SKBF KBS TEKNISK RAPPORT 79-10

# Model calculations of groundwater conditions on Sternö peninsula

Carl-Lennart Axelsson
Leif Carlsson

Geological Survey of Sweden September 1979

SVENSK KÄRNBRÄNSLEFÖRSÖRJNING AB / PROJEKT KÄRNBRÄNSLESÄKERHET

*POSTADRESS: Kärnbränslesäkerhet, Box 5864, 102 48 Stockholm, Telefon 08-67 95 40*

# MODEL CALCULATIONS OF GROUNDWATER CONDITIONS ON STERNÖ PENINSULA

Carl-Lennart Axelsson
Leif Carlsson

Geological Survey of Sweden September 1979



A list of other reports published in this series is attached at the end of this report. Information on KBS technical reports No. 1 - 120 in an earlier series is available through SKBF/KBS.

CONTENTS

| | Page |
|---|---|
| SUMMARY | 1 |
| INTRODUCTION | 2 |
| Background | |
| Scope | |
| CALCULATION OF GROUNDWATER CONDITIONS | 3 |
| Topographic conditions | |
| Geologic and tectonic conditions | |
| Model assumptions | |
| Calculation procedure | |
| Results | |
| CALCULATION OF FLOW TIMES | 9 |
| Calculation procedure | |
| Results | |
| DISCUSSION | 11 |
| REFERENCES | 13 |

SUMMARY

The groundwater condition within the bedrock of Sternö was calculated by the use of a two-dimensional FEM-model. Five sections were laid out over the area. The sections had a depths of five km and length between two and six km. First the piezometric head was calculated in two major tectonic zones where the hydraulic conductivity was set to $10^{-6}$ m/s. In the other sections of which two cross, the tectonic zones the bedrock was assumed to have hydraulic conductivities of $10^{-8}$ m/s in the uppermost 300 m and $10^{-11}$ m/s in the rest.

From the maps of the piezometric head obtained, the flow time was calculated for the groundwater from 500 meters depth to a tectonic zone or to the 300 meters level below the sea. This calculation was performed for two sections both with and without tectonic zones. Also the influence of groundwater discharge from a well in one point in one of the tectonic zones was calculated. The kinematic porosity was assumed $10^{-4}$. The result showed that the flow time varied between 1000 to 500 000 years within the area with the exception of the nearest 100 m zone to any of the tectonic zones. For further calculations the use of three-dimensional models was proposed.

# INTRODUCTION

## Background

The Geological Survey of Sweden, SGU (Sveriges geologiska undersökning), was commissioned by KBS to carry out a calculation of the groudnwater conditions on the Sternö peninsula in the province of Blekinge on the southeast coast of Sweden. These calculations have been carried out with the aid of a numerical model based on the finite element method (FEM). The work was included in the supplementary work occasioned by a parliamentary resulution of 5 October 1978 requiring additional geological data in order to demonstrate the existence of sufficiently large rock formations suitable for the final storage of high-level waste.

## Scope

The groundwater conditions on the Sternö peninsula were calculated within four sections and the results reported in KBS technical report 79-08. These calculations were performed under the assumption of constant hydraulic conductivity throughout the entire area. This means that existing tectonic zones with higher hydraulic conductivity and the fact that hydraulic conductivity decreases with depth (as shown in KBS technical report 79-06) have not been taken into account. The calculations presented in this report take the above conditions into consideration. The numerical model used presumes two-dimensional plane-parallel or axisymmetrical flow in a confined aquifer. Axisymmetrical flow refers to flow directed radially around a symmetrical axis. Because the calculation has been limited to two-dimensional flow, certain assumptions have had to be made with regard to groundwater inflow our outflow within the calculated section (this is discussed further on in the report).

## CALCULATION OF GROUNDWATER CONDITIONS

### Topographic conditions

The Sternö peninsula is situated approximately 3 km south of the town of Karlshamn in the province of Blekinge on the southeastern coast of Sweden. The northern part of Sternö is bounded on the west, north and east by inlets of the Baltic Sea, see Fig. 1. On the northeast, there is an approximately 350 m wide land bridge to the mainland north of Sternö. The southern part of Sternö is separated from the northern part by a 750 m wide neck.

The northern part of Sternö is characterized topographically be a centrally located elevated area whose highest point is located about 50 m above sea level. This point is located 500 m from the Baltic Sea on the east and between 600 and 1200 m from the Baltic Sea on the southwest, west and northwest. The distance to Munkahus-viken Bay on the north is about 900 m.

From the elevated area, the ground slopes steadily down towards the surrounding water. This is interrupted only on the west and northwest by small rises with heights of about 10 m above sea level. The pass point, about 25 m above sea level, is located on the borderline between northern and southern Sternö.

## Geologic and tectonic conditions

A general picture of the geology and tectonics of the Sternö peninsula has been presented in KBS technical reports 79-05 and 79-09. According to these reports, the homogeneous bedrock within the rock formations west of the diabase vein that cuts through Sternö can be characterized from the viewpoint of permeability as follows: Below a depth of about 300 m, the rock has a hydraulic conductivity of $10^{-11}$ m/s or lower. Above this level, conductivity varies between $8 \times 10^{-10}$ and $2 \times 10^{-8}$ m/s.

There are a number of fracture zones in and around Sternö. The hydraulic conductivity and width of these fracture zones have been evaluated on the basis of the aforementioned technical reports. The extent of these zones is illustrated in Fig. 1.

A general picture of the bedrock in western Blekinge is provided in KBS technical report 25.

## Model assumptions

The hydraulic conductivity of the homogeneous rock within the Sternö peninsula has been assumed to be $10^{-8}$ m/s for the uppermost 300 metres and $10^{-11}$ m/s for the lower levels. These conditions have been assumed to prevail within all of the bedrock within and adjacent to Sternö, with the exception of the fracture zones. The conductivity in all the fracture zones has been set at $10^{-6}$ m/s, and $5 \times 10^{-6}$ m/s for intersections between the fracture zones. The hydraulic conductivity conditions that have been assumed in the model calculations are shown in Fig. 2. All existing fracture zones have been assumed in the models to be vertical on the basis of KBS technical report 79-05. The width of the fractures has been assumed on the basis of assessments and weightings of their hydraulic properties based on measurements of hydraulic conductivity and mapping of drill cores, where such are available.

The assumed widths of the different fracture zones are presented in Table 1.

Table 1

Assumed width of the fracture zones in the model used

| Fracture zone No. | Width m |
|---|---|
| 1 | 30 |
| 2 | 30 |
| 3 | 5 |
| 4 | 10 |
| 5 | 5 |
| 6 | 10 |

## Calculation procedure

The vertical flow picture has been calculated in five sections (A - E) laid out over the Sternö peninsula and the surrounding water and land (see Fig. 1) with the aid of a finite element model (GEOFEM-G) (Runesson et al 1978). The depth of the calculated sections is 5 km. The sections were selected on the basis of topographic, geologic and tectonic conditions. The groundwater conditions have been calculated assuming a) natural conditions and b) a water discharge rate of 0.05 l/s (4 $m^3$/d). The calculations have not taken into account the possible effects of temperature and viscosity conditions on hydraulic conductivity. Nor have they taken into account the influence of hydraulic pressure on hydraulic conductivity.

The groundwater conditions within existing fracture zones are important as limiting conditions for the flow of groundwater in the homogeneous rock. This is due to the great difference in hydraulic conductivity between the fractures and the homogeneous rock in combination with topographic and geometric conditions. Therefore, as a first step, the groundwater conditions (i.e. the groundwater head) was calculated for the sections A and B along presumed fracture zones. The groundwater head was then calculated for the homogeneous rock in sections C, D and E. These calculations were carried out assuming a) natural conditions and b) a fictitious discharge of 0.05 l/s in fracture zone 4. The following assumptions have been made in the calculations.

Sections A and B

- Within sections A and B, it has been assumed that the groundwater head basically follows the topography, but at a certain distance below it. Water level measurement in borehole Ka 3 shows that the water table is located at about +18 m above sea level (Feb. 1979), i.e. 8 m below ground level. The location of borehole Ka 3 as well as the topography of the Sternö peninsula are described in KBS technical report 79-06. Fig. 3 shows the groundwater levels assumed in the upper parts of the bedrock within sections A and B, upon which the calculations of the groundwater conditions are based. The influence of any rock caverns within the area has not been taken into consideration.

- The fictitious discharge in fracture zone 4 is assumed to be located in the point of intersection between sections A and C, where the influence of the groundwater conditions in section C is greatest. The discharge takes place from the water table down to a depth of 100 m. The groundwater level in the upper parts of the bedrock at this discharge is shown by Fig. 3.

- On the basis of hydrogeologic and topographic conditions, plane-parallel flow is assumed in sections A and B.

Sections C, D and E

- In calculating the groundwater conditions along section C, the groundwater head calculated for sections A and B in the points of intersection with section C, is used. The groundwater conditions for section D are calculated in a similar manner. Figs. 4 and 5 show the groundwater head as a function of the depth at these points of intersection. Fig. 6 shows the groundwater head as a function of the depth at the point of intersection between sections C and A, assuming a) natural conditions and b) a discharge rate of 0.05 l/s.

- With the exception of the intersections referred to above, the groundwater head in the uppermost parts of the bedrock in sections C, D and E has been assumed to be equal to that at ground level and sea level.

- In sections C and D, axisymmetrical flow has been assumed between the central elevated area and the intersections with section A, on the basis of topographic conditions. The axis of symmetry is the centre of the central elevated area. Plane-parallel flow has been assumed in the rest of sections C and D.

- Axisymmetrical flow has been assumed in all of section E, with the centre of the elevated area as the axis of symmetri.

Results

The groundwater head along sections A - E is illustrated in Figs. 7-13. In addition to the previously described conditions with respect to tectonics and distribution of hydraulic conductivity, Fig. 9 presents a calculation where it is assumed that there are no fractures in section C. The distribution of conductivity within the bedrock is, however, as given in Fig. 2 as far as the homogeneous rock mass is concerned.

The groundwater flow within the centrally located elevated area is largely downward, i.e. the area constitutes an inflow area, as is evident from Figs. 10-12. The groundwater flow between the two fracture zones 4 and 2 is slightly downward, but largely parallel to the surface of the ground. The greater part of the groundwater flow takes place within the upper parts of the bedrock due to the higher hydraulic conductivity and the topographic conditions.

## CALCULATION OF FLOW TIMES

Calculation procedure

The calculation of the groundwater flow time is based on the calculations of the groundwater head in the previously specified sections.

The flow time was calculated from a level of 500 m below sea level until the groundwater reaches a fracture zone or reaches the uppermost 300 m of the bedrock. This means that the time for the groundwater's flow has only been calculated within the homogeneous rock, where hydraulic conductivity has been assumed to be $10^{-11}$ m/s and kinematic porosity has been assumed to be $10^{-4}$.

Results

The flow time for the groundwater in sections C and D is reported in Figs. 14 and 15. The distance in the sections is counted from the central elevated area.

In section C, Fig. 14, the flow times were calculated both with and without fracture zones in the section. Moreover, the times were calculated with a groundwater discharge of 0.05 l/s within the upper 100 m of bedrock at the intersection with fracture zone 4.

Between the central elevated area and fracture zone 4, the flow times under natural conditions are considerably shorter when the fracture zone is taken into account. This is because the groundwater flow does not penetrate so deep, owing to the pressure-equalizing effect of the fracture zone. The flow times between fracture zone 4 and fracture zone 2 are longer, when the fractures have been taken into consideration, except for about 100 m from fracture zone 2. This is because the groundwater flow is directed slightly downwards when the fractures are taken into consideration. When the fractures are not taken into consideration, however, the flow is upwards, which shortens the flow path. In combination with the higher pressure gradient, this results in shorter flow times between fracture zone 4 and fracture zone 2 when there are no fractures.

With groundwater discharge at the intersection with fracture zone 4, the flow times in section C will be shorter within the area between the central elevated area and fracture zone 4, as shown by Fig. 14. The groundwater discharge causes a reduction of the hydraulic gradient within the area between fracture zones 4 and 2. This results in an increase of the flow times in this area, compared with a situation without groundwater discharge.

In section D, Fig. 15, the flow times have been calculated taking into account fractures in the section. The discontinuity in the curve between fracture zones 4 and 2 is due to the fact that the groundwater flow between fracture zone 4 and approximately 100 m to the west takes place towards fracture zone 4. The groundwater flow farther to the west in section D takes place towards fracture zone 2. This is shown by the head distribution in the section, Fig. 12.

## DISCUSSION

The calculations were carried out using a two-dimensional numerical model based on finite elements. In calculations over large areas, and especially with large dimensions in the vertical direction, the use of two-dimensional approaches leads to the introduction of approximations. Thus, it is assumed that all flow in sections A and B takes place along the respective sections. The same assumptions are made with regard to the other calculated sections where the intersections with the fracture zones lead to an inflow or outflow of groundwater to or from the sections via the fracture zones.

The vertical distribution of the hydraulic conductivity and the geometric orientation of the fracture zones are of great importance for the flow pattern along the sections. Relatively simple assumptions have been made in the calculations concerning conductivity distribution and fracture geometry. These assumptions are based on available information from boreholes and geologic/tectonic mapping within the area. The calculated flow times must be considered against the background of both the limitations of the model and the validity of the input data.

The calculated flow times are based on conservative assumptions concerning hydraulic conductivity from available data. The following are required in order to further refine the calculations

- the use of a three-dimensional model
- further information on the geometric orientation of the tectonic zones
- further information on the distribution of hydraulic conductivity in the homogeneous rock mass
- further information on the distribution of hydraulic conductivity in the tectonic zones.

REFERENCES

KBS technical report 25: Blekinge kustgnejs, geologi och hydrogeologi. ("The Blekinge coastal gneiss, geology and hydrogeology"). I I Larsson, T Lundgren and U Wiklander 1977.

KBS technical report 79-05: Kompletterande berggrundsundersökningar inom Finnsjö- och Karlshamnsområdena, ("Supplementary bedrock studies within the Finnsjö and Karlshamn areas"), A Olkiewicz, S Scherman, K-A Kornfält 1979.

KBS technical report 79-06: Kompletterande permeabilitetsmätningar i Karlshamnsområdet. ("Supplementary hydraulic conductivity measurements in the Karlshamn area"). G Gidlund, K Hansson, U Thoregren 1979.

KBS technical report 79-08: Beräkningar av grundvattenrörelser inom Sternöområdet i Blekinge. ("Calculations of groundwater movement within the Sternö area in Blekinge). J Stokes 1979.

KBS technical report 79-09: Utvärdering av de hydrogeologiska och berggrundsgeologiska förhållandena på Sternö. ("Evaluation of the hydrogeology and bedrock geology of the Sternö peninsula"). K Ahlbom, L Calrsson, G Gidlund, C-E Klockars, S Scherman, U Thoregren 1979.

Runesson, K, Tägnfors, H, Wiberg, N-E 1978: GEOFEM-G. Computer program for groundwater seepage including confined aquifer analysis. User's manual. - Chalmers University of Technology 1978.

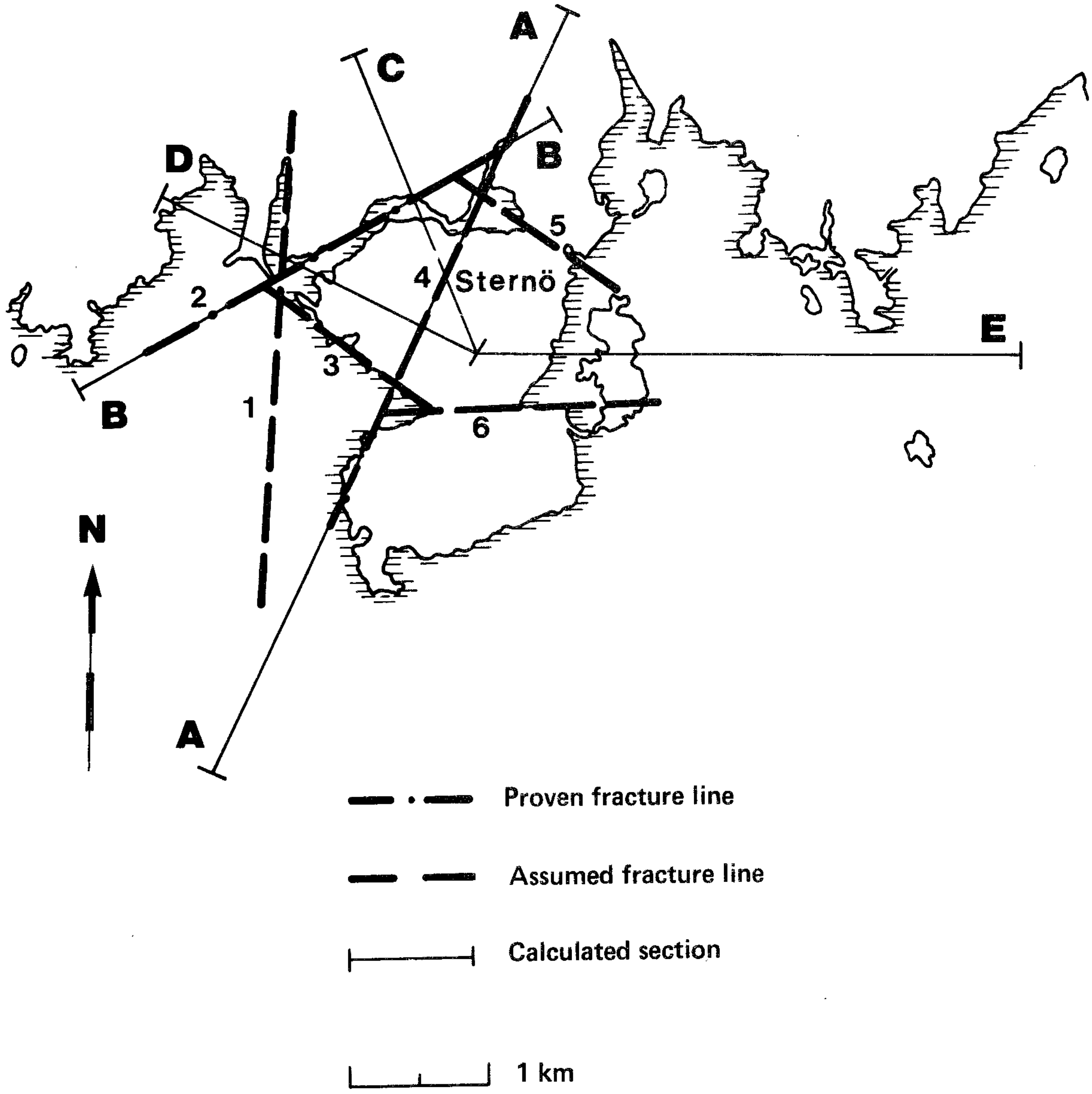



*Figure 1. Map of Sternö with fracture zones (1–6) and calculated sections (A–E).*

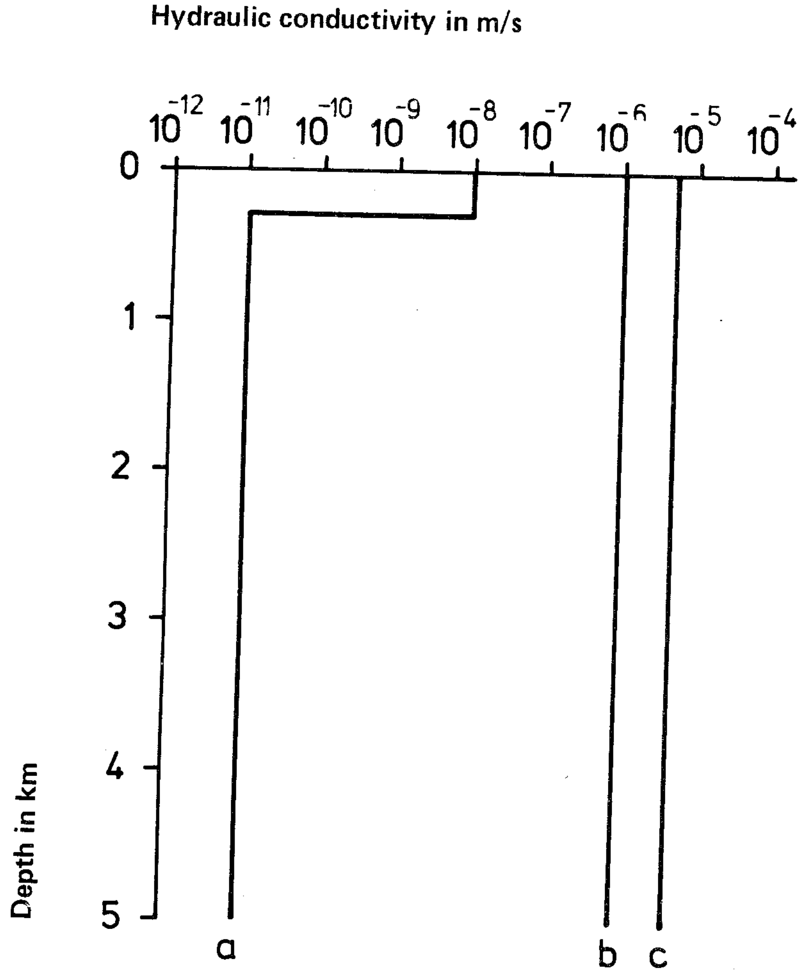
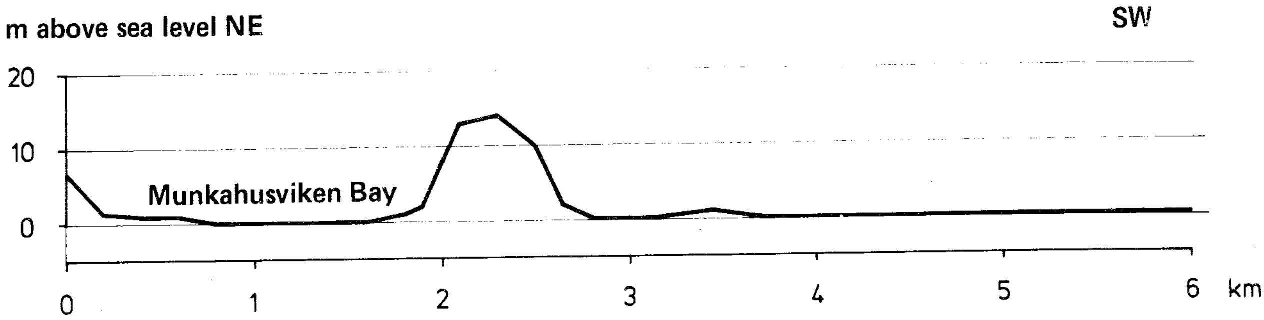
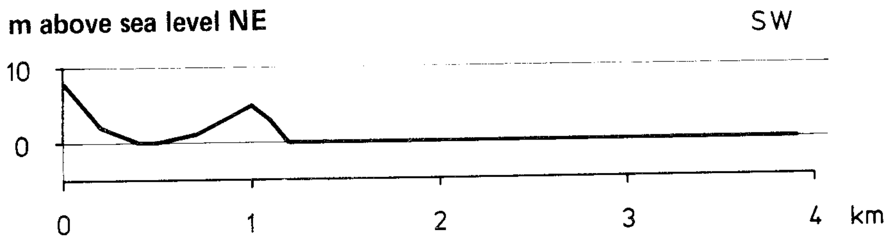



*Figure 2. Assumed values of hydraulic conductivity of a) homogeneous rock mass, b) fracture zones and c) intersection between fracture zones.*

SECTION A




SECTION B




SECTION A

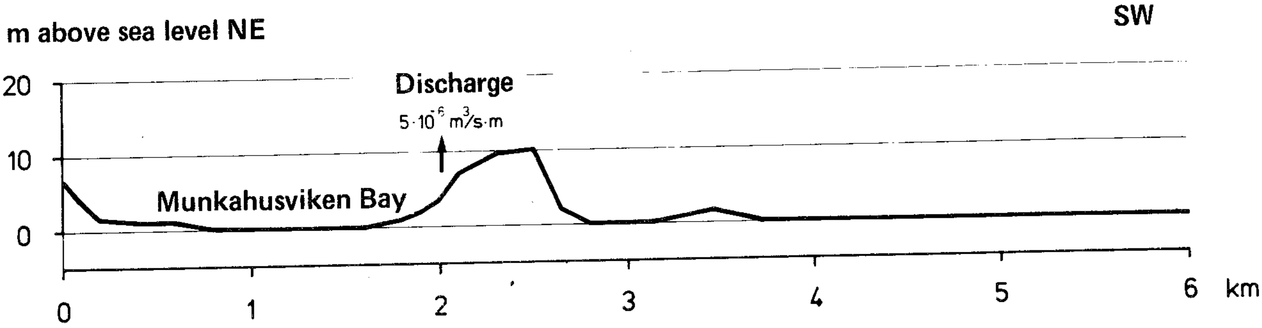



*Figure 3. Assumed groundwater levels in the upper part of the bedrock along sections A and B and along section A with groundwater discharge at the intersection with section C.*

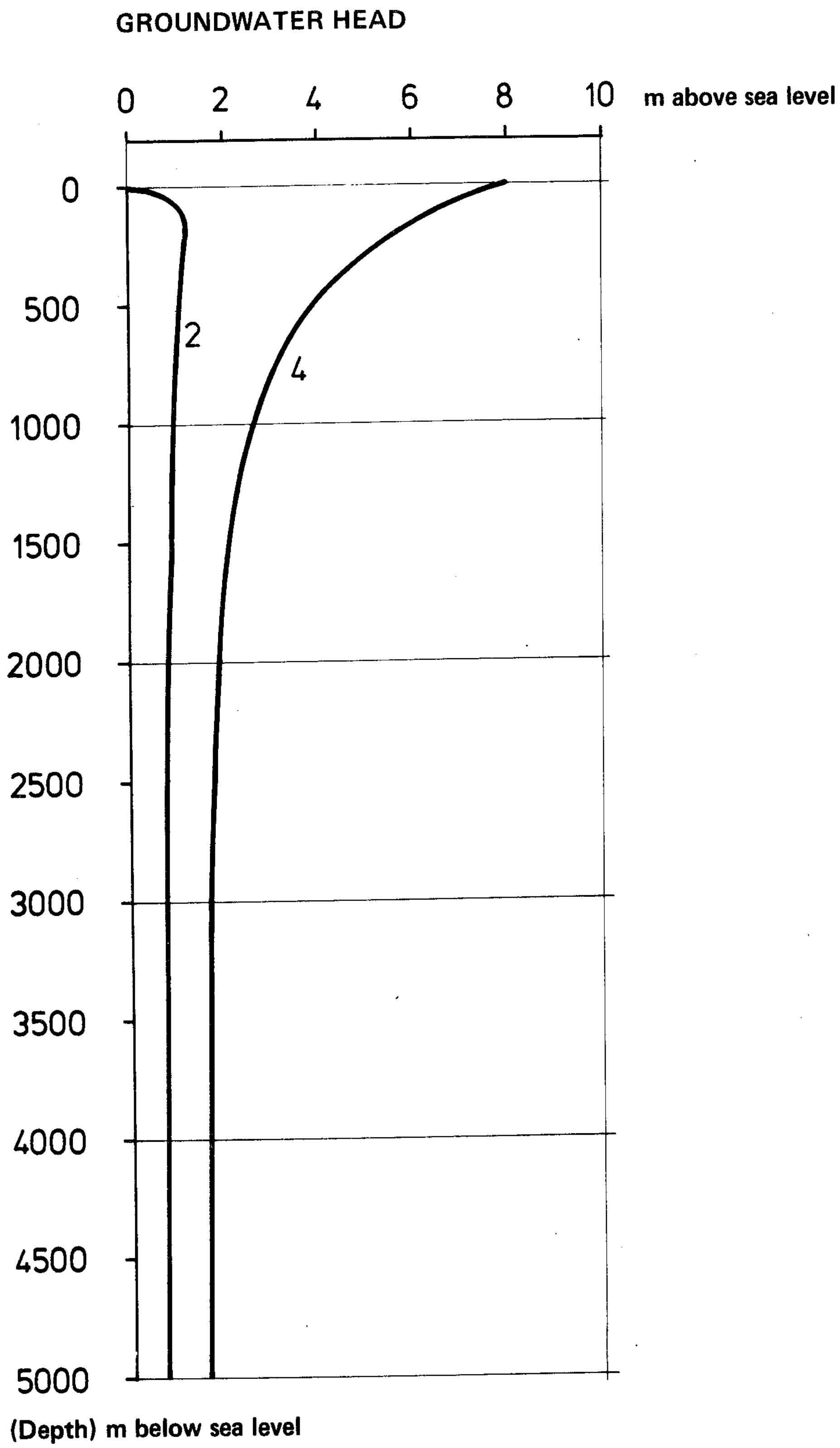



*Figure 4. Groundwater head in fracture zones 2 and 4 at their intersections with section C under natural conditions.*

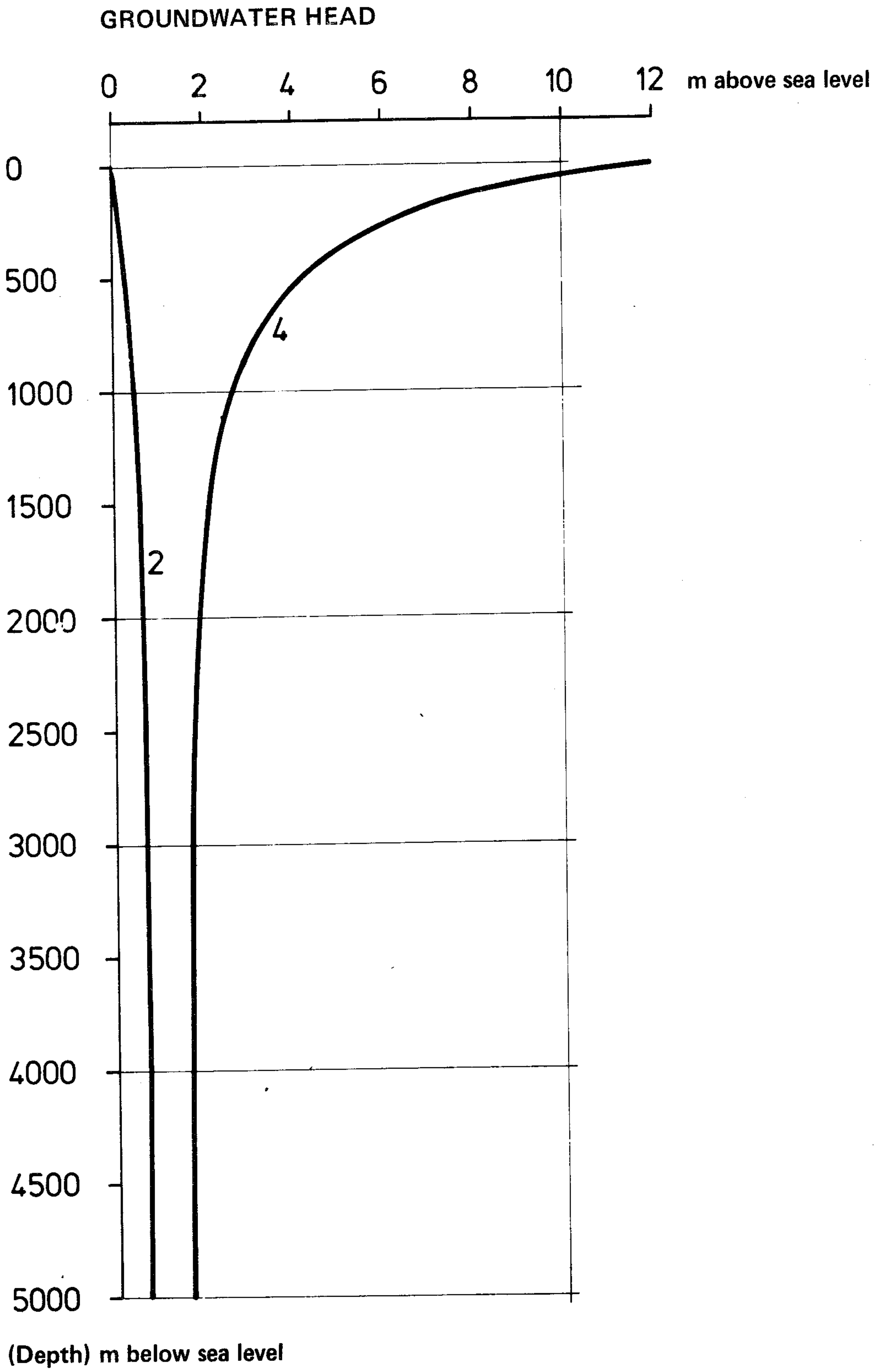



*Figure 5. Groundwater head in fracture zones 2 and 4 at their intersections with section D under natural conditions.*

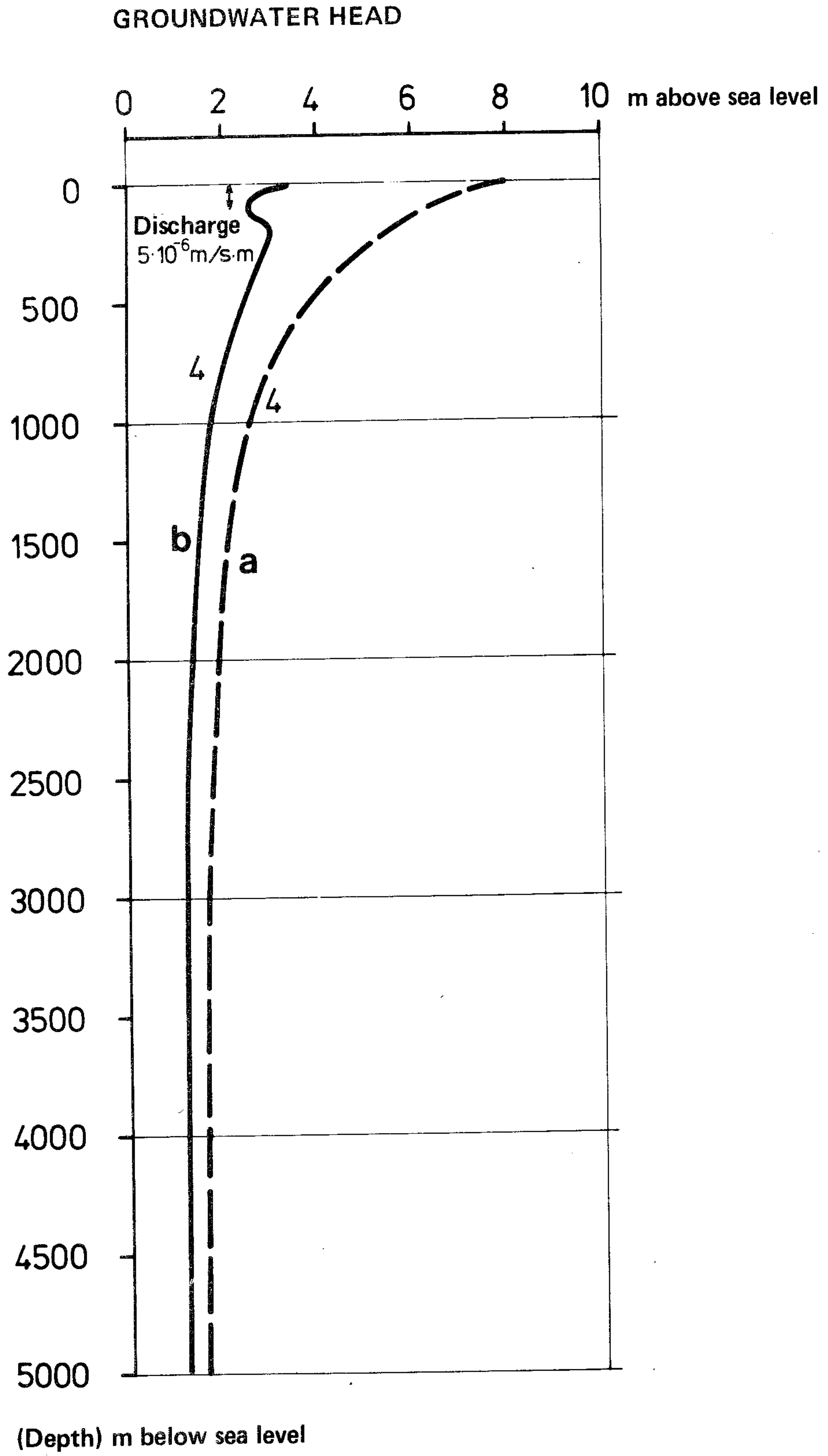



*Figure 6. Groundwater head in intersection between fracture zone 4 and section C under natural conditions (a) and with a discharge of 0.05 l/s (b).*

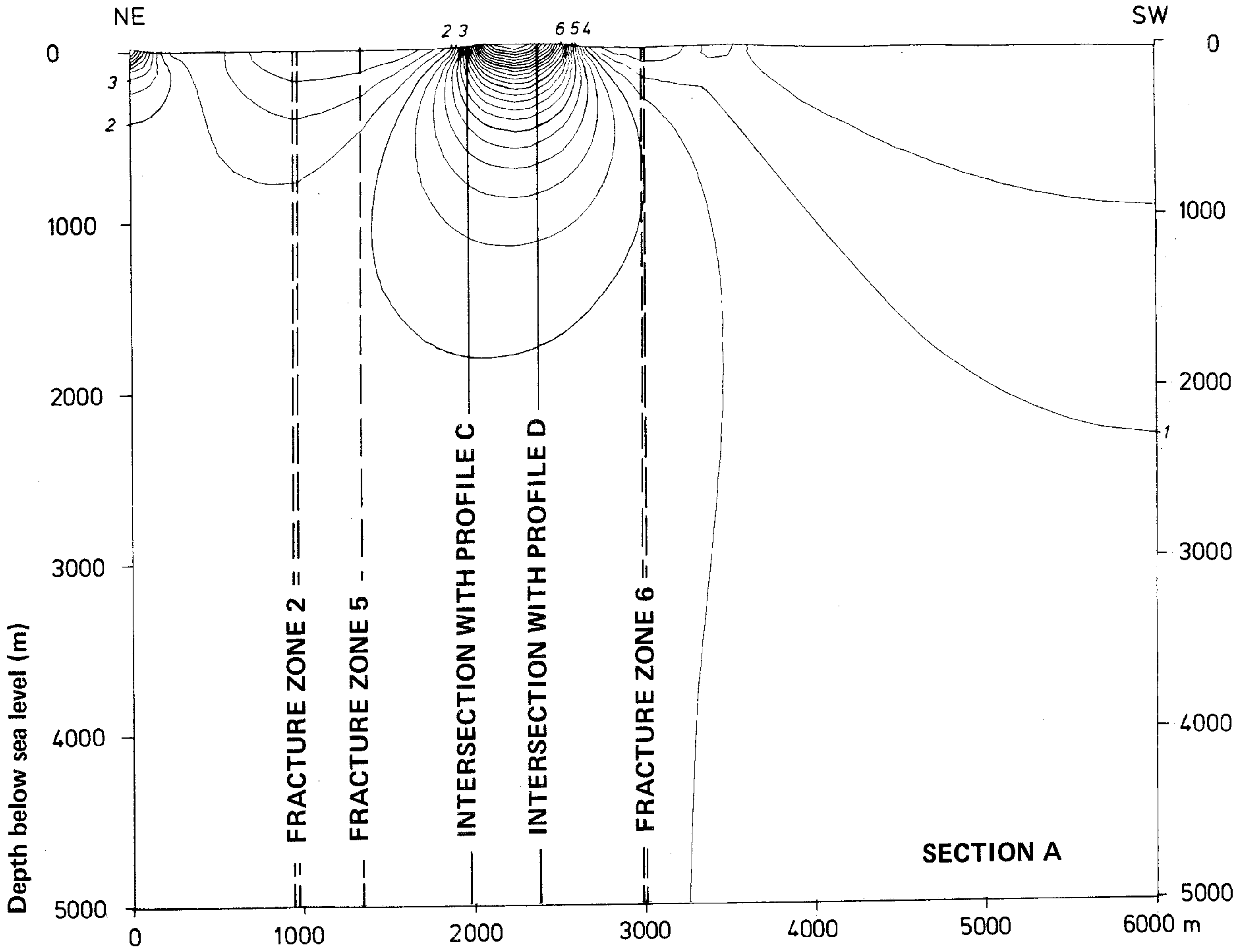



*Figure 7. Groundwater head in m above sea level in section A (fracture zone 4) under natural conditions.*

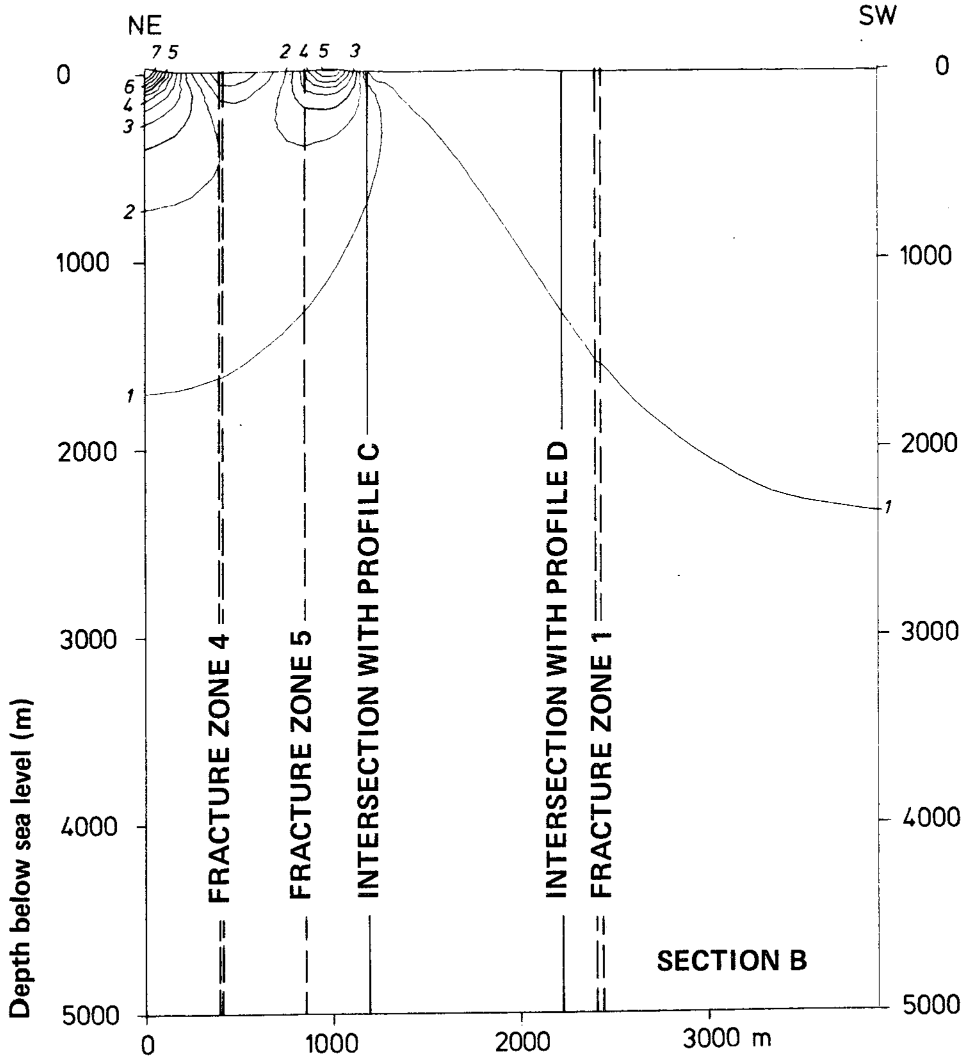



*Figure 8. Groundwater head in section B (fracture zone 2).*

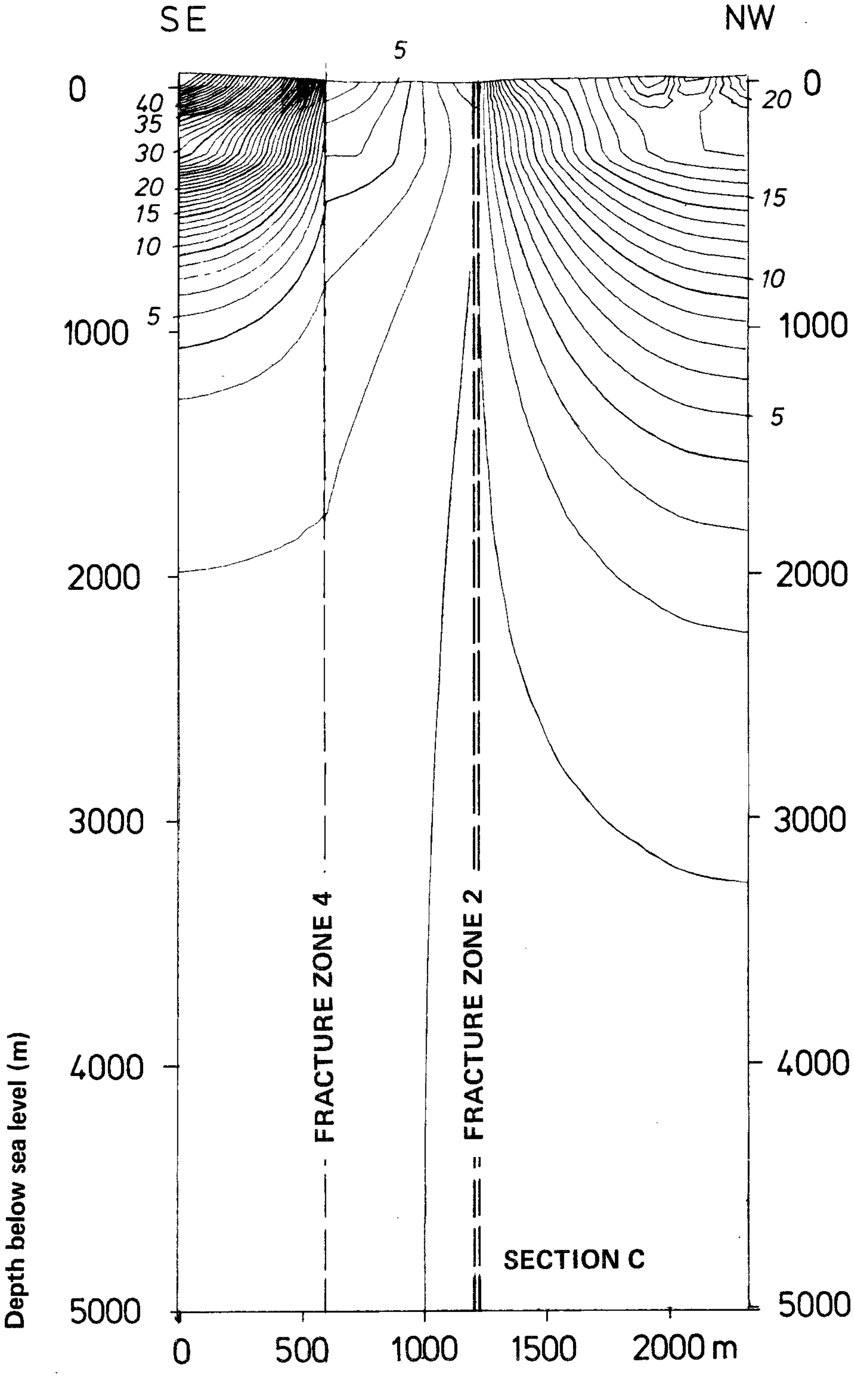



*Figure 10. Groundwater head in m above sea level in section C under natural conditions with fracture zones.*

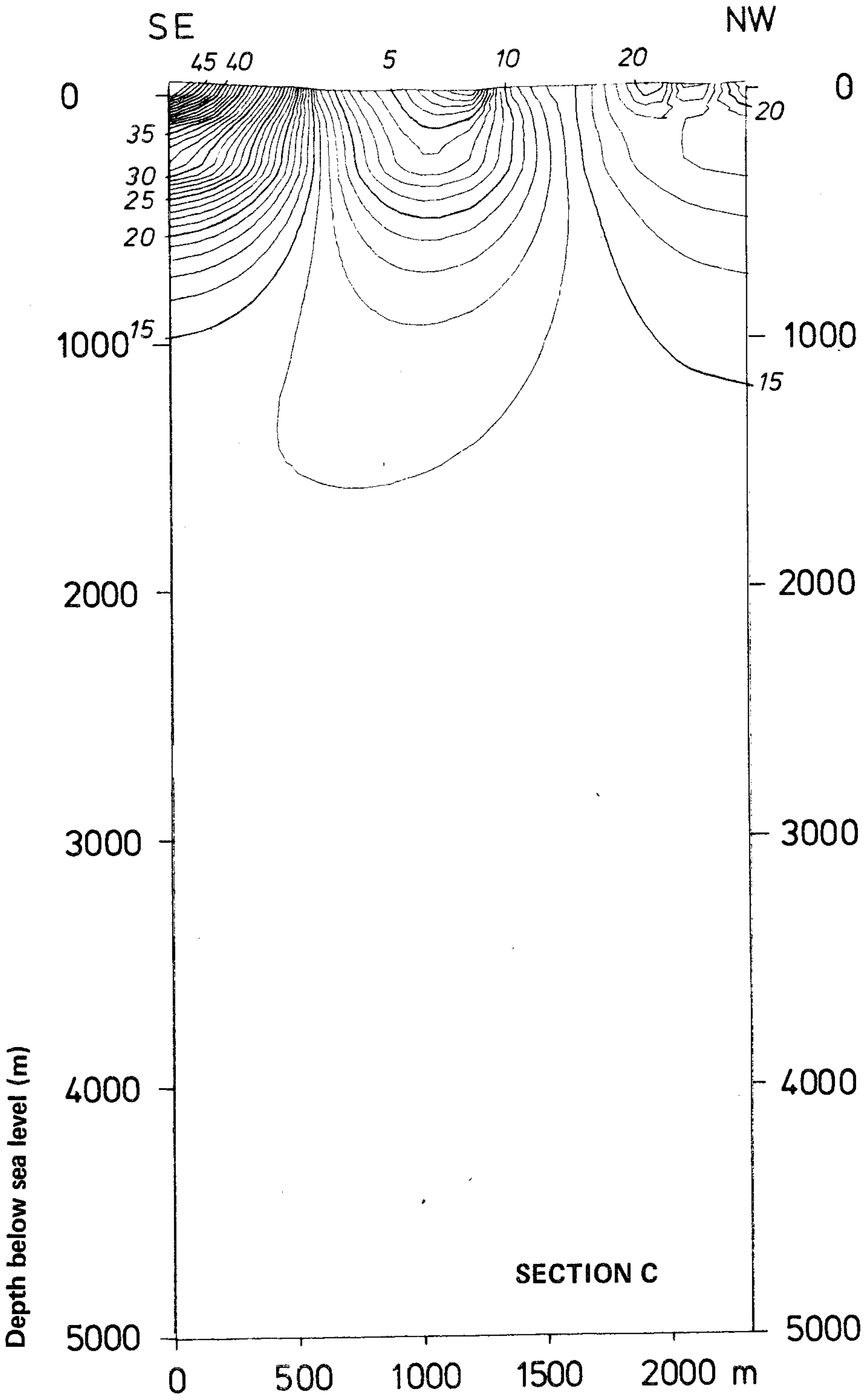



*Figure 9. Groundwater head in m above sea level in section C under natural conditions without any fracture zones.*

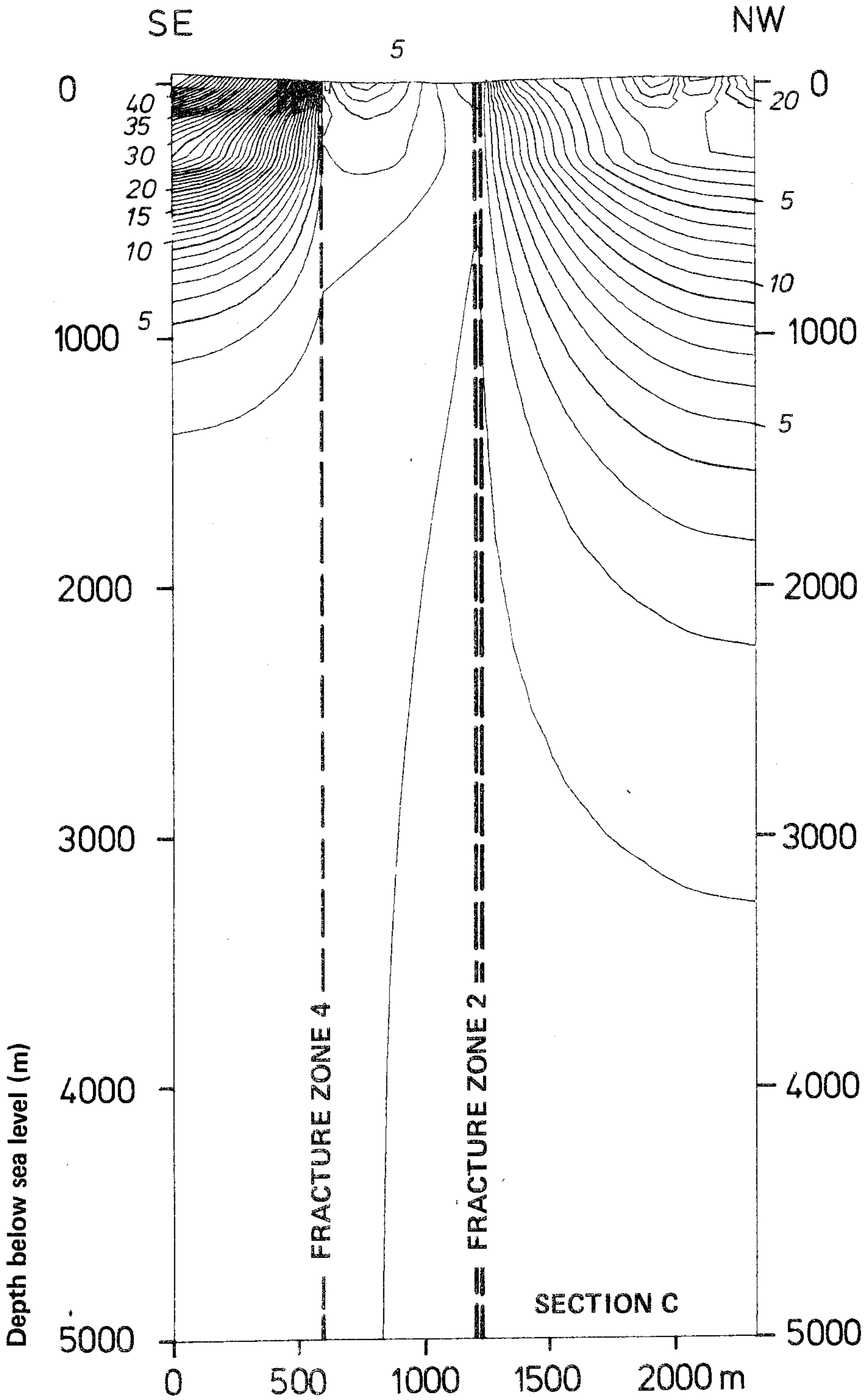



*Figure 11. Groundwater head in m above sea level in section C with fracture zones at a discharge of 0.05 l/s in fracture zone 4.*

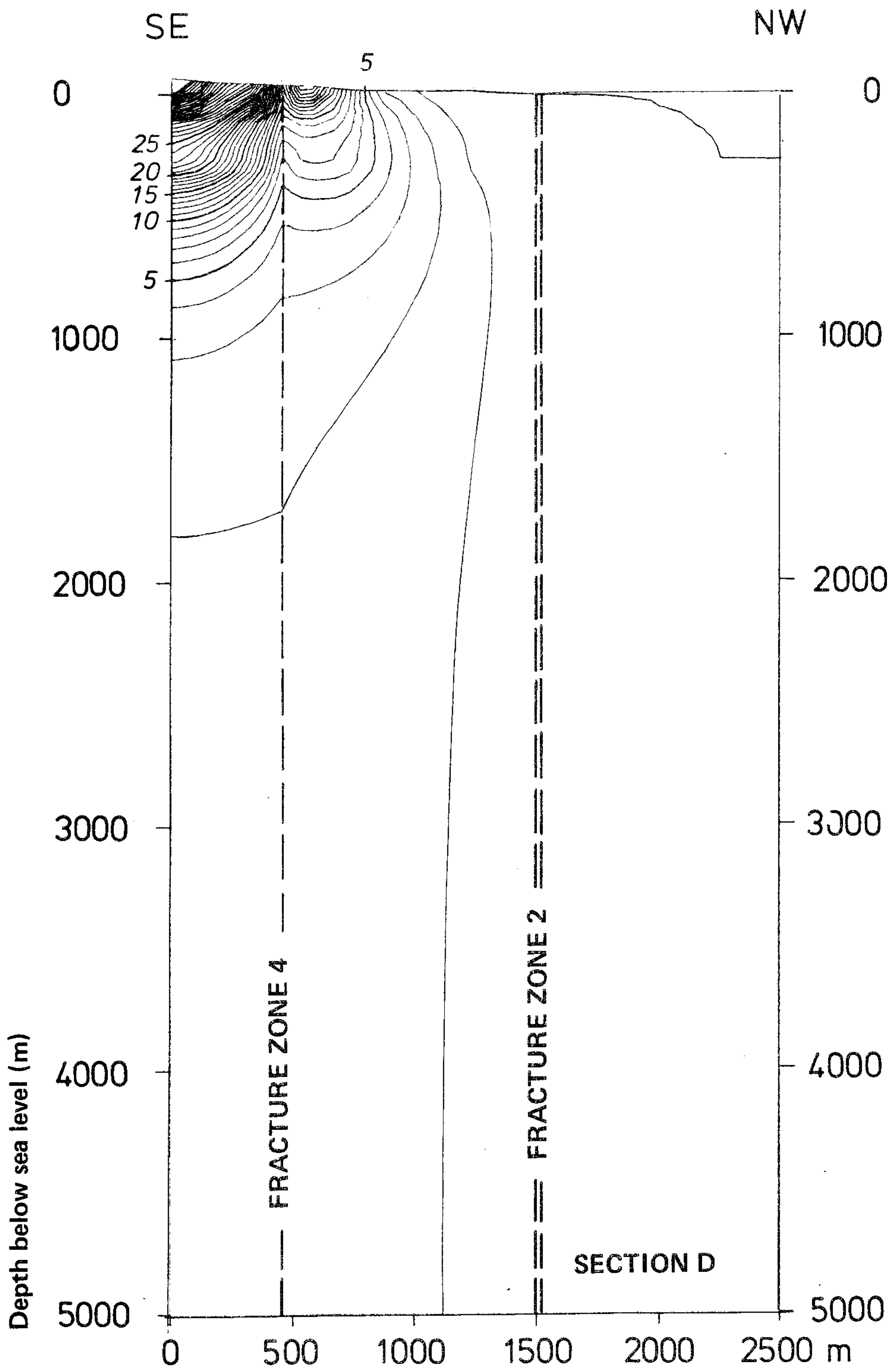



*Figure 12. Groundwater head in m above sea level in section D with fracture zones.*

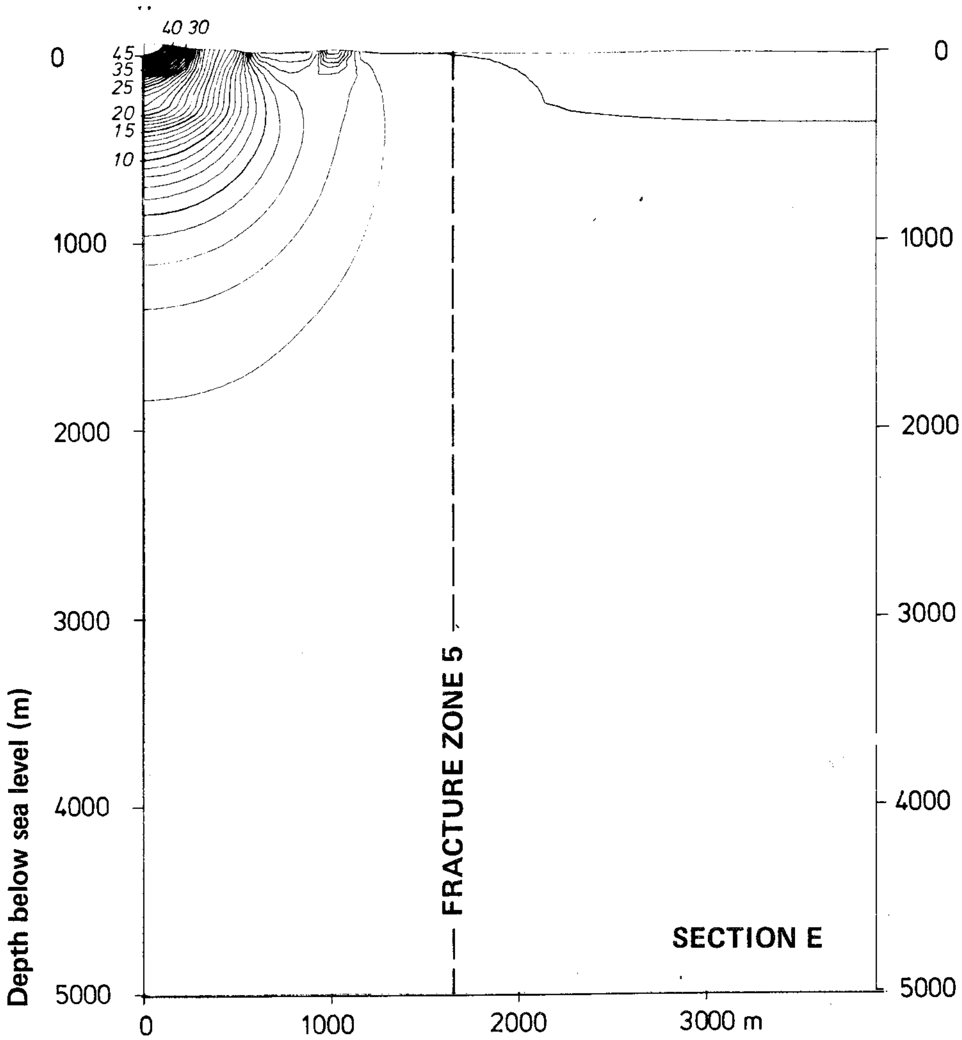



*Figure 13. Groundwater head in m above sea level in section E with fracture zones.*

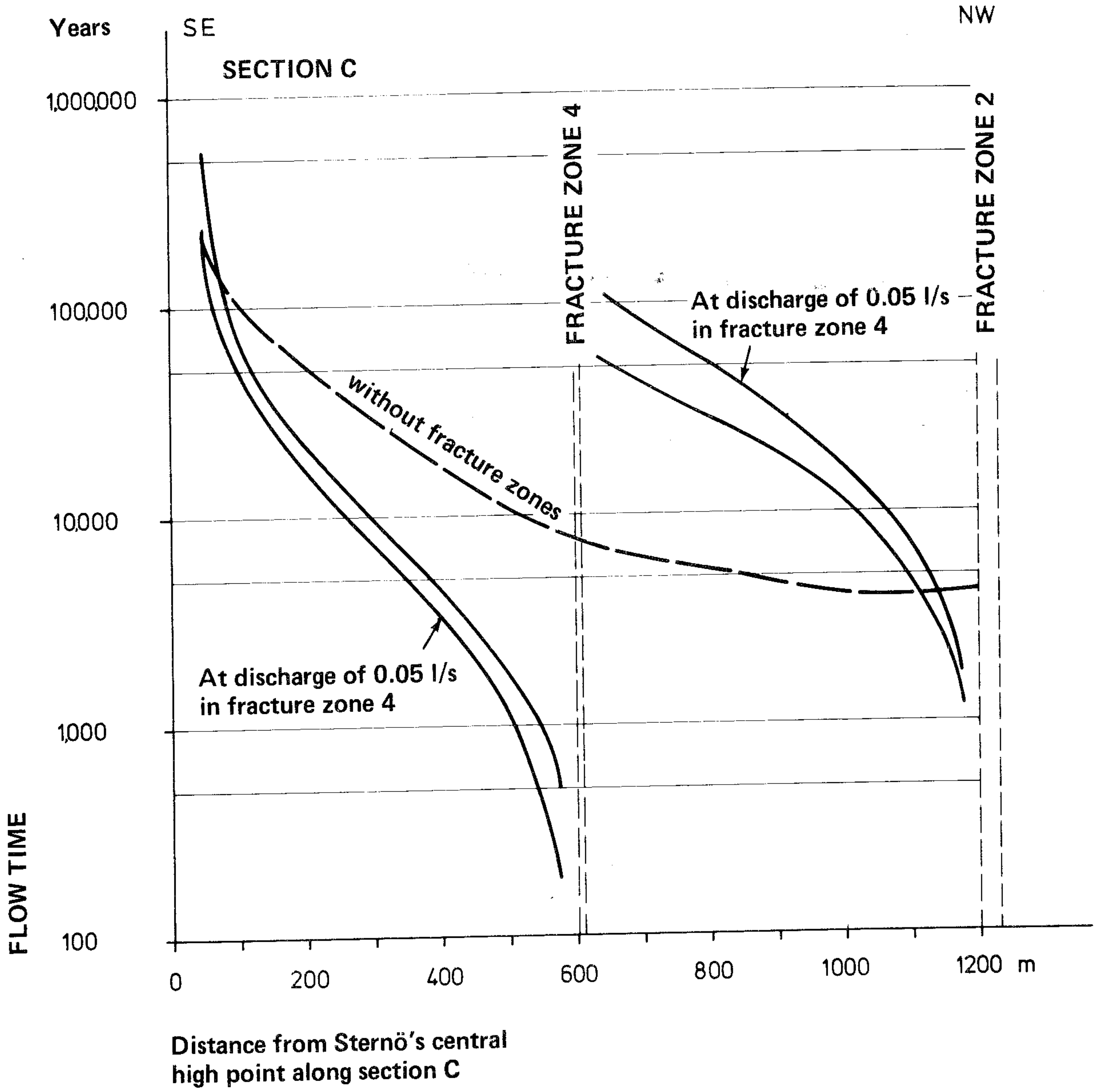



*Figure 14. Flow times for groundwater from 500 m depth at various distances from the central elevated area within section C. The flow time is calculated only within the homogeneous rock with a hydraulic conductivity of $10^{-11}$ m/s and a kinematic porosity of $10^{-4}$, and in the flow direction to the nearest fracture zone or the level 300 m below the surface. The dashed line marks the flow time without any fracture zones.*

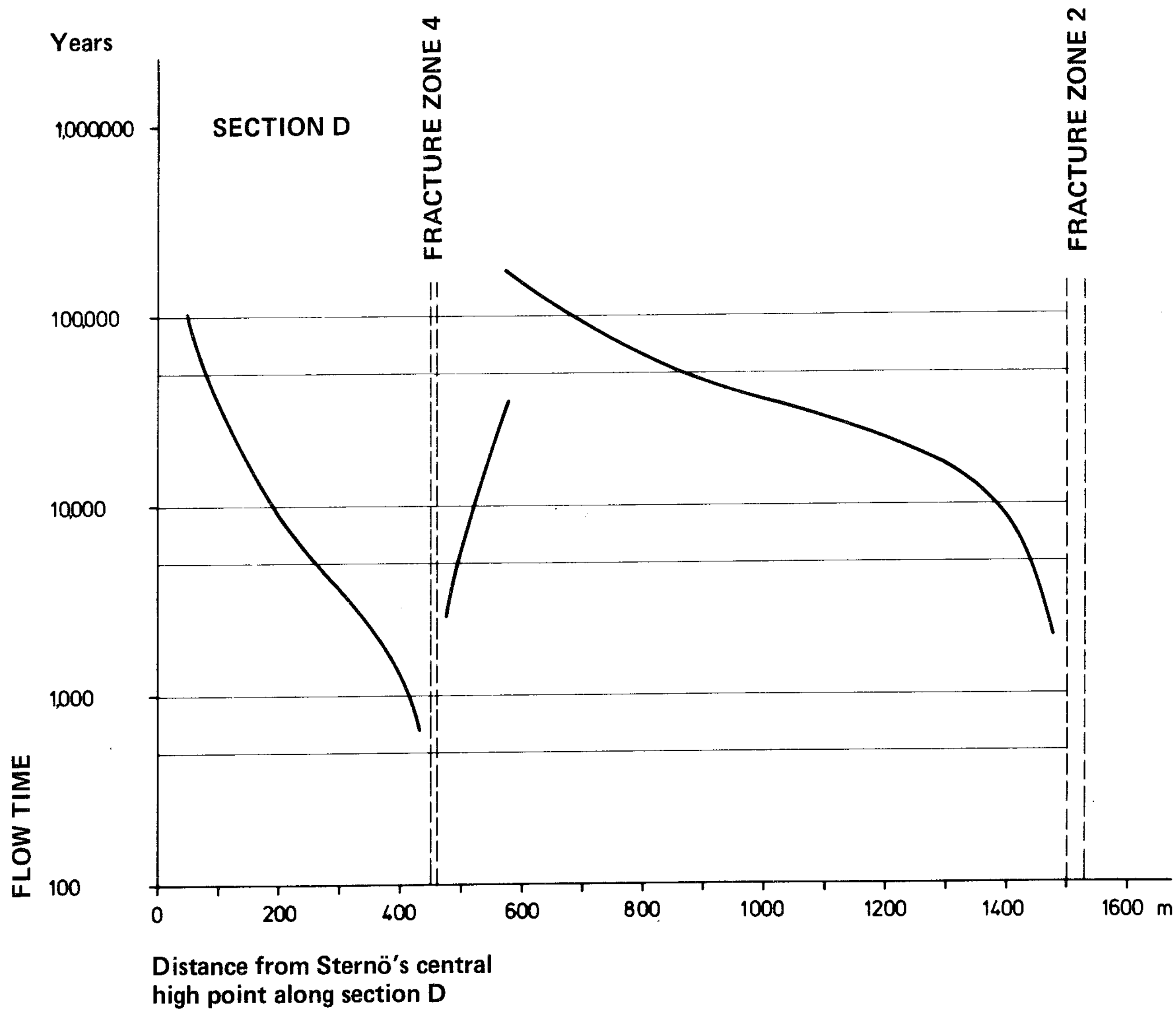



*Figure 15. Flow times for groundwater from 500 m depth at various distances from the central elevated area within section D. The flow time is calculated only within the homogeneous rock with a hydraulic conductivity of $10^{-11}$ m/s and a kinematic porosity of $10^{-4}$, and in the flow direction to the nearest fracture zone or the level 300 m below the surface.*

FÖRTECKNING ÖVER SKBF PROJEKT KBS TEKNISKA RAPPORTER

79-01 Clay particle redistribution and piping phenomena in bentonite/quartz buffer material due to high hydraulic gradients
Roland Pusch
University of Luleå 1979-01-10

79-02 Försöksområdet vid Finnsjön
Beskrivning till berggrunds- och jordartskartor
Karl-Erik Almén
Lennart Ekman
Andrzej Olkiewicz
Sveriges Geologiska Undersökning november 1978

79-03 Bergmekanisk bedömning av temperaturbelastning vid slutförvaring av radioaktivt avfall i berg
Ove Stephansson
Bengt Leijon
Högskolan i Luleå 1979-01-10

79-04 Temperatur- och spänningsberäkning för slutförvar
Taivo Tarandi
VBB Vattenbyggnadsbyrån, Stockholm februari 1979

79-05 Kompletterande berggrundsundersökningar inom Finnsjö- och Karlshamnsområdena
Andrzej Olkiewicz
Sören Scherman
Karl-Axel Kornfält
Sveriges Geologiska Undersökning 1979-02-02

79-06 Kompletterande permeabilitetsmätningar i Karlshamnsområdet
Gunnar Gidlund
Kenth Hansson
Ulf Thoregren
Sveriges Geologiska Undersökning februari 1979

79-07 Kemi hos berggrundvatten i Blekinge
Gunnar Jacks
Institutionen för Kulturteknik, KTH, februari 1979

79-08 Beräkningar av grundvattenrörelser inom Sternöområdet i Blekinge
John Stokes
Institutionen för Kulturteknik, KTH, februari 1979

79-09 Utvärdering av de hydrogeologiska och berggrundsgeologiska förhållandena på Sternö
Kaj Ahlbom
Leif Carlsson
Gunnar Gidlund
C-E Klockars
Sören Scherman
Ulf Thoregren
Sveriges Geologiska Undersökning, Berggrundsbyrån, februari 1979

79-10 Model calculations of groundwater condition on Sternö peninsula
Carl-Lennart Axelsson
Leif Carlsson
Geological Survey of Sweden september 1979

79-11 Tolkning av permeabilitet i en befintlig berganläggning
Ulf Lindblom
Alf Norlén
Jesús Granero
Kent Adolfsson
Hagconsult AB februari 1979

79-12 Geofysisk borrhålsmätning i 2 st borrhål på Sternö
Kurt-Åke Magnusson
Oscar Duran
Sveriges Geologiska Undersökning februari 1979

79-13 Bildning av fritt väte vid radiolys i lerbädd
Trygve Eriksen
Johan Lind
Institutet för Kärnkemi KTH 1979-03-28

79-14 Korrosionsprovning av olegerat titan i simulerade deponeringsmiljöer för upparbetat kärnbränsleavfall. Slutrapport.
Sture Henrikson
Marian de Pourbaix
Studsvik Energiteknik AB 1979-05-07

79-15 Kostnader för hantering och slutförvaring av högaktivt avfall och använt kärnbränsle
Arne W Finné
Åke Larson Byggare, april 1979

79-16 Beräkning av permeabilitet i stor skala vid bergrum i Karlshamns hamn
Ulf Lindblom
J J Granero
Hagconsult AB Göteborg, 23 augusti 1979

79-17 Water percolation effects on clay-poor bentonite/quartz buffer material at high hydraulic gradients
R Pusch
Div. Soil Mechanics, University of Luleå, 1979-05-31