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TECHNICAL REPORT 89-21

BIOSPHERE MODELLING FOR A DEEP RADIOACTIVE WASTE REPOSITORY: SITE-SPECIFIC CONSIDERATION OF THE GROUNDWATER-SOIL PATHWAY

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NOVEMBER 1990

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This report was prepared as an account of work sponsored by Nagra. The viewpoints presented and conclusions reached are those of the author(s) and do not necessarily represent those of Nagra.

Preface

In the framework of its Waste Management Programme the Paul Scherrer Institute is performing work to increase the understanding of radionuclide transport in the biosphere. These investigations are performed in close cooperation with, and with the financial support of NAGRA. The present report is issued simultaneously as a PSI report and a NAGRA NTB.

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Abstract

Scenario evaluations indicate that groundwater is the most probable pathway for released radionuclides to reach the biosphere from a deep underground nuclear waste repository. This report considers a small valley in northern Switzerland where the transport of groundwater to surface soil might be possible. The hydrological situation has been examined to allow a system of compartments and fluxes for modelling this pathway with respect to the release of radionuclides from an underground repository to be produced.

Assuming present day conditions the best estimate surface soil concentrations are calculated by dividing the soil into two layers (deep soil, surface soil) and assuming an annual upward flux of 10 mm from the groundwater through the two soil layers. A constant unit activity concentration is assumed for the radionuclides in the groundwater. It is concluded that the resultant best estimate values must still be considered to be biased on the conservative side, in view of the fact that the more typical situation is likely to be that no groundwater reaches the surface soil. Upper and lower estimates for the surface soil radionuclide concentrations are based on the parameter perturbation results which were carried out for three key parameters, i.e. precipitation surplus, upward flux and solid-liquid distribution coefficients (K_d). It is noted that attention must be given to the functional relationships which exist between various model parameters. Upper estimates for the surface soil concentration are determined assuming a higher annual upward flux (100 mm) as well as a more conservative K_d value compared with the base case. This gives rise to surface soil concentrations more than two orders of magnitude higher than the best estimate values. The lower estimates are more easily assigned assuming that no activity reaches the surface soil via this pathway.

Two appendices are included in this report. The first contains the calculations presented in the BIOMOVS study for the Mol region in Belgium, as defined in Scenario B6b. The second appendix presents an assessment of the potential significance of upward water movement in soil, due to capillary rise from groundwater in Switzerland, based on soil use maps.

Résumé

Les évaluations de scénario ont indiqué que le relâchement de radionucléides d'un dépôt final souterrain vers la biosphère aurait lieu le plus probablement par des nappes d'eaux souterraines. Ce rapport considère une petite vallée dans une région dans le nord de la Suisse où le transport d'eaux souterraines vers la surface serait possible. La situation hydrologique a été étudiée pour determiner un système de compartiments et de fluxs en vue de la modélisation de telle voie d'acheminement.

Sur la base des conditions actuelles, les concentrations de radionucléides dans le sol ont été estimées en subdivisant le sol en deux couches (sol profond, sol en surface). On hypotise un flux montant des eaux souterraines de 10 mm par an à travers ces deux couches. En considérant que dans la situation réelle la plus probable sera qu'aucune eau souterraine ne parviendra dans le sol de surface, on conclue que cette estimation est conservative. L'estimation des concentrations maximales et minimales de radionucléides dans le sol résultent de la variation de trois paramètres clés, à savoir: l'exédence des précipitations, le flux d'eau ascendant et les coefficients de sorption (K_d) du sol. On relève qu'il faut prêter attention aux relations fonctionelles existantes entre les différents paramètres du modèle. L'estimation des concentrations maximales dans le sol de surface est déterminée en considérant un flux montant annuel plus élevé (100 mm) ainsi que des coefficients K_d plus conservatifs que pour le cas de base. Cela donne des concentrations dans le sol de surface supérieures de plus de deux ordres de grandeurs par rapport aux valeurs de l'estimations de base. Les estimation minimales donnent des concentrations nulles puisqu'on présume, d'après la situation réelle, qu'il n'y a pas de flux d'eau ascendante.

Le rapport inclue deux appendices. Le premier présente les calculs pour le scénario B6b effectués dans le cadre de l'étude BIOMOVS pour la région de Mol en Belgique. L'autre présente une évaluation de la signification de la montée par capillarité d'eaux souterraines en Suisse, élaborée sur la base de cartes d'utilisation des sols.

Zusammenfassung

Szenarien-Studien zeigen, dass Radionuklide aus einem tiefliegenden Endlager für radioaktive Abfälle am ehesten über Grundwasser in die Biosphäre gelangen. Dieser Bericht betrachtet ein kleines Tal in der Nordschweiz, wo Grundwasser die oberflächennahe Bodenschicht erreichen könnte. Die hydrologischen Verhältnisse werden untersucht, um ein System von Kompartimenten und Wasserflüssen aufzubauen, das für die Modellierung des Grundwasser-Pfades geeignet ist.

Unter Annahme heutiger Bedingungen wird eine beste Schätzung der Nuklidkonzentrationen in der oberen Bodenschicht berechnet, indem der Boden in zwei Schichten (eine untere und eine obere) unterteilt und ein aufwärtsgerichteter Fluss aus dem Grundwasser von 10 mm pro Jahr angenommen wird. Dabei wird eine konstante Einheitsaktivität für die Radionuklide im Grundwasser vorausgesetzt. Weil tatsächlich eher weniger oder gar kein Grundwasser in den oberen Boden aufsteigt, liegen die resultierenden Werte auf der konservativen Seite. Obere und untere Schätzungen der Konzentrationen im oberen Boden basieren auf den Resultaten von Sensitivitätsanalysen, die für drei wichtige Parameter durchgeführt wurden, nämlich für Niederschlagsüberschuss, aufwärtsgerichteten Wasserfluss und Boden-Sorptionskoeffizient (K_d). Dabei müssen die funktionalen Beziehungen zwischen verschiedenen Modellparametern berücksichtigt werden. Die oberen Schätzwerte der Konzentration werden unter Annahme eines höheren jährlichen Aufwärtsflusses (100 mm pro Jahr) sowie eines konservativeren K_d-Wertes bestimmt. Die Ergebnisse liegen mehr als zwei Grössenordnungen höher als die der besten Schätzung. Die unteren Schätzungen lassen sich einfacher durchführen: Man nimmt an, dass keine Aktivität aus dem Grundwasser den oberen Boden erreicht.

Dieser Bericht schliesst zwei Anhänge ein. Der erste enthält die im Szenario B6b der BIOMOVS-Studie durchgeführten Berechnungen für das Gebiet um Mol in Belgien. Der zweite präsentiert, basierend auf Bodeneignungskarten, eine Abschätzung der Bedeutung des kapillaren Aufstieges aus dem Grundwasser in der Schweiz.

1 Introduction

In the safety analysis of a deep geologic nuclear waste repository all scenario evaluations indicate that groundwater is the most probable pathway for radionuclides to reach the biosphere. In Project Gewähr (NAGRA, 1985) this pathway comprised the base case and biosphere calculations were made for the Laufenburg area of northern Switzerland (Grogan, 1985). For these calculations it was assumed that groundwater passed directly through the soil rooting zone and that the associated radionuclides were then taken up into the crops, thus entering the foodchain and ultimately giving rise to doses to man.

Acknowledging that this is a very conservative approach, a more realistic description of this system has been sought. This initially involved a division of the soil into two layers, an upper soil rooting zone and an underlying deep soil layer. Groundwater is then assumed to pass directly through the deep soil layer with only a certain fraction passing upwards into the surface soil layer. The extent of this upwards water movement is determined based on climatological considerations with evapotranspiration as the driving force. A complete account of this modelling approach can be found in a previous report (Baeyens et al. 1990) where the results obtained have been compared with those presented in Project Gewähr for the Laufenburg area. Closer examination of the Laufenburg area has, however, indicated that such a scenario is very unlikely for this region (Müller, 1989). This is because the average annual depth of the groundwater table is anywhere between 15m and 35m below the surface. This distance is too great for capillary rise to draw water up to the surface soil. However, such a process would appear more feasible in the smaller Hellikon valley, situated just south of the Laufenburg area. In this report the Hellikon region is examined for illustrative purposes in more detail with particular reference to the hydrological situation. From this a more realistic system of compartments and fluxes are defined. For clarification it should be noted that the Hellikon region was also considered in Project Gewähr as a variation of the base case. It represented a small river valley with minimal dilution of solutes potentially present in groundwater as it entered the biosphere. At that time the modelling was carried out in the same way as for the Laufenburg base case.

The potential significance of this scenario with respect to waste disposal is further demonstrated by its inclusion in the BIOMOVS exercise, an international study to test models designed to predict the environmental transfer and bioaccumulation of radionuclides and other trace substances. The initial calculations were presented for a generic region (Scenario B6a) and this was followed up (Scenario B6b) by considering two test regions; Hellikon in Switzerland and Mol in Belgium, for which participants were supplied with site-specific data for the modelling. The Hellikon region is the same as that described in this report and therefore includes those results presented in the BIOMOVS study. For completeness Appendix I summarises the PSI/NAGRA calculations presented in the BIOMOVS exercise for the Mol region.

To place this scenario in perspective a short study has also been carried out to assess the potential significance of capillary rise from groundwater in Switzerland as a whole. This study is based upon information presented in the soil use map of Switzerland (1:200000) (Frei et al., 1980) and is summarised in Appendix II.

2 Hydrological Situation

2.1 Introduction

The Hellikon region extends over 27.5 hectares and is a small river valley in northern Switzerland which drains into the river Rhine. Figure 1 presents a simplified cross section of this region.

The aim of this chapter is to provide a hydrological basis for a scenario with upward movement due to capillary rise from the groundwater in this region and the work already carried out by Jiskra (1985) and Baeyens et al. (1990) forms the starting point for this exercise. However, given the existing data, it is not possible to define the hydrological regime in the Hellikon area exactly. This report therefore describes a hypothetical case, based on data from the test area and from surrounding regions.

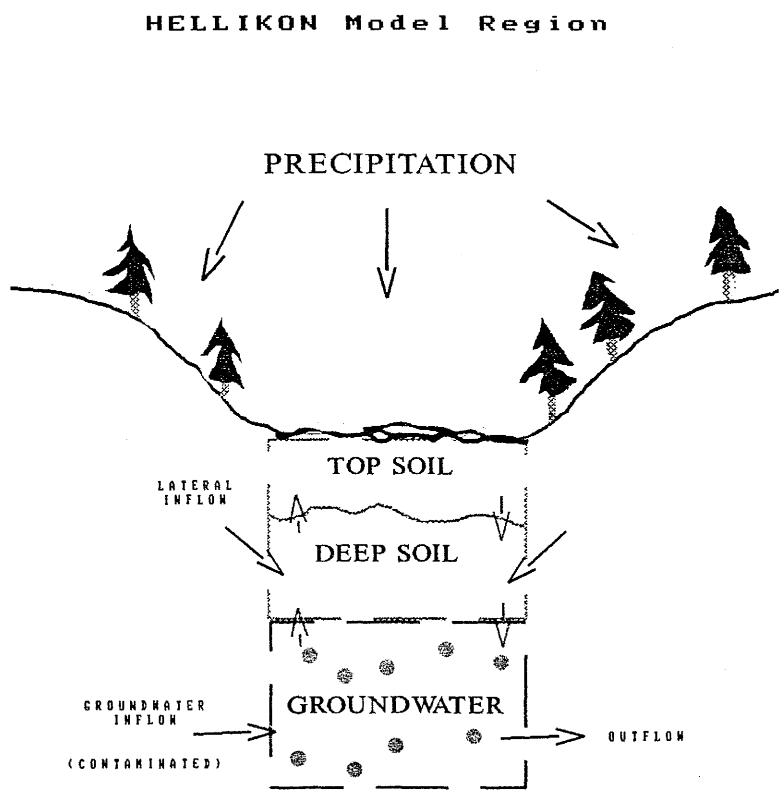

Figure 1: The Hellikon Model Region

2.2 Soil Profile

It is assumed that the local soil type "Hard" (Kaisten, Canton Aargau) described in Vogelsanger (1983) is characteristic of this region. This is an acidic sandy parabrownearth overlying carbonate containing alluvially deposited gravel. The profile is characterised by a boundary layer at a depth of around 1.5 m which separates the upper weathered gravel, which is penetrated by roots and brown in colour from the underlying unweathered white gravel, which contains no roots. The information about the roots is based on forested areas but can also be applied to other vegetation types. The simplified soil profile is shown in Figure 2. For the purposes of modelling it is assumed that the majority of roots of an agricultural crop are located in the top 25 cm of the soil which is effectively equivalent to the A horizon. In the model this is defined as the top soil (soil rooting zone) whereas the deep soil represents the underlying soil which would approximate to the B horizon of the soil profile.

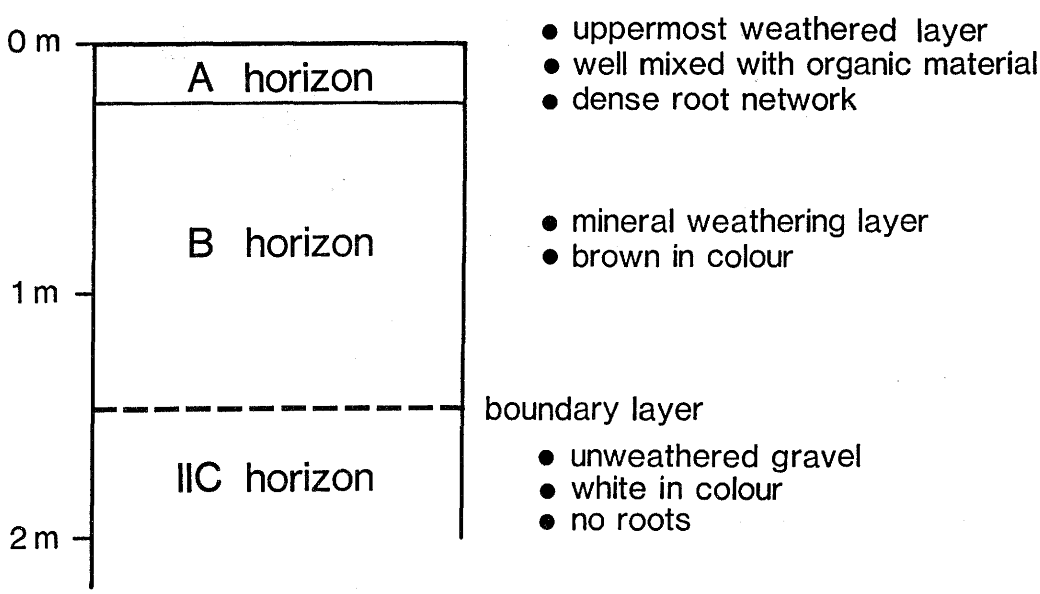

Figure 2: Simplified Soil Profile for the Hellikon Region

2.3 Groundwater Table and Upward Fluxes

According to the hydrological map of Canton Aargau for the Rheinfelden region (Kempf, 1982), the groundwater table in the Hellikon area lies between 0.5 and 4 m below the soil surface as an annual average. Using this information and the characteristic features of the soil profile described above (c.f. Figure 2) three cases can be distinguished with respect to the upward movement of groundwater resulting from capillary rise namely, the groundwater table lies

i) more than 1 m below the boundary layer

ii) less than 1 m below the boundary layer

iii) above the boundary layer.

In the following section each case is discussed in turn.

<u>i) Groundwater table lies more than 1 m below the boundary layer</u>

In this case capillary rise is zero. This is because measurements of the soil suction in the unweathered gravel (i.e. within the IIC horizon) usually range between 50 mbar and 100 mbar (Vogelsanger, 1983) which is insufficient to bring about capillary rise over the required distance in excess of 2 m. This is comparable with the results of Renger and Strebel (1980) which indicate that capillary rise is negligible if the groundwater table is more than 1.5 to 2 m below the soil surface.

<u>ii) Groundwater table lies less than 1 m below the boundary layer</u>

In this situation, capillary rise is very small or, even more likely, zero. This is because the boundary layer effectively functions as a transport barrier (Vogelsanger, 1983; Flühler, 1988) due to the different matrix structure of the two zones, the IIC horizon comprises a coarse matrix of unweathered gravel whereas the upper layers have a much finer texture. Vogelsanger observed that upward water flow occurred on only a few days in autumn in the IIC-horizon of soil beneath forest. Furthermore, the hydraulic conductivity was so small that the rate of rise was only 0.005-0.01 mm d^{-1} (Vogelsanger, 1983, p 220, Table 45). In these investigations, the water table was at a depth of around 15 m. If it had been situated just below the boundary layer the capillary fringe may have extended beyond the boundary layer although it is unlikely that any significant upward movement would have resulted.

For steady-state conditions, it is relatively easy to estimate the capillary rise from the groundwater into the rooting zone. Reference could, for example, be made to the results of Giesel et al. (1972) and their values for gravelly sand would give a good approximation. The exact location of the groundwater table in relation to the boundary layer is the critical factor. Under natural conditions, however, it is doubtful whether a steady-state would occur below the boundary layer. To summarise, for a groundwater table situated less than 1 m below the boundary layer a value of 10 mm a^{-1} is considered to be a very conservative estimate for an upward groundwter flux.

iii) Groundwater table is situated above the boundary layer

In this case, the groundwater table is practically at the lowest extent of the rooting zone but still above the boundary layer. The factor restricting the penetration of groundwater into the rooting zone is therefore no longer the water-bearing characteristics of the boundary layer but the extent of capillary rise within the rooting zone. If this is sufficient such that the capillary fringe intersects the surface then evaporation of the water from the surface soil will result in a dynamic flux upwards.

Measurements of the water balance for a pasture at Möhlin (Germann, 1976) which is also located in northern Switzerland in the vicinity of the Laufenburg and Hellikon areas have been taken to provide an estimate of the potential magnitude of upward water movement. For the particular twelve month period over which measurements were carried out the upward flux was 60 mm a^{-1} at a depth of 0.4 m and 52 mm a^{-1} at a depth of 1 m. These figures can be derived from Table 1 which is taken from Germann's publication, as the sum of all monthly averages with negative percolation (i.e. positive rise) from April to October.

If more water had been available to the plants, it is possible that they would have transpired more since the potential evapotranspiration in this area is around 630 mm a^{-1} and a small precipitation deficit of approximately 70 mm a^{-1} is typical (Mohrmann and Kessler, 1959) which occurs during the summer months. At the same time, however, there is an annual precipitation surplus of 260 mm which means the net water movement in the soil profile is downwards. Furthermore, in areas such as Hellikon lateral inflow (see section 2.4) from the valley sides also provides water to the rooting zone and the layers above the groundwater table. These factors have the effect of reducing the contribution of groundwater to the upward water flux. For the case, with a groundwater table between the rooting zone and the boundary layer a value of 100 mm a^{-1} is considered a conservative value for upward movement from the groundwater.

Table 1: Waterbalance for a field in Möhlin (1971/1972) (taken from Germann, 1976).

	April '71	May '71	June '71	July '71	Aug. '71	Sept. '71	Oct. '71	April – Oct. '71 Summer Total	Nov. – March '72 Winter Total
P (mm)	22.6	40.2	116.7	92.7	122.4	40.5	28.0	463.1	198.9
ETP (mm)	28.1	36.8	131.6	131.4	105.7	42.6	45.4	521.6	70.0
ΔW_{40} (mm)	-2.5	-19.4	5.3	22.3	-18.4	5.1	9.2	1.5	-29.0
$F_{D,40}$ (mm)	-8.1	-16.0	-9.6	-16.4	-1.7	3.0	-8.2	-57.0	99.9
ΔW_{100} (mm)	14.4	8.9	-13.9	11.3	-7.2	9.5	0.3	23.3	-22.4
$F_{D,100}$ (mm)	6.3	-7.1	-23.5	-5.1	-8.9	12.5	-7.9	-33.7	77.5

where:
- P : precipitation onto soil
- ETP : evapotranspiration
- ΔW_{40} : change in water content in top soil (0 - 40 cm)
- $F_{D,40}$: water flux at 40 cm depth
- ΔW_{100} : change in water content in deep soil (40 - 100 cm)
- $F_{D,100}$: water flux at 100 cm depth

and

$$F_{D,40} = P - ETP + \Delta W_{40}$$
$$F_{D,100} = F_{D,40} + \Delta W_{100}$$

2.4 Lateral Inflow From Valley Sides

In the Hellikon region subsurface flow (interflow) of water from the valley sides should also be considered for modelling the water fluxes in this region. The work of Zuidema (1985) deals with the different types of lateral transport which may occur. For the Hellikon region subsurface stormflow is the most relevant. This is where infiltrating precipitation moves in the soil profile along non-capillary flowpaths parallel to the slope e.g. soil pipes, root channels, cracks and all kinds of larger pores. Since these pathways are connected the resultant high flow velocities ($\sim$ 0.01 m s^{-1}) mean that travel times can be very short. These flowpaths are only effective when the immediate surroundings are saturated and are therefore of most significance during periods of heavy rainfall (hence the name). The majority of these flowpaths are probably situated in the IIC-horizon, with a small proportion in the B-horizon. Lateral inflow into the A-horizon is probably insignificant. It is arbitrarily assumed that 80% of the water flows in the IIC-horizon and 20% in the B-horizon. It should also be noted that although the soil profile for the valley side is not the same as that for the valley floor both are assumed to have the same three main components. A diagram of the lateral inflow in the Hellikon valley is shown Figure 3.

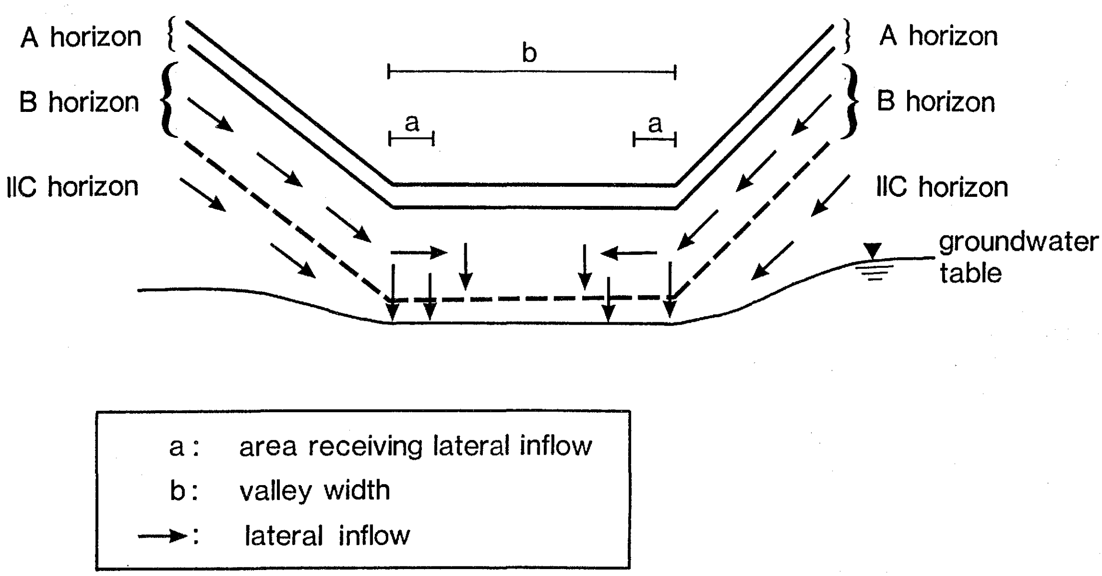

Figure 3: Schematic representation of lateral inflow in the Hellikon valley

When the inflow in the IIC-horizon reaches the valley floor, it reaches the groundwater immediately or after only brief storage (Figure 3). For the purposes of biosphere modelling it can be assumed that this flow to the IIC-horizon is a direct influx to the groundwater compartment.

The inflow in the B-horizon, which represents the deep soil, penetrates a certain distance **a** across the valley floor (Figure 3). The horizontal flow component then disappears and the water is either stored, percolates downwards or undergoes capillary rise. The biosphere modelling therefore has to take into account that the inflow to the deep soil is not distributed over the entire compartment but only a fraction **2a/b** thereof, where

b is the valley width. A somewhat arbitrary figure of 1/8 is assumed for **a/b** so that 1/4 of the total lateral inflow enters the deep soil compartment. The remainder flows directly to the groundwater contributing to the influx of uncontaminated groundwater in the modelling.

2.5 Compartment Division

Based on the earlier work of Jiskra (1985) and Baeyens et al. (1990) and taking into account the above considerations, the compartment division depicted in Figure 4 is proposed for modelling the Hellikon region.

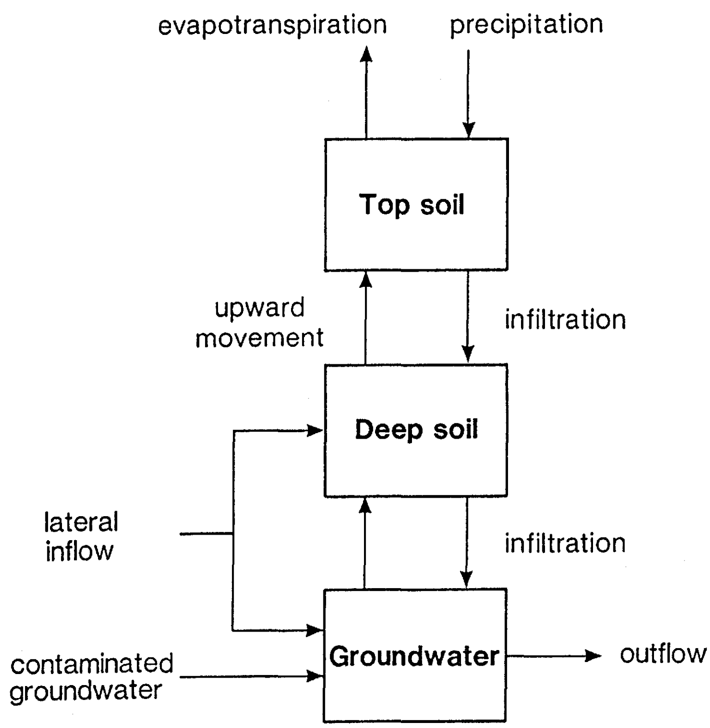

Figure 4: Compartment division for the Hellikon Region

Compartment volumes

The surface area is assumed to be 27.5 ha (Jiskra 1985) with a 0.25 m thick top soil which represents the crops' rooting zone. The resultant values for the volumes of top soil and soilwater (namely 4.8 x 10^4 m^3 and 2.1 x 10^4 m^3) are calculated assuming 70% and 30% by volume, respectively, as described in Jiskra (1985 p. 23).

Three different cases are distinguished for upward water movement which influence the way the volumes of the deep soil layer are determined. However, in all cases the deep soil is assumed to have no roots and is always directly overlain by the top soil (see Figure 5). In the first, the groundwater table is below 2.5 m depth. Capillary rise (upward movement) is then zero which saves any biosphere modelling and volume determinations from having to be made. For the second case, it is asssumed that the groundwater table is at a depth of 1.75 m, i.e. in the IIC-horizon. The deep soil layer is then assumed to be 1.25 m thick extending as far as the boundary layer. The deep soil and soilwater volumes are thus 24 x 10^4 m^3 and 10 x 10^4 m^3, respectively. For the third case, the groundwater table is assumed to be 1 m below the soil surface. The deep soil layer is then 0.75 m thick so that the deep soil and soil water volumes are 14 x 10^4 m^3 and 6.2 x 10^4 m^3, respectively.

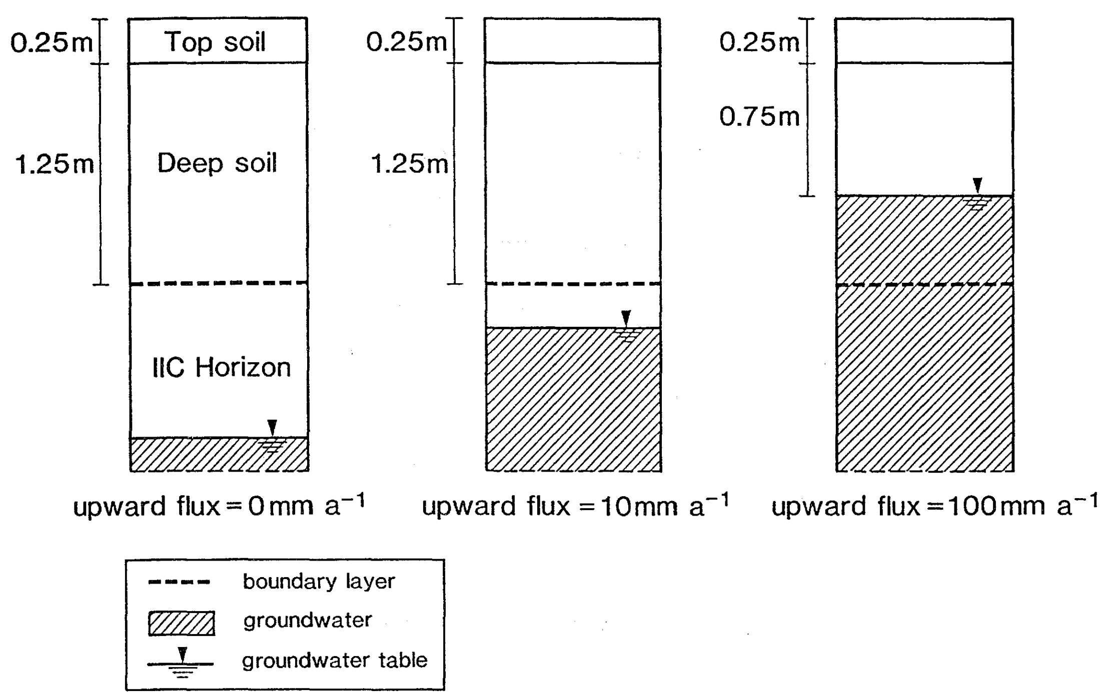

Figure 5: Three situations indentified for modelling upward groundwater movement in the Hellikon region

The groundwater compartment volume is estimated assuming an average thickness of 6 m for the aquifer and a porosity of 0.25 which gives a figure of 41 x 10^4 m^3. The porosity value is based on measurements carried out by Vogelsanger (1983) in the IIC-horizon.

The volume of the sink is arbitrarily taken as 10^{16} m^3 (Jiskra 1985).

<u>Water fluxes</u>

A value of 500 mm a^{-1} precipitation surplus is used which is the same as in Jiskra (1985) and assumes 1000 mm a^{-1} precipitation and 500 mm a^{-1} potential evapotranspiration, which broadly corresponds to the current situation in northern Switzerland. This is equivalent to a figure of 1.4 x 10^5 m^3 a^{-1} in the test area.

As already described three cases are distinguished for upward water movement, the first with zero rise (no modelling necessary), the second with 10 mm a^{-1} rise and the third with 100 mm a^{-1}. For the test area, this gives upward fluxes of 2.8 x 10^3 m^3 a^{-1} and 2.8 x 10^4 m^3 a^{-1}, respectively for the latter two cases. The inflow rate of contaminated groundwater is based on values presented on the Canton Aargau hydrological map, Rheinfelden sheet, which specifies a source discharge of 2.6 x 10^5 m^3 a^{-1} for a well in the muschelkalk. It is assumed that the entire groundwater source is uncontaminated with radionuclides and discharges directly into the groundwater compartment. However, if the source were to be tapped for man's use e.g. pumping, this would no longer be realistic. It is also assumed that the two sources of groundwater mix completely. This is an unlikely situation as the contaminated deep groundwater would be expected to travel below the massive influx of surface derived groundwater. Exfiltration of groundwater into the main drainage channel (small river) is currently ignored in the modelling.

The groundwater flow rate (F_w) from the groundwater compartment to the sink, which effectively represents the groundwater flow through the lower boundary of the geographical area, is approximately 3.0 x 10^6 m^3 a^{-1}. This is calculated from Darcy's law as follows:

$$F_w = K.i.S$$

where:	K	is the hydraulic conductivity	[m a^{-1}]
	i	is the hydrostatic gradient	[m m^{-1}]
	S	is the flow cross sectional area	[m^2]

The following data were taken from the hydrological map:

Aquifer width:	150 m
Aquifer depth:	(3/4) x 6 m + (1/4) x 15 m $\approx$ 8 m
Gradient:	16 x 10^{-3} m m^{-1}

A hydraulic conductivity value of 5 x 10^{-3} m s^{-1} (1.58 x 10^{5} m a^{-1}) was assumed which is the average of the range of hydraulic conductivities (10^{-2} - 10^{-3} m s^{-1}) reported for similar areas in this region (Schweizerische Geotechnische Kommission, 1972).

This groundwater flow is made up of the following components:

1. Source discharge

2. Groundwater flow at the upper end of the area. This is very small and can be considered together with 3.

3. Lateral inflow into the groundwater from the valley sides

4. Percolation from the B-horizon (deep soil) into the groundwater. This is made up of the precipitation surplus and the lateral inflow into the B-horizon.

The total lateral inflow for the Hellikon region is effectively the sum of components 2 to 4 excluding the precipitation surplus, i.e. 3.0 x 10^{6} m^{3} a^{-1} – 2.6 x 10^{5} m^{3} a^{-1} – 1.4 x 10^{5} m^{3} a^{-1} = 2.6 x 10^{6} m^{3} a^{-1}. This value appears to be fairly realistic if one considers the catchment area for lateral inflow and the precipitation surplus of 500 mm a^{-1}.

As previously discussed in section 2.4, it is assumed that around 20% of the lateral inflow enters in the B-horizon (deep soil) of which only 25% contributes to the compartment, the rest essentially percolates down to the groundwater table. Lateral inflow to the deep soil layer is therefore 1.3 x 10^{5} m^{3} a^{-1} for the Hellikon region.

The resultant system of compartments and water fluxes for the two situations with capillary rise which are used for model calculations are presented in Figures 6 and 7, respectively.

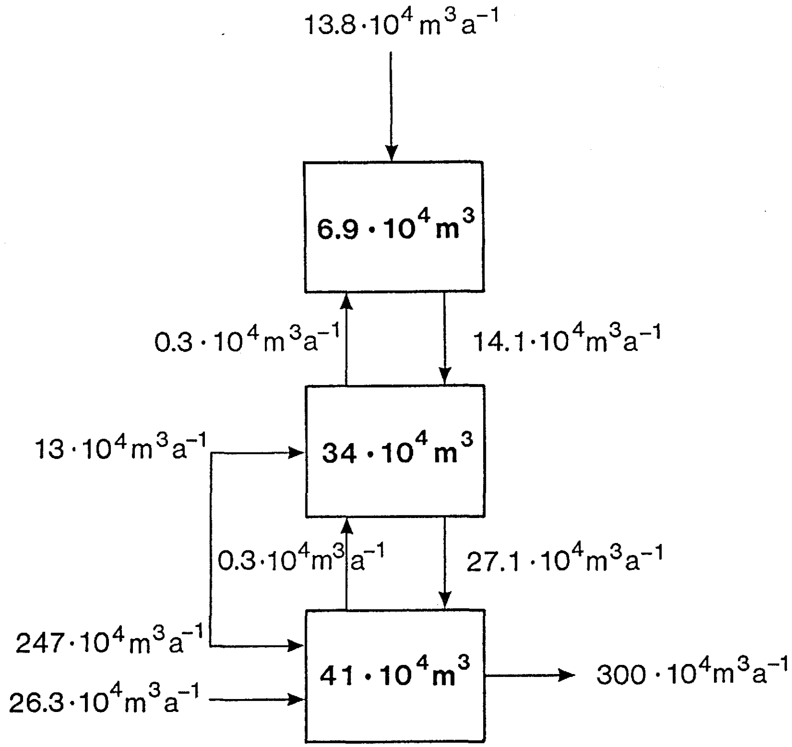

Figure 6: System of compartments and fluxes used to model 10 mm a^{-1} upward groundwater movement in the Hellikon region

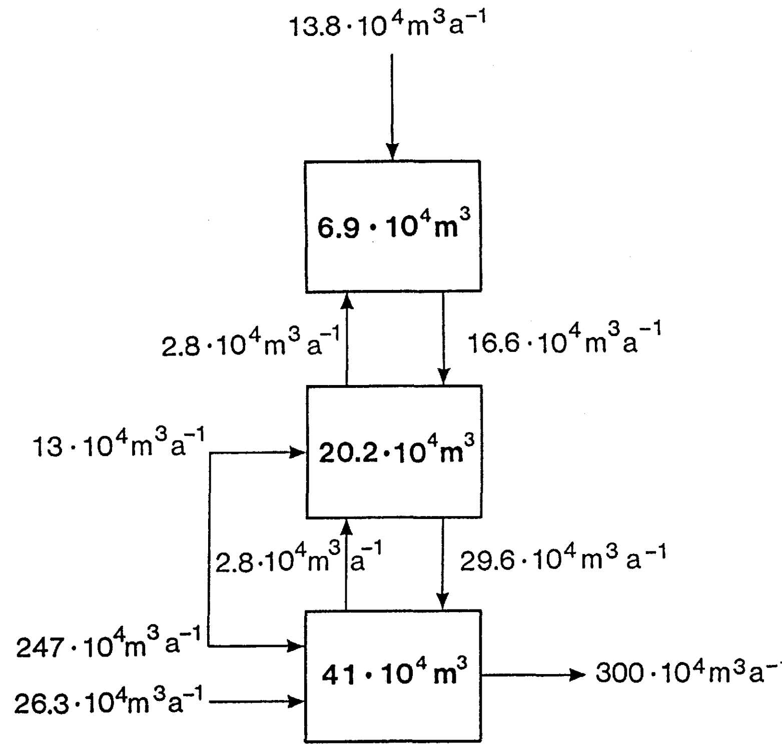

Figure 7: System of compartments and fluxes used to model 100 mm a^{-1} upward groundwater movement in the Hellikon region

3 Model Calculations

3.1 Introduction

The radionuclide concentration in the root-zone soil resulting from contaminated groundwater in the Hellikon region has been calculated for two radionuclides, ^{129}I and ^{237}Np using the computer code BIOPATH (Röjder et al. 1987). For further details the reader is referred to Grogan and van Dorp (1986). These two radionuclides have been chosen to maintain consistency with the BIOMOVS exercise in which the Hellikon region is being studied (Scenario B6b) as well as the Mol region in Belgium. These radionuclides were selected because of their significance for radioactive waste disposal problems and their different mobility and behaviour in the environment. For the calculations the following assumptions are made:

- there is a flux of 1 Bq per year and hectare of each radionuclide in the groundwater to the soil below the rooting zone
- it is a homogeneous farming area
- there are no irrigation practises.

The time-dependent concentrations of ^{129}I and ^{237}Np in the root-zone soil are calculated up to steady-state. A limited number of parameter variations have also been carried out and although the results have been used to generate uncertainty estimates they do not aim to estimate the real uncertainty about the predicted values. Instead the parameter variations are regarded as a useful tool for learning more about the system being modelled.

3.2 Base Case

The configuration of compartments and fluxes used to model the base case are presented in Figure 4, chapter 2, along with a description of the key parameters and their values.

The base case parameter values are selected assuming present day conditions and therefore provide the best estimate values for this scenario. The upward flux is set at 10 mm a^{-1} based on the evidence presented in chapter 2, although it is recognised that this is still probably a somewhat conservative estimate. The annual precipitation surplus is assumed to be 500 mm. This is characteristic for the present day climate in this region where the average precipitation is approximately 1000 mm a^{-1} and the evapotranspiration 500 mm a^{-1} (Jiskra, 1985).

The best estimate K_d values for both radionuclides are listed in Table 2 and are based on a review of the data by Baeyens et al. (1990) where an account of how these values were selected is given. The same K_d value was used in both soil layers for each radionuclide.

Table 2: ^{129}I and ^{237}Np K_d values

Radionuclide	K_d value (m^3 kg^{-1})		
	Best estimate	minimum	maximum
^{129}I	0.01	0.001	0.05
^{237}Np	0.05	0.001	1.0

The predicted ^{129}I and ^{237}Np concentrations in both top and deep soil are presented graphically in Figure 8. The radionuclide concentrations increase smoothly with time until steady-state is reached and this is attained more rapidly for I than Np. The I concentrations are a factor of 5 lower than the Np ones, for both soil layers. This result reflects the higher mobility that is assumed for I and this is modelled by assigning a lower K_d value. The selected iodine K_d value is exactly five times smaller than the neptunium K_d value.

The deep soil concentrations are 51 times higher than the surface soil concentrations for both radionuclides. This difference occurs because the radionuclides enter the system from below via the groundwater and only a small fraction of the contaminated groundwater moves upwards to the surface soil. The upward flux, which is equivalent to 10 mm a^{-1}, is 51 times smaller in magnitude than the downward flux which results from the precipitation surplus.

3.3 Parameter Variations

In this section the sensitivitiy of the predicted concentrations to key input parameters are examined in order to gain further understanding of the system and define upper and

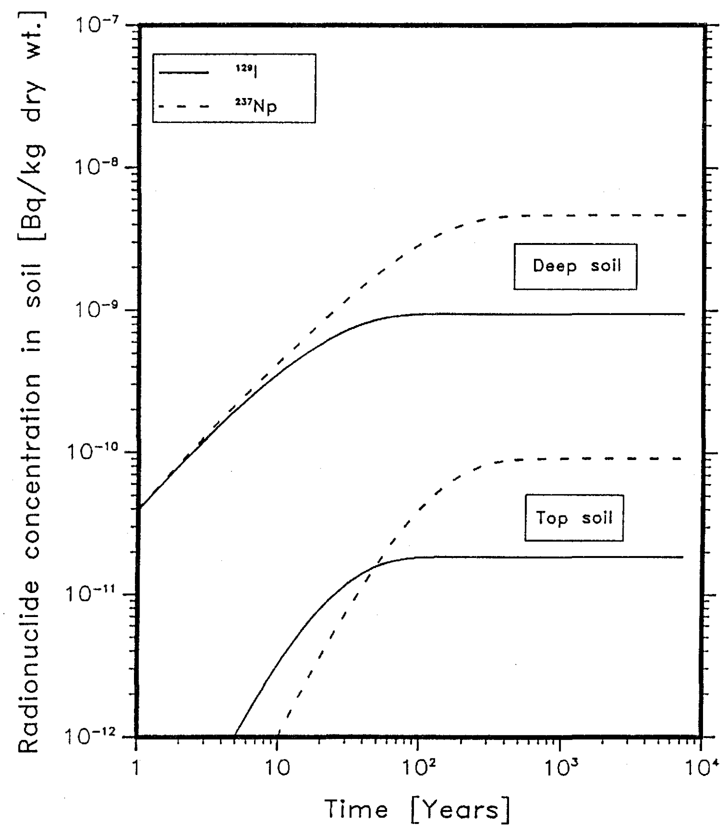

Figure 8: Best estimates for the ^{129}I and ^{237}Np concentration in both top and deep soil, as a function of time.

lower uncertainty estimates for the best estimate values.

Upward Flux

An upper estimate for the upward flux was conservatively concluded to be 100 mm a^{-1} based on the discussions in chapter 2 (section 2.3). Since 100 mm a^{-1} is only anticipated when the groundwater table lies above the boundary layer in the soil profile, the depth of the deep soil layer is reduced to 0.75 m for the modelling compared with 1.25 for the base case situation (c.f. Figure 5). Calculations were then made holding all other parameters at their base case values. The minimium estimate for capillary rise is zero and this therefore requires no model calculation. In fact, it should be noted that the best estimate value of 10 mm a^{-1} is really considered to be conservative.

The results are presented in Figures 9 and 10 for ^{129}I and ^{237}Np, respectively. Increasing the upward flux by an order of magnitude from 10 mm a^{-1} to 100 mm a^{-1} results in a proportionately much larger increase in the surface soil concentrations ($\sim$ 78). This situation occurs because the transport of contaminated groundwater to the top soil is a two stage process, the first stage is from the aquifer to the deep soil and the second stage is from the deep soil to the surface soil. As a result of this the deep soil concentrations of both radionuclides are nearly an order of magnitude (9.15) greater when 100 mm a^{-1} upward flux is assumed compared with 10 mm a^{-1}. This difference is further accentuated in the second stage of this upward flux, where the greater flux comes from the soil with an already higher radionuclide concentration. The exact degree to which the radionuclides accumulate in each soil layer is thus determined by the ratio of the upward to downward fluxes, whereby the latter is composed of non contaminated water coming either directly or indirectly from infiltrating precipitation.

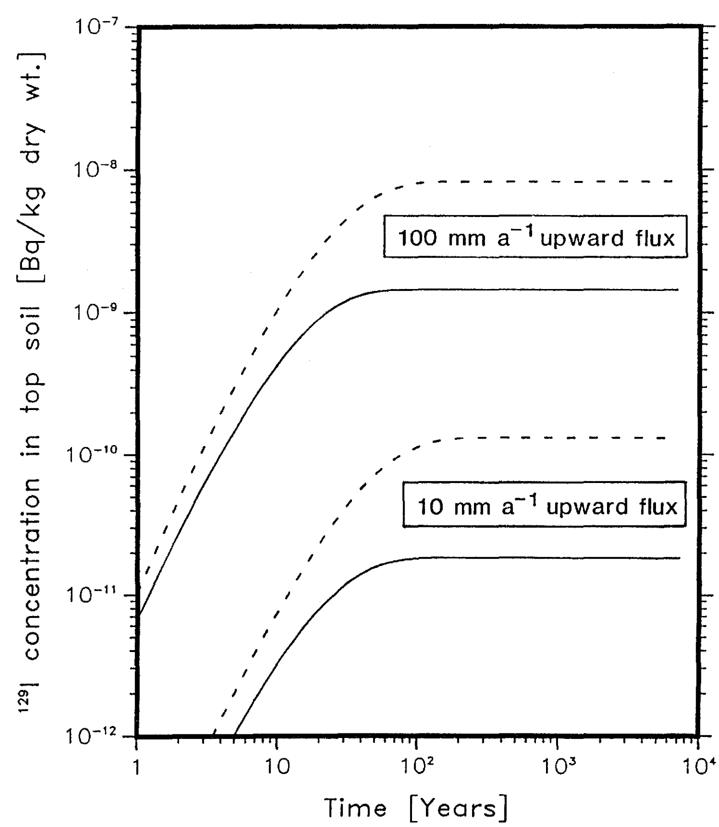

Figure 9: ^{129}I concentration in top soil assuming different upward fluxes at 500 mm a^{-1} precipitation surplus (solid lines) and at 250 mm a^{-1} precipitation surplus (broken lines).

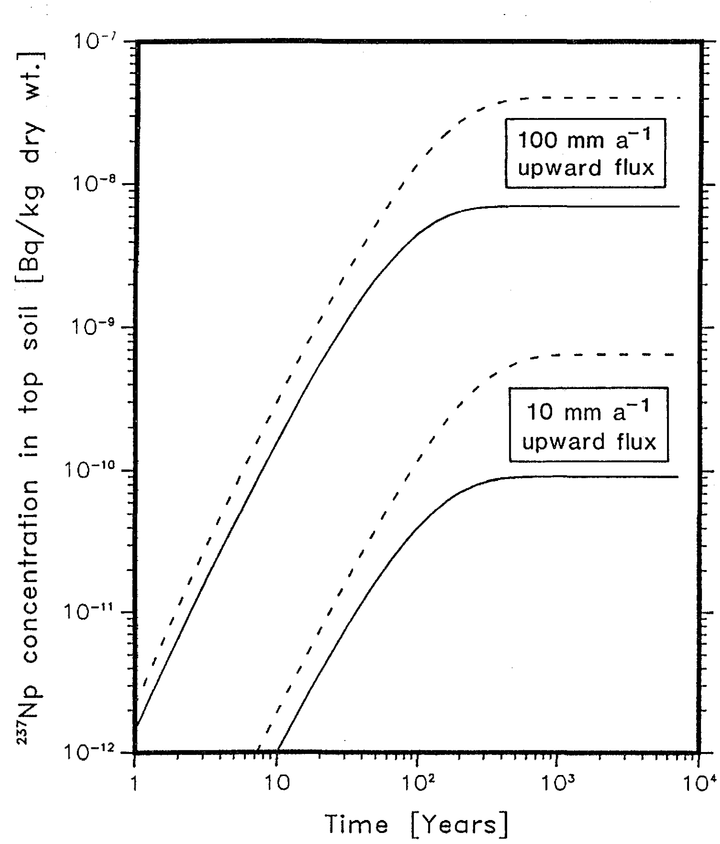

Figure 10: ^{237}Np concentration in top soil assuming different upward fluxes at 500 mm a^{-1} precipitation surplus (solid lines) and at 250 mm a^{-1} precipitation surplus (broken lines).

Precipitation Surplus

For examining the influence of the precipitation surplus on the surface soil concentrations it is also necessary to adjust the volume of lateral inflow and uncontaminated groundwater. Naturally, if the precipitation surplus decreases the net infiltration to the entire catchment area will also decrease. A 50 % reduction in the precipitation surplus was therefore coupled to a proportional reduction in the value of the other two fluxes. The value of 250 mm a^{-1} precipitation surplus was selected assuming an increase in the amount of evapotranspiration to 750 mm a^{-1}. This value reflects the annual potential evapotranspiration of more southern locations in Switzerland e.g Sion, Geneva (Mohrmann and Kessler, 1959). Therefore still assuming 1000 mm annual precipitation and no annual deficit the resultant precipitation surplus would be 250 mm a^{-1}.

Calculations were made for 250 mm a^{-1} precipitation surplus assuming both 10 mm a^{-1} and 100 mm a^{-1} upward fluxes (Figures 9,10), respectively. However, despite the fact that reduced precipitation surplus and hence increased evapotranspiration will act to accentuate the upward movement, it is considered unreasonable to assume that the latter situation with 100 mm a^{-1} upwards flux occurs. This flux (100 mm a^{-1}) is assumed for situations where the groundwater table lies above the boundary layer and according for the reduced precipitation surplus such a situation would appear even less likely. It is not considered reasonable to reduce the precipitation surplus further because this would imply a region and climate with significantly different characteristics to Hellikon with no net downward flux of water.

The results are included in Figures 9 and 10 for ^{129}I and ^{237}Np, respectively. Decreasing the precipitation surplus by a factor of two from 500 mm a^{-1} to 250 mm a^{-1} does not simply result in the surface soil concentrations increasing by the same factor, instead they increase by a factor of 7.1 if 10 mm a^{-1} upwards flux is assumed and a factor of 5.8 if 100 mm a^{-1} upwards flux is assumed. This situation occurs because the lateral inflow and the uncontaminated groundwater flow are positively correlated to the precipitation surplus. Therefore as the precipitation surplus decreases so does the dilution provided by the meteoric water.

Soil K_d

The K_d value specifies the partitioning of an element between the soil and soilwater, so that a low K_d value e.g. 0.001 m^3kg^{-1} indicates that the element is predominantly associated with the soilwater rather than the soil solid phase. Earlier work (Grogan and van Dorp, 1986) has demonstrated that the predicted soil concentrations are sensitive to the value of the solid-liquid distribution coefficient (K_d). Calculations were therefore made assuming a minimum, maximum and best estimate K_d value for each radionuclide. The range in K_d values was selected based on the work described in Baeyens et al. (1990) and are summarised in table 2.

For these calculations it was always assumed that the two soil layers had the same K_d value. In fact, the steady-state surface soil concentrations are always determined by the surface soil K_d value independent of the K_d value selected for the deep soil layer. It is the dynamics for achieving steady-state which vary. The impact of assigning different K_d values to the two soil layers is discussed in more detail in Baeyens et al. (1990). The results are presented in Figures 11 and 12 for ^{129}I and ^{237}Np, respectively.

The steady-state soil concentrations are linearly related to the soil K_d for values of K_d above $\sim$ 0.01 m^3 kg^{-1} as is the time required to reach steady-state. For example, increasing the ^{129}I K_d value by a factor of five from 0.01 m^3 kg^{-1} to 0.05 m^3 kg^{-1} (Figure 11) results in the steady-state soil concentration also increasing by one order of magnitude from 1.8 x 10^{-11} Bq kg^{-1} to 9.0 x 10^{-11} Bq kg^{-1}; likewise the time required to reach steady-state increases by a factor of five. Assuming a higher K_d value implies that the radionuclide is less mobile, sorbing more strongly to the soil solid phase where it accumulates rather than being leached away with the passing water.

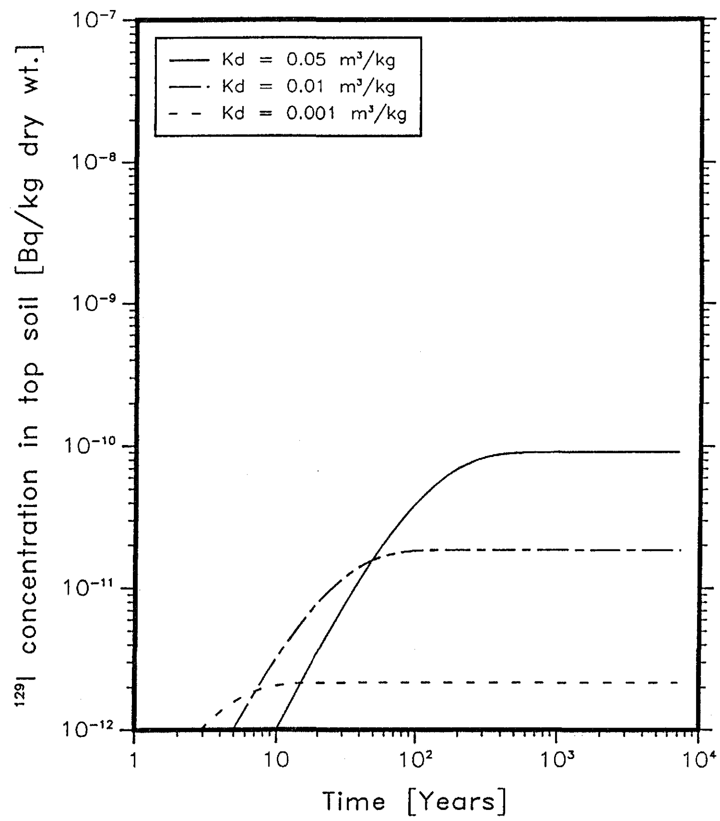

Figure 11: Influence of K_d value on the ^{129}I concentrations predicted in top soil

3.4 Uncertainty Estimates

The best estimate values for the steady-state ^{129}I and ^{237}Np concentrations in the surface soil in the Hellikon region resulting from contaminated groundwater are presented in Table 3. These values have been calculated assuming present day climatological, hydrological and pedological conditions whereby the upward movement of contaminated groundwater is brought about by capillary rise at a rate of 10 mm a^{-1}. However it is acknowledged that this value probably errs on the side of conservatism.

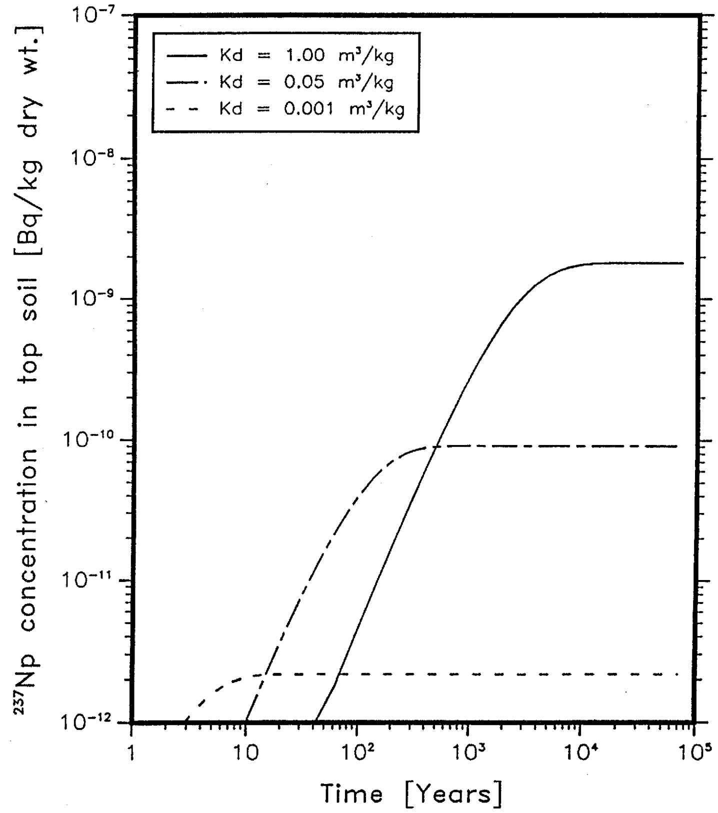

Figure 12: Influence of K_d value on the ^{237}Np concentrations predicted in top soil

The lower estimate values were more easily assigned and assume that no activity reaches the surface soil via this pathway. This may in fact represent the more typical situation in this region.

In order to determine the upper estimates for the surface soil radionuclide concentrations the results of the parameter perturbations which were carried out for three key parameters, precipitation surplus, upward flux and soil K_d were analysed. Decreasing the precipitation surplus to half its present day value resulted in the surface soil concentrations increasing by less than one order of magnitude. In contrast increasing the upward flux from 10 mm a^{-1} to 100 mm a^{-1} resulted in almost two orders of magnitude increase. This value can really be considered as an upper estimate. Although the calculations were also made assuming both the reduced precipitation surplus (250 mm a^{-1}) and the maximal upward flux (100 mm a^{-1}), this is considered to be an unrealistic parameter combination for determining upper estimates of the soil concentration with the reduced infiltration; the probability that the groundwater table lies above the boundary layer thus allowing the correct conditions for such an upward flux is very small. The conservative K_d values for iodine and neptunium are five and twenty times greater than the respective best estimate values (see Table 2) and result in a proportionate increase in soil concentrations. At all times it was assumed that the contaminated groundwater mixed instantaneously and homogenously with the meteoric groundwater.

To summarise, the best estimate values are determined assuming 10 mm a^{-1} upward flux and 500 mm a^{-1} precipitation surplus. The lower estimate is zero and assumes that no activity reaches the surface soil. The upper estimate values are determined assuming 100 mm a^{-1} upward flux, 500 mm a^{-1} precipitation surplus and a more conservative K_d value (factor 5). This results in upper estimates of the soil concentrations that are 280 times greater than the best estimate values for both radionuclides (Table 3).

Table 3: Best estimate values with upper and lower estimates for the steady state radionulide concentrations in surface soil

Radionuclide	Surface Soil Concentration (Bq kg^{-1} dry wt)		
	Best estimate value	minimum value	maximum value
^{129}I	1.8×10^{-11}	0	5.0×10^{-9}
^{237}Np	9.2×10^{-11}	0	3.5×10^{-8}

4 Conclusions

The upward transport of deep groundwater into the surface soil is a possible pathway for radionuclides to reach the biosphere following release from a deep geologic repository and it is therefore prudent to investigate the radiological consequences of such a situation. However, it is unrealistic to assume that this pathway is of universal significance because it will only be characteristic of groundwater discharge areas. Solutes in the groundwater could reach the soil surface as a result of capillary rise with evapotranspiration as the driving force, but for this process to be effective the groundwater table must lie within a reasonable distance (i.e. up to a few metres) of the soil surface. Indeed appraisal of the Laufenburg region of northern Switzerland for which this pathway was originally assumed in the Project Gewähr calculations, has demonstrated that it is extremely unlikely to occur. At this site the groundwater table lies far below the soil surface (15 - 35 m). Alternatively, fluctuations in the height of the watertable could also bring about solute transport to the surface soil whereby the watertable rises very close to the surface at times.

A preliminary evaluation using soil use maps has shown that the majority of areas with potential capillary rise are situated north of the alps. This is largely due to topographical reasons since this process tends to occur in flat areas. Furthermore the survey demonstrated that although the number of sites is considerable, in terms of volume, capillary rise may in fact be insignificant in many cases.

The Hellikon region of northern Switzerland has been identified as an area where the transport of groundwater to surface soil is feasible. The hydrological situation of this and surrounding regions has been examined to allow a more realistic system of compartments and fluxes for modelling this pathway with respect to the release of radionuclides from an underground repository to be produced.

It was concluded that the extent of the upward flux is determined by the depth of the water table, soil profile characteristics and climatological factors (e.g. precipitation, evapotranspiration). The soil profile for this region is characterised by a boundary layer at a depth $\sim$ 1.5 m which acts as a barrier to water movement. Consequently if the watertable lies below this feature, only limited upward transport is anticipated. If, however, the watertable is situated above this feature the upward flux is then determined by the amount of evapotranspiration assuming the capillary fringe intersects the surface. For a small valley, lateral inflow of meteoric water from the valley sides also represents a significant source to the near surface soil. The net effect is to reduce the significance of the deep groundwater in contributing to the upward flux of solutes.

Assuming present day conditions, the best estimate surface soil concentrations are calculated by dividing the soil into two layers (deep soil, surface soil) and assuming 10 mm a^{-1} upward flux from the groundwater through the two soil layers. It is concluded that the resultant best estimate values must still be considered to be biased to the conservative side, in view of the fact that the more typical situation is likely to be that no groundwater reaches the top soil.

The results from the modelling demonstrate that the radionuclide concentration in the top soil is determined by the radionuclide concentration in the groundwater, the extent of radionuclide sorption on the soil, the volume of groundwater moving upwards, as well as dilution from precipitation surplus.

These key factors were varied for the modelling in order to further investigate the behaviour of the system. Increasing the sorption coefficient (K_d) by an order of magnitude resulted in a proportionate increase in the top soil concentration, as well as the time taken to attain steady-state (assuming a constant input). Consideration should be given to the time at which steady-state is reached, if the time is longer than the expected lifetime of the soil itself this will influence the interpretation of the results for assessment purposes.

Increasing the upward flux by an order of magnitude, from 10 mm a^{-1} to 100 mm a^{-1}, but still holding all other parameters constant, resulted in a proportionately much larger increase in the surface soil concentrations ($\sim$ 80). This is because the upward movement of radionuclides is modelled as a two stage process; from the groundwater aquifer to the deep soil and, from the deep soil to the top soil, the exact degree to which the radionuclides accumulate in each soil layer being determined by the ratio of the upward to downward fluxes.

In some instances it is important to account for pararameter correlations when changing a parameter's value. For example decreasing the amount of precipitation surplus implies not only a decrease in direct infiltration of water down the soil profile but also a reduction in the lateral inflow of water into the soil. At the same time, a decrease in the groundwater table may be expected which also influences the distance over which capillary rise may be considered reasonable. For this reason a 50% reduction in the precipitation surplus resulted in a seven fold increase in the predicted surface soil concentration, assuming a constant upward flux (10 mm a^{-1}).

From this work it can be concluded that uncertainties in the top soil concentrations are caused by uncertainties in a number of different factors, many of which are interrelated, such as:

- depth of the watertable
- soil characteristics
- climate (precipitation surplus, potential evapotranspiration)
- radionuclide sorption properties
- choice of compartment sizes

This list is not exhaustive and other factors clearly exist which influence the soil concentrations. The mixing of deep groundwater containing solutes with the near surface groundwaters is a particular example which has not been addressed here. In the previous report on this topic (Baeyens et al. 1990) it was concluded that sorption shows the largest uncertainty and therefore accounts for most of the uncertainty in the calculated soil concentrations. The results from the Hellikon region demonstrate that other factors may also contribute significantly to the uncertainty in the calculated soil concentrations. Furthermore, due to correlations between the various water fluxes, the system shows a non-linear response.

5 Acknowledgements

The preparation of this report was greatly aided by information and ideas contributed by colleagues at PSI and NAGRA with particular thanks to Piet Zuidema for his assistance. Particular thanks are also expressed to Peter Barry (AECL) for his thorough review of this report and the many useful and constructive comments which he brought forward. The authors would also like to thank J. Hadermann for his interest in this work and R. Bercher and E. Hochstrasser for typing the manuscript.

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Appendix I

Calculations for the Mol Region, Belgium as defined in Scenario B6b from the BIOMOVS study

This appendix summarises the calculations presented by PSI/NAGRA for the Mol Region, Belgium, as defined in BIOMOVS, Scenario B6b for calculating the transfer of radionuclides from groundwater to surface soil.

Mol Site Description (as provided to BIOMOVS participants)

The following description of the Mol region in Belgium was supplied to participants of the BIOMOVS exercise.

Water Balance

The water balance corresponds to the scheme shown below:

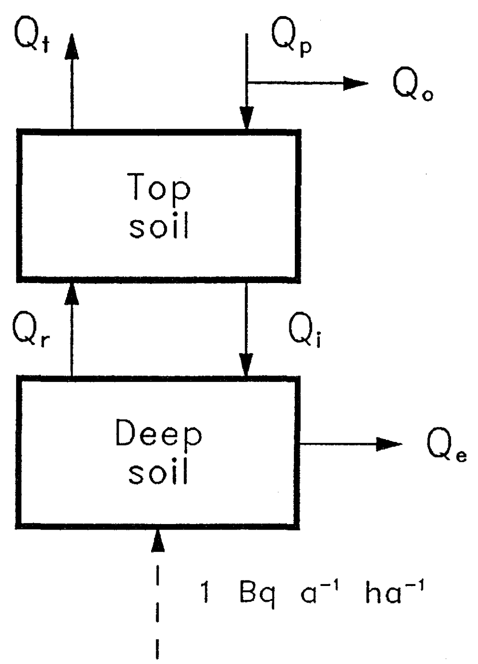


Figure 13: Compartments and fluxes for the Mol Region

where: $Q_p = 800 \text{ mm a}^{-1}$ $Q_i = 360 \text{ mm a}^{-1}$
$Q_t = 450 \text{ mm a}^{-1}$ $Q_r = 60 \text{ mm a}^{-1}$
$Q_o = 50 \text{ mm a}^{-1}$ $Q_e = 300 \text{ mm a}^{-1}$

For this water balance the upward movement of water from the deeper soil to the root-zone was derived from the difference between the actual evapotranspiration and the precipitation in the dry periods of the year.

With respect to the general scheme, the lateral drainage flux from the root-zone soil is negligible and so is the input flux of groundwater into the total soil. The lateral input flux may be neglected since the soil compartment is assumed to extend from the separation zone between two different basins, the vertical input flux of groundwater is negligible because of the iso-potentials in the saturated zone extending vertically.

The water table height varies during the year; from one year to another, however, it remains nearly unchanged. During short periods, the water table may reach the root-zone soil.

Soil characteristics

The soil consists of a 10 m thick layer of glauconitic sands (from medium to fine sand; MMD: 120 - 150μ) lying on a clay layer.

The root-zone soil may be assumed to extend over a thickness of 0.3 m and shows an effective porosity of 0.4 and a bulk density of 1300 kg m^{-3} (DW). The remaining part of the sand layer (thickness approx. 10 m) shows an effective porosity of 0.33 and a bulk density of 1650 kg m^{-3} (DW).

Given this information participants were requested to calculate the radionuclide concentrations in the top soil at 1, 10, 100, 1000 and 10000 years assuming a constant radionuclide flux of 1 Bq per year and hectare of ^{237}Np and ^{129}I in the groundwater entering the soil below the rooting zone. It is assumed to be a homogenous farming area with no irrigation.

Description of Compartments and Waterflows

A simplified sketch of a cross section through this region is presented in Figure 14.

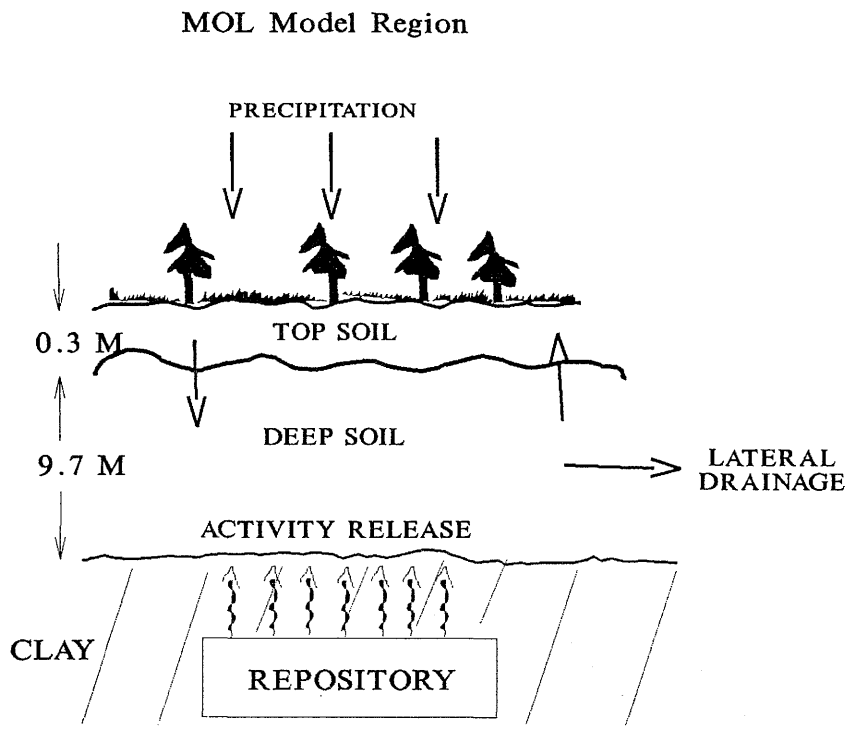


Figure 14: Mol Model Region

Figure 13 shows the system of compartments and waterflows used to model the Mol region at PSI with the computer code BIOPATH. In producing this system it was assumed that the root zone soil is 0.3 m thick and the deep soil 9.7 m deep. The bulk densities assumed for each soil layer were the same as those defined in the site description. The effective porosities were interpreted such that the root zone soil (top soil) contains 30% water and 10% air and the deep soil, 30% water and 3% air. It should be noted, however, that the flow in an unsaturated system is not modelled.

The best estimate K_d values for both ^{129}I and ^{237}Np are one order of magnitude lower than those used for modelling the Hellikon region, being 0.001 m^3 kg^{-1} and 0.005 m^3 kg^{-1}, respectively. These values were selected because the Mol Soil is specifically described as sand as is therefore expected to sorb the radionuclides less. The K_d values were held constant for both soil layers.

Results and Discussion for the Mol Region

The results of the best estimate calculations are presented in Figure 15. The radionuclide concentrations increase smoothly with time until steady-state is reached and this occurs more rapidly for ^{129}I than ^{237}Np, because it is assumed to sorb less on the soil solid phase. For the same reason the ^{129}I steady-state soil concentration is five times lower than the ^{237}Np soil concentration which is exactly the factor by which the K_d values differed.

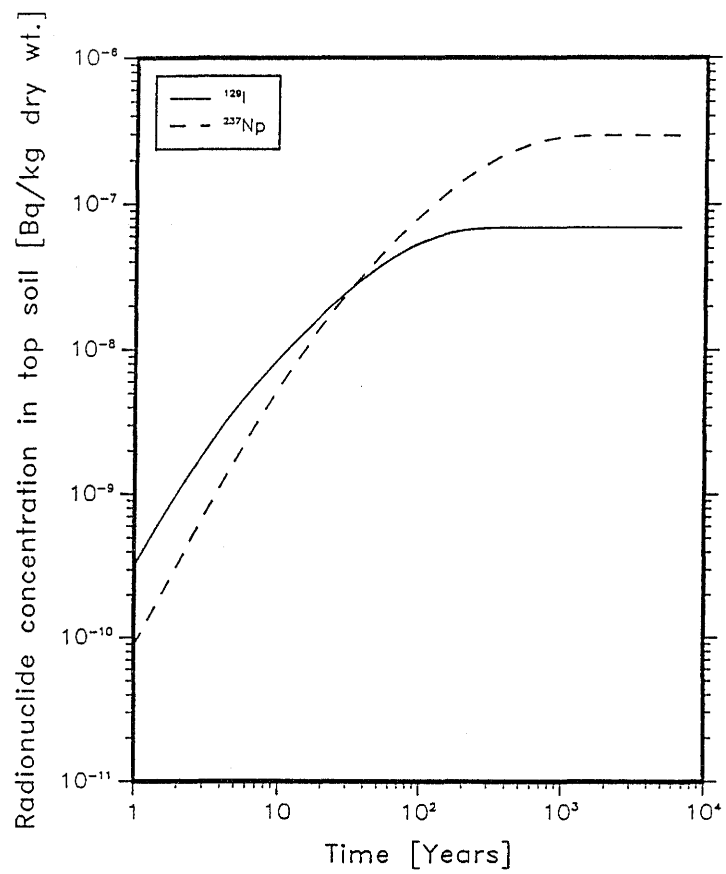


Figure 15: Best estimate values for the radionuclide concentrations in the top soil.

The sensitivity of the resultant soil concentrations to the K_d value is shown in Figures 16, 17 where three different values were assumed for each radionuclide. Both figures demonstrate that the steady-state soil concentrations are linearly related to the K_d value selected, so that increasing the K_d value by a factor of 10 results in a proportional increase in the predicted soil concentration. A further observation is that if a high sorption coefficient value is chosen, even though a high steady-state concentration may ultimately result, the radionuclide accumulates more slowly and for a longer period of time than when a lower K_d value is selected. It is therefore concluded that when interpreting the results, attention must be given to these timescales since a soil will also have a finite lifetime. For instance, it is unlikely that a radionuclide with a K_d of 0.1

or above will ever attain steady-state in the soil if the average soil lifetime is assumed to be of the order of one to several thousand years.

The uncertainty estimates for the soil concentrations (Table 4) were based solely upon the uncertainty in the K_d value, in which a factor of ten uncertainty was assumed in both directions. It is recognised that uncertainty in the annual precipitation and the waterfluxes between the compartments will also influence the predicted concentrations. However in the absence of any supporting data it was not possible to meaningfully assess their importance to the predicted concentrations.

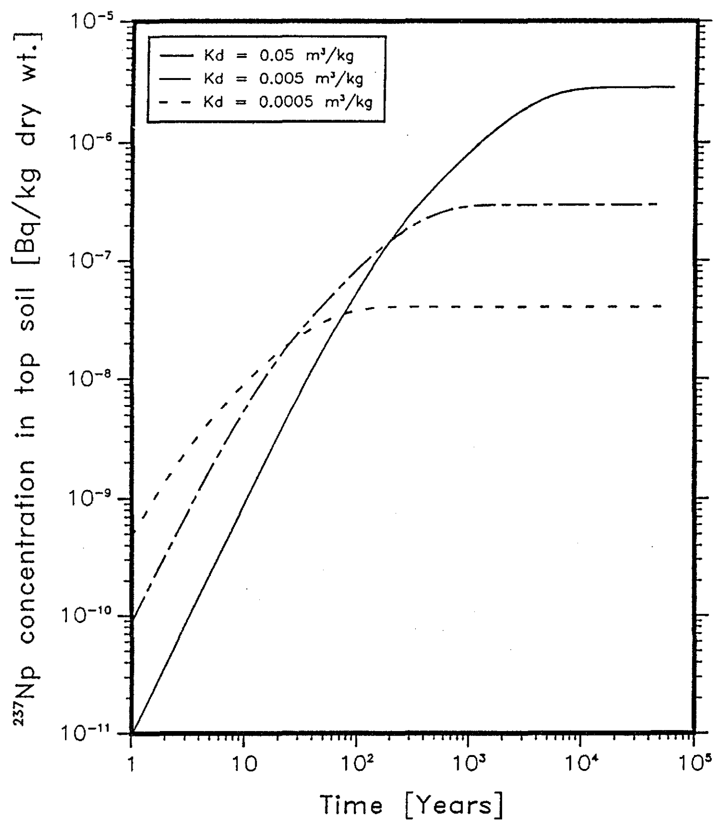


Figure 16: Influence of K_d value on the ^{237}Np concentrations predicted in top soil

Table 4: Best estimate values and minimum and maximum concentrations for ^{129}I and ^{237}Np in the top soil at steady–state.

Radionuclide	Best Estimate (Bq kg^{-1} dry soil)	Minimum (Bq kg^{-1} dry soil)	Maximum (Bq kg^{-1} dry soil)
^{129}I	6.9 x 10^{-8}	1.8 x 10^{-8}	5.7 x 10^{-7}
^{237}Np	2.9 x 10^{-7}	4.1 x 10^{-8}	2.8 x 10^{-6}

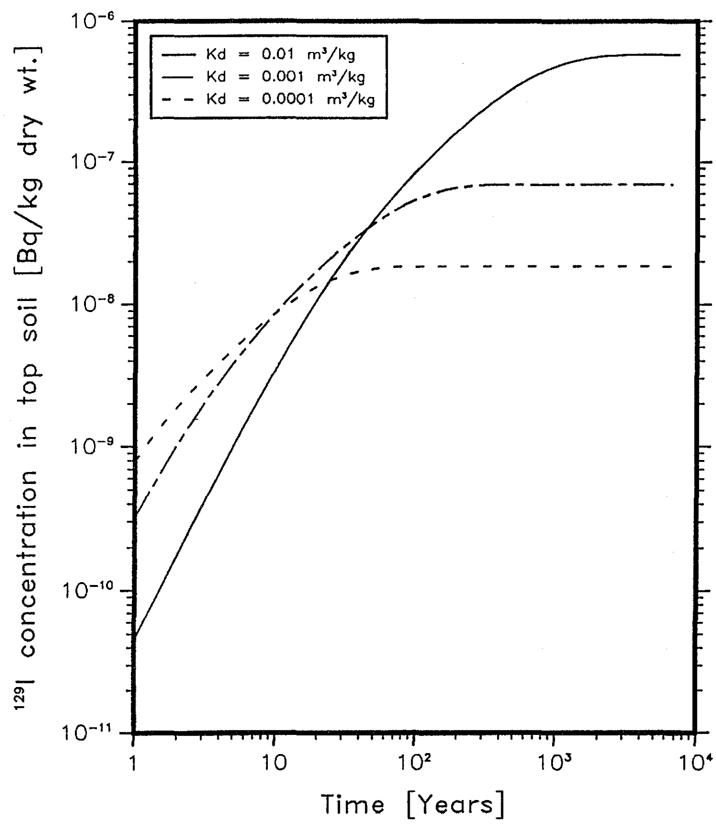


Figure 17: Influence of K_d value on the ^{129}I concentrations predicted in top soil

Appendix II

Assessment of the significance of capillary rise from groundwater in Switzerland based on the soil use maps

Introduction

As described in the introduction to the main report, the biosphere modelling carried out to date, for an underground waste repository, has been based on the assumption that there is upward transport of contaminated groundwater into the soil rooting zone where agricultural crops are assumed to grow. This has raised the question of how representative such a scenario is under present-day conditions in Switzerland. This appendix attempts to address this question by providing initial estimates for the areas where capillary rise could be anticipated in Switzerland. The soil use map 1:200,000 for Switzerland (Frei et al. 1980) is used as the basis for this survey.

Method

The map distinguishes 141 separate units for classifying the types of soil use. The first step involves selecting from these 141 units, those for which capillary rise from the groundwater is actually conceivable. To do this the following criteria, which were extracted from the map legend, were used.

a) Degree of wetting (damp, slightly wet, wet)
b) Slope gradient < 10%

Slopes with a gradient less than 10% were considered because while groundwater is clearly not to be expected in steeply sloping areas, restricting the survey to those with gradients up to only 3% would have the effect of ruling out some areas where groundwater is present.

Based on these two criteria the following 24 units remain:

B2, B5, C1, C4, F1, F3, F4, G1,
G4, H1, H4, J1, K1, L2, O1, P8,
Q1, Q3, R1, R2, R3, Z1, Z2, Z3.

On the map the 141 units are allocated to 18 different colour classes. These classes represent the different categories of soil use. The soil units extracted above are divided between these different categories, which are represented by roman numerals, as follows:

Colour Class	Map unit
I	H1
II	K1
III	F4
IV	B2,B5,C4,G4,J1,O1,Q1,R1,Z1
V	Z2
IX	F3
X	C1,F1,G1,H4,Q3
XI	L2,P8,R3,Z3
XIII	R2

Evaluation of the Methodology

In order to evaluate the applicability of this technique a number of random samples were taken for examination. These random samples actually amounted to areas for which local knowledge is available and which could therefore be compared with the map unit describing it. Four areas have been considered and are discussed in turn.

- **Hellikon test area**

  The Hellikon test area belongs to unit B2. According to the selection made above, capillary rise is conceivable in this unit and this does, in fact, correspond to reality.

- **Laufenburg test area**

  The Laufenburg test area belongs to unit F2, for which no capillary rise is anticipated; this also corresponds to reality.

- **Hasle-Burgdorf area**

  An investigation of the heat balance of the groundwater is being conducted in this area. It belongs to J1, one of the units for which capillary rise is possible. Based on the groundwater levels, this would appear to be realistic, but probably not for the whole area.

- **Sargans and the surrounding area**

  Units Q1 and Q3 (which belong to those selected above) are found in the vicinity of Sargans. Capillary rise could occur here, but not over the whole area. To the east of Sargans, the groundwater table was lowered considerably during the reclamation of the Saar plain and capillary rise has lost its significance in this area.

West of Sargans in the Seez valley, the area covered by Q3 could be influenced by lateral inflow from valley sides as well as by the groundwater.

The second method employed to evaluate the appropriateness of this technique was a comparison with larger scale maps. The 1:25,000 soil map (FAP, 1986) covering the Wohlen area was abitrarily chosen for this. The following units for which capillary rise is feasible can be found on the 1:200,000 soil use map in the Wohlen area.

F4, G1, G4, H1, H4, J1

These surfaces cover a considerable part of the area.

To allow a comparison of the two maps, one must first select from the 1:25,000 soil map those units for which capillary rise is conceivable; these are the units in which wet soils occur and can be listed as follows:

Small letters for water regime	Complex number
k,l,m,n	300-399
s,t,u	500-599
v,w	600-699
x,y	700-799
z	800-899

Once again, because a slope gradient of 10% cannot be exceeded, the small letter for the land form must belong to the following group: a, b, c, d, e.

Soil types which must be taken into consideration are gleys:

G fahl gley
V brown-earth gley
W coloured gley

Based on this information, a comparison was carried out between the two maps. By way of illustration, there follows for one or (where available) two surfaces of each of the six named units of the 1:200,000 map a list of the relevant units from the 1:25,000 map. For the 1:25,000 map, only those units for which capillary rise is feasible are taken into account. The comparison is presented in Table 5.

Table 5: Comparison between the 1:200,000 and 1:25,000 Map Units used to describe the same area

Unit on 1:200,000 map	Name of Location	Units on 1:25,000 map
F4	Bünz	kK1d, lK2d, 308d
	Aabach	tV1d
G1	Hallwil	kB2a, kK2d, tW3a, tW3d, wG4d, 504e, 650d
	Waltenschwil	wG2d,306a
G4	Anglikon	kB1a, kB3a, lW1a, tW1a, tW7a
	Niederrohrdorf	–
H1	Hendschiken	–
	Bergdietikon	yG3d
H4	Hägglingen	kB1d, tW2a, 550a
	Büttikon	wG1d
J1	Ammerswil	kB2b,kB2d,kB6d,tV2d

In general the comparability between the two maps is fairly good; many of the discrepancies can be explained, to some extent, by the difference in scale. Small surfaces (with or without capillary rise) which are represented on a scale of 1:25,000 disappear on the 1:200,000 map. A similar situation exists for the slope gradient classes. Where the 1:200,000 map shows uniformly flat areas (with gradients up to 10%), the 1:25,000 map gives some slope gradients in excess of 10%. This is particularly true for unit H1 which covers a hilly area beneath which there is no groundwater.

The discrepancies are also caused to some extent by the selection of the units. For example the 1:200000 map does not distinguish between the following three types of soils: those which become waterlogged after heavy rainfall (e.g. at Hallwil); those which become wet due to the influence of the watertable or thirdly, those which become wet due to the influence of lateral inflow. The 1:25000 map does make this distinction and in our case it is only the second situation which is of interest.

Nevertheless there is a relatively good qualitative agreement between the two maps. The quantitative aspect is, however, less promising in that the 1:200,000 map generally overestimates the surfaces with potential capillary rise.

Conclusions about the Methodology

The regions where capillary rise from the groundwater is feasible can be identified reasonably well with the 24 mapping units selected from the 1:200,000 soil use map. In fact, the agreement is better than one might initially anticipate. However there is, as a rule, an overestimation of the area of the relevant surfaces. This is because within a mapped surface, capillary rise from the groundwater usually only occurs in isolated areas. Further work would be required to quantify the extent of this overestimation. Consequently, the soil use map gives an indication of whether or not capillary rise is present but does not allow any further quantitative information to be deduced.

Spatial Distribution of the 24 selected mapping units

Having established that the selected mapping units identify areas where capillary rise can occur, it is of interest to gain an overview of their spatial distribution throughout Switzerland. To achieve this the soil use map was divided into quadrants of 20 km x 20 km and all the units belonging to the 24 selected units were noted for each of these quadrants. The results are presented in Figure 18. From this it can be seen that the majority of areas with potential capillary rise lie north of the Alps. There are only isolated areas in the Alps themselves and further south.

It is also evident that capillary rise north of the Alps is not restricted to extremely small surfaces. However, the overestimation of the relevant surfaces by the soil use map must be taken into account.

It is worth noting here that capillary rise from the groundwater clearly occurs in flat areas. In an alpine country such as Switzerland, such areas naturally occur less frequently but they are more important than sloping areas because they are cultivated more intensively.

Conclusions

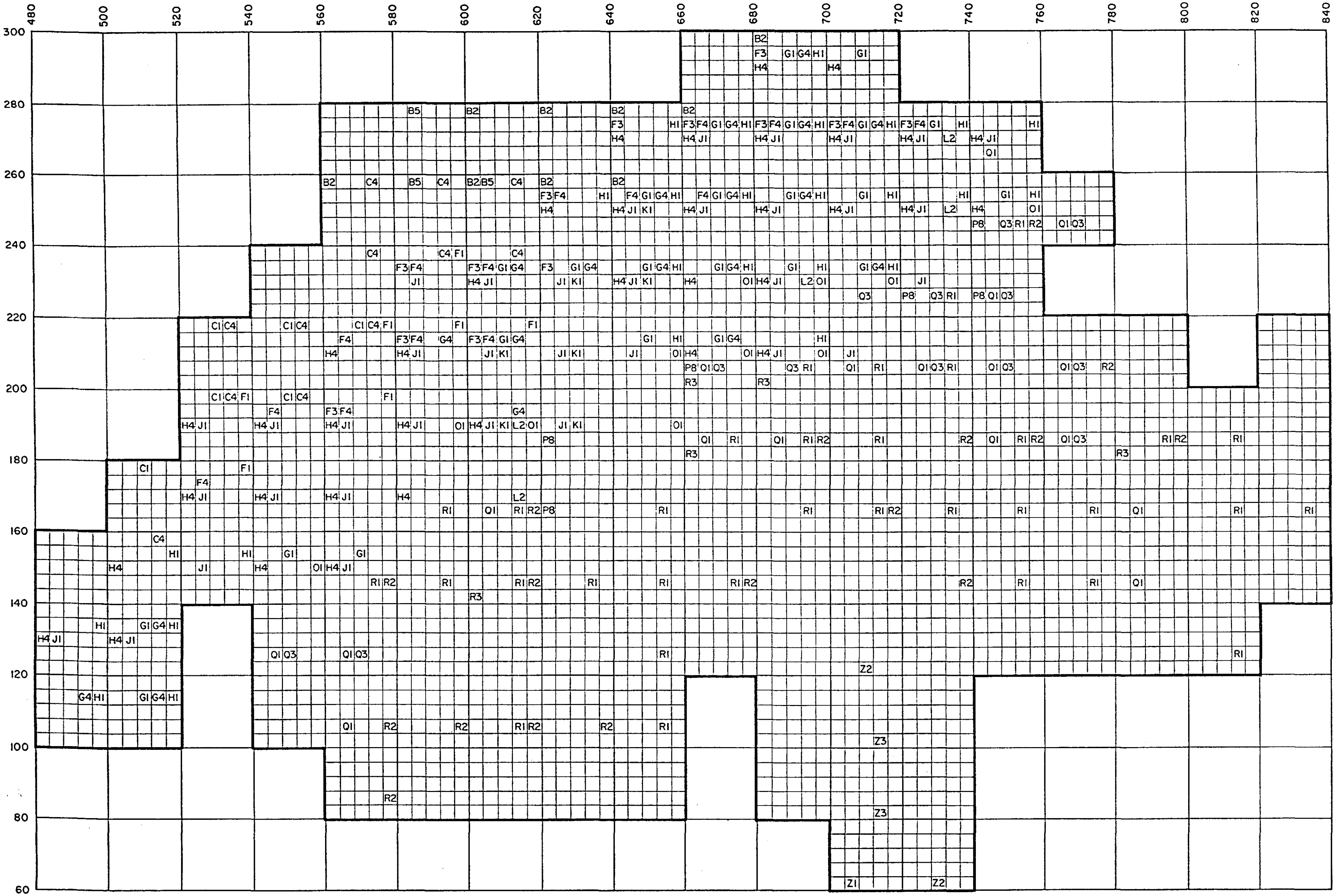
The 1:200,000 soil use map for Switzerland provides a relatively good indication of the areas for which capillary rise from the groundwater is conceivable but it generally overestimates the relevant surfaces, sometimes to a very large extent.

While areas with capillary rise are somewhat restricted in the Alps and to the south thereof, the areas to the north (Mittelland) are quite considerable, even taking into account the overestimation by the soil use map. However, in terms of volume, capillary rise is in fact insignificant in many cases.

Figure 18: Spatial distribution of the 24 selected mapping units from the 1:200,000 Swiss soil use map. (see figure on right site)

Distribution is given for 20 km-quadrants. The numbers at the side of the grid are the topographical coordinates. In order to facilitate location of a particular unit, the individual fields are marked as follows:

B2 B5 C1 C4 F1
F3 F4 G1 G4 H1
H4 J1 K1 L2 O1
P8 Q1 Q3 R1 R2
R3 Z1 Z2 Z3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120
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