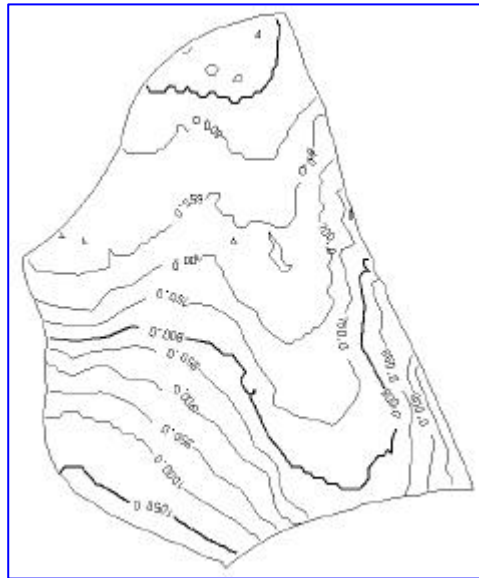


Fig.9 Result of the Mass Transport Initials

MASS TRANSPORT BOUNDARIES

In the **Mass transport boundaries** menu, constant concentrations are assigned for the outer borders where water can enter the model. Optional concentration can be set at each node along the border.

The quality and the quantity of the irrigation return flow should be assigned as the mass flux on the top slice in this menu. The time-varying values that quality(mg/l) is multiplied by quantity(m/day) are set at the each node using the **Time-varying function ID's**.

MASS TRANSPORT MATERIALS

We assign the mass transport material's parameters such as porosity, molecular diffusion, longitudinal dispersivity, transverse dispersivity, decay rate and etc..

(4) Step 4 : Run the simulation

To enter the **Simulator run** shell menu, we select "**Run**"-"**Start simulator**". We can start the simulation by clicking on the "**(Re-)Run simulator**" button. FEFLOW automatically generates various windows that detail the ongoing results for the wells, observation points, hydraulic head, and contaminant concentrations. These windows are displayed as diagrams as shown in the Fig.10. The simulation will require approximately 1/4 hour on a Pentium 700Mhz.

In this version of FEFLOW, we cannot save the results of the simulation though we can save the generated model and the set values in the model.

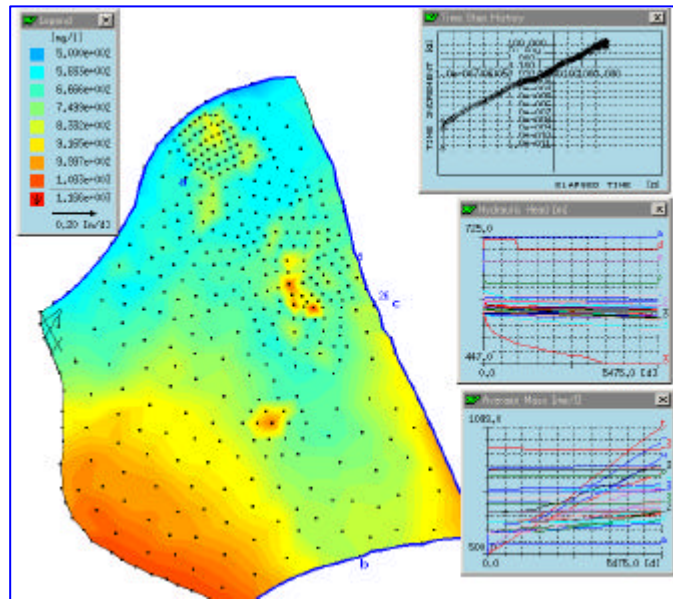


Fig.10 Simulation screen

(5) Step 5 : Features analyzing the model results

Having interrupted the simulation, we can analyze the results of the current time steps with the options offered in the **Halt & View Results** menu (isoline maps, velocities, particle tracking, line sections & segments), the **Budget analyzer**, the **Fluid flux analyzer** or in the **Spatial operations** menu.

The following figures show the main results of the South Amman model in the case 3-A (60% reduction of the groundwater abstraction and no change of irrigation water use) in the year of 2040.

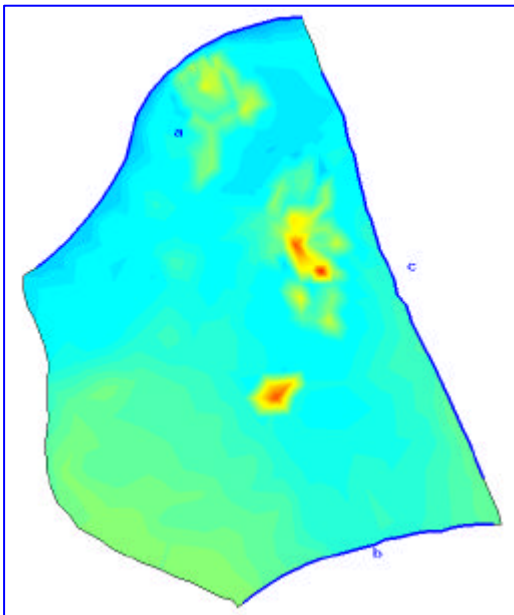


Fig.11(a) Fringe map of salinity

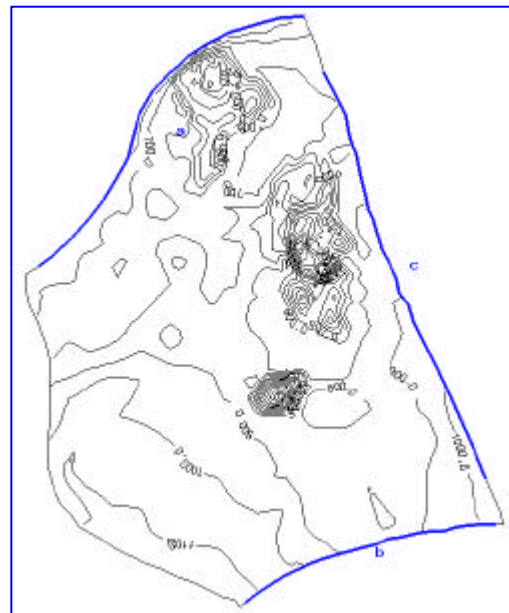


Fig.11(b) Isoline map of salinity



Fig.12(a) Lines for the sections

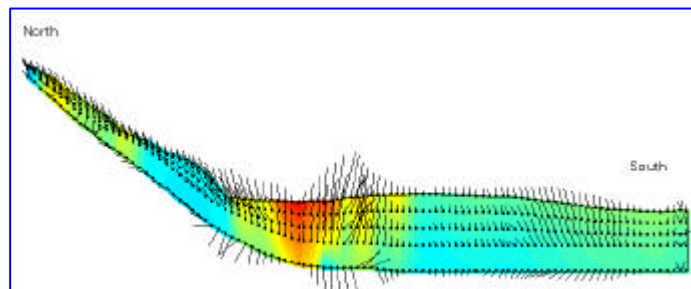


Fig.12(b) N-S Section shown as fringes for salinity with velocities



Fig.12(c) N-S Section shown as isolines for salinity

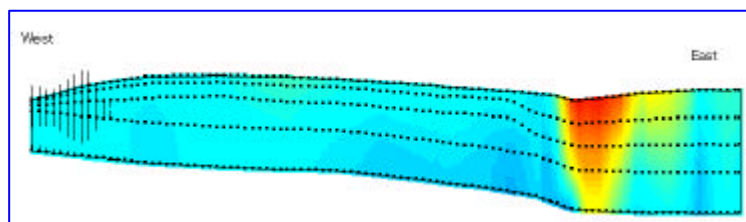


Fig.12(d) W-E section shown as fringes for salinity with velocities

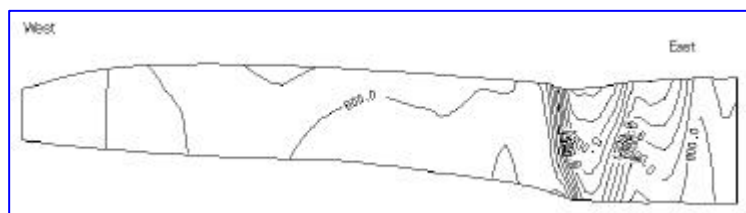


Fig.12(e) W-E section shown as isolines for salinity

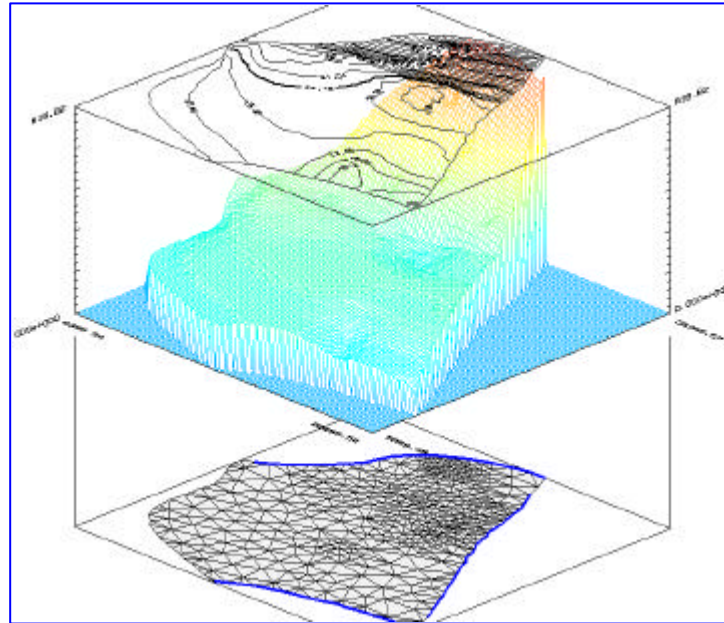


Fig.13 3-D view of the groundwater levels

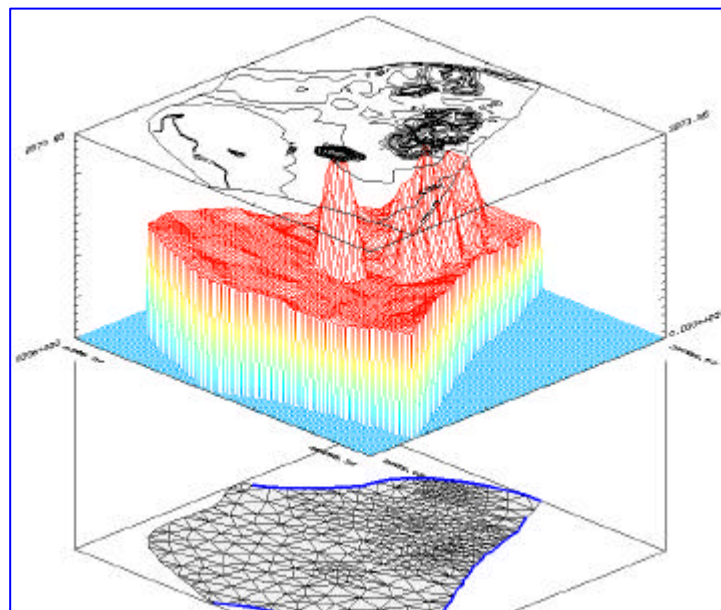


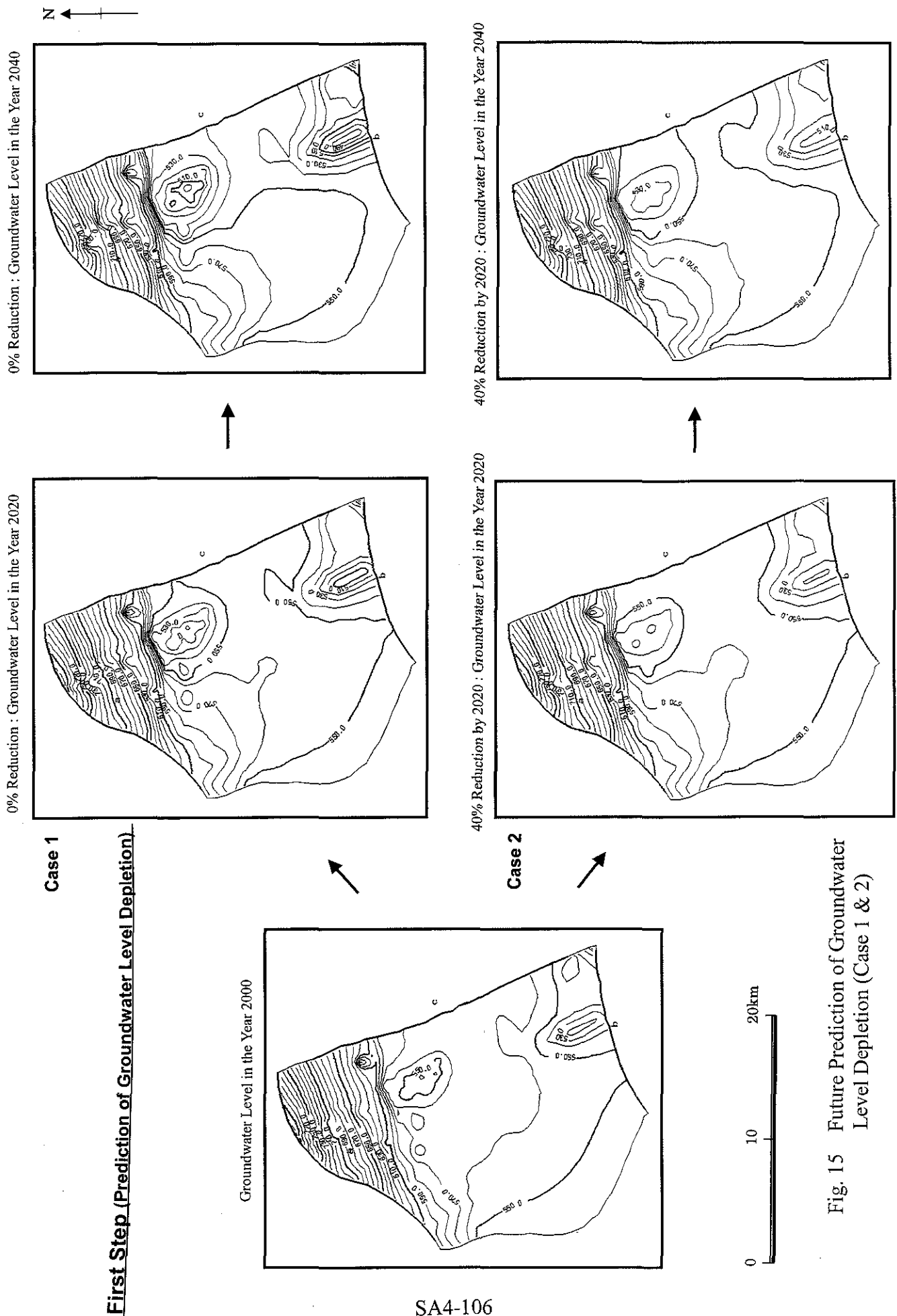
Fig.14 3-D view of the salinity distribution

4. Results of the Simulation

The results of the simulation for groundwater level depletion are shown in Fig.15 and Fig.16.

The results of the simulation for groundwater salinity change are shown in Fig.17 and Fig.18.

The results of the simulation for change of nitrate concentration in groundwater are shown in Fig.19 and Fig.20.



First Step (Prediction of Groundwater Level Depletion)

Fig. 15 Future Prediction of Groundwater Level Depletion (Case 1 & 2)

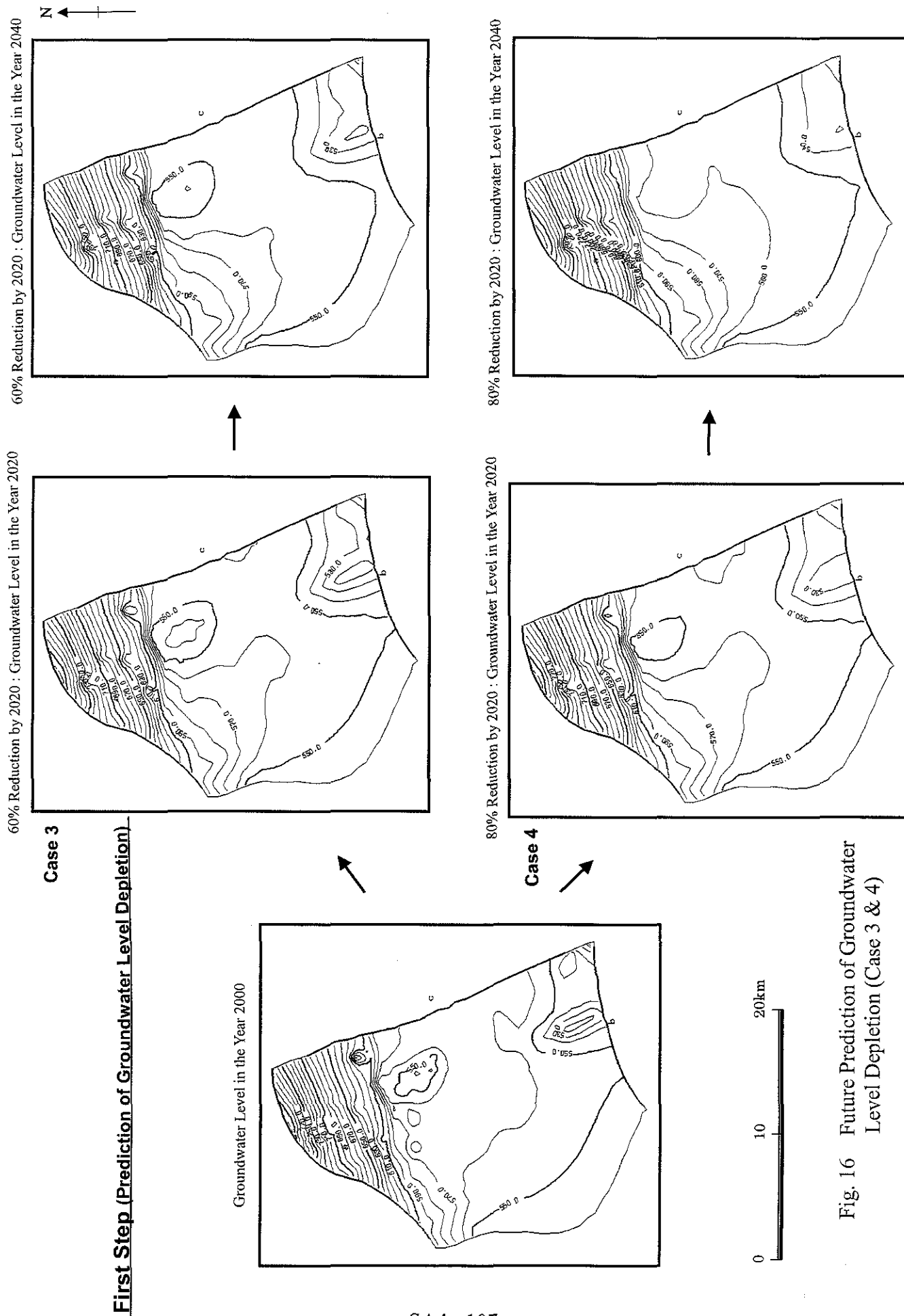
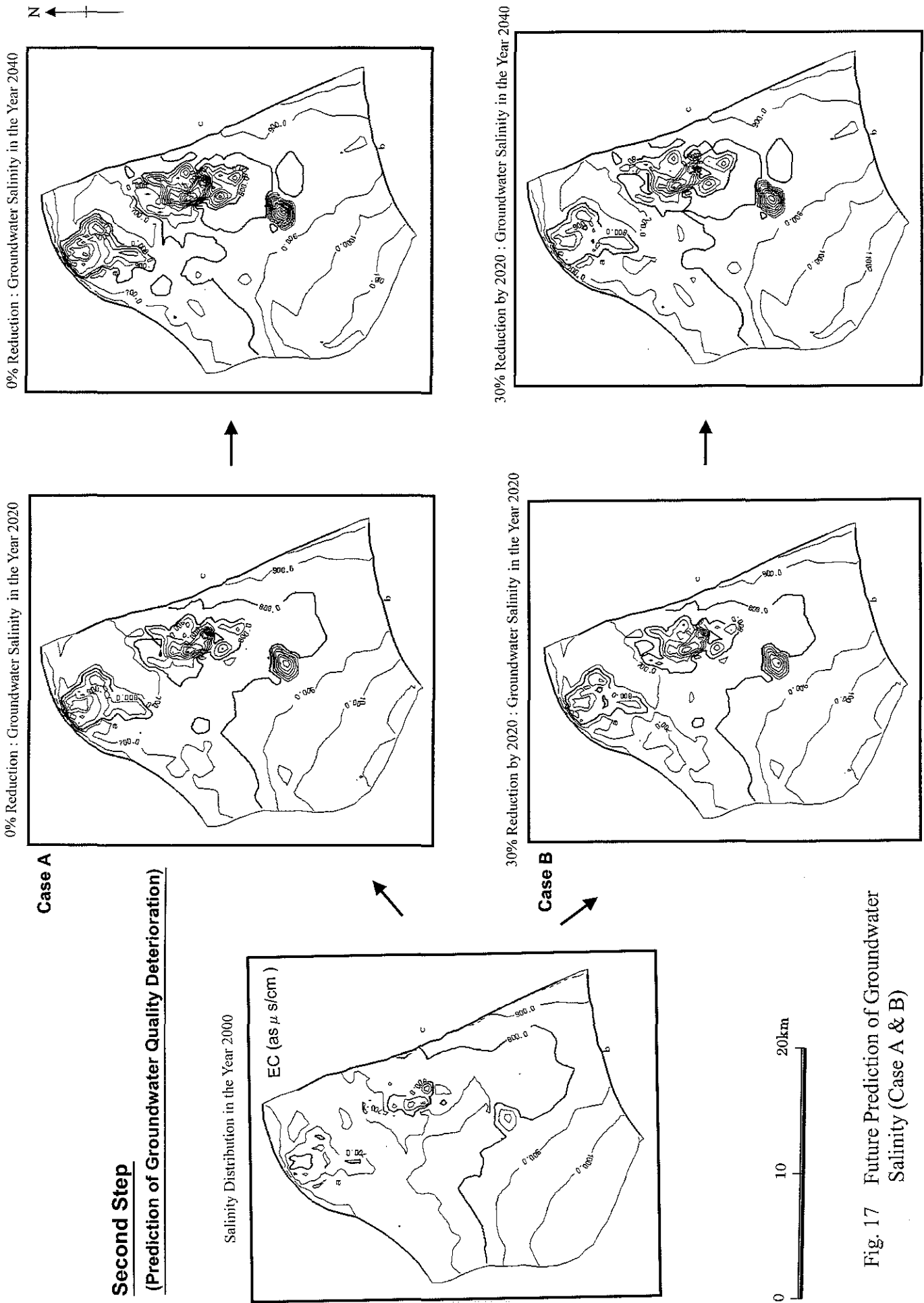


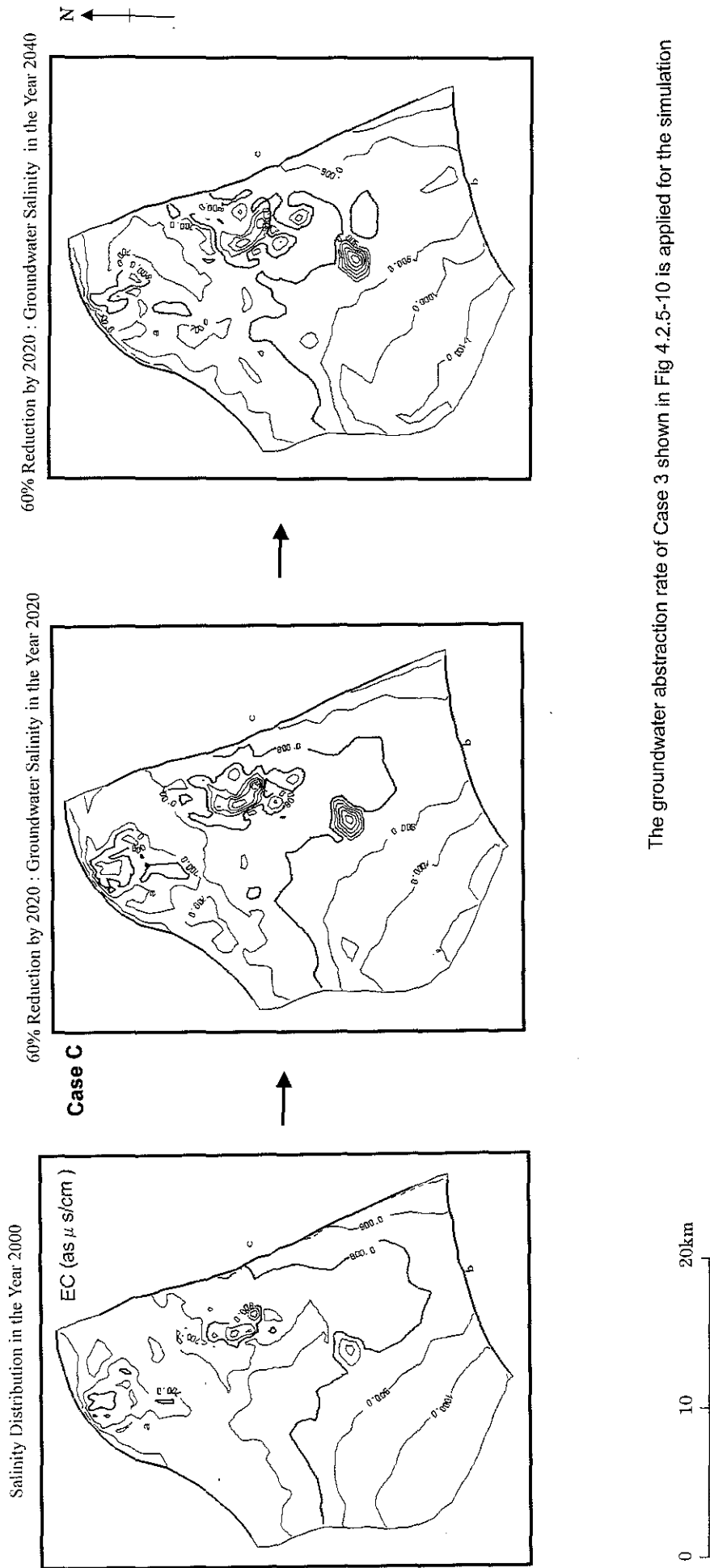
Fig. 16 Future Prediction of Groundwater Level Depletion (Case 3 & 4)



The groundwater abstraction rate of Case 3 shown in Fig 4.2.5-10 is applied for the simulation

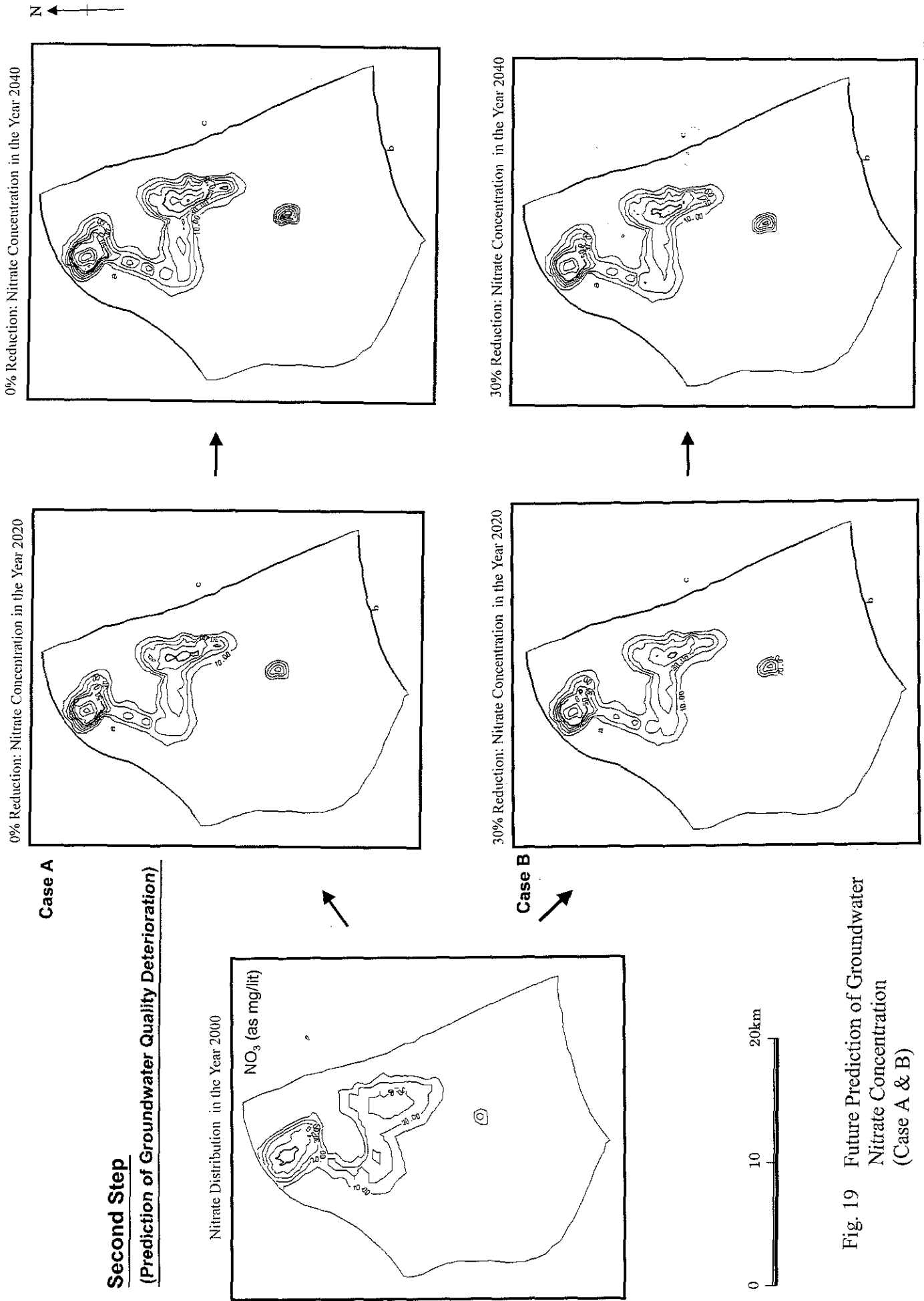
Fig. 17 Future Prediction of Groundwater Salinity (Case A & B)

Second Step (Prediction of Groundwater Quality Deterioration)



The groundwater abstraction rate of Case 3 shown in Fig 4.2.5-10 is applied for the simulation

Fig. 18 Future Prediction of Groundwater Salinity (Case C)



The groundwater abstraction rate of Case 3 shown in Fig 4.2.5-10 is applied for the simulation

Fig. 19 Future Prediction of Groundwater Nitrate Concentration (Case A & B)

Second Step (Prediction of Groundwater Quality Deterioration)

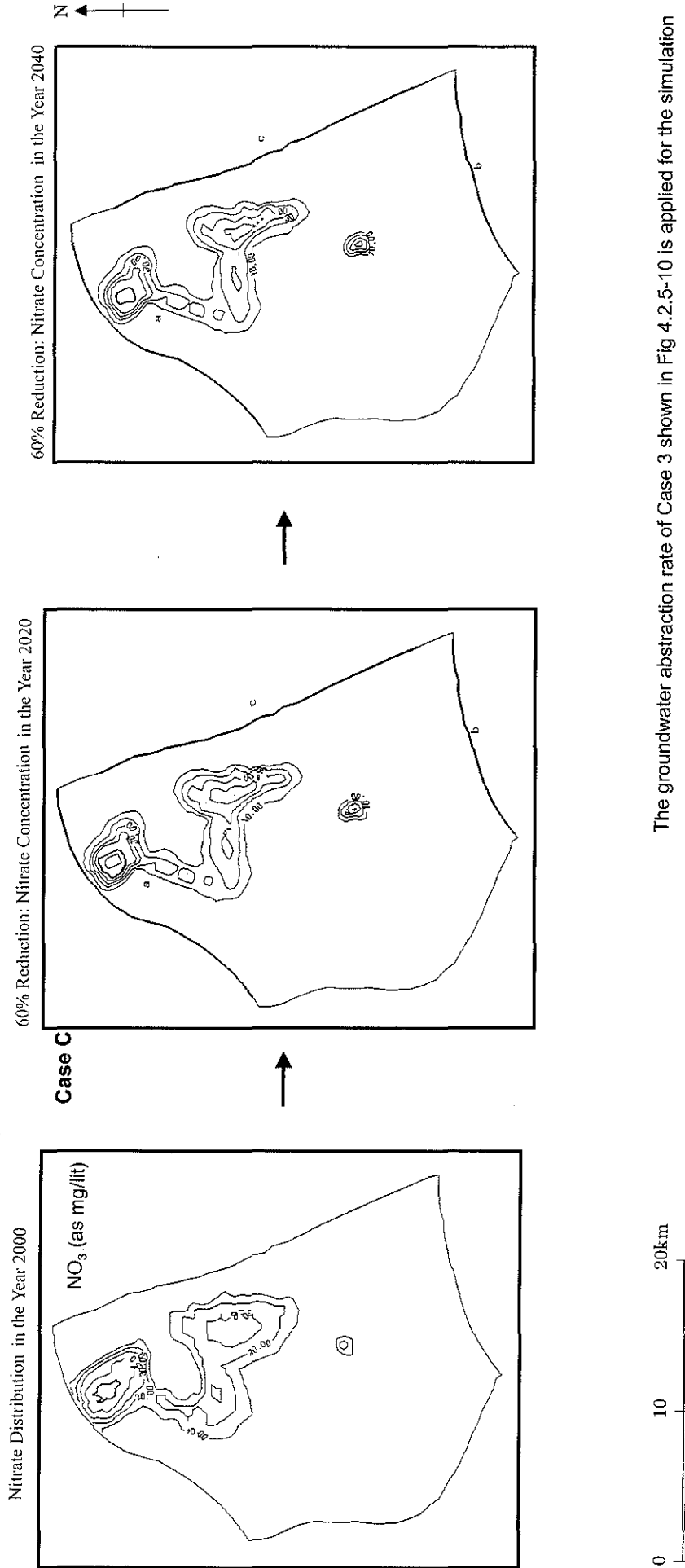


Fig. 20 Future Prediction of Groundwater Nitrate Concentration (Case C)