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– interim report

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1 BACKGROUND

The European union plant protection product directive 91/414/EEC is changing the pesticide approval and authorisation procedure in Finland. In the future, a pesticide registered in any of the member states must be registered in all the other member states if applied, unless a member state can prove that the agricultural, climatic or environmental conditions differ significantly. All the active ingredients will be assessed and approved collectively by the Member States into Annex 1 (positive list) of the directive. Only products containing active ingredients included in Annex 1 can be registered.

The directive also sets the principles and guidelines for the risk assessment of active ingredients and products. The biggest change to the present situation is the use of pesticide fate models to assess the leaching of pesticide to groundwater and surface waters. Until now only simple calculations of predicted environmental pesticide concentrations have been incorporated in the risk assessment. This has mostly been due to the lack of suitable models. In the common EU registration system, the Commission provides the member states with models to be used in the risk assessment. For this purpose, the Commission has appointed a working group to select and evaluate the suitable models for European use and to prepare the scenarios needed for the models to ensure the high level of protection of the environment and health in the new registration procedure.

As a result, two work groups (FOCUS Groundwater and FOCUS Surface water; FOrum of the Co-ordination of pesticide fate models and their USe) have selected and parameterised existing pesticide fate models and prepared scenarios for the use on the EU. The work of FOCUS groundwater group is almost completed by the autumn 1999. The work includes a complete package of four groundwater leaching models parameterised for the EU pesticide risk assessment purposes and 9 different leaching scenarios. Each of the leaching scenarios represents a climatic and agricultural area of EU and contains weather data, soil properties and crop properties typical of that area. The scenarios are presented in the final report of the workgroup of FOCUS (FOCUS 2000).

These 9 scenarios and 4 models can be used when assessing the risk for pesticide leaching to groundwater in all the European union countries. Member states are, however, allowed to prepare their own scenarios in order to assure the safety of pesticide use before the registration of a product. Some work has to be carried out nationally, for example pesticides used in forestry can not be modelled using the present scenarios.

There is a growing concern on the effects of common approval procedure on the chemical safety in agriculture. This report deals with the FOCUS groundwater models and the possible limitations of the use of European risk assessment scenarios in the environmental and agricultural conditions of Finland. In addition, Finnish Environment Institute and Agricultural Research Centre of Finland in Jokioinen have prepared a data set of Finnish soils and weather in order to provide scenarios for pesticide risk assessment which would be more focused for the specific environment prevailing in Finland.

2 THE GROUNDWATER MODELS

Use of modelling with practical studies has been seen the only route to scientific risk assessment (Boesten et al. 1995). Model calculations can be used to improve planning and to interpret the results of "worst case" leaching studies. The high costs of leaching studies and reliable chemical analyses limit the amount of data available of the substances. There are several monitoring programmes going on in Europe to study the quality of groundwater, but their applicability to the present purpose has been questioned (WRc 1998) as their aim is to serve the EC Drinking Water Directive and the data is not collected in sufficient quantities to achieve an accurate picture of the risk caused by the use of agrochemicals. Furthermore, though models are usually validated in test fields, the lack of reliable data on the presence of chemicals in groundwaters also makes it impossible to validate wider scale models (relating to areal amounts and manners of use) needed in higher levels of risk assessment. In Finland very few studies of pesticides in either ground or surface waters have been conducted, which makes it very difficult to assess the success of risk management measures taken so far.

The concentration of a pesticide in soil is dependent on the weather, soil and crop properties in a way that they affect transformation, leaching, hydrology, volatilisation and sorption of the substance. The models that will be used in the groundwater risk assessment to estimate the leaching of pesticides in the European pesticide approval are PRZM, PELMO (PEsticide Leaching Model), PESTLA (PESticide Leaching and Accumulation) and MACRO. However, PESTLA may give way to PEARL, a new Dutch model.

PRZM 3.12 is a finite-difference model to simulate vertical one-dimensional movement of pesticides in the unsaturated zone within and below the root zone. Model was developed by Center for Exposure Assessment Modeling (CEAM) in the USA. It does not consider preferential flow of soil water or solutes, and should thus be used only for sandy soils.

PELMO is developed by Staatliche Lehr- und Forschungsanstalt für Lantwitschaft (SLFA) in Neustadt (G) and Fraunhofer-Institut für Umweltchemie und Ökotoxikologie, in Braunschweig (G), to estimate the leaching potential of pesticides through distinct soil horizons. It does not consider preferential flow of soil water or solutes, and should thus be used only for sandy soils.

MACRO is a water and solute transport model in macroporous field soils. This model is developed by the Swedish Agricultural University (SLU), Soil Survey and Land Research Centre (UK) and IACR Rothamstedt Experimental Station (UK). It is not meant for leaching of pesticides only, but can also be used to simulate leaching of other substances, including, for example, chloride and tritium. It is the only model for pesticide approval, which considers preferential flows (due to *permanent* macropores). MACRO has been chosen most suitable for Danish soils (Modelling of leaching... 1995). However, only one of the FOCUS groundwater leaching scenarios (Châteaudun) has been parameterised for MACRO in the official EU pesticide risk assessment.

PESTLA is a Dutch leaching model used for the evaluation of the potential risk of leaching of pesticides to groundwater in pesticide risk assessment. It is a part of the general chemical risk assessment system "Uniform System for Evaluation of Substances (USES). PESTLA was developed by DLO Winand Staring Centre (NL). It consists of submodels for water and heat flow (Soil-Water-Atmosphere, SWAP) and for pesticide behaviour. PESTLA's soil temperature and groundwater level modelling do not correspond to Finnish conditions, as it does not consider groundfrost or snow cover insulation.

All the models consider the effect of temperature on pesticide degradation. PRZM3, MACRO and PESTLA use the Arrhenius equation to assess the transformation rate[1]. PELMO uses a different approach. There is a continuous discussion going on whether there is an agreed method for estimating transformation rates at low temperature from measurements made at 20° C (Boesten et al. 1997). This is unclear even for the mean temperatures of 10° C, not to mention that the long-term measurements in Jokioinen (Heikinheimo and Fougstedt 1992) suggest the 5-day mean soil temperatures being more than 10°C only from early June to mid September (in 20 cm depth). The debate on the fate of chemicals in low temperatures continues, and for the time being all the decisions are to be made with the present knowledge.

Another point of serious discussion concerning the models used for risk assessment is how to deal with the macropore flow, which may be a major factor affecting the fate of chemicals in clay soils. This question is discussed in more detail in Appendix I.

MACRO, PELMO and PRZM3 calculate the share precipitation falling as snow depending on temperature. In PESTLA precipitation is always considered rainfall. This is a real deficiency in soil hydrology modelling.

No validation work for the models has been conducted in environmental conditions of Finland. However, it is generally believed that the present leaching models are reliable in assessing the leaching levels above 1%. Persistence models tend to estimate slower degradation than is found in the plough layer. (Boesten 2000).

[1] FOCUS group found that activation energies in general vary more between studies conducted with one substance than between different substances. Thus, it is possible to use a general estimate for the activation energy E_a instead of substance specific value (Boesten et al. 1997).

3 THE FOCUS SCENARIO JOKIOINEN AND FINLAND

The FOCUS scenarios for assessment of pesticide leaching into the groundwater were built following these principles (FOCUS 2000):

- The number of locations should not exceed 10
- Realistic crop, soil, climate and agronomic conditions
- Overall vulnerability is described approximating 90th percentile
- Vulnerability is split evenly between soil properties and weather

The locations were chosen based on major agricultural regions, covering the range of temperatures and rainfall occurring in EU arable agriculture. The scenarios carry the name of the site, though they **represent the region.** All the scenarios are in different countries, one of them located in Finland (Jokioinen). However, neither the soil or the weather of the Jokioinen scenario are physically from Jokioinen, nor is it meant to represent Finnish conditions.

The scenario locations are shown in Figure 1. Agricultural regions represented by the scenarios and governed by the climate are presented in Table 1. It should be noted that the region Jokioinen represent covers only 1% of the arable land in Europe. The soil chosen (Table 2) for each scenario was significantly more vulnerable[2] than the median soil of the region it represents. Selected crops were realistic for the scenario and region, though not necessarily for all the parts of the region[3].

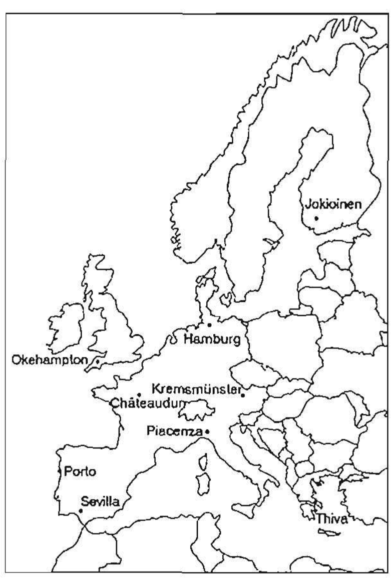

Figure 1. Focus groundwater leaching scenario locations (FOCUS 2000).

The risk of pesticide leaching into groundwater in any scenario is mostly dependent on three factors: properties of the pesticide used, soil and climatic properties.

[2] Vulnerability was defined with respect to chromatographic leaching, which means that leaching is greater in sandy soils than in loamy or clay soils (FOCUS 2000).
[3] This does not mean realistic for Jokioinen area or even Southern Finland in general.

Table 1. Climatic regions of EU (including Norway and Switzerland) (FOCUS 2000).

Precipitation (mm)	Annual temperature (°C)	% of arable land	% of total area	Representative locations	Abbr.
601 – 800	5 - 12,5	31	19	Hamburg/Châteaudun	H/C
801 – 1000	5 - 12,5	18	13	Kremsmünster	K
1001 – 1400	5 - 12,5	15	12	Okehampton	N
601 – 800	>12,5	13	11	Sevilla/Thiva*	S/T
801 – 1000	>12,5	9	8	Piacenza	P
0 – 600	>12,5	4	4	Sevilla/Thiva	S/T
0 – 600	5 - 12,5	3	2	(Châteaudun)	C
1001 – 1400	>12,5	3	3	Porto	O
0-600	<5	1	11	Jokioinen	J
>1400	5 - 12,5	1	1	--	
1001 – 1400	<5	1	4	--	
601 – 800	<5	1	8	--	
801 – 1000	<5	0	3	--	
>1400	<5	0	0	--	
>1400	>12,5	0	0	--	

*) with irrigation

Table 2. Scenario details. I stands for irrigation (FOCUS 2000).

Location	Annual temp. (°C)	Annual Rainfall (mm)	Surface Soil Texture	Organic Matter (%)
Châteaudun	11.4	648 + I	silty clay loam	2.4
Hamburg	9.2	786	sandy loam	2.6
Jokioinen	4.3	638	loamy sand	7.0
Kremsmünster	8.8	900	loam/silt loam	3.6
Okehampton	10.4	1038	loam	3.8
Piacenza	13.3	857 + I	loam	1.7
Porto	14.8	1150	loam	6.6
Sevilla	18.1	493 + I	silt loam	1.6
Thiva	16.2	500 + I	loam	1.3

Originally, sandy soils were suspected to be most vulnerable, because of their high hydraulic conductivity. However, clay soils may also present high risk for the contamination of groundwater or surface water (via subsurface drainage pipes), because soils with high clay content tend to crack and contain macropores in upper layers. The amount of precipitation trapped up by vertical soil cracks may be up to 60% (Al-Soufi 1999). Thus, the transport of pesticide from the top to the deeper layers in clay soils may be very rapid despite their hydraulic conductivity appears to be low because of effective porosity (Al-Soufi 1999). Macropore flow occurs both during the growing season and the period, when the soil is frozen or melting.

Substances transported via preferential flow route are not as directly affected by the sorption properties of soil or the substance (Larsson and Jarvis 1999). Preferential flow modelling has developed lately, but since the phenomenon itself is very closely related to spatial and temporal variation, it seems impossible to develop a universal model. Thus, the current models are very site-specific because of the validation process (macropore flow is much more related to soil characteristics than chromatographic flow).

MACRO is the most common pesticide model and the only FOCUS model that simulates the existence and properties of macropores. However, due to the site specific nature and difficulties in parameterisation, FOCUS workgroup developed macropore flow parameters for only one scenario (Châteaudun) for demonstrating the effect. In a coarse soil, such as loamy fine sand in the Jokioinen scenario, the inclusion of macropores in the modelling should not make any difference in the results, because chromatographic flow dominates water movements.

The most important climatic properties affecting the pesticide leaching are precipitation, air temperature (=> soil temperature) and global radiation (affects evapotranspiration and water movements in soil).

3.1 Comparison of Jokioinen scenario soil characteristics with Finnish arable soils

For starters, it is important to point out that Jokioinen scenario is not supposed to represent Finnish environment and agricultural circumstances. The Focus scenarios each represent a climatic and agricultural region. Finland is thus only a part of the region Jokioinen scenario represents. Thus, the examination below must be seen as a Finnish point of view only.

The Jokioinen soil is Gleyic Podzol (FAO 1988) which is texturally fine sand (Table 3). In order to be able to evaluate how well Jokioinen scenario can estimate the risk of a pesticide leaching in Finnish conditions, the properties of soil, climate and crops in the scenario have to be compared with real Finnish data. The final judgement can not be made until in context with the risk assessment of each pesticide, as the significance of the scenario properties to the degree of leaching is dependent on the pesticide properties. The most important factors are the half-life in the environment and the organic matter partition coefficient of the substance.

Table 3. Soil parameters for Jokioinen (FOCUS 2000). The groundwater level is approximately 1.52 m below soil surface.

Horizon	*depth*	*Classification*	pH_{H_2O}	*texture mm*			*OM**	*bulk density*	*Depth factor@*
	cm			*<2*	*2-60*	*>60*	*%*	$g\ cm^{-3}$	*-*
Ap	*0 - 30*	*loamy fine sand*	*6.2*	*3.6*	*23.2*	*73.2*	*7.0*	*1.29*	*1.0*
Bs	*30 - 60*	*loamy fine sand*	*5.6*	*1.8*	*12.2*	*86.0*	*1.45*	*1.52*	*0.5*
BC1	*60 - 95*	*loamy fine sand*	*5.4*	*1.2*	*14.9*	*83.9*	*0.62*	*1.64*	*0.3*
BC2	*95 - 100*	*loamy fine sand*	*5.4*	*1.7*	*18.9*	*79.4*	*0.50*	*1.63*	*0.3*
BC2	*100 - 120*	*loamy fine sand*	*5.4*	*1.7*	*18.9*	*79.4*	*0.50*	*1.63*	*0.0*
Cg	*120 - 150*	*fine sand*	*5.3*	*1.9*	*8.6*	*89.5*	*0.36*	*1.66*	*0.0*

@ The depth factor indicates the relative transformation rate in the soil layer.
**) OM% = 1.73 * OC%*

3.1.1 Soil pH

The pH in the topsoil of the Jokioinen scenario is 6.2, decreasing to 5.3 in deeper layers, being 5.6 under plough layer. The high pH in top soil results from liming.

The average pH of arable soils of Finland varies within the country, the total average being 5.84 (Viljavuuspalvelu Oy 1997). The average pH of arable soils is highest in Southern Finland and gradually decreases to the North, owing to the increasing proportion of organic soils. Regionally, pH average > 6 is found only in the South Western corner of the country. In the areas of most intensive agriculture, pH is approximately 5.8-6.2. Thus, the top soil pH in the Jokioinen scenario is slightly higher than the average of cultivated soils of Finland. In the recent years, the mean pH of soil samples sent to soil testing has been been lower than earlier (Figure 2). This, however, does not necessarily mean acidification of soils of Finland but may also be a result of the compulsory soil analysis for all the farms in the environmental subsidy programme.

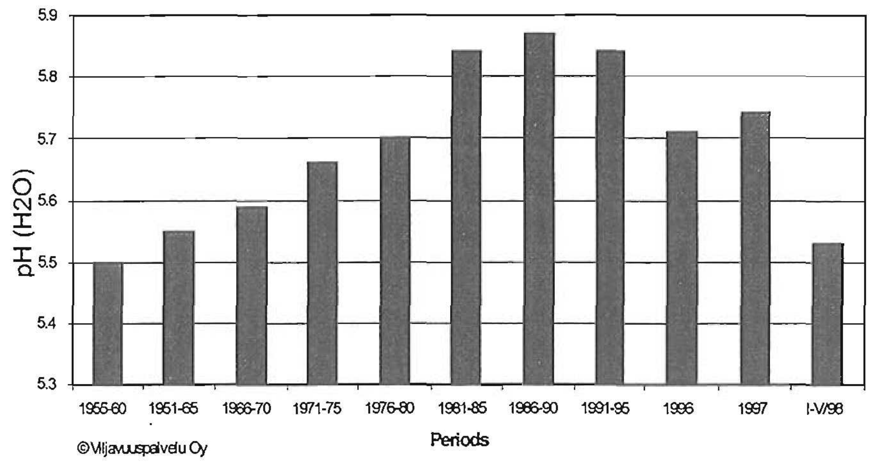

Figure 2. Mean pH of Finnish agricultural soils based on soil testing in several periods (Viljavuuspalvelu Oy 2000).

The major reason for the low pH in Finnish soil is the quality of the primary rock. The soil is inherently acidic, because the parent material is non-calcareous, rich in acid (silica) and low in bases. There are hardly any carbonatic rocks in Finland.

3.1.2 Texture and related properties

The uppermost 120 cm in the soil of the Jokioinen scenario is permeable podzolised loamy fine sand[4]. At 120-150 cm the soil has a texture of fine sand. The clay content of various horizons is very low (1-4%), which is also reflected in the low cation exchange capacity (CEC) particularly in the subsoil. In the topsoil, the CEC is mostly attributable to organic matter. Field capacity in this permeable soil is low, and percolating water easily ends up as groundwater, which can be seen as high hydraulic conductivity.

The soil does not crack or form crust, and due to the coarse texture, macropores do not dominate its hydrology. Thus, the role of preferential flow of water may not be as important in the fate of pesticides as in cracking (clayey) soils.

[4] The Finnish classification of the soil is 'karkea hieta' (KHt).

Soils like the one in Jokioinen FOCUS scenario are fairly common in Finland (Viljavuuspalvelu Oy 1997). However, most Finnish soils are more fine textured, and 17% are unsegregated glacial tills (in some areas the proportion of glacial tills may be up to 70%). In the regions of intensive agriculture (Southern and South-Western Finland), clay soils are dominant and may cover up to 40-50% of the agricultural land area.

Finnish clay soils can contain a very high fraction of clay, in the heaviest subsoils up to 95%. Dry heavy clays (>60% clay fraction) may crack as deep as 1-2 m, creating a preferential flow route directly to groundwater (though the crack is not necessarily continuous).

Table 4. The distribution (%) of the textural soil types and organic soils in agricultural land by agricultural centre regions[5] (Viljavuuspalvelu Oy 1997). The Finnish abbreviations of the soil classes are given in parentheses.

Region	*Glacial till (Mr)*	*Sand (Hk)*	*Loamy fine sand (KHt)*	*Coarse silt (HHt)*	*Fine silt (Hs)*	*Clay (Sa)*	*Mull soils* (Mm)*	*Peat** (T)*
Uusimaa	*2.5*	*0.1*	*16.8*	*9.3*	*22.2*	*41.7*	*7.1*	*0.2*
Nylands sv. Lbs.	*6.4*	*0.4*	*15.6*	*9.5*	*9.3*	*53.3*	*5.2*	*0.6*
Varsinais-Suomi	*6.8*	*0.2*	*28.5*	*10.6*	*6.4*	*41.8*	*5.3*	*0.7*
Finl. Hush. Sällskap.	*9.0*	*0.3*	*29.9*	*13.6*	*0.9*	*43.1*	*3.0*	*0*
Satakunta	*10.1*	*0.5*	*16.5*	*26.2*	*10.2*	*19.5*	*16.1*	*1.0*
Pirkanmaa	*6.7*	*0.1*	*3.6*	*20.1*	*54.1*	*5.8*	*9.1*	*0.4*
Häme	*5.7*	*0.1*	*22.8*	*19.0*	*17.0*	*24.4*	*10.5*	*0.3*
Päijät-Häme	*16.4*	*0.1*	*11.6*	*31.4*	*28.2*	*3.2*	*8.5*	*0.7*
Kymenlaakso	*6.6*	*0.2*	*19.8*	*21.0*	*13.3*	*29.2*	*9.6*	*0.3*
Etelä-Karjala	*31.2*	*0.2*	*10.6*	*23.5*	*12.4*	*5.0*	*15.2*	*1.8*
Mikkeli	*70*	*0.2*	*9.3*	*5.9*	*2.1*	*0*	*9.7*	*2.6*
Kuopio	*26.1*	*0.3*	*6.4*	*19.0*	*30.3*	*0.4*	*12.6*	*1.5*
Pohjois-Karjala	*20.3*	*0.5*	*15.9*	*19.4*	*28.5*	*0.3*	*12.8*	*2.2*
Keski-Suomi	*25.0*	*0.2*	*5.5*	*22.9*	*29.0*	*0.1*	*14.3*	*3.1*
Etelä Pohjanmaa	*12.5*	*0.3*	*15.6*	*39.0*	*2.9*	*5.9*	*22.1*	*1.6*
Österbotten	*8.9*	*0.2*	*22.3*	*41.4*	*0.2*	*11.3*	*14.7*	*1.2*
Keski-Pohjanmaa	*7.7*	*0.1*	*33.4*	*24.3*	*3.1*	*0.1*	*21.5*	*8.7*
Oulu	*12.6*	*1.1*	*28.0*	*22.7*	*3.8*	*0.8*	*20.9*	*9.7*
Kainuu	*41.2*	*0.4*	*12.0*	*13.5*	*7.5*	*0*	*9.9*	*15.5*
Lappi	*30.5*	*1.2*	*12.9*	*13.6*	*2.1*	*0.2*	*9.4*	*29.9*
Ahvenanmaa	*33.6*	*1.2*	*20.1*	*20.4*	*-*	*20.5*	*3.2*	*1.2*
Total	*17.2*	*0.4*	*17.2*	*20.7*	*14.6*	*13.6*	*12.7*	*3.3*

*) 20-40% organic matter
**) > 40% organic matter

3.1.3 Organic matter content

Organic matter (OM) content of the Jokioinen scenario soil is 7% (4.1% organic carbon). Below the plough layer the OM content decreases rapidly to

[5] The soil sampling is biased, because agricultural soil analysis has been voluntary until late 1990's. After that, also less active farmers have had to get their soils analysed because of the environmental subsidy programme.

1.45% (between 30-60 cm). Below 60 cm the OM content is 0.36-0.62%. Soil organic matter (OM) is an important soil constituent adsorbing pesticides and products formed upon their degradation. Relatively high content of OM in soils of Finland contributes to enhanced sorption of many pesticides in Finland (examples of this can be seen in (Greve et al. 1998). Adsorption decreases groundwater leaching but also degradation, as the absorbed pesticide is not biologically available for microbes.

Most models estimate the degradation rate of chemical in deeper soil layers being proportional to the organic matter content. In most FOCUS models organic matter (OM) or carbon (OC) content is needed to transform pesticide distribution factor K_d.

In general the organic matter content of Finnish arable soils is quite high. The high content of organic matter results mainly from slow degradation in cold climate. 77% of Finnish arable soils are mineral soils, and the rest 23% organic soils (more than 20% OM) (Kähäri et al. 1987). High content of OM usually contributes also to the low pH in top soil. In deeper soil layers, the content of organic matter is usually lower.

Only 4% of the Finnish mineral top soils contain less than 3% OM. More than 55% have an OM content of 3-6%. One third (30.1%) contains OM 6-12%. (Kähäri et al. 1987). Therefore the Jokioinen scenario has a rather typical OM content.

3.1.4 Depth of ground water

Groundwater level varies throughout the year depending on precipitation, temperature, soil properties (water holding capacity) and drainage. In Jokioinen scenario, the initial groundwater level is 152 cm. In the course of PESTLA-simulations, the level varies approximately ± 80 cm (SWAP 2.07a, see Figure 3), depending on the annual rainfall. The SWAP model does not take into account cold period precipitation falling down as snow. Thus wintertime precipitation also forms groundwater. In reality also water movement in soil is slow in winter due to groundfrost (though preferential flow may occur).

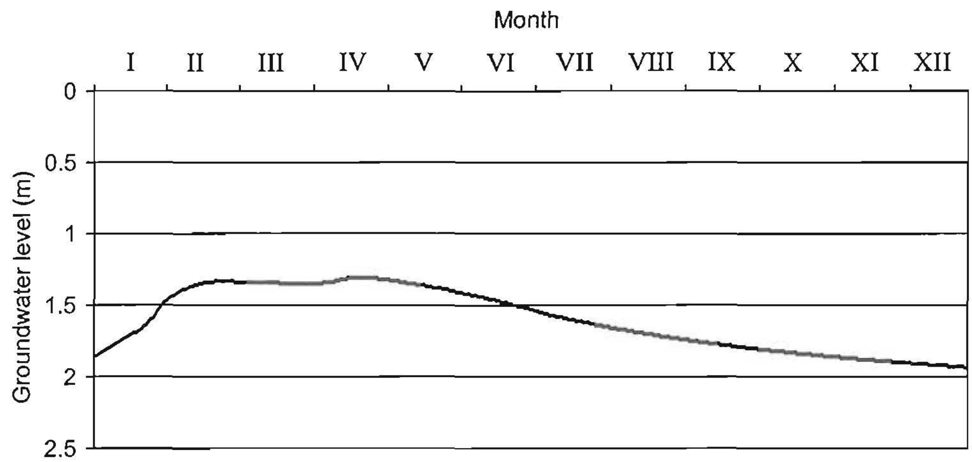

Figure 3. Simulated groundwater level fluctuation during one year in the-Jokioinen scenario. Simulation was run with SWAP 2.07a, the hydrological submodel of PESTLA 3.1.

The groundwater levels in undrained areas of Finland follow a typical annual cycle resulting from weather conditions (Figure 4). Due to the soil frost and snowfall, the amount of groundwater does not increase in winter (as SWAP modelling suggests) until frost thaw in April or May (regional and annual variation). Snow melting waters can then be seen as rising groundwater table. The early summer is usually quite dry, and groundwater levels decrease. Autumn brings more rainfall and the groundwater levels rise until soil freezes and snow cover is formed.

According to the areal groundwater observation network (Hyvärinen 1999), the groundwater level varies seasonally approximately one meter. However, groundwater levels are strongly related to the weather conditions, especially rainfall, which also varies annually a lot.

Perhaps the biggest difference between the simulated (Figure 3) groundwater level and measured level (Figure 4) is that in general the groundwater table is at the highest level after snow melt period in spring/early summer, when the pesticide treatments for most crops take place.

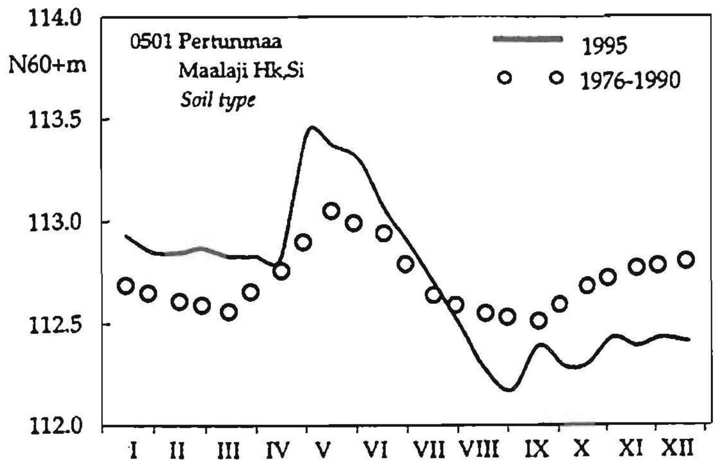

Figure 4. Example of a typical Finnish groundwater level fluctuation. Measured areal groundwater level in Pertunmaa national observation station in 1995 (Hyvärinen 1999). The peak in late April is caused by the snow melting water infiltration. The soil type is silt.

3.1.5 Soil temperature

Soil temperature has a profound, but not very well known effect on both biological and chemical transformation of a chemical in soil. Temperature affects the biological activity in soil: generally hardly any microbiological degradation is believed to occur in temperatures under +4°C, but it could be expected that microbes from colder regions tolerate low temperatures better than microbes from warmer conditions. Microbial biomass from central Sweden has been shown to grow at temperatures below 0°C (Wardle 1992). Temperature also contributes to the speed of chemical reactions in soil: all chemical reactions are slow in low temperatures (for example hydrolysis). Third, the fate of the solute is dependent of the fate of the solution: in frozen ground the movements of soil water are slow.

The relationship between the air and soil temperature depends on soil heat capacity and conductivity and insulation (for example snow or plant residue cover). The more water in the soil, the less the soil temperature reacts on the air temperature changes due to the high specific heat of water. The soil heat conductivity also depends on the soil texture (porosity, weight and organic matter content).

In PESTLA, the soil temperature is modelled using SWAP submodel (it is also possible to use a cosinus-equation or measured data for soil temperature). In SWAP, the soil temperature follows the air temperature quite closely (Figure 5), failing to take into account snow cover insulation. Thus, the simulated winter temperatures are lower than measured, even in 1 m depth. This low soil temperatures are very exceptional (Figure 6). As the soil temperatures affect the movements of water, biological and chemical activity, the results of the FOCUS scenario with PESTLA model have to be interpreted with caution.

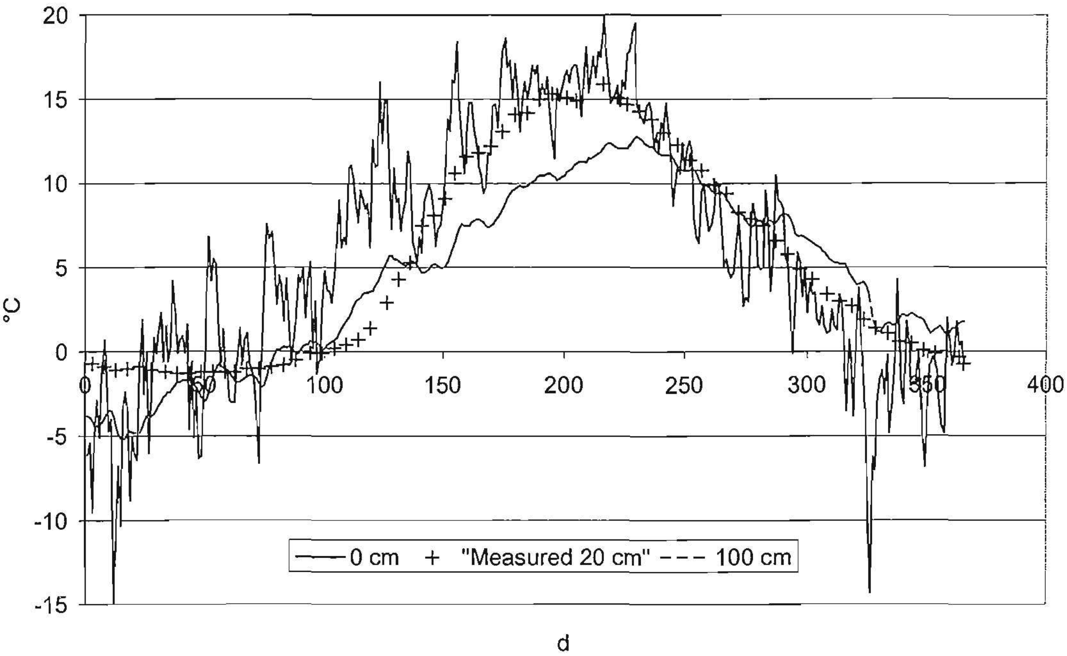

Figure 5. Calculated soil temperatures in Jokioinen FOCUS scenario in 0 cm, and 100 cm and measured temperatures in 20 cm (Heikinheimo and Fougstedt 1992). The model results are from SWAP version 2.07 used for PESTLA simulations.

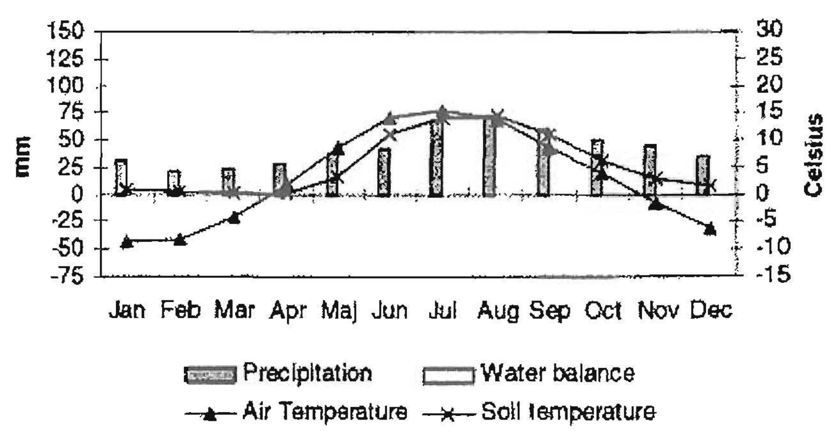

Figure 6. Precipitation, soil (50 cm) and air temperatures in Ylistaro, South Ostrobothnia Research Station of Agricultural Research Centre. Annual mean soil temperature, measured at 50 cm below soil surface, is 5.5°C. (Greve et al. 1998).

Soil temperatures in Finland have been compiled (Heikinheimo and Fougstedt 1992) and interpreted according to the criteria of the temperature regimes of U.S. Soil Taxonomy (Yli-Halla and Mokma 1998). Those results show that the mean annual soil temperature (MAST), measured at 50 cm below soil surface, in mineral agricultural soils in Southern and Central Finland is between 5 and 7 °C, and in Northern Finland between 2 and 4 °C. Mean summer soil temperatures are between 12 and 14 °C in Southern and Central Finland and commonly less than 10 °C in the North.

Mean annual soil temperatures are commonly estimated by adding +1° C to the mean annual air temperature. However, Yli-Halla and Mokma (1998) show that in Finland mean annual soil temperatures in 50 cm are 2° to 5°C higher than air temperatures. The difference is related to the duration of snow cover: the longer the soil is covered with snow, the higher the mean soil temperature is compared to the mean air temperature. Thus, in Northern Finland the difference is higher than in Southern Finland. Annual mean air temperature in Jokioinen in 50 cm depth is 5.9°C.

The soils in Finland are substantially cooler than the soils of any other locations of the FOCUS scenarios. According to the U.S. Soil Taxonomy, agricultural soils of Finland are within the cryic temperature regime. Sweden, South of Uppsala, belongs to the frigid regime while Hamburg, the second northernmost FOCUS location, is within the mesic soil temperature regime (MAST >8°C). That is why the degradation of pesticides in soils of Finland is likely to be substantially slower than in the rest of the locations.

The low temperatures also contribute to less evaporation and, consequently, to more runoff water, as compared to the warmer locations. On the other hand, the soil is frozen for a considerable period each year in Finland, and therefore, the leaching of the soil profile may not be equally effective as in frost-free humid areas.

The depth and existence of groundfrost varies a lot depending on temperatures and thickness of snow cover. Thus, the frost depth varies greatly even within small areas (Figure 7). Consequently, groundfrost depth varies spatially and temporally. In winter 1999 Agricultural Research Centre measured up to 95 cm groundfrost depth in Northern Ostrobothnia Research Station (see: http://www.mtt.fi/atu/ppo/routa.html).

The snow cover is a good insulation. In winter, the soil temperatures start rising during the snow cover, as the snow insulates the soil from the low temperatures above and heat flow from the ground increases the soil temperature.

In general, the ground frost may be thicker in the Southern parts of the country (though mean air temperatures are higher than in the North), where also the agriculture and pesticide use is more intensive. As a result also the conditions for biological degradation may be worse during the frost period.

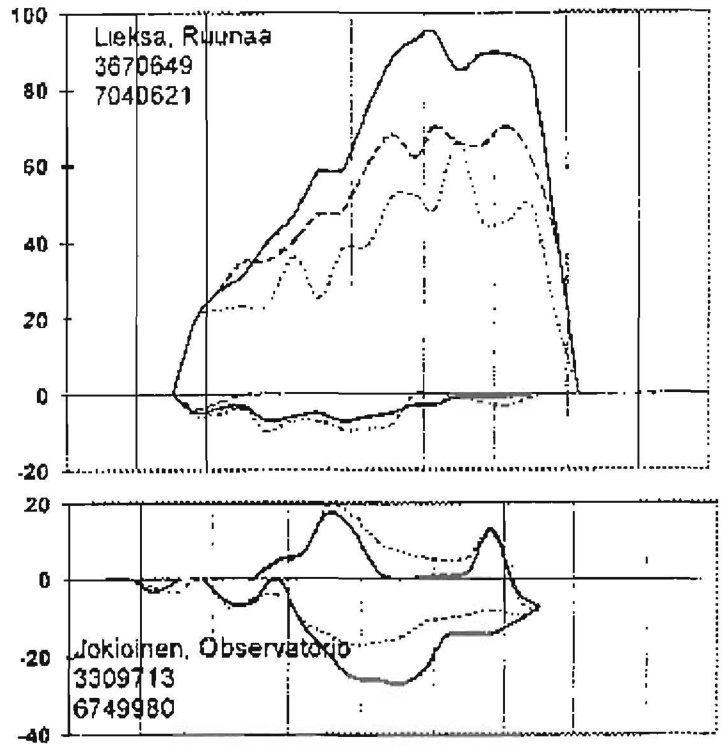

Figure 7. Soil frost depth variation (below zero) and snow cover thickness (above zero) in open place (____), forest (-----) and bog (.....) in Jokioinen and in Lieksa (Hyvärinen 1999). Ground level is marked with 0. Note the close relationship between snow cover and frost depth.

3.2 Comparison of FOCUS weather scenario characteristics with Finnish weather data

The most important climatic factors contributing to pesticide leaching are precipitation, air temperature and radiation. In this chapter the parameters of FOCUS scenario Jokioinen parameters are compared with real Finnish weather data.

3.2.1 Temperature

Jokioinen scenario climate is based on measured weather data, but not from Jokioinen. The data was collected in Tallinn and Tampere weather stations. The mean temperature of the scenario is 3.7 °C, which is normal in the Southern Finland. The ten year daily maximum temperatures in FOCUS scenario Jokioinen are close to measured temperatures in summer, but tend to be higher in winter (Figure 8). However, the overestimation of degradation in winter due to higher temperature can be considered small, because degradation in low temperatures is negligible.

In the agriculturally active regions of Finland the annual mean air temperatures vary from +5°C in the South-Western coast to 0° C in the Kainuu region and Southern parts of Lapland. The 0° C annual mean limit is located slightly below the Arctic circle.

Winter, when the mean temperature is below 0° C, lasts 100 days in south-western parts of the country and more than 200 days in the northern Lapland. Winter is thus the longest season.

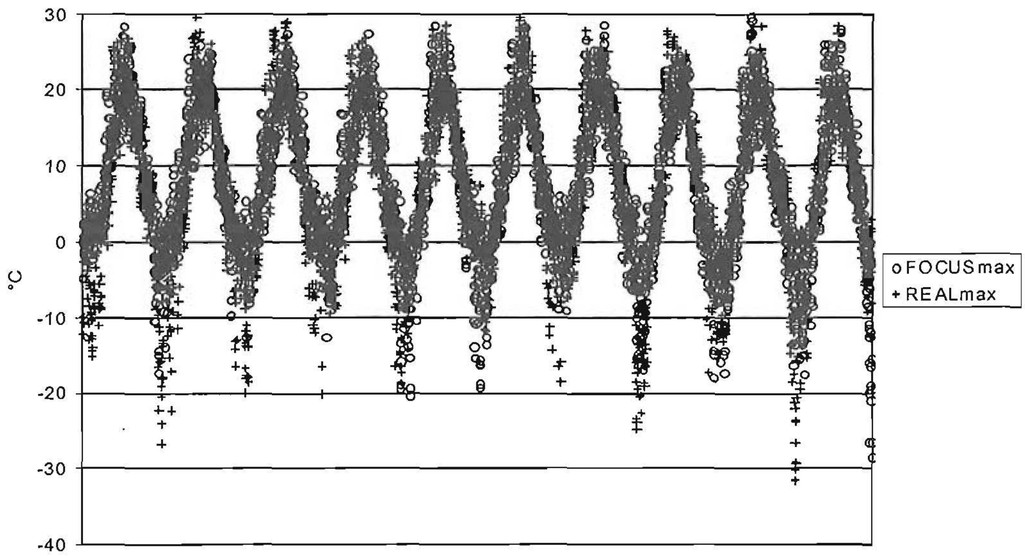

Figure 8. Ten year FOCUS scenario Jokioinen daily maximum temperatures and real Jokioinen measured temperatures.

3.2.2 Radiation

The radiation energy of the sun is an important factor controlling the climate of the area. In Finland the amount of radiation varies considerably between different parts of the country (North-South) and different seasons. Cloud cover, which increases from north-eastern part of the country towards the south-western Finland, also affects the amount of radiation. The ten year daily radiation amounts in FOCUS scenario Jokioinen and Jokioinen weather station show similar amounts of radiation, though the daily variation in real measurements is higher (Figure 9).

Radiation is also needed for photolysis, chemical transformation of substances. The annual amount of sunshine hours is highest in the south-western coastal regions (1900 hours) and lowest in eastern Lapland (1300 hours).

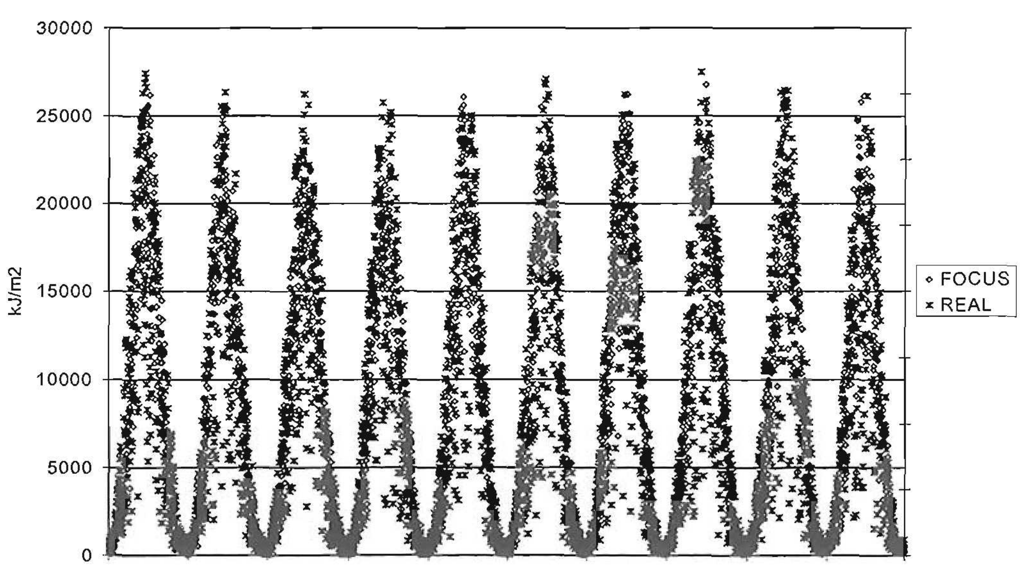

Figure 9. Radiation (kJ/m2) in FOCUS scenario Jokioinen and real measured data from Jokioinen.

3.2.3 Length of growing season

The termic growing season is determined to start when the daily mean temperature exceeds +5° C in five following days and the mean temperature sum (> 0° C) of the next five day period is at least 20 degree days. In the south it starts in late April and a month later in the North. However, the growing season does not really begin until the snow has melted and the frost has disappeared.

The length of termic growing season in Jokioinen is about 170 d (Table 5). The growing season length varies from the average of 180 d in the South to 110 d in the North. Length of growing season limits the selection of crops, and agriculture is practised in regions where growing season is at least 150 d. However, in the short growing season regions the grasslands dominate the agricultural land use, as animal husbandry is more common than in the Southern Finland. This also reflects to pesticide use.

Table 5: Thermal growing season length (Finnish Meteorological Institute 2000).

	Thermal growing season (days)
Southern Finland	*165-180*
Central Finland	*150-165*
Ostrobothnia	*150-165*
Northern Finland	*110-145*

3.2.4 Effective temperature sum (ETS)

Effective temperature sum (ETS, sum of daily mean temperatures exceeding +5°C) in Jokioinen area is between 1200-1300 dd. ETS varies in Finland from 1350 dd (degree-days) in the South to less than 300 dd in Northern Finland (Table 6). Most of the arable land area is above 1200 dd. Hardly any field cultivation is practised in the regions where ETS less than 750-800 dd, due to the short growing season.

Table 6. Effective temperature sum in different parts of the country (Finnish Meteorological Institute 2000).

	ETS (dd)
Southern Finland	*1 200-1 350*
Central Finland	*1 000-1 200*
Ostrobothnia	*950-1 100*
Northern Finland	*500-950*

3.2.5 Precipitation

The annual rainfall in Jokioinen scenario varies between 300 and 1000 mm (Figure 10). However, at least in the first ten years, many years seem either exceptionally wet or dry, instead of being "average" with rainfall of approximately 600 mm.

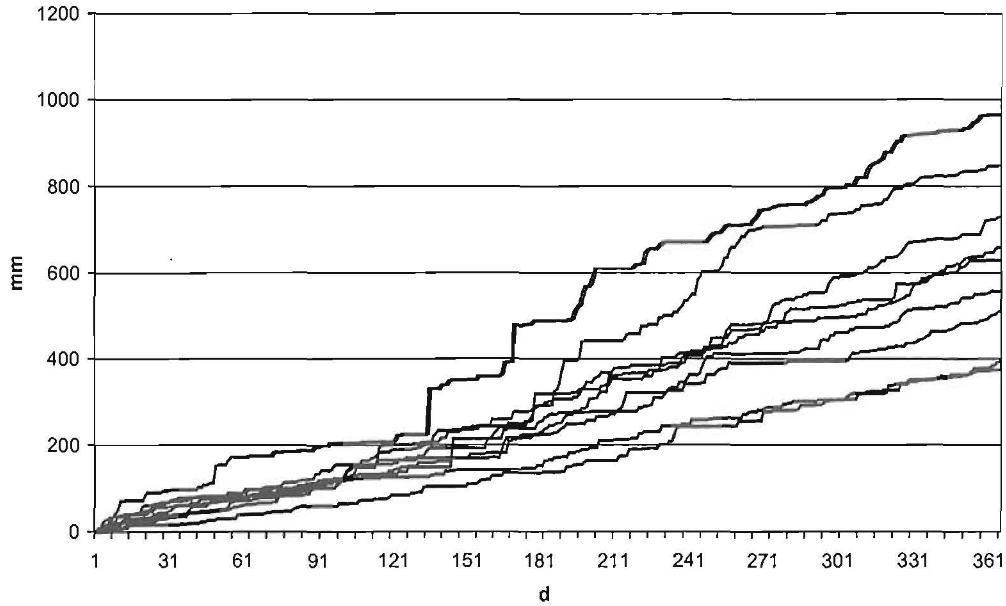

Figure 10. The cumulative rainfall in FOCUS scenario J in years 1-10 (mm).

Precipitation and evaporation during the growing season vary between different parts of the country. The average annual rainfall is between 600-700 mm, but may vary between 200-300 mm to 1100 mm (700 mm in the North). The basic rule is that there is more rain in the South than in the North, where half of the precipitation falls as snow.

In general, in the eastern Finland precipitation is approximately equal to the west coast, but evaporation is smaller. Thus, in the eastern parts of the country, the higher percentage of the precipitation creates runoff (surface runoff or percolation).

Daily rainfall exceeds 10 mm on 10 to 15 days every year. Highest daily rainfall ever recorded is 150 mm / d.

During the growing season the precipitation varies between 200 and 450 mm (Table 7). In the Southern Finland the rainfall is highest, more than 350 mm. Based on the 30 year average precipitation, the amount of precipitation during the growing season appears to be approximately 400 mm in the agricultural areas.

Table 7. Precipitation during growing season (Finnish Meteorological Institute 2000).

	Precipitation
Southern Finland	*310-400*
Central Finland	*350-470*
Ostrobothnia	*310-420*
Northern Finland	*210-410*

4 CROP SCENARIO

The use of the 2 000 000 hectares of arable land in Finland is fairly stable and the annual variations in crop areas are small (Table 8). Weather conditions may, however, have a major effect both on the area of crops (especially winter cereals) and the dates of agricultural operations. The variation between the regions of the country are high in respect to crops cultivated and the agricultural operation dates. Length of growing season limits the cultivation of some crops: for example, wheat and sugar beet are only grown in the Southern part of the country. Consequently, only small share of cultivated grassland (hay, silage, green fodder, pasture) is in the South (Information Centre of the Ministry of Agriculture and Forestry 1999).

Table 8. Use of agricultural area (1000 ha) (Information Centre of the Ministry of Agriculture and Forestry 1999).

In thousands, ha	*1990*	*1994*	*1997*	*1998*	*1999*
Grassland	*682*	*684*	*689*	*682*	*672*
Cereals, total	*1 251*	*948*	*1 118*	*1 157*	*1134*
-- wheat	*192*	*89*	*125*	*137*	*128*
-- rye	*83*	*9*	*23*	*36*	*12*
-- barley	*503*	*506*	*583*	*578*	*581*
-- oats	*461*	*334*	*369*	*387*	*404*
-- mixed grain	*14*	*10*	*16*	*16*	*18*
Oil plants	*65*	*67*	*61*	*65*	*63*
Sugar-beets	*31*	*34*	*35*	*33*	*35*
Potatoes	*37*	*37*	*33*	*33*	*32*
Other crops	*22*	*27*	*33*	*30*	*30*
Area in production	*2 088*	*1 797*	*1 968*	*2 000*	*1965*
Fallow	*183*	*505*	*162*	*167*	*211*
Cultivated area	*2 271*	*2 302*	*2 130*	*2 166*	*2177*
Other land	*273*	*204*	*384*	..	..
Arable area, total	*2 544*	*2 506*	*2 514*	..	..
-- drained area	*1 283*	*1 357*	..	..	..

Apples are grown for sale only on 464 hectares in 1998 (Information Centre of the Ministry of Agriculture and Forestry 1999). The area has increased in the last decade by 90 hectares.

5 FINNISH SOIL SCENARIO CANDIDATES

Because of the limitations in both FOCUS scenarios and the mathematical models used, the leaching assessment of any pesticide can not be based only on the official leaching scenarios. In order to be sure of the high standards of chemicals control Finnish soil scenarios for national risk assessment were prepared. These scenarios and the additional value they bring to the risk assessment of pesticides are discussed in this chapter.

The aim was to find realistic arable soils in respect to pH, soil organic matter, permeability, sorption characteristics etc. Some national soil scenario candidates were chosen based on following principles (Table 9):

- existing characterised soils that differ from the FOCUS scenario soil in properties that contribute most to the fate of pesticides (OM content, pH, texture)
- different soil types, taking into account the variation of arable soils
- uniform profile for easier modelling
- typical arable soils, not necessarily "worst case" soils
- permeable and less permeable soils: same soils could be used for surface run-off models

Table 9. The plough layer properties (Yli-Halla et al. 2000) and the names of the representative soil candidates for modelling according to the revised FAO (FAO 1988) and WRB (FAO 1998) systems.

Soil	*Classification*	*Clay %*	*Silt% (UK)*	*Sand %(UK)*	*OM %**	*pH(H2 0)*
Jokioinen 05	*heavy clay, subsoil heavy clay* *Vertic Cambisol (FAO)* *Vertic Cambisol (WRB)*	*64*	*22*	*17*	*6.2*	*6.2*
Pälkäne 02	*fine sand* *Dystric Regosol (FAO)* *Orthidystric Arenosol (WRB)*	*6*	*14*	*80*	*3.3*	*5.5*

**) OM% = 1.73x OC%*

The agricultural soil Jokioinen 05 is extremely fine-textured. In the upper horizons (0-35 cm), there is some sand (0.06-2 mm), probably originating from the glacial till areas surrounding the field. In the deeper horizons, clay content is above 90%. The soil pH increases with depth, and base saturation is high. In the upper horizons, Ca dominates in the exchangeable cations while in the deeper layers, Mg is the most abundant. Owing to the fine texture, water moves extremely slowly throughout the soil, except in the cracks and biopores. The grey colours tell that aquic conditions prevail in this soil.

The agricultural soil Pälkäne 02 is a coarse-textured soil throughout the profile down to 150 cm, the content of sand (0.06-2 mm) being above 80%. The content of sand is 56% also below 150 cm, but at that depth clay content increases to 15% of soil mass. At this depth, redox concretions and depletions show that reducing and oxidising conditions fluctuate. Water permeability is good in the topsoil and down to 150 cm where water movement is slowed down by the more fine-textured horizon. The content of organic matter is highest and pH lowest in the plough layer. The relatively high pH throughout the subsoil is in accordance to the fact that no podsolisation was observed in this soil. However, marked leaching of base cations has already taken place resulting in a low base saturation in the coarsest horizons of the subsoil.

6 FINNISH WEATHER SCENARIO

A weather scenario for MACRO-DB was prepared based on real measurements of the Finnish Meteorological Institute weather station in Jokioinen. The national weather scenario contains the weather and climate data from the year 1978 to 1999 (until 30 June). The simulation length of the current version of MACRO-DB is limited to a 10 years, but the scenario prepared for 20 year runs.

6.1 Precipitation

The annual rainfall in national Jokioinen scenario varies between 484 and 776 mm (Figure 11). The biggest daily rainfall in the period 1-10 years is 79 mm. However, daily rainfall exceeding 20 mm are quite rare. Variation of the annual precipitation is smaller than in FOCUS scenario Jokioinen.

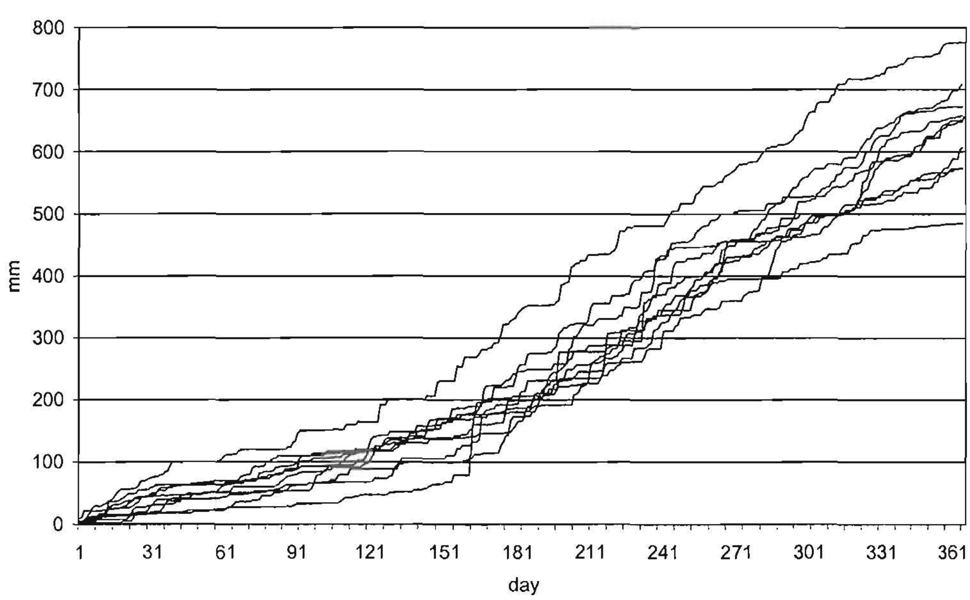

Figure 11. The cumulative rainfall in Jokioinen national scenario 1978-1987.

6.2 Mean temperature

Daily maximum mean temperature in Jokioinen climate is 8.1° C and daily minimum mean temperature 0.3° C. Daily average temperature (calculated from daily mean maximum and minimum) is 4.2° C, which is 0.5°C higher than the mean of FOCUS scenario Jokioinen.

7 TESTING NATIONAL WEATHER SCENARIO AND SOIL CANDIDATES

7.1 Model simulation runs with various scenarios

MACRO-DB model (Jarvis et al. 1997) was used to simulate the fate of three herbicides in Jokioinen 05 and Pälkäne 02 soils. To test the performance of the Finnish soils, an additional clay soil Västerby was included from the Swedish soil database Markdata.

MACRO was chosen for use with the national scenarios because of its capability of taking into account snowfall and preferential flows. The national scenarios were not parameterised for the rest of the models in FOCUS Groundwater, because of their obvious deficiencies to take into account specific Finnish environmental conditions. One of the key requirements of a model used for assessing risk for groundwater in Finland is that the model simulates **also** degradation in low temperatures (including soil temperature, as it affects the movement of water and reaction speed), snowfall and preferential flows. Preferential flow simulation is important from the Finnish point of view, because of our common heavy clay soils (See Appendix I). MACRO can also be used to simulate sandy soils without macropore component.

The simulations were run to study the performance and results of the national scenarios in modelling. It was also seen important to study how the candidate soils perform with different kinds of substances- in another words- what kind of results can be expected. Also a respective simulation was carried out with the FOCUS scenario Jokioinen with PESTLA (there is no Jokioinen FOCUS scenario parameterised for MACRO). This was needed to be able to interpret the results of FOCUS in the future.

7.2 Soil parameterisation

The performance of the soils in modelling is dependent on both the measured characteristics of the soils (such as texture, pH) and the parameterisation (saturated conductivity, boundary tensions) of soils. There is a strong relationship between the soil texture and the water percolation properties.

There were no measured water retention curves (pF-curves) for the Finnish soils available for the scenarios. It was not possible to perform the experiments for this purpose either, because there were no undisturbed soil samples stored. PESTLA needs this information, but MACRO-DB uses automatic estimation procedures (pedo-transfer functions) which translate the input information (soil particle size distribution, organic carbon content and bulk density) of soils into model parameter values (Jarvis et al. 1995), (Jarvis et al. 1997). Because of this, however, it is not possible for the user to set all the parameters (for example hydraulic conductivity K_{sat}).

Some problems were experienced with the structural characteristics of the soils. Some of the properties needed were available for the Finnish soil candidates (structure parameters concerning the size and formation of soil aggregates), some were not (bulk density[6]). The existence and properties of

[6] Bulk density measurement in undisturbed soil samples is not a standard analysis in Finnish soil testing.

macropores in soil had a major effect on the water percolation characteristics. However, the soil characterisation based on real data on the soil resulted in very low saturated conductivity for Jokioinen clay (Jokioinen1). In order to carry out some sensitivity analysis and get more percolation, another dataset for the Jokioinen clay 2 (Jokioinen2) was prepared based on the Swedish soil database in MACRO-DB (See Appendix 3). The only difference between Jokioinen1 and Jokioinen2 clay soils is thus the structural characterisation of aggregates (size, form and development), which is based on visual assessment of undisturbed soil profiles. Both datasets for the Jokioinen soil were used in simulation. The structural characterisation of Pälkäne sandy soil was solely based on the data from the similar soils in the MACRO-DB soil database.

The key properties and parameters of the soils used in the simulation are presented in Table 10.

Table 10. Pälkäne sand and Jokioinen and Västerby clay soil key parameters by horizons.

Property/parameter	***Jokioinen clay1***	***Jokioinen clay2***	***Pälkäne***	***Västerby***
Soil name	*Vertic Cambisol*	*Vertic Cambisol*	*Dystric Regosol*	
Thickness	*150 cm* *(35+25+20+30+40)*	*190 cm* *(35+25+20+30+80)*	*160 cm* *(30+25+65+30+10)*	*150 cm* *(25+25+25+7*
Texture (A-hor.)	*Clay*	*Clay*	*Loamy sand*	*Clay*
Bulk density (g/cm3)	*1.4* *1.4* *1.4* *1.4* *1.4*	*1.4* *1.4* *1.4* *1.4* *1.4*	*1.3* *1.5* *1.7* *1.7* *1.7*	*0.96* *1.38* *1.36* *1.29*
Organic carbon (%)	*5.9* *0.9* *0.6* *0.6* *0.6*	*5.9* *0.9* *0.6* *0.6* *0.6*	*3.3* *0.6* *0.4* *0.5* *0.5*	*3.3* *0.2* *0.1* *0.1*
pH	*6.3* *6.4* *6.8* *6.9* *7.0*	*6.3* *6.4* *6.8* *6.9* *7.0*	*5.5* *6.1* *6.4* *6.3* *6.3*	*7.0* *7.2* *7.5* *8.0*
Structure	*weak fine blocky* *moderate fine blocky* *strong medium blocky* *strong coarse blocky* *moderate coarse prismatic*	*strong coarse blocky* *moderate coarse blocky* *moderate coarse blocky* *moderate coarse blocky* *moderate coarse blocky*	*weak coarse blocky* *weak coarse blocky* *weak coarse blocky* *weak coarse blocky* *weak coarse blocky*	*N/A* *strong medium blocky* *strong medium blocky* *moderate coarse blocky*
Saturated conductivity (mm/h)	*10.00* *7.59* *0.11* *0.11* *0.09*	*100.00* *7.59* *0.11* *0.11* *0.09*	*104.30* *115.07* *75.32* *43.32* *14.19*	*100.00* *25.10* *0.19* *0.22*
Boundary tension (cm)	*25* *43* *43* *43* *83*	*25* *43* *43* *43* *83*	*8* *9* *9* *10* *11*	*26* *36* *32* *36*
Saturated water content (m3/m3)	*0.448* *0.464* *0.465* *0.465* *0.465*	*0.448* *0.464* *0.465* *0.465* *0.465*	*0.493* *0.429* *0.358* *0.357* *0.357*	*0.618* *0.473* *0.481* *0.506*
Effective aggregate half-width	*5- 10- 30- 75- 100*	*75-50-50-50-50*	*25-25-25-25-25*	*75- 30- 30- 50*
Pore size distribution index (mic.)	*0.065 – 0.050*	*0.065-0.050*	*0.219- 0.105*	*0.072- 0.057*
Pore size distribution index (mac.)	*5- 5- 5- 5- 6*	*5- 5- 5- 5- 6*	*4- 4- 4- 4*	*5- 5- 5- 5*

The only difference between the Jokioinen clays 1 and 2 is the layer specific structure describing parameters (size, form, development) which are used for the pedotransfer functions input in MACRO-DB. As a result, saturated conductivity of the clay soil Jokioinenl is extremely small compared to Jokioinen2 and Västerby clays, despite the similar textures. This also indicates that a large proportion of surface runoff could be expected in simulation of Jokioinen1, which is not a very desirable property of a groundwater modelling soil. In addition, the aggregate size is considerably larger in Jokioinen2 and Västerby clays than in Jokioinen1, which increases saturated conductivity and pore size. Västerby soil bulk density is very low in topsoil, and thus also the porosidy is high. Below the plough layer the Västerby clay saturated conductivity is markedly higher than in Jokioinen clays.

Several choices for pesticide fate simulation had to be made in modelling. Subsoil degradation was set proportional to organic carbon. As a result of this, high OC content in soil tends to lead to low half-lives and vice versa.

7.3 Pesticide parameterisation

Three herbicides (Table 11) were parameterised based on ecotoxicological risk assessment reviews (Table 12). The pesticides were chosen to cover different K_{oc} –values and half-lives and though their GUS[7] values suggest the are all leachers (Gustafson 1989). The fate of these substances was simulated with MACRO-DB in eight different scenarios:

	Jokioinen1	Jokioinen2	Pälkäne 02	Västerby
Jokioinen climate	x	x	x	x
Uppsala climate	x	x	x	x

In addition, the herbicides and crops chosen were simulated with Jokioinen FOCUS-scenario, in order to study to which extent the conclusions on the environmental risks caused by the substances are dependent on the scenarios and models chosen.

Table 11. The herbicides and crop parameters used for national scenario testing with MACRO-DB.

Pesticide	*Crop*	*Emergence*	*MaxLAI, date*	*Harvest*	*Root depth*	*Application*
Metribuzin	*Potato*	*05/06*	*LAI 5 30/08*	*25/9*	*0.6 m*	*350 g/ha, every other year*
Tribenuron methyl	*oat*	*18/05*	*LAI 4.5 30/06*	*25/08*	*0.8 m*	*10 g/ha once every second year*
Ethofumesate	*sugar beet*	*25/05*	*LAI 5 10/08*	*15/10*	*0.9 m*	*Total 740 g/ha in three applications, every second year*

[7] Groundwater Ubiquity Score = log [(DT50 at 20°C)*(4-logK_{oc})]

Table 12. Pesticide parameters used in simulations.

Parameter	*Tribenuron methyl*	*Metribuzin*	*Ethofumesate*
GUS value	*3.3**	*4.1*	*3.5*
Ionic state	*Acid*	*non-ionic*	*non-ionic*
K_{oc} *(cm^3/kg)*	*2.5* <<	*82.0* <	*156*
Pka	*4.7*	*N/A*	*N/A*
Half-life (days), [t°C]	*8 [25°C]* <<	*97 [20°C]* ≈	*91 [20°C]*
Vapour pressure (Pa) [t°]	*1.7E-07 [25°C]*	*0.000058 [20°C]*	*0.00065 [25°C]*

*) Calculated with DT50 at 25°C

Metribuzin and tribenuron methyl were simulated for ten years (which is the maximum simulation period for MACRO-DB). Ethofumesate was simulated only for 6 years, because the model failed to run a longer period with three annual applications. A longer simulation is possible only when the end of simulation data is used as soil concentration data for a new run. In PESTLA the substances were simulated for 26 years, with the additions starting from year 7. Application rates and periods were the same as in MACRO-DB. Use of ethofumesate and metribuzin in consecutive years is forbidden in Finland, which was taken into account in simulations.

7.4 The climate scenarios Jokioinen and Uppsala

The national climate scenario Jokioinen is based on real measured data from Jokioinen weather station between the years 1978-1999. Uppsala weather data is also real measured data included in the MACRO-DB weather database. The difference in daily minimum and maximum air temperature is bigger in Jokioinen than in Uppsala (Figure 12). Summer solar radiation is also higher in Jokioinen, which may result from differences in analysis or equipment. Wind speed is in general higher in Uppsala, as is also the variation in vapour pressure.

The biggest difference between the two climate scenarios is, however, in the rainfall. The total precipitation in Uppsala is less than 80% of the precipitation in Jokioinen. In addition, Jokioinen scenario also contains some very heavy rainfall events (60-80mm/day), which may affect the pesticide leaching.

Real Jokioinen weather. Real Uppsala weather.

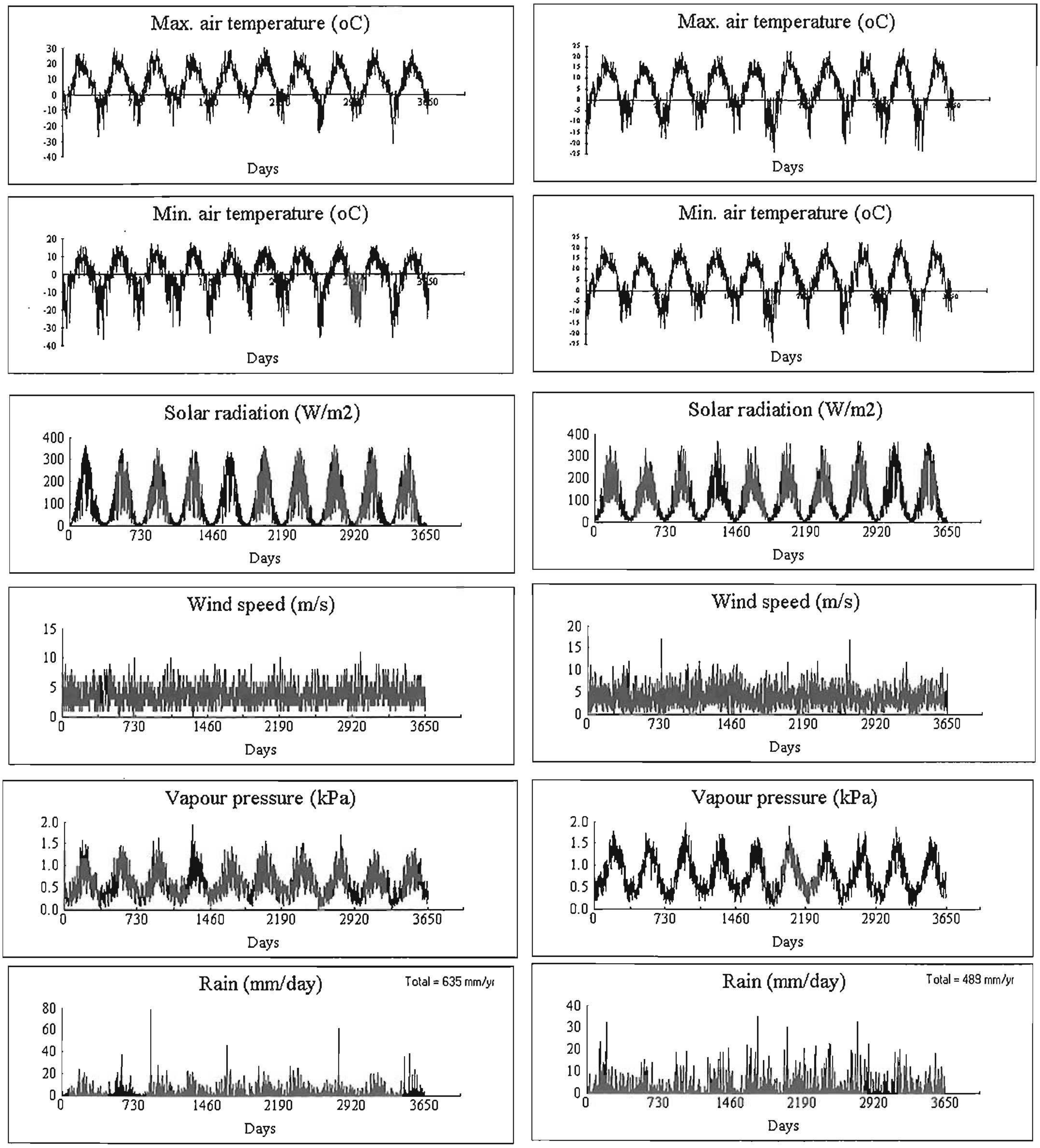

Figure 12. Comparison of measured Jokioinen and Uppsala weather. Notice different scales in some pictures.

8 MODELLING RESULTS

The results from simulations are presented in tables in this chapter. The interpretation is in chapter 9. Simulation period length was 10 years for tribenuron-methyl and metribuzin and six years for ethofumesate.

Table 13. Dissipation of the active ingredient in the simulation period (%).

Dissipation		
Tribenuron-methyl	**Jokioinen**	**Uppsala**
Jokioinen clay1	99	100
Jokioinen clay2	99	100
Pälkäne 02	99	99
Västerby	97	99
Metribuzin	**Jokioinen**	**Uppsala**
Jokioinen clay1	81	86
Jokioinen clay2	80	86
Pälkäne 02	82	87
Västerby	66	75
Ethofumesate	**Jokioinen**	**Uppsala**
Jokioinen clay 1	85	88
Jokioinen clay 2	85	89
Pälkäne 02	86	87
Västerby	77	83

Differences in dissipation rates depended on the substance. Tribenuron-methyl degraded almost completely during the simulation period, unlike metribuzin and ethofumesate.

Dissipation was slowest in Västerby soil in both climates. This was probably due to degradation being proportional to OC-content; in Västerby soil OC decreases rapidly with depth. In all cases dissipation was more efficient in Uppsala climate than in Jokioinen climate. Soil temperature is higher in Uppsala, and thus also degradation.

Table 14. The amount of active ingredient stored in soil (%).

Storage		
Tribenuron-methyl	**Jokioinen**	**Uppsala**
Jokioinen clay 1	0	0
Jokioinen clay 2	0	0
Pälkäne 02	1	0
Västerby	1	0
Metribuzin	**Jokioinen**	**Uppsala**
Jokioinen clay 1	7	5
Jokioinen clay 2	7	6
Pälkäne 02	13	11
Västerby	10	9
Ethofumesate	**Jokioinen**	**Uppsala**
Jokioinen clay 1	8	6
Jokioinen clay 2	8	6
Pälkäne 02	14	13
Västerby	11	10

The soil storage is inevitably dependent on the properties of the chemical. Pälkäne sandy soil appeared to sorb most, 13-14% of the applied metribuzin and ethofumesate, though the Västerby and Jokioinen clays were not far behind. Reasons for the differences can be found in the OM content of the soils and the water percolation properties: obviously macropore flow also decreases sorption into the top soil.

However, residues of this magnitude can be considered a real problem with the continuous use of pesticides.

Table 15. Leaching of the active ingredient into the groundwater zone (%).

Leaching

Tribenuron-methyl	Jokioinen	Uppsala
Jokioinen clay 1	0	0
Jokioinen clay 2	0	0
Pälkäne 02	0	0
Västerby	1	0

Metribuzin	Jokioinen	Uppsala
Jokioinen clay 1	0	0
Jokioinen clay 2	1	0
Pälkäne 02	5	5
Västerby	18	11

Ethofumesate	Jokioinen	Uppsala
Jokioinen clay 1	0	0
Jokioinen clay 2	0	0
Pälkäne 02	0	0
Västerby	7	3

Tribenuron-methyl did not leach significantly in any scenario. Metribuzin leached little in Jokioinen clay but considerably in Västerby clay. This may be a result from the difference in maximum daily percolation, which is higher in Västerby because of higher macropore content. Thus, rainfall enters deep soil layers sooner than in Jokioinen clay, though both have macropore flow. In Pälkäne soil some leaching was simulated, and the weather did not effect on the amount of leaching.

Leaching was higher in Jokioinen climate than in Uppsala climate. This is probably due to

Table 16. The amount of active ingredient lost to surface runoff (%).

Lost to runoff

Tribenuron-methyl	Jokioinen	Uppsala
Jokioinen clay 1	1	0
Jokioinen clay 2	1	0
Pälkäne 02	0	0
Västerby	1	0

Metribuzin	Jokioinen	Uppsala
Jokioinen clay 1	12	9
Jokioinen clay 2	11	8
Pälkäne 02	0	0
Västerby	6	4

Ethofumesate	Jokioinen	Uppsala
Jokioinen clay 1	8	5
Jokioinen clay 2	7	5
Pälkäne 02	0	0
Västerby	5	5

The share of pesticide lost to runoff appeared to be mostly dependent on the water conductivity properties: the more runoff, the more pesticide is lost to it. Consequently, in the permeable Pälkäne sandy soil runoff is not a problem, like it is in clay soils.

The biggest losses to runoff were in Jokioinen clay1, which had the lowest saturated conductivity K_{sat}. However, the difference to Jokioinen clay2 was not big.

Table 17. Julian number of the first day the concentrate of the active substance in leachate exceeds 0.1 µg/l (for at least 7 day period). Time theoretically needed for water flow thorugh the soil without macopores is calculated for comparison.

Leaching speed

Tribenuron-methyl	**Jokioinen**	**Uppsala**
Jokioinen clay 1	-	-
Jokioinen clay 2	-	-
Pälkäne 02	-	-
Västerby	-	-

Metribuzin	**Jokioinen**	**Uppsala**
Jokioinen clay 1	1196	2251
Jokioinen clay 2	600	1008
Pälkäne 02	1056	1427
Västerby	239	204

Ethofumesate	**Jokioinen**	**Uppsala**
Jokioinen clay 1	-	-
Jokioinen clay 2	1057	1923
Pälkäne 02	1559	2184
Västerby	239	262

Water	
Jokioinen clay 1	377
Jokioinen clay 2	376
Pälkäne 02	1
Västerby	197

Leaching speed is described here with the first simulation date, when the leachate concentration exceeds 0.1 µg/l below the unsaturated layer.

Clays leached fast, the Swedish Västerby clay considerably faster than Jokioinen clays. The difference is marked, considering both soils having a srong macropore structure. This results from the Västerby soil percolation capacity, which is considerably higher than in Jokioinen clays (results in Appendix 2). This results from higher Ksat values in Västerby soil. Structure parameters in Jokioinen soil did not change the daily amount of percolated water. The difference in percolation is very closely related to leaching of water soluble substances, and some more investigation is needed.

It is also important to notice that groundwater is closest to the surface (150 cm) in Jokioinen clay 1, in which the leachate transport was slowest.

The time theoretically needed for water flow through the soil was calculated:

$$TIME = \sum_{i=1}^{n} \left(\frac{layer\_thickness\_i}{Ksat\_i}\right)$$

Table 18. Number of days the concentration in leachate exceeds 0.1 µg/l.

Length of exceeding

Tribenuron-methyl concentration did not exceed 0.1 µg/l at any point of simulation.

Metribuzin	**Jokioinen**	**Uppsala**
Jokioinen clay 1	1993	98
Jokioinen clay 2	3037	2666
Pälkäne 02	2597	2227
Västerby	3413	3459

Ethofumesate	**Jokioinen**	**Uppsala**
Jokioinen clay 1	0	0
Jokioinen clay 2	984	46
Pälkäne 02	633	8
Västerby	2012	1941

The length of exceeding equals the number of days the leachate concentration exceeded 0.1 µg/l in the simulation period. Also individual daily exceeding are calculated.

Västerby clay performed worst: the number of days with high leachate concentration was approximately 2/3 of all days simulated. This is due to the highest amount of macropores and their big size.

In Uppsala climate the leaching was not as common and in Jokioinen. The difference is probably mostly due to differences in precipitation.

Table 19. Share of evapotranspiration with different climates and crops.

Evapotranspiration%

Oats	Jokioinen	Uppsala
Jokioinen clay 1	66	66
Jokioinen clay 2	63	64
Pälkäne 02	79	78
Västerby	72	72

Potato	Jokioinen	Uppsala
Jokioinen clay 1	42	42
Jokioinen clay 2	40	40
Pälkäne 02	58	55
Västerby	51	50

Sugar beet	Jokioinen	Uppsala
Jokioinen clay 1	41	41
Jokioinen clay 2	39	38
Pälkäne 02	58	53
Västerby	50	49

The amount of precipitation that was evapotranspirated depended on the crop and soil but surprisingly there was no difference in it between Jokioinen and Uppsala climate.

In Jokioinen Clay1 evapotranspiration was always approximately 2% higher than in Jokioinen clay 2, due to the difference in water conductivity.

Pälkäne sand had clearly the biggest evapotranspiration, due to capillary rise of water and clearly lowest wilting point.

Table 20. Share of infiltration with different climates and crops.

Infiltration%

Oats	Jokioinen	Uppsala
Jokioinen clay 1	22	23
Jokioinen clay 2	24	26
Pälkäne 02	20	22
Västerby	22	23

Potato	Jokioinen	Uppsala
Jokioinen clay 1	39	42
Jokioinen clay 2	42	44
Pälkäne 02	40	44
Västerby	41	43

Sugar beet	Jokioinen	Uppsala
Jokioinen clay 1	39	42
Jokioinen clay 2	41	44
Pälkäne 02	39	43
Västerby	42	43

There were very small differences in the proportion of infiltration between the soils. Thus, infiltration does not explain the differences in leaching, though it is seen as an important factor.

The amount of water infiltrated into soil depends on both crop and climate. The differences between different crops were quite high: oat cultivation let little water for infiltration, as potato and sugar beet were about equal.

Infiltration is important, because only infiltrated water can cause leaching into the groundwater. As expected, Jokioinen clay1 had slightly smaller infiltration as clay2, because of the lower water conductivity. However, low infiltration capacity increases risk for surface runoff.

9 CONCLUSIONS

The fate of active ingredients varied depending on soils, climates and models used. The national scenarios can be used to refine the pesticide risk assessment to identify the safe as well as problematic uses. Consequently, reliable and valid national risk assessment modelling scenarios are needed both for the sake of the environment and agriculture. Some of the differences presented below can not be explained on the basis of existing information, and the verification of the results remains for future projects.

9.1 MACRO-DB simulations

Tribenuron-methyl did not leach into the groundwater in any of the scenarios in concentrations exceeding 0.1 μg/l, though it can be expected to leach based on its GUS value. However, the exercise did not consider surface run-off losses with rainfall events soon after application. Metribuzin is a highly water soluble compound with a high GUS value as well. Ethofumesate has a very high application rate, K_{oc} and fairly long half-life. Thus, it can also be expected to leach.

The results of evapotranspiration and percolation are interesting. Sandy soil Pälkäne had clearly the highest evapotranspiration rate (Table 19) in all the scenarios, which can be expected on the basis of capillary rise of water in such soils. Percolation rates are equal (Table 20), which is perhaps surprising because Pälkäne soil was clearly most permeable by texture. The net precipitation has been shown to be an important factor in leaching of pesticides (Ministry of environment... 1995). In this exercise, however, it can not explain the differences in leaching.

Looking at the percolation pictures of the simulations (percolation mm/d, figures in APPENDIX 2) reveals a difference between clay and sandy soils in simulation: with the same weather data the rainfall events were seen as percolation peaks in clay soils almost immediately, as the percolation is sandy soils was much more stable and only one or two peaks could be observed within the simulation periods. As a result also the leachate concentrations were much more stable with Pälkäne soil. In Västerby soil, the daily percolation was as high as in Pälkäne soil, which may result from high saturated conductivity in B-horizon and macropore flow.

The results concerning the soils and simulations in Jokioinen climate are presented below.

9.1.1 Jokioinen clays 1 and 2

The Jokioinen candidate soil was heavy clay, and the texture is quite close to the Swedish Västerby soil. Leaching into the groundwater was minimal and independent of the structure parameterisation (Jokioinen1/Jokioinen2). However, there were differences in the share of surface runoff, which in turn was a major factor contributing to the fate of pesticides modelled. The differences resulting from different parameterisation were also seen in hydrology: in Jokioinen1 with lower K_{sat}, evapotranspiration and runoff were always higher and percolation lower than in Jokioinen2. K_{sat} values differed markedly only in surface soil.

In both cases (Jokioinen1 and Jokioinen2) the amounts of active ingredients leached were very small, 1% at the maximum. Leachate concentrations were quite high only for metribuzin. The leaching was not affected by K_{oc} or other pesticide properties. However, 11% of metribuzin was lost to runoff.

The groundwater level in Jokioinen2 was deeper (190 cm) than in other test soils, but according to the soil storage profiles this was not the reason for the low leaching: the amount of pesticide in deeper layers was not higher than in other soils. In fact, the amount of pesticide bound in soil was least in Jokioinen among all soils used in modelling. It took 600 days for metribuzin to enter the groundwater zone and 1057 days for ethofumesate. The leaching speed is quite low compared to the similar Swedish soil Västerby, where the respective dates were 239. This probably results from macropore and soil structure parameterisation. Surprisingly, but probably owing to the presence of macropores in clay soils, the pesticide transport into the groundwater was **slowest** in the most permeable sandy soil Pälkäne, where the percolation was highest.

The presented use of tribenuron-methyl in Jokioinen soil did not cause risk to the groundwater, but for the most of the time, the leachate metribuzin concentrations exceeded the drinking water quality standard 0.1 µg/l and for almost half of the days there was an excessive amount of ethofumesate in leachate.

The lower saturated conductivity in Jokioinen1 had expected consequences in the results: the share of surface runoff (both water and leachate) increased slightly, and the leaching into groundwater was lower, respectively. However, the differences were minor, perhaps surprisingly, because the difference in saturated conductivity (10 mm/h in Clay1 and 100 mm/h in Clay2) was so high.

As a result, based on these simulations, the Jokioinen clay soil can be characterised as follows:

- high surface runoff expected (higher in Jokioinen1 than Jokioinen2)
- high degradation expected, because the OC content is high in subsoil
- little pesticide residues in soil expected
- little groundwater leaching, independent on K_{oc} of the substance, expected. Leaching in Jokioinen2 is higher because of the hydraulic properties.
- mediocre flow speed to groundwater zone
- fast leaching due to preferential flow possible.

9.1.2 Pälkäne 02

The degradation of pesticides in Pälkäne soil was as fast as in Jokioinen. Surprisingly, leaching was not directly related to K_{oc} of the substance, because metribuzin did leach into the groundwater but ethofumesate did not (highest K_{oc}). However, this can be explained by the slow transport of the pesticide to the groundwater level: the substance did have time to degrade before getting to 150 cm or it would leach later (can not tell due to short simulation period). The leaching of metribuzin was greater than in Jokioinen soil, but much smaller than in Västerby. There was no runoff in Pälkäne.

In Pälkäne soil the storage of pesticides in soil was high for substances with high K_{oc}. Up to 13-14% of metribuzin and ethofumesate was stored in soil after simulation period. This is probably due to the high OM content in top soil, and it explains also the small leaching into the groundwater.

The entry of pesticide into the groundwater zone was slowest in Pälkäne soil. It took 1000-1500 days for metribuzin and ethofumesate to get to 150 cm with concentrations bigger than 0.1 µg/l. Thus also the number of days the leachate exceeded the drinking water quality standard was clearly slowest.

As a result the Pälkäne soil can be characterised as follows:

- no surface runoff expected
- high degradation expected, because of high OC content in subsoil
- little groundwater leaching, independent on K_{oc} of the substance, expected
- slow flow speed to groundwater zone

9.1.3 Västerby

The simulated degradation of the pesticides was slowest in Västerby. This can be explained by the measurable soil properties: OM content was slightly lower. The degradation percentages were especially low with substances with high K_{oc}. This may be related to the fast movement of pesticide in soil: the entry of the active ingredient into the groundwater zone was clearly fastest, probably owing to the preferential flow (3 months after the first application) and high B-horizon saturated conductivity. Because of this, the number of days during which the leachate exceeds the 0.1 μg/l level is the highest.

Also the residues of soil bound pesticide were high on substances with high K_{oc}. Leaching was high as well, especially on substances with longer half-life.

Some runoff occurred, contributing to the losses of pesticides. As a result the Västerby soil could be characterised as follows:

- surface runoff expected
- slower degradation expected, because of low OC content in subsoil
- high pesticide residues in soil expected, depending on K_{oc}
- high groundwater leaching, depending on K_{oc} of the substance, expected
- fast movement of substance through the soil profile

The Västerby soil is a more sensitive soil for groundwater modelling than Jokioinen and Pälkäne soils, in which the transport of pesticides in soil is slow. Thus, when Västerby soil is used in modelling, even readily biodegradable compounds can cause high pesticide concentrations in groundwater (tribenuron-methyl). The Västerby soil behaves quite differently from the clay soils of Finland, and a close analysis on the parameterisation of the Finnish soils for MACRO is needed in the further work.

9.1.4 Climate

Jokioinen and Uppsala climate differ most from each other in respect to rainfall and temperature. Jokioinen precipitation is 30% higher than in Uppsala. Jokioinen scenario also has 2 high rainfall peaks (over 60 and 80 mm/d). Surprisingly the solar radiation is higher in Jokioinen in the summertime, as is also the variation of temperatures. Uppsala appears to be more windy.

It appears that compared to Uppsala weather data, the Jokioinen national weather scenario causes:

- slower degradation, due to lower temperature and Arrhenius equation
- slightly higher bound residue, due to slower degradation
- higher leaching, faster entry of substances into the groundwater zone
- more runoff (precipitation)

However, some or all of the factors may have a strong dependence on the soil used, and thus can only be regarded as preliminary guidelines for choosing simulation weather. The differences in runoff were very small, and more simulations would have been required to test the conclusions. In addition, the higher residue is probably related to slower degradation. All this depends also on the leaching potential of the substance: if the substance is not sorbed, it will more likely leach in Jokioinen than in Uppsala.

9.2 FOCUS simulation with PESTLA

PESTLA simulations with Jokioinen FOCUS scenario were run with the same pesticide data, applications and crops (Appendix 2) as MACRO-DB simulations. However, PESTLA simulation periods were longer (26 years) than MACRO-DB simulations (6 or 10 years), but the conclusions refer to similar periods to MACRO-DB simulations (which is arbitrary but necessary for comparisons). PESTLA simulations also contained a six-year warm-up period before the pesticides were applied.

The degree of leaching was very low for all the substances, considerably lower than with the MACRO-DB model. During the ten year application period, tribenuron-methyl did not leach at all below the soil system. The degradation was very efficient, as in MACRO-DB as well. Some minor concentrations in groundwater were calculated, but the general conclusion based on Jokioinen FOCUS scenario was, that tribenuron-methyl does not leach.

Metribuzin results were controversial, as the concentration in groundwater was high after few years of use, but leaching below 1 m depth was 0. The calculated concentration in groundwater in the end of the ten year period was 1 µg/l. The problem in the model run could not be traced. Concentrations in groundwater started to rise in year 6 after the start of use. Metribuzin also started to leach out of the soil system approximately 4000 days after the start of use in high concentrations. Degradation was more efficient than in MACRO-DB simulations, being more than 90%. The rest was taken up by plants. The leachate appears to enter the groundwater zone slower in PESTLA simulations than with MACRO-DB (due to chromatographic flow).

Ethofumesate started leaching into the groundwater after the six year simulation period. However, the concentration peak in year 7 was only 0.01 µg/l groundwater. None of the applied pesticide was calculated to leach below the soil system. Degradation was more efficient than calculated with MACRO-DB (>95%). Based on Jokioinen scenario, ethofumesate should be considered non-leaching, at least not within six year scale.

In PESTLA simulations the amount of water percolated was slightly higher than in the MACRO-DB: the amount of water percolated in ten years was 2600 mm for spring cereal, for potato 3000 mm and for sugar beet only 1500 mm (in MACRO-DB simulations the percolation for sandy soil was 2200, 2600 and 1500 mm, respectively). This does not tell anything about the models because also the weather data differed, but is noted for the result comparison.

In general, the differences between the results of FOCUS scenario Jokioinen with PESTLA and national scenarios with MACRO-DB are:

- Leaching out of the soil system (150 cm) is slower and smaller with PESTLA
- Average concentrations leaching below the depth of 1m (FOCUS results) are 0 µg/l for all the substances. However, the metribuzin result is most likely mistaken and should be checked with a latter version of PESTLA, because the concentrations in groundwater are very high. MACRO-DB results suggest pesticide leaching into the groundwater

- National scenarios with MACRO-DB show faster and higher degree of leaching for these substances
- According to FOCUS simulation, none of the pesticides leaches. According to national scenarios and MACRO, leaching may be very fast in clay soils (due to macropores) and metribuzin and ethofumesate concentrations exceed 0.1 µg/l for a considerable period (in coarse soil in Jokioinen climate 2597 days (71% of simulation days) for metribuzin and 633 days (29% of simulation days) for ethofumesate)
- Degradation is faster in PESTLA. This is obviously because in MACRO DB the degradation was related to OC content of the soil layers, and in PESTLA the degradation coefficients for each layer were set.
- PESTLA simulation gives calculated results in groundwater, the level of which changes according to net precipitation. However, these results should be validated for the Finnish conditions before using them in risk assessment. In addition, the calculation hardly works for clay soils.

10 FURTHER ACTIVITIES

Based on this preliminary work, FOCUS scenario with PESTLA suggests smaller amount of pesticide leaching than MACRO-DB with the national scenario candidates. Additional work should be carried out in order to determine the best tools and scenarios to properly assess the risk of leaching of pesticides to groundwater in Finland. It is clear that more than one scenario is needed in order to meet the demands of environmental protection and agriculture.

The national scenarios presented in this study should be used to support the risk assessment of pesticides, until more information and possible measured data can be obtained. The conclusions obtained with present methods and results with the FOCUS scenarios should be compared to the results of the models used with national scenarios.

More soils of Finland should be parameterised for groundwater models to study the vulnerability of the soil candidates. Therefore, a soil with high hydraulic conductivity and low OM content should be used in simulations in order to study the range of leaching and develop result interpretation. The soils used here were quite high in OM in top soil, which prevents leaching but creates more pesticide residues bound to the soil.

The soil candidates of the current scenario should be tested more, and soil parameters should be measured and calibrated against field data. This work is continuous, because the models will develop and their suitability has to be reassessed. The focus of further testing should be in the evaluation of the reality of the results, because the risk assessment of pesticides will be more and more based on the use of models in the future.

An additional weather scenario representing the climate in the Eastern Finland, where most of the same crops can be grown as in Jokioinen, is possibly needed. There are differences in precipitation and infiltration due to evaporation. In addition, the changes in weather scenario and climatic properties also affect the growth stage parameters of the crops: in general the planting takes place later due to the snow and frost disappearing in spring.

Different models give different results of pesticide leaching, depending on the structure and assumption made in models. The use of models that accept direct input of soil parameters should be studied (this would have prevented the problem experienced with saturated hydraulic conductivity K_{sat} of Jokioinen clay soil). MACRO-DB may not be the most suitable model in this respect, because all the data on the soils can not be inserted into the model by the user.

The preliminary result suggest that in the two models used in this study, there are significant differences between the proportion of precipitation that percolates the soil. Therefore, the water movement calculations of the models have to be studied more closely. The availability of hydrological data from Finland and from similar environments (other Nordic countries, Canada) should be studied and the model calculations must be re-assessed. Realistic estimates of pesticide leaching in cracking clay soils can only be obtained with a model which takes into account preferential flow of water and solutes through the soil profile.

Water movements have to calculated correctly in cracking soil. Before a suitable model for this exists, exact results can not be obtained. The present data on this should be collected, but apparently more research on water movements in soils is needed.

Leaching of high sorption pesticides in eroding soil particles reminds phosphorus leaching, which is also dominated by aggregate transport. This is marked in dry soils with cracks (clays) in the start of rainfall events. The existing information available for phosphorus leaching should be used to assess significance of leaching of soil bound pesticides.

So far, no effort has been put to the evaluation of uncertainty of the model predictions. This is because of the lack of reliable experimental data available for the model calculations. This task has to be dealt with in further studies, before models can be fully incorporated in risk assessment. Validation project for national scenarios is going on for instance in Denmark.

One of the most important questions in the use of models in the risk assessment are, however, in the interpretation of the results. How will the national results relate to the FOCUS results? How much emphasis can be put on results of models that are not validated in Finnish conditions? How much leaching of a pesticide is allowed on the basis of simulated scenario before leaching can be regarded as a risk for the environment? Can risk reduction measures be based on simulation modelling? Is it possible to judge safe uses and safe soils for pesticide use based on national scenarios that take into account local circumstances? This discussion will need input also from the pesticide industry.

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Yli-Halla, M., and D.L. Mokma. 1998. Soil Temperature Regimes in Finland. Agricultural and Food Science in Finland 7: 507-512.

APPENDIX I Macropore flow

Sandy soils were earlier considered to be most vulnerable for pesticide leaching, because of their high hydraulic conductivity. This is because rain-water moves downwards in soil matrix, due to potential energy differences. However, it has been found that chemical vertical movement in clay soils can be as fast or even faster, due to structural cracks and holes in the matrix.

Macropores are continuous macrosized canals in soil (Bewen and Germann 1982), originating from:

1. biopores
   - decomposition of roots, especially permanent in acid sulfate soils, where the walls are stabilised by ferrous oxide,
   - animal holes (earthworms),
2. pores created by tillage operations,
3. openings caused by freeze-thaw cycles and
4. soil cracks (shrinking) (Al-Soufi 1999).

The water flow in macropores is much faster than that described by Darcy's law (which has been used in models to describe water movement is soil since the 19th century). Thus, macropores in soil affect considerably the water fluxes, and thus also the fate of chemicals in water: the biologically and chemically active top soil layer may be by-passed. Macropore flow is often called **preferential flow or bypass flow**, which occurs when the water does not infiltrate though the soil matrix, micropores.

In addition to the more permanent macropores, **soil cracks** occur in clay soils and to some extent in silty soils. Soils cracks are dependent on the water content of the soil, and thus related to the precipitation, soil hydraulic properties and evaporation. The occurrence of soil cracks can be described and dealt with using soil shrinkage characteristics properties, but this requires very much soil data. Cracks may contribute to the water/substance movements a great deal.

The solutes in the macropore flow may originate directly from precipitation (pesticide sprayings) or from runoff water when the intensity of the precipitation exceeds the infiltration capacity of the soil. Solutes are also leached from the crack walls, and vice versa.

Macropore flow or flow through soil crack differs from micropore flow (water going through the soil matrix) also because of its non-equilibrium nature. In general, the concentration of a substance in water in soil matrix is a result of an equilibrium state after a certain contact period between the sorbing component (soil, especially organic matter) and water. The amount of time needed for the equilibrium state depends on the substance, temperature and the nature of the sorption process. In macropore flow this equilibrium is seldom reached, which may cause the conventional solute transport models estimate incorrectly the concentrations of substances in the water flow entering the deeper soil layers. The concentration can be estimated either too high (when the pesticide is stored in the soil matrix, not on the surface) or too low (when the pesticide is carried from the top soil layer).

In general, macropore flow and its relation to water flows and to the substances in it in soil can be characterised as follows:

- faster water movements. However, the macropores do not start conducting water until the soil around them is nearly saturated, because of their large size;

- drainage increases, surface runoff decreases;
- a significant amount of water flows only through a relatively small portion of the total soil volume;
- the substances may enter the groundwater faster (because of the faster water flow) leading to higher concentrations. The leaching of less mobile pesticides increases most, by more than four orders of magnitude (Larsson and Jarvis 1999);
- leaching of some very mobile compounds is found to reduce due to macropore flow (Larsson and Jarvis 1999);
- concentrations of the substances in deeper layers of soil may increase, due to the shortened time for degradation. In addition, the degradation rate is slower in deeper layers; and
- the significance of properties of the chemical decreases while macropore flow increases (Larsson and Jarvis 1999), because the contact time between soil matrix and the substance in water decreases.

With respect to the protection of groundwaters macropore flow may cause several problems:

- the substance of concern may be carried into deeper soil layers or even groundwater virtually undegraded;
- the conventional models which do not take into account macropore flow may not be suitable for calculating PECs (Predicted Environmental Concentrations) in groundwater or deep soil layers in soils with macropores;
- the degradation of chemicals below the plough layer is slow, generally resulting in slower degradation of the substance; and
- chemicals can get carried into deeper soil layers sorbed in soil particles, which are eroded from top soil.

Macropore system in soil consist of both horizontal and vertical pores creating a network, where some of the pores are continuous and some end holding the water. A dye study (Omoti and Wild 1979) reports nearly all earthworm channels (2-10mm) in English loam soil being continuous to 14 cms, 10% of them to 70 cms. At present there is little knowledge on the relation of measurable soil properties and the development and quality of macropores, and the general belief is that there is no relationship. The phenomenon itself is very difficult to master, as it is so closely related to weather conditions, soil properties, normal agricultural actions (for example, tillage) and their interactions. However, some work has been carried out:

Swedish macropore flow model MACRO enables quantitative evaluation of macropore flow and solutes transported. The total porosity of each soil layer is divided into micropores and macropores depending on the water content and potential. Micropore and macropore flows are considered separate routes. The net precipitation is divided between these routes based on the saturation of the soil among other variables. Macroporosity is not constant but takes into account swelling and shrinking of the soil.

Soil-Water-Atmosphere-Plant (SWAP) is a model used by PESTLA to calculate the soil hydrology. It does not consider the total effect of macroporosity, but calculates the water and solute transport in cracked clay soils. The lateral movement (diffusion) of solutes from the soil crack into the soil matrix and vice versa require calibration, which is why the use of the feature in the model is laborious. This feature is not used in the FOCUS scenarios.

APPENDIX 2 SIMULATION RESULTS

In this section MACRO-DB and PESTLA simulation results are presented. Altogether 4 soils are used in MACRO-DB simulations. Two of the soils are the same Jokioinen clay soil parameterised in two different ways: Jokioinen1 is parameterised using observed characteristics on soil structure. Jokioinen2 is parameterised in certain respects based on the Swedish soil database MARKDATA, because the use of observed parameters in the soil lead into very low saturated conductivity (K_{sat}) in the soil. Leaching is to a large extent dependent on boundary hydraulic conductivities. In addition, in Jokioinen Clay1 the groundwater level is 150 cm, as in Clay2 with higher K_{sat} it is 190 cm.

Pesticide leaching was simulated also for Pälkäne soil (fine sand), and for Västerby soil (clay) from Sweden (in MACRO-DB database). Altogether 8 runs are presented for each of the three pesticides (4 soils in two climates). In MACRO-DB, it is possible to choose either average or worst case parameterisation for the pesticide. All the model runs presented here are regarded as average cases.

FOCUS scenario Jokioinen is simulated with PESTLA based on the present information. This scenario and model may, however, still change in the course of decision making on the European forum.

Tribenuron methyl simulation

Simulation 1: Jokioinen Clay1 soil + Jokioinen climate

Compound : Tribenuron-methyl (Source = User-defined)
Soil : Jokioinen Clay1 (Source = User-defined)
Profile depth : 1.50 m

Groundwater at 1.5 m

Risk assessment : Average-case
Subsoil degradation : Proportional to organic carbon

Weather data : Jokioinen 1978-1999
Simulation from 19780101 to 19871231

Year 1	: Oat :	0.01 kg/hectare	on day 159
Year 2	: Oat :	0.01 kg/hectare	on day 159
Year 3	: Oat :	0.01 kg/hectare	on day 159
Year 4	: Oat :	0.01 kg/hectare	on day 159
Year 5	: Oat :	0.01 kg/hectare	on day 159
Year 6	: Oat :	0.01 kg/hectare	on day 159
Year 7	: Oat :	0.01 kg/hectare	on day 159
Year 8	: Oat :	0.01 kg/hectare	on day 159
Year 9	: Oat :	0.01 kg/hectare	on day 159
Year 10	: Oat :	0.01 kg/hectare	on day 159

RESULTS

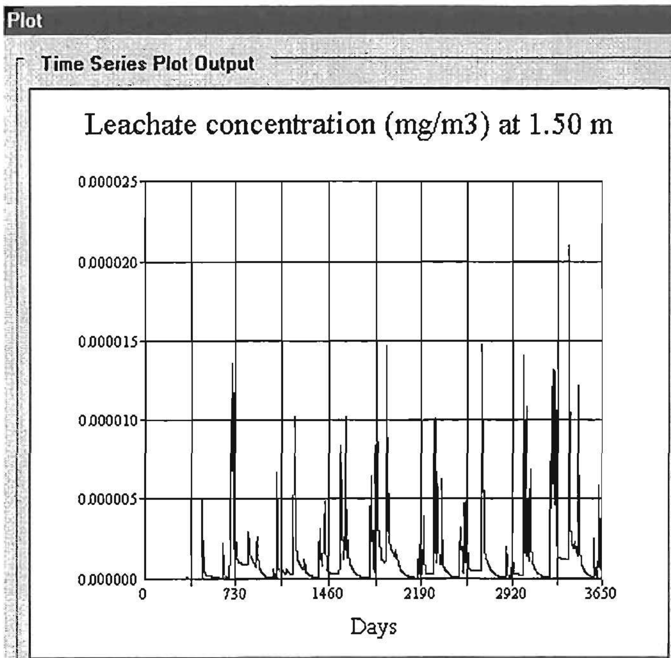
WATER BALANCE (mm)		PESTICIDE BALANCE (mg/ m^2)	
Precipitation	6360	Applied amount	10.00
Evapotranspiration	4180	Dissipated	9.88
Change in storage	56	Stored	0.04
Percolation	1420	Leached	0.00
Drainage	0	Lost to drains	0.00
Runoff	704	Lost to runoff	0.08

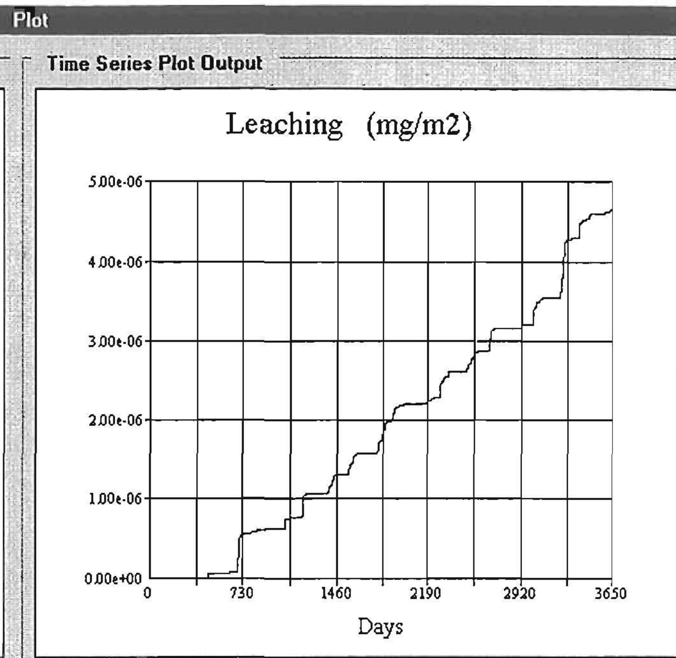
Pesticide balance
Leachate concentrations in groundwater (150 cm, fixed) were very low and did not exceed the level of 0.1 µg/l. The first notable traces of the substance appeared in the groundwater in spring of the second year.

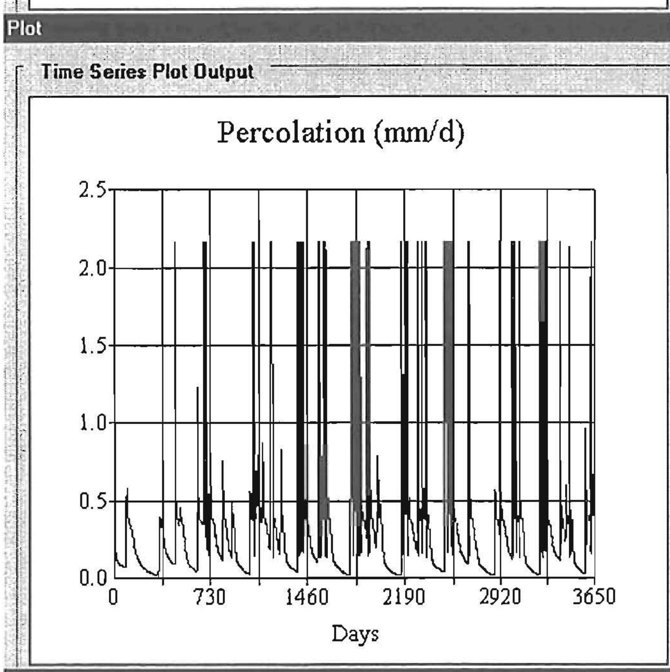
A remarkable peak in topsoil concentration can be seen in year 7. This result can not be explained by rainfall condition, as the percolation appears to be normal. In addition, the topsoil concentration should be approximately at the same level each year after application, unless accumulation occurs.

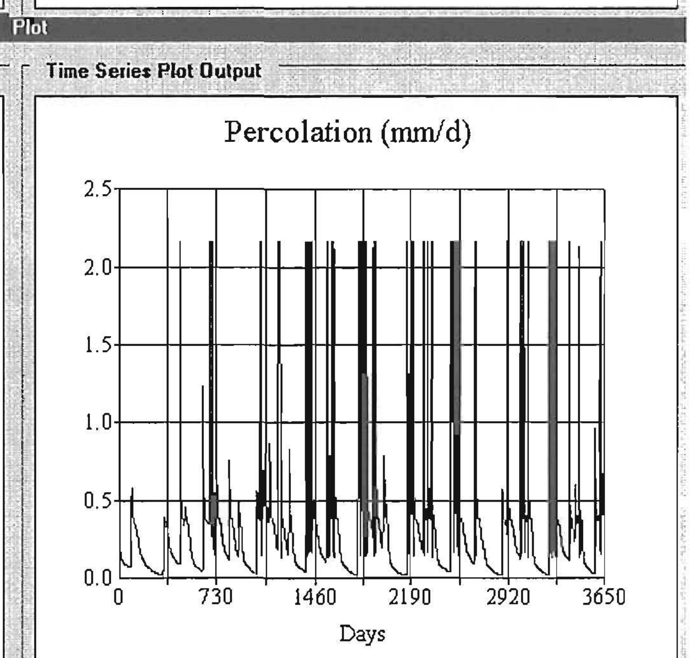
In the end of the simulation period, the soil storage was a bit more than 0.2 µg /kg in top soil (10 cm layer). No pesticide was stored below 20 cm layer.

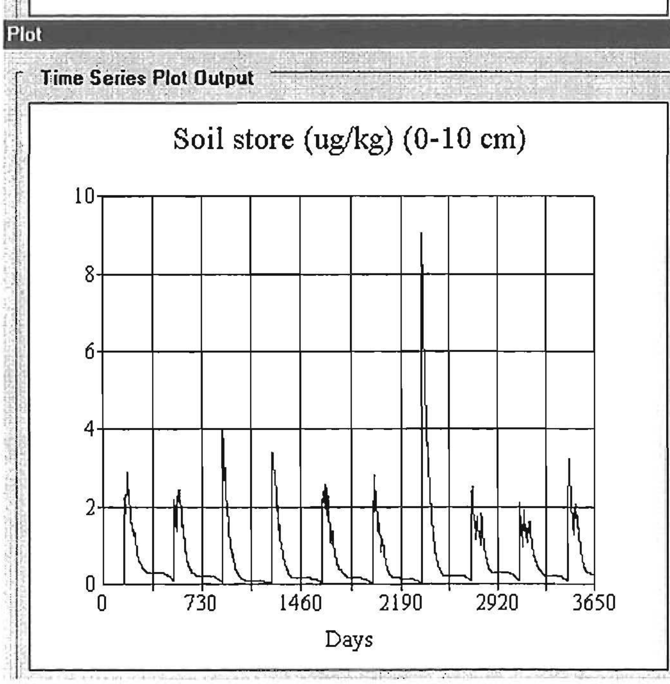
Water balance
The scenario was simulated without drainage. 66 % of the precipitation was evapotranspirated. 22 % percolated through the soil. 11 % was lost due to surface runoff.

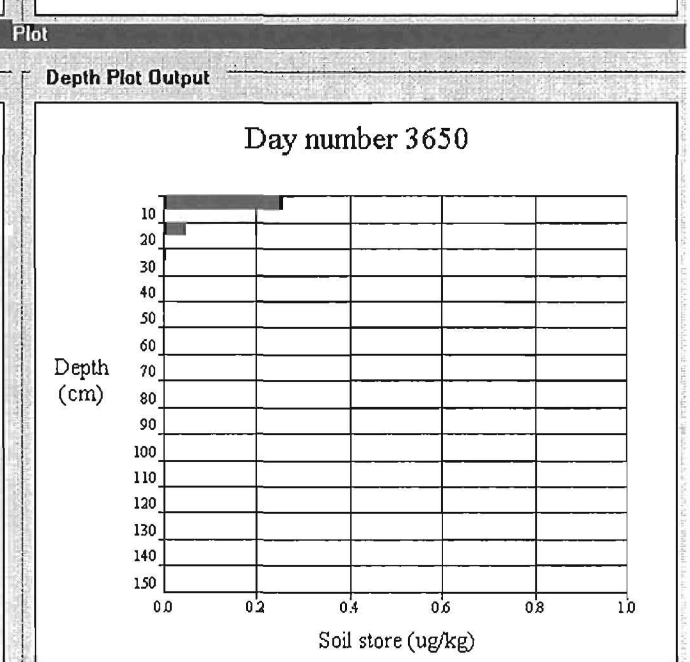

Plot
Time Series Plot Output
Leachate concentration (mg/m3) at 1.50 m
0.000025
0.000020
0.000015
0.000010
0.000005
0.000000
0
730
1460
2190
2920
3650
Days


Plot
Time Series Plot Output
Leaching (mg/m2)
5.00e-06
4.00e-06
3.00e-06
2.00e-06
1.00e-06
0.00e+00
0
730
1460
2190
2920
3650
Days


Plot
Time Series Plot Output
Percolation (mm/d)
2.5
2.0
1.5
1.0
0.5
0.0
0
730
1460
2190
2920
3650
Days


Plot
Time Series Plot Output
Percolation (mm/d)
2.5
2.0
1.5
1.0
0.5
0.0
0
730
1460
2190
2920
3650
Days


Plot
Time Series Plot Output
Soil store (ug/kg) (0-10 cm)
10
8
6
4
2
0
0
730
1460
2190
2920
3650
Days


Plot
Depth Plot Output
Day number 3650
Depth (cm)
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
0.0
0.2
0.4
0.6
0.8
1.0
Soil store (ug/kg)

Tribenuron methyl simulation

Simulation 2: Jokioinen Clay2 soil + Jokioinen climate

Compound : Tribenuron-methyl (Source = User-defined)
Soil : Jokioinen Clay2 (Source = User-defined)
Profile depth : 1.90 m

Groundwater at 1.9 m

Risk assessment : Average-case
Subsoil degradation : Proportional to organic carbon

Weather data : Jokioinen 1978-1999
Simulation from 19780101 to 19871231

Year 1	: Oat :	0.01 kg/hectare	on day 159
Year 2	: Oat :	0.01 kg/hectare	on day 159
Year 3	: Oat :	0.01 kg/hectare	on day 159
Year 4	: Oat :	0.01 kg/hectare	on day 159
Year 5	: Oat :	0.01 kg/hectare	on day 159
Year 6	: Oat :	0.01 kg/hectare	on day 159
Year 7	: Oat :	0.01 kg/hectare	on day 159
Year 8	: Oat :	0.01 kg/hectare	on day 159
Year 9	: Oat :	0.01 kg/hectare	on day 159
Year 10	: Oat :	0.01 kg/hectare	on day 159

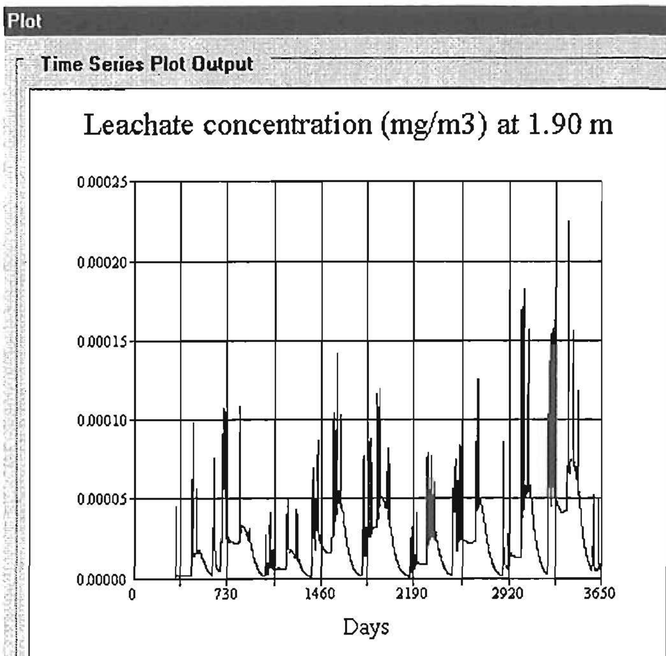
RESULTS

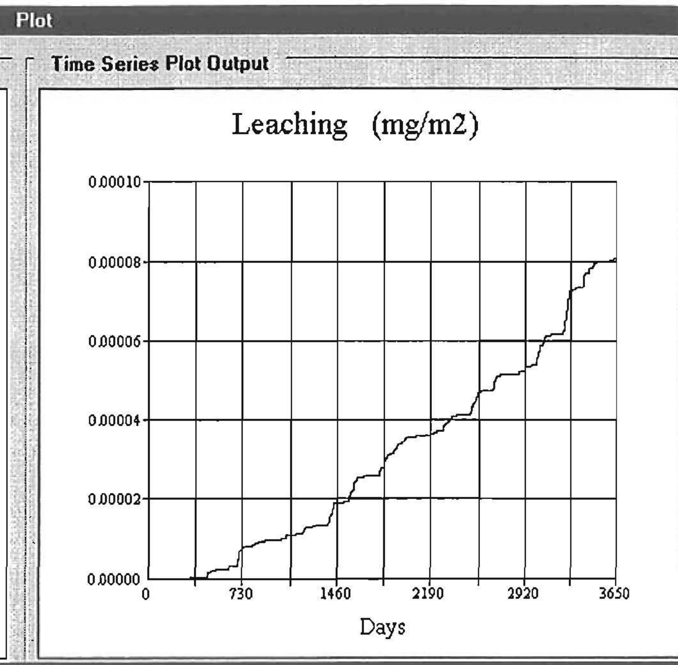
WATER BALANCE (mm)		PESTICIDE BALANCE (mg/ m^2)	
Precipitation	6360	Applied amount	10.00
Evapotranspiration	4030	Dissipated	9.87
Change in storage	79	Stored	0.04
Percolation	1550	Leached	0.00
Drainage	0	Lost to drains	0.00
Runoff	701	Lost to runoff	0.09

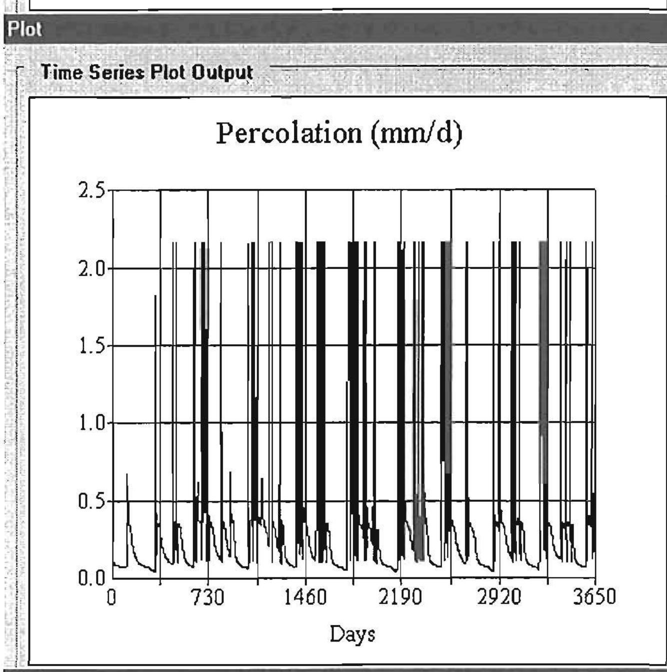
Pesticide balance
Leachate concentrations in groundwater (190 cm, fixed) were very low and did not exceed the level of 0.1 μg/l. However, leaching was a bit higher than with Clay1. Unlike with clay 1, no obvious peak in the top soil concentration was simulated.

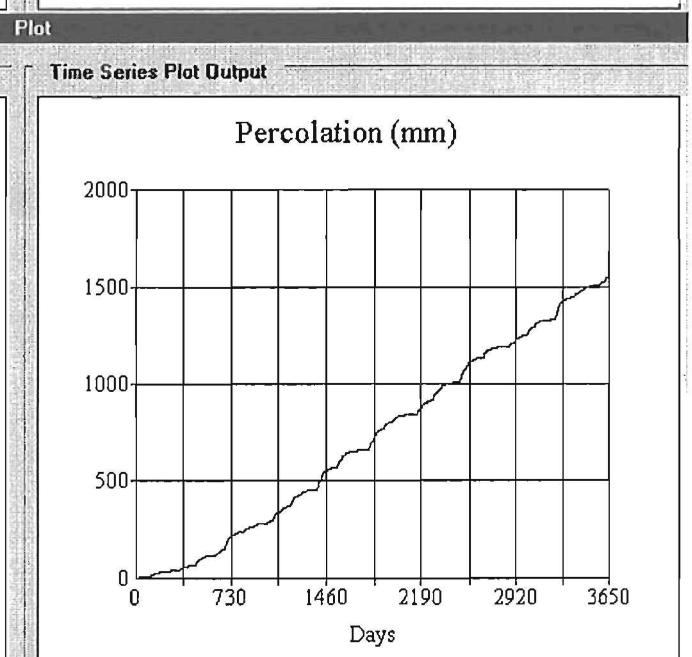
Also the pesticide leached into the deeper soil layers than with clay1. In the end of the simulation period, the soil storage was a bit more than 0.2 μg /kg in top soil (10 cm layer), and some traces were seen up to 50 cm.

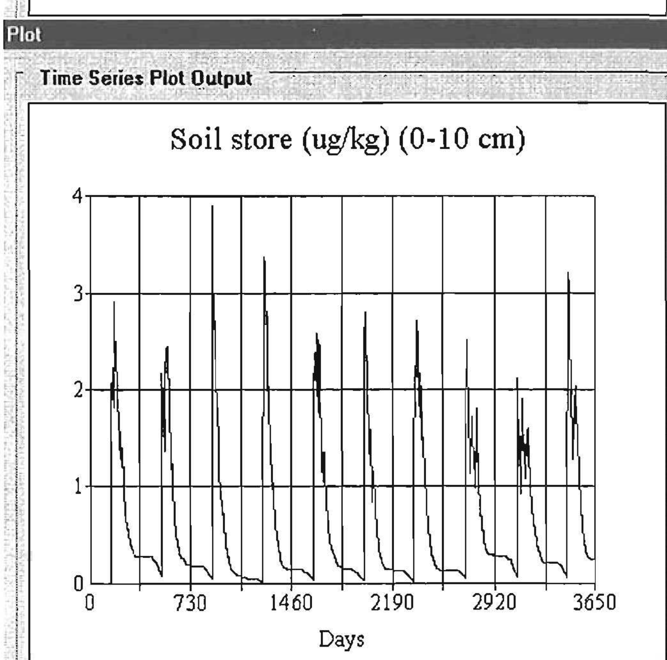
Water balance
The scenario was simulated without drainage. 63 % of the precipitation was evapotranspirated. 24 % percolated through the soil. 11 % was lost due to surface runoff.

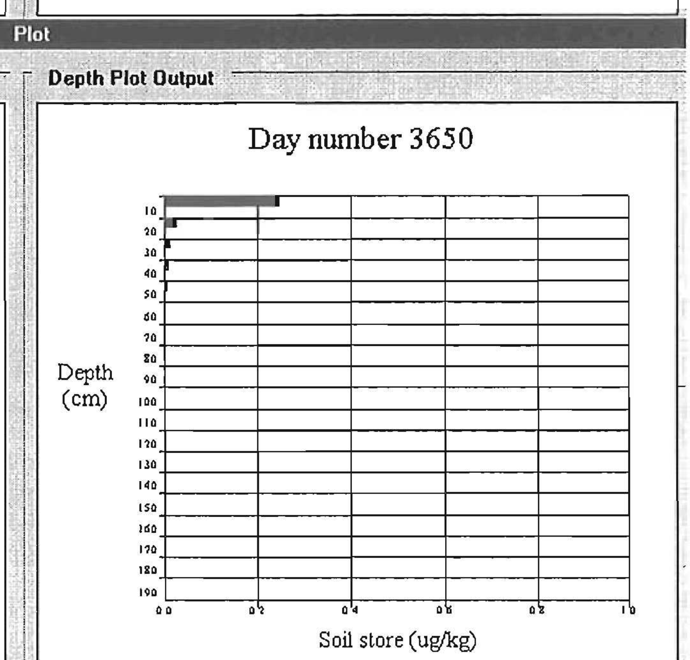

Plot
Time Series Plot Output
Leachate concentration (mg/m3) at 1.90 m
0.00025
0.00020
0.00015
0.00010
0.00005
0.00000
0
730
1460
2190
2920
3650
Days


Plot
Time Series Plot Output
Leaching (mg/m2)
0.00010
0.00008
0.00006
0.00004
0.00002
0.00000
0
730
1460
2190
2920
3650
Days


Plot
Time Series Plot Output
Percolation (mm/d)
2.5
2.0
1.5
1.0
0.5
0.0
0
730
1460
2190
2920
3650
Days


Plot
Time Series Plot Output
Percolation (mm)
2000
1500
1000
500
0
0
730
1460
2190
2920
3650
Days


Plot
Time Series Plot Output
Soil store (ug/kg) (0-10 cm)
4
3
2
1
0
0
730
1460
2190
2920
3650
Days


Plot
Depth Plot Output
Day number 3650
Depth
(cm)
Soil store (ug/kg)

Simulation 3: Pälkäne 02 soil + Jokioinen climate

```
Compound : Tribenuron-methyl (Source = User-defined)
Soil : Pälkäne 02 (Source = User-defined)
Profile depth : 1.60 m
Groundwater at 1.6 m

Risk assessment : Average-case
Subsoil degradation : Proportional to organic carbon

Weather data : Jokioinen 1978-1999
Simulation from 19780101 to 19871231

Year  1  : Oat :            0.01 kg/hectare on day  159
Year  2  : Oat :            0.01 kg/hectare on day  159
Year  3  : Oat :            0.01 kg/hectare on day  159
Year  4  : Oat :            0.01 kg/hectare on day  159
Year  5  : Oat :            0.01 kg/hectare on day  159
Year  6  : Oat :            0.01 kg/hectare on day  159
Year  7  : Oat :            0.01 kg/hectare on day  159
Year  8  : Oat :            0.01 kg/hectare on day  159
Year  9  : Oat :            0.01 kg/hectare on day  159
Year  10 : Oat :            0.01 kg/hectare on day  159
```

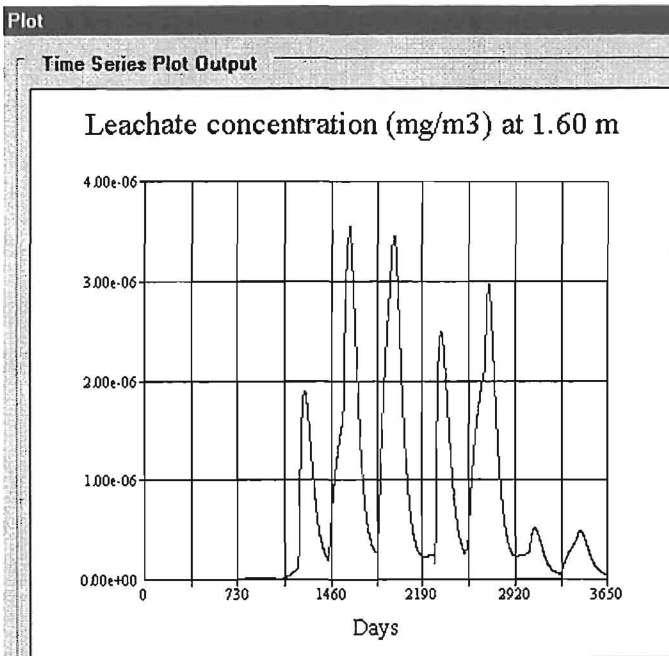
RESULTS

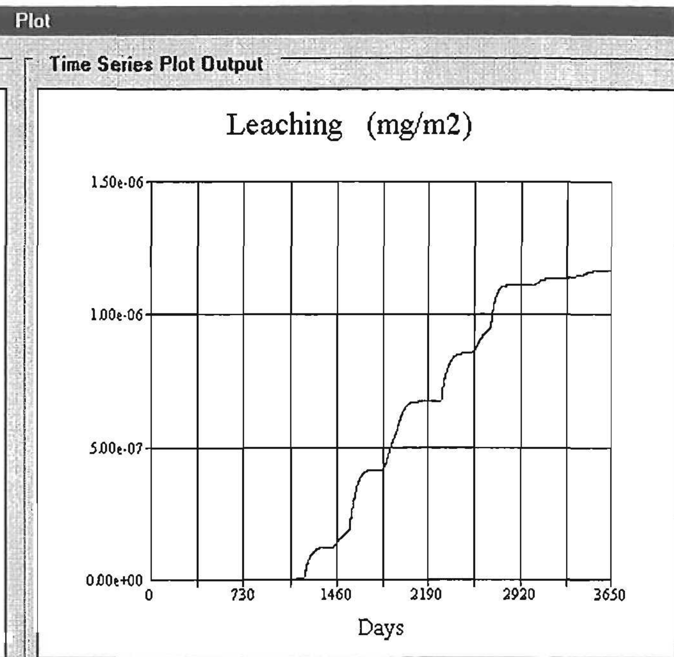
WATER BALANCE (mm)		PESTICIDE BALANCE (mg/ m^2)	
Precipitation	6360	Applied amount	10
Evapotranspiration	5030	Dissipated	9.90
Change in storage	70	Stored	0.10
Percolation	1260	Leached	0.00
Drainage	0	Lost to drains	0.00
Runoff	0	Lost to runoff	0.00

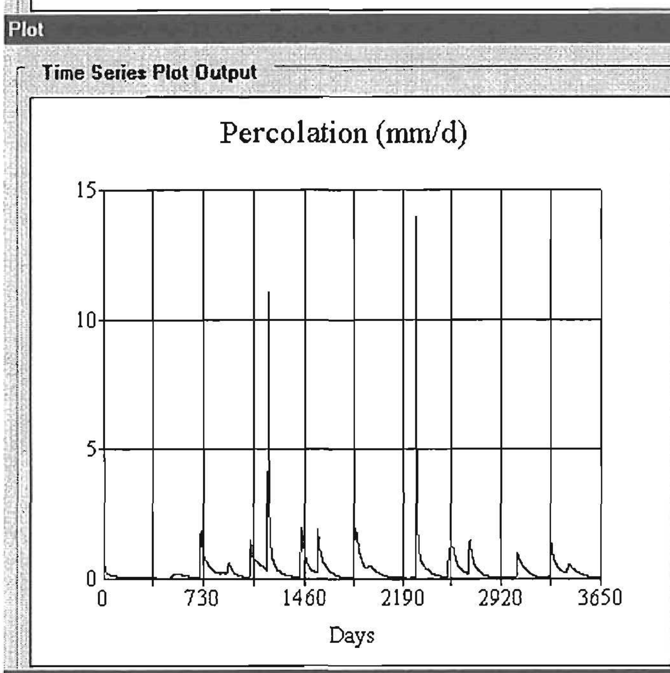
Pesticide balance
Leachate concentrations in groundwater (160 cm, fixed) were very low and did not exceed the level of 0.1 μg/l. The cumulative leaching in the ten year period was 0.00008 μg/m2. Early in the year 3, traces of pesticide leached into the groundwater. Thus, the leaching was considerably slower than in clay soil, where the Richard's equation water movements should be slower (if preferential flow is excluded).

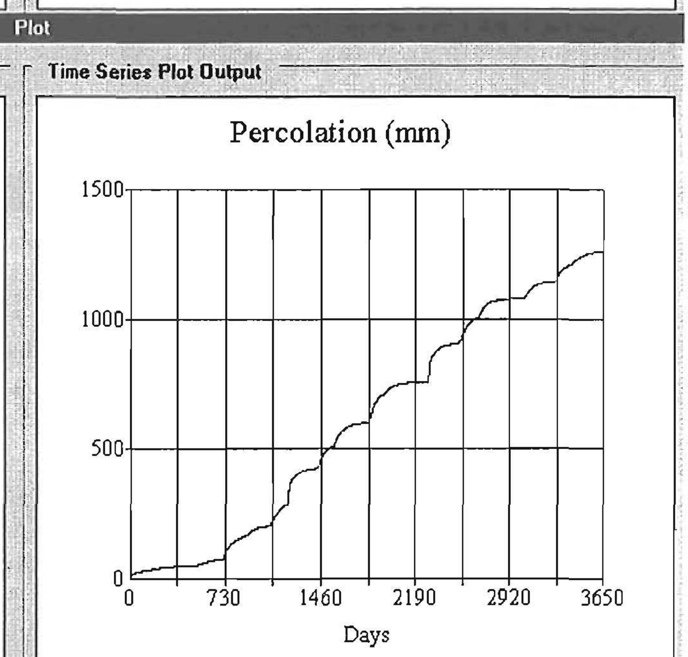
In the end of the simulation period, the soil storage below 0.6 μg /kg top soil (10 cm layer). Most of the pesticide stored in soil was in the first 10 cm. No pesticide was below the 30 cm layer of soil.

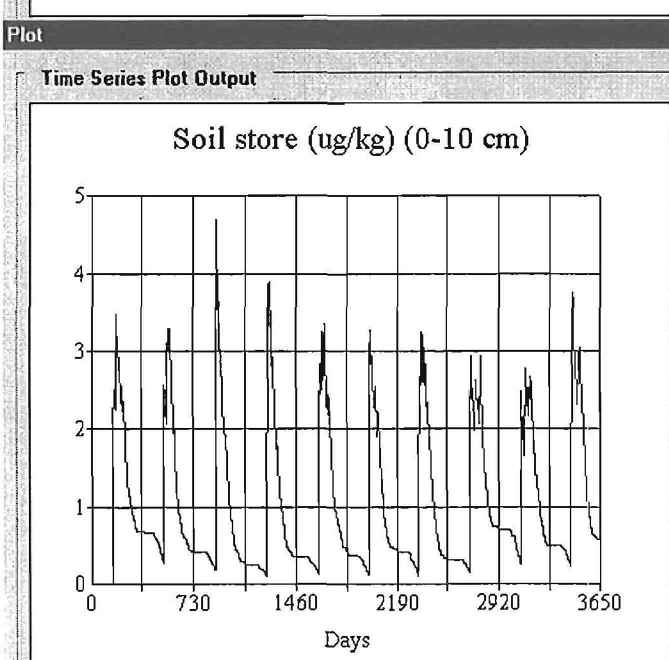
Water balance
The scenario was simulated without drainage. 79 % of the precipitation was evapotranspirated, which is more than in clay soil scenario. Percolation was somewhat lower than in clay soil (20 % of the precipitation). The result is a bit surprising, as percolation through the sandy soil Pälkäne 02 could be expectoed to be much higher than in clay soil Jokioinen Clay2. However, this can possibly be explained with the prefential macropore flow occuring in clay soils. In additition, the pesticide was leached much faster in clay soil, which indicates the presence of macropore flow.

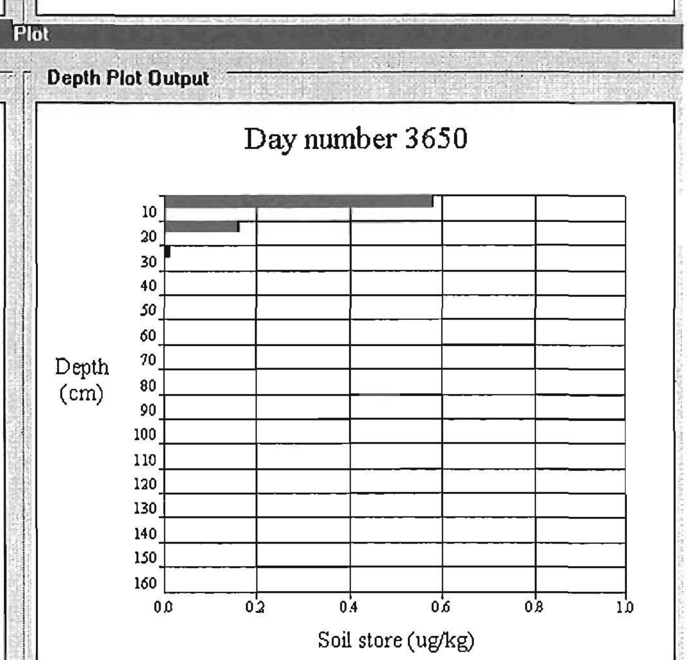

Plot
Time Series Plot Output
Leachate concentration (mg/m3) at 1.60 m
4.00e-06
3.00e-06
2.00e-06
1.00e-06
0.00e+00
0
730
1460
2190
2920
3650
Days


Plot
Time Series Plot Output
Leaching (mg/m2)
1.50e-06
1.00e-06
5.00e-07
0.00e+00
0
730
1460
2190
2920
3650
Days


Plot
Time Series Plot Output
Percolation (mm/d)
15
10
5
0
0
730
1460
2190
2920
3650
Days


Plot
Time Series Plot Output
Percolation (mm)
1500
1000
500
0
0
730
1460
2190
2920
3650
Days


Plot
Time Series Plot Output
Soil store (ug/kg) (0-10 cm)
5
4
3
2
1
0
0
730
1460
2190
2920
3650
Days


Plot
Depth Plot Output
Day number 3650
Depth (cm)
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
0.0
0.2
0.4
0.6
0.8
1.0
Soil store (ug/kg)

Simulation 4: Västerby soil + Jokioinen climate

```
Compound : Tribenuron-methyl (Source = User-defined)
Soil : VÄSTERBY (Source = MARKDATA)
Profile depth : 1.50 m
Groundwater at 1.5 m

Risk assessment : Average-case
Subsoil degradation : Proportional to organic carbon

Weather data : Jokioinen 1978-1999
Simulation from 19780101 to 19871231

Year  1  : Oat :           0.01 kg/hectare on day  159
Year  2  : Oat :           0.01 kg/hectare on day  159
Year  3  : Oat :           0.01 kg/hectare on day  159
Year  4  : Oat :           0.01 kg/hectare on day  159
Year  5  : Oat :           0.01 kg/hectare on day  159
Year  6  : Oat :           0.01 kg/hectare on day  159
Year  7  : Oat :           0.01 kg/hectare on day  159
Year  8  : Oat :           0.01 kg/hectare on day  159
Year  9  : Oat :           0.01 kg/hectare on day  159
Year  10 : Oat :           0.01 kg/hectare on day  159
```

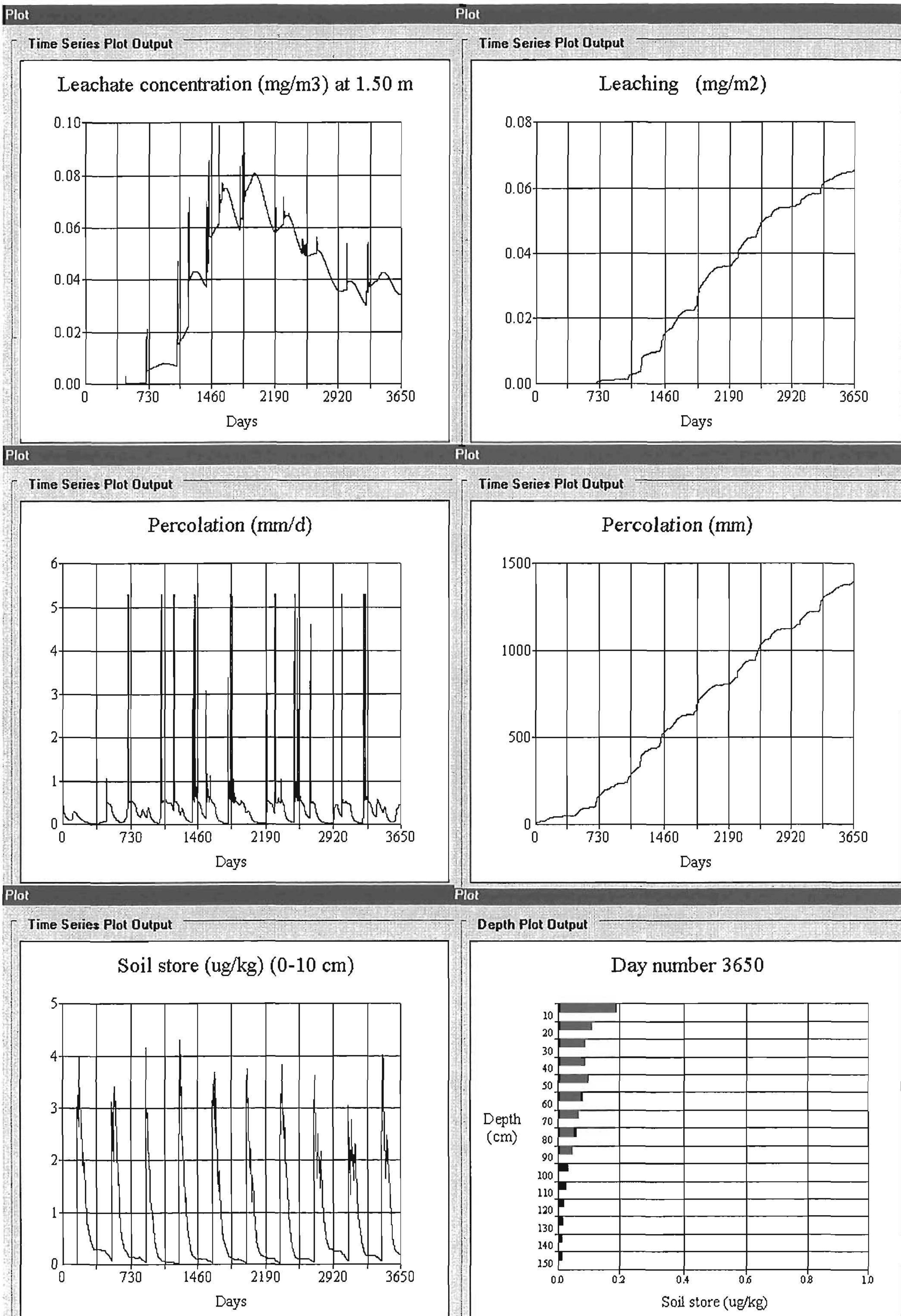
RESULTS

WATER BALANCE (mm)		PESTICIDE BALANCE (mg/ m^2)	
Precipitation	6360	Applied amount	10
Evapotranspiration	4600	Dissipated	9.70
Change in storage	68	Stored	0.12
Percolation	1400	Leached	0.07
Drainage	0	Lost to drains	0.00
Runoff	292	Lost to runoff	0.12

Pesticide balance
Leachate concentrations in groundwater (150 cm, fixed) were low and did not exceed the level of 0.1 µg/l. The cumulative leaching in the ten year period was 0.07 mg/m2, which is conciderably more than with the Finnish soils. In the first year of use, no pesticide leached into the groundwater. The amount of pesticide lost to runoff was 0.1 %.

In the end of the simulation period, the soil storage was less than 0.2 µg /kg top soil (10 cm layer), which is approximately at the same level as with Jokioinen soil, but much less than with Pälkäne soil.

Water balance
The scenario was simulated without drainage. The evapotranspiration and percolation levels were 72 % and 22 % of the precipitation, respectively.


Plot
Time Series Plot Output
Leachate concentration (mg/m3) at 1.50 m
0.10
0.08
0.06
0.04
0.02
0.00
0
730
1460
2190
2920
3650
Days
Plot
Time Series Plot Output
Leaching (mg/m2)
0.08
0.06
0.04
0.02
0.00
0
730
1460
2190
2920
3650
Days
Plot
Time Series Plot Output
Percolation (mm/d)
6
5
4
3
2
1
0
0
730
1460
2190
2920
3650
Days
Plot
Time Series Plot Output
Percolation (mm)
1500
1000
500
0
0
730
1460
2190
2920
3650
Days
Plot
Time Series Plot Output
Soil store (ug/kg) (0-10 cm)
5
4
3
2
1
0
0
730
1460
2190
2920
3650
Days
Plot
Depth Plot Output
Day number 3650
Depth
(cm)
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
0.0
0.2
0.4
0.6
0.8
1.0
Soil store (ug/kg)

Simulation 5: Västerby soil + Uppsala climate

```
Compound : Tribenuron-methyl (Source = User-defined)
Soil : VÄSTERBY (Source = MARKDATA)
Profile depth : 1.50 m
Groundwater at 1.5 m

Risk assessment : Average-case
Subsoil degradation : Proportional to organic carbon

Weather data : Uppsala
Simulation from 19610101 to 19701231

Year  1  : Oat :              0.01 kg/hectare on day  159
Year  2  : Oat :              0.01 kg/hectare on day  159
Year  3  : Oat :              0.01 kg/hectare on day  159
Year  4  : Oat :              0.01 kg/hectare on day  159
Year  5  : Oat :              0.01 kg/hectare on day  159
Year  6  : Oat :              0.01 kg/hectare on day  159
Year  7  : Oat :              0.01 kg/hectare on day  159
Year  8  : Oat :              0.01 kg/hectare on day  159
Year  9  : Oat :              0.01 kg/hectare on day  159
Year  10 : Oat :              0.01 kg/hectare on day  159
```

WATER BALANCE (mm)		PESTICIDE BALANCE (mg/ m^2)	
Precipitation	4900	Applied amount	10.00
Evapotranspiration	3540	Dissipated	9.94
Change in storage	29	Stored	0.03
Percolation	1140	Leached	0.02
Drainage	0	Lost to drains	0.00
Runoff	191	Lost to runoff	0.01

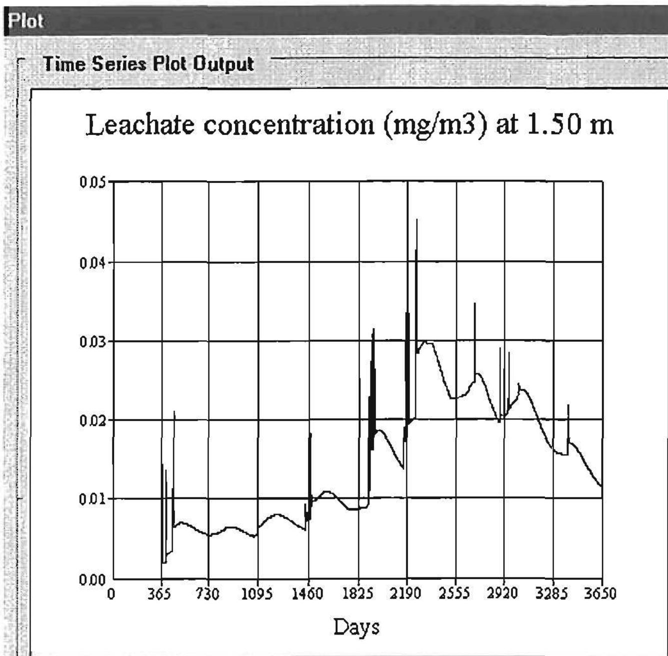
Pesticide balance

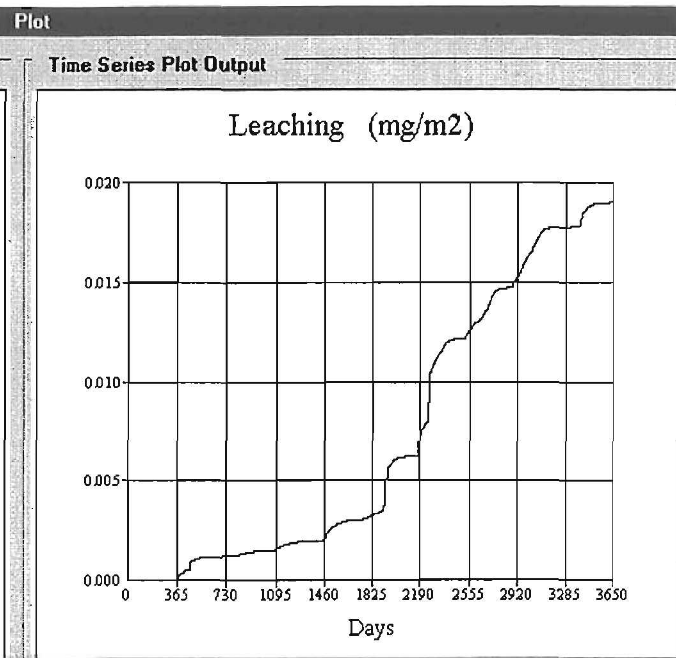
Leachate concentrations in groundwater (150 cm, fixed) rose 6 months after the first application, but remained approximately on the same level until year 5. In years 5, 6 and 7 the leaching and the concentrations increased but started to decrease in year 8. Perhaps a bit surprisingly, the leachate concentrations decreased considerably towards the end of the simulation. The pesticide leached into the groundwater already within the first year of use. The total losses of pesticide due to leaching were 0.2 %.

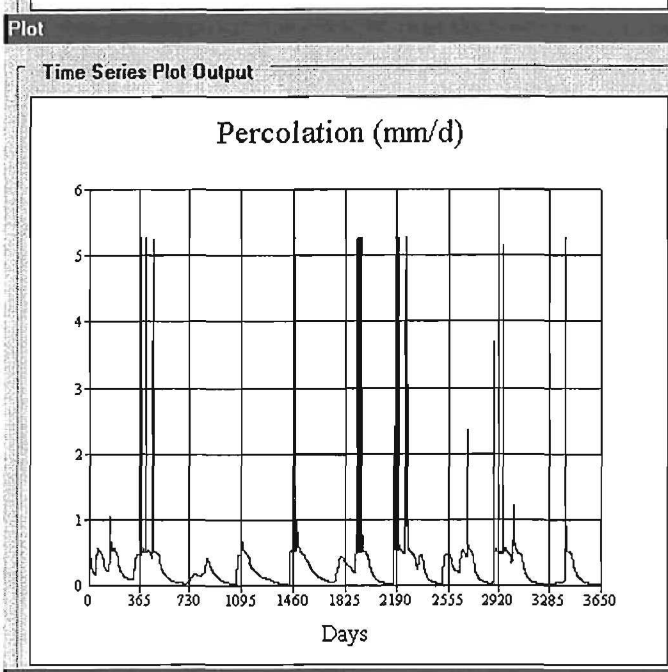
The cumulative leaching in the ten year period was less than 0.02 mg/m2. As can be seen in the depth plot, tribenuron-methyl leached into the deeper layers, but was mostly degraded (99 %).

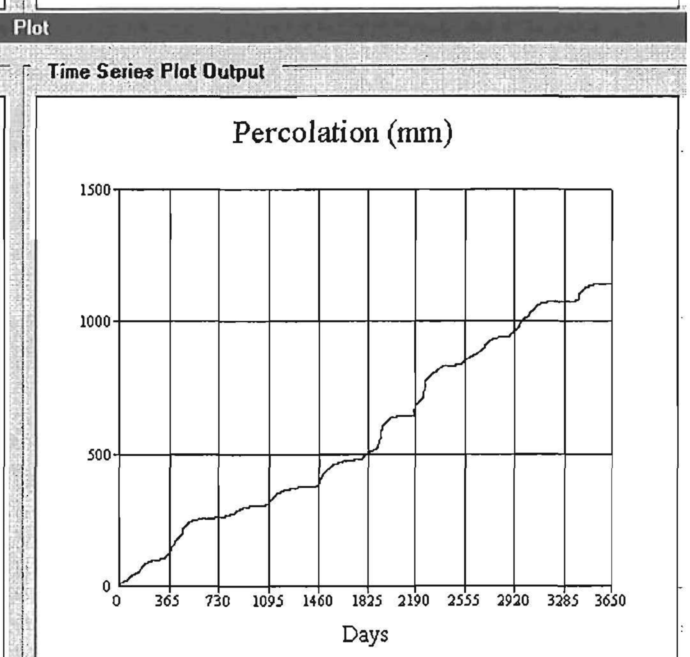
Water balance

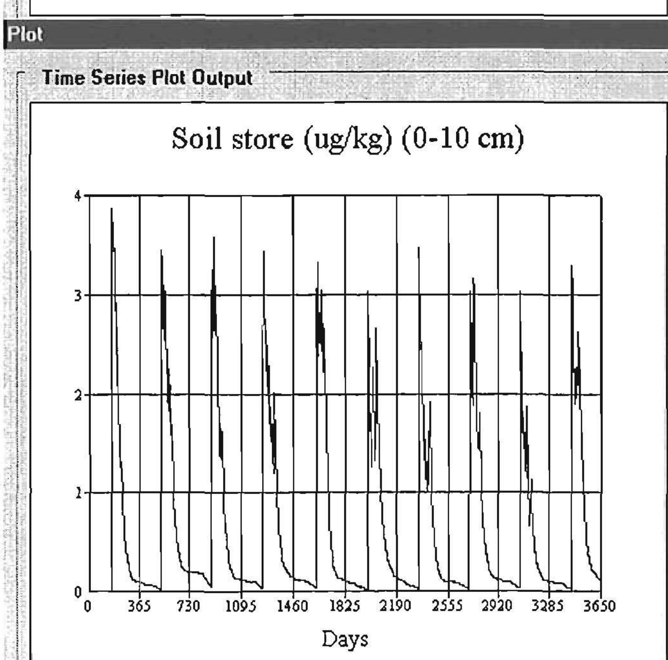
The scenario was simulated without drainage. 72 % of the precipitation was evapotranspirated. 23 % was percolated through the soil. 4 % was lost to runoff.

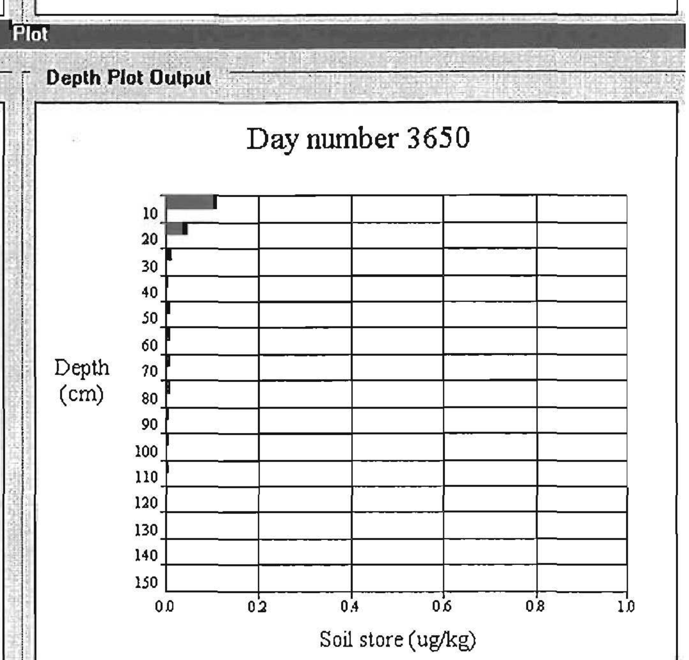

Plot
Time Series Plot Output
Leachate concentration (mg/m3) at 1.50 m
0.05
0.04
0.03
0.02
0.01
0.00
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Time Series Plot Output
Leaching (mg/m2)
0.020
0.015
0.010
0.005
0.000
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Time Series Plot Output
Percolation (mm/d)
6
5
4
3
2
1
0
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Time Series Plot Output
Percolation (mm)
1500
1000
500
0
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Time Series Plot Output
Soil store (ug/kg) (0-10 cm)
4
3
2
1
0
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Depth Plot Output
Day number 3650
Depth (cm)
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
0.0 0.2 0.4 0.6 0.8 1.0
Soil store (ug/kg)

Simulation 6: Jokioinen Clay1 Soil + Uppsala climate

Compound : Tribenuron-methyl (Source = User-defined)
Soil : Jokioinen Clay1 (Source = User-defined)
Profile depth : 1.50 m
Groundwater at 1.5 m

Risk assessment : Average-case
Subsoil degradation : Proportional to organic carbon

Weather data : Uppsala
Simulation from 19610101 to 19701231

Year 1	: Oat :	0.01 kg/hectare on day	159
Year 2	: Oat :	0.01 kg/hectare on day	159
Year 3	: Oat :	0.01 kg/hectare on day	159
Year 4	: Oat :	0.01 kg/hectare on day	159
Year 5	: Oat :	0.01 kg/hectare on day	159
Year 6	: Oat :	0.01 kg/hectare on day	159
Year 7	: Oat :	0.01 kg/hectare on day	159
Year 8	: Oat :	0.01 kg/hectare on day	159
Year 9	: Oat :	0.01 kg/hectare on day	159
Year 10	: Oat :	0.01 kg/hectare on day	159

WATER BALANCE (mm)		PESTICIDE BALANCE (mg/ m^2)	
Precipitation	4900	Applied amount	10.00
Evapotranspiration	3250	Dissipated	9.97
Change in storage	39	Stored	0.02
Percolation	1150	Leached	0.00
Drainage	0	Lost to drains	0.00
Runoff	461	Lost to runoff	0.01

PESTICIDE BALANCE

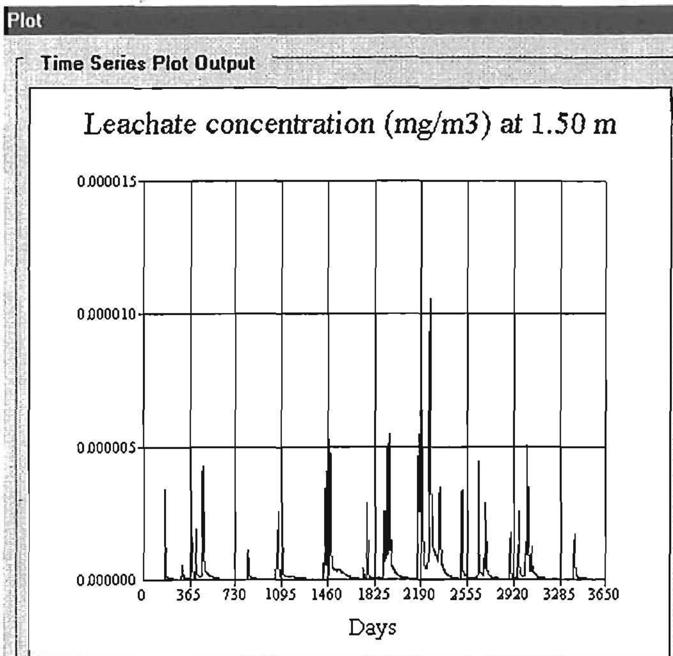
In Uppsala weather, a peak of the substance leaching to the groundwater was observed soon after the first application. Metribuzine concentrations varied a lot, but were very low during the simulation period.

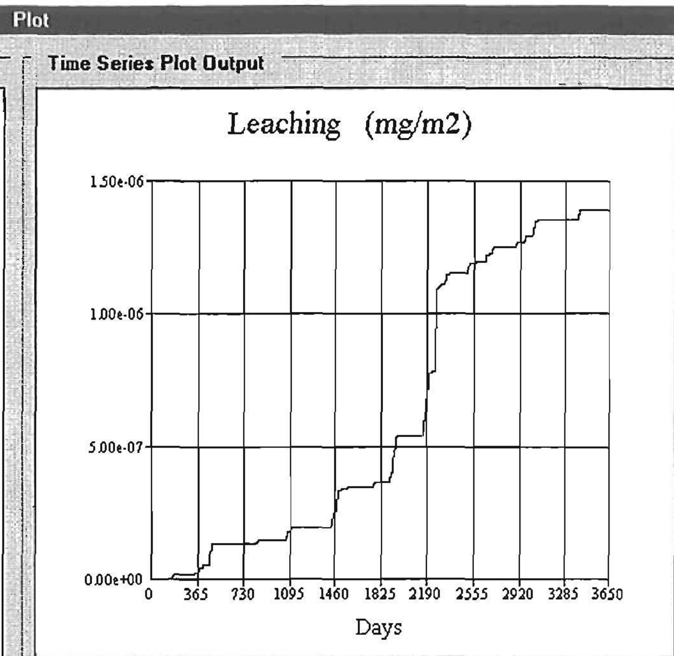
As in Jokioinen climate, the depth profile in the end of the simulation revealed no stored pesticide under 20 cm layer.

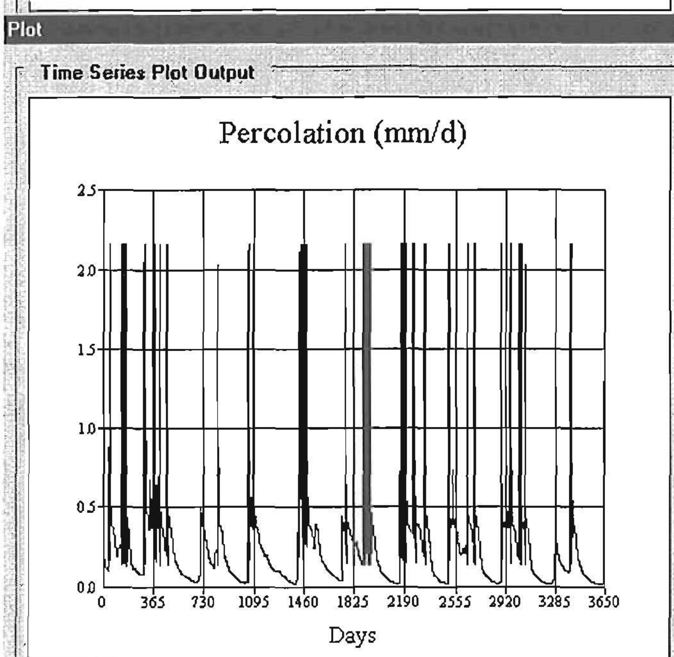
With Uppsala climate the amount of metribuzine dissipated was a bit higher than with Jokioinen climate (99.7 % mg/m2 and 99.0 mg/m2, respectively).

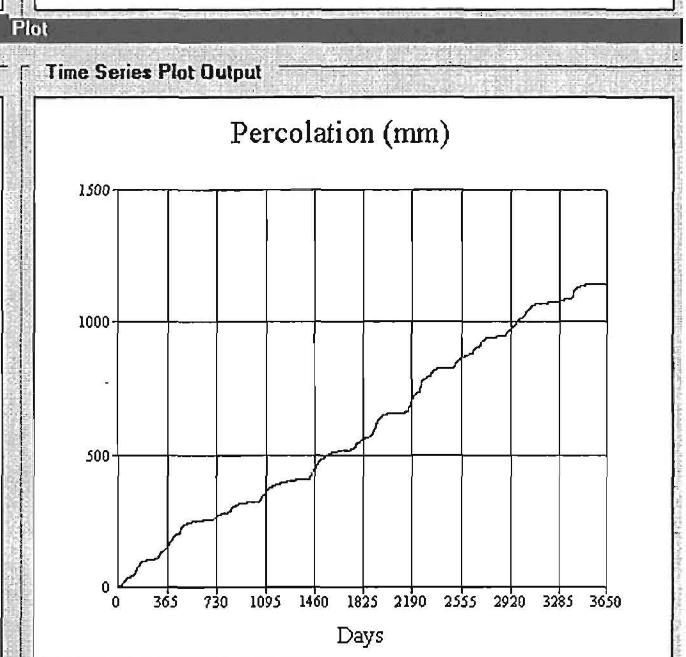
WATER BALANCE

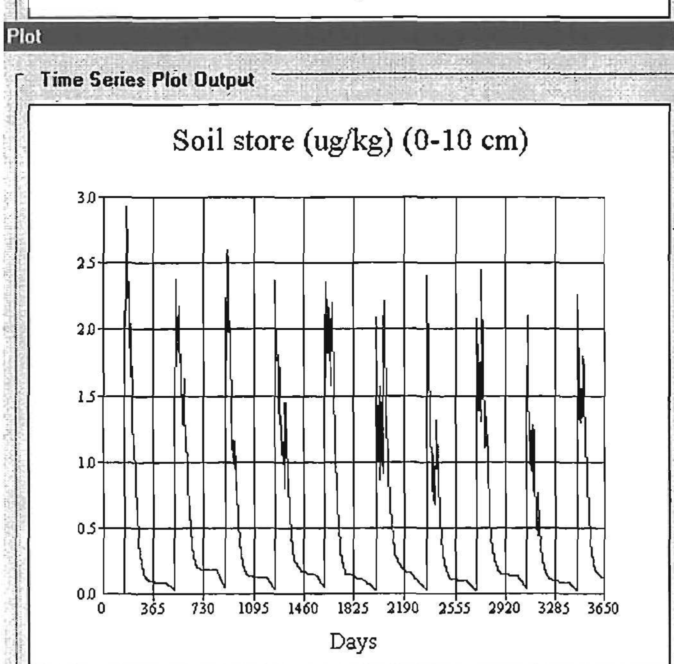
66 % of the water was evapotranspirated. 23 % percolated through the soil matrix. 9 % was lost to surface runoff.

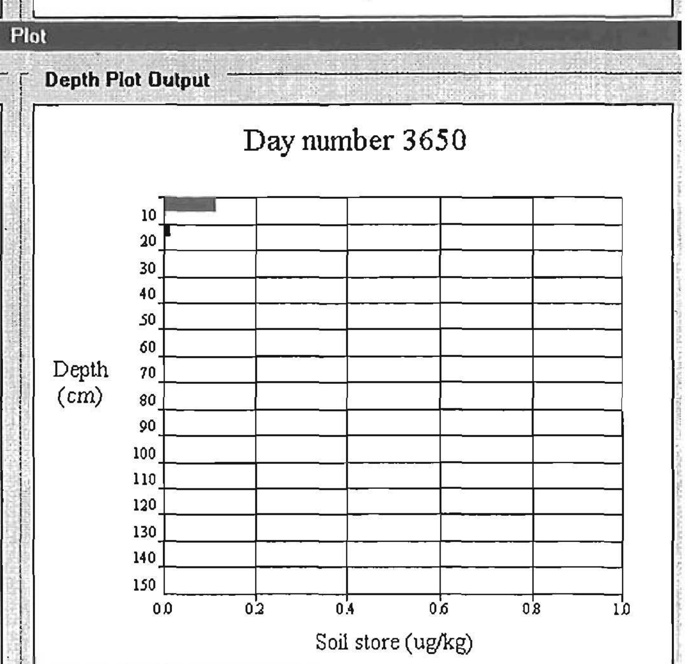

Plot
Time Series Plot Output
Leachate concentration (mg/m3) at 1.50 m
0.000015
0.000010
0.000005
0.000000
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Time Series Plot Output
Leaching (mg/m2)
1.50e-06
1.00e-06
5.00e-07
0.00e+00
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Time Series Plot Output
Percolation (mm/d)
2.5
2.0
1.5
1.0
0.5
0.0
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Time Series Plot Output
Percolation (mm)
1500
1000
500
0
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Time Series Plot Output
Soil store (ug/kg) (0-10 cm)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Depth Plot Output
Day number 3650
Depth (cm)
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
0.0 0.2 0.4 0.6 0.8 1.0
Soil store (ug/kg)

Simulation 7: Jokioinen Clay2 + Uppsala

```
Compound : Tribenuron-methyl (Source = User-defined)
Soil : Jokioinen Clay2 (Source = User-defined)
Profile depth : 1.90 m
Groundwater at 1.9 m

Risk assessment : Average-case
Subsoil degradation : Proportional to organic carbon

Weather data : Uppsala
Simulation from 19610101 to 19701231

Year  1  : Oat :          0.01 kg/hectare on day  159
Year  2  : Oat :          0.01 kg/hectare on day  159
Year  3  : Oat :          0.01 kg/hectare on day  159
Year  4  : Oat :          0.01 kg/hectare on day  159
Year  5  : Oat :          0.01 kg/hectare on day  159
Year  6  : Oat :          0.01 kg/hectare on day  159
Year  7  : Oat :          0.01 kg/hectare on day  159
Year  8  : Oat :          0.01 kg/hectare on day  159
Year  9  : Oat :          0.01 kg/hectare on day  159
Year  10 : Oat :          0.01 kg/hectare on day  159
```

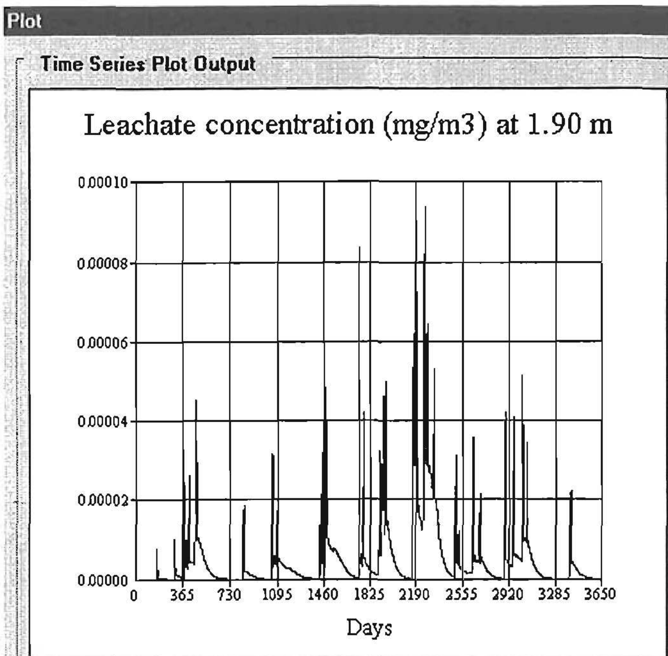
WATER BALANCE (mm)		PESTICIDE BALANCE (mg/ m^2)	
Precipitation	4900	Applied amount	10.00
Evapotranspiration	3160	Dissipated	9.97
Change in storage	49	Stored	0.02
Percolation	1250	Leached	0.00
Drainage	0	Lost to drains	0.00
Runoff	441	Lost to runoff	0.01

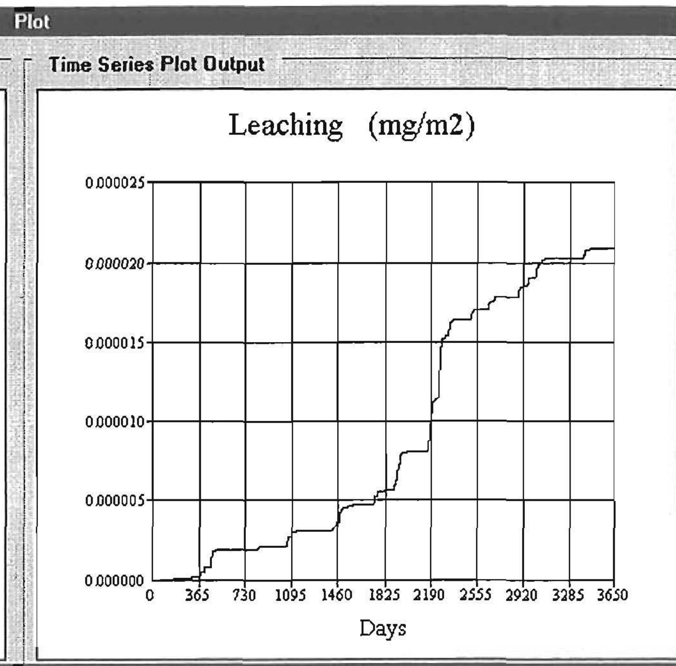
PESTICIDE BALANCE

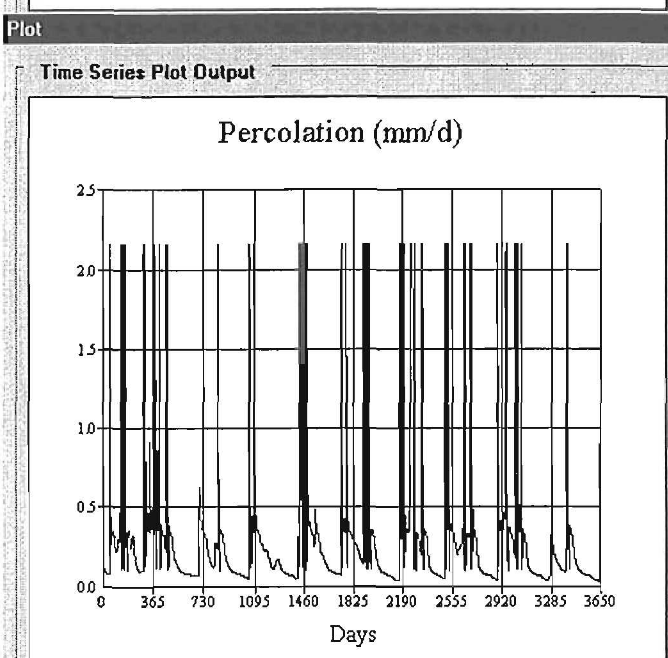
In Uppsala weather, a peak of the substance leaching to the groundwater was observed soon after the first application. Metribuzine concentrations varied a lot, but remained below the drinking water quality stardard. Neither in soil concentrations there was no trend observed.
With Uppsala climate the amount of metribuzine dissipated was a bit higher than with Jokioinen climate (99.7 % mg/m2 and 99.0 mg/m2, respectively).

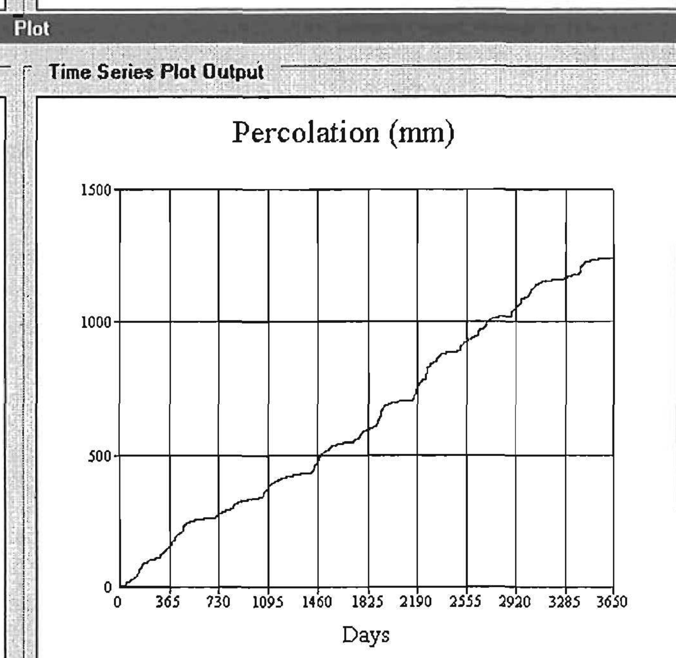
WATER BALANCE

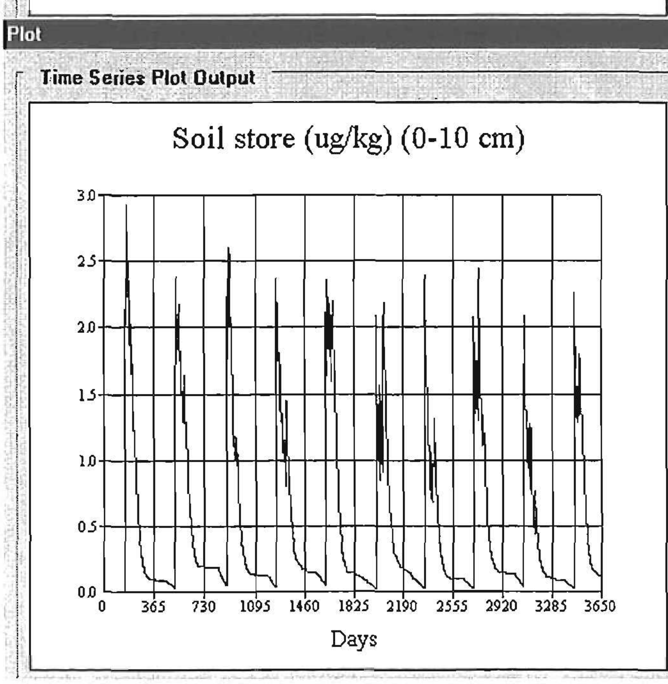
64 % of the water was evapotranspirated. 26 % percolated through the soil matrix. 9 % was lost to surface runoff.

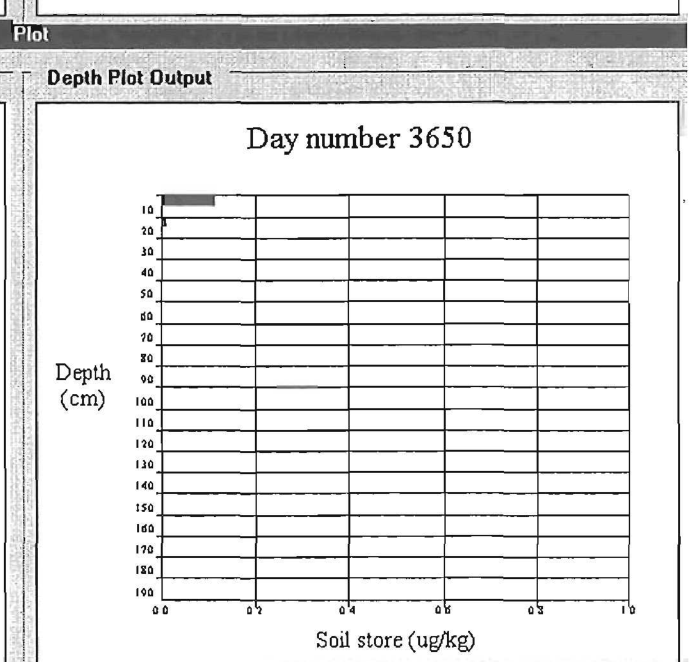

Plot
Time Series Plot Output
Leachate concentration (mg/m3) at 1.90 m
0.00010
0.00008
0.00006
0.00004
0.00002
0.00000
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Time Series Plot Output
Leaching (mg/m2)
0.000025
0.000020
0.000015
0.000010
0.000005
0.000000
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Time Series Plot Output
Percolation (mm/d)
2.5
2.0
1.5
1.0
0.5
0.0
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Time Series Plot Output
Percolation (mm)
1500
1000
500
0
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Time Series Plot Output
Soil store (ug/kg) (0-10 cm)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Depth Plot Output
Day number 3650
Depth (cm)
Soil store (ug/kg)

Simulation 8: Pälkäne 02 + Uppsala

```
Compound : Tribenuron-methyl (Source = User-defined)
Soil : Pälkäne 02 (Source = User-defined)
Profile depth : 1.60 m
Groundwater at 1.6 m

Risk assessment : Average-case
Subsoil degradation : Proportional to organic carbon

Weather data : Uppsala
Simulation from 19610101 to 19701231

Year  1  : Oat :          0.01 kg/hectare on day  159
Year  2  : Oat :          0.01 kg/hectare on day  159
Year  3  : Oat :          0.01 kg/hectare on day  159
Year  4  : Oat :          0.01 kg/hectare on day  159
Year  5  : Oat :          0.01 kg/hectare on day  159
Year  6  : Oat :          0.01 kg/hectare on day  159
Year  7  : Oat :          0.01 kg/hectare on day  159
Year  8  : Oat :          0.01 kg/hectare on day  159
Year  9  : Oat :          0.01 kg/hectare on day  159
Year  10 : Oat :          0.01 kg/hectare on day  159
```

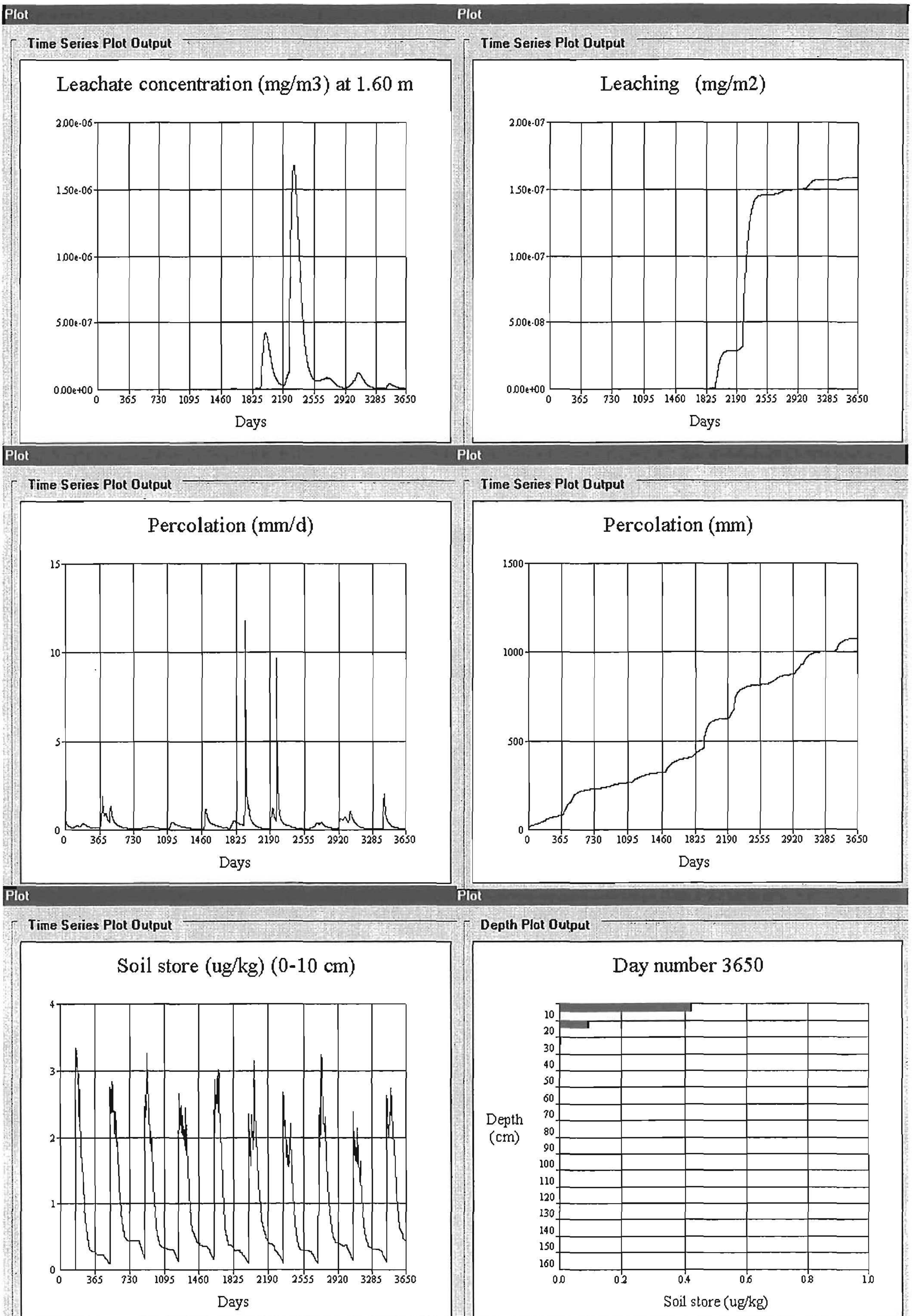
WATER BALANCE (mm)		PESTICIDE BALANCE (mg/ m²)	
Precipitation	4900	Applied amount	10.00
Evapotranspiration	3810	Dissipated	9.93
Change in storage	10	Stored	0.07
Percolation	1080	Leached	0.00
Drainage	0	Lost to drains	0.00
Runoff	0	Lost to runoff	0.00

PESTICIDE BALANCE

It took 5 years until very small concentrations of substance was leached into the groundwater. A notable peak in concentration was seen in years 6 and 7 after bigger rainfall events, but the absolute concentrations were very small and decreased after that. 99 % of the substance degraded and very little was leached below plough layer. However, the highest concentrations of the substance were also eith Uppsala climate in Pälkäne top soil 10 cm layer.

WATER BALANCE

78 % of the water was evapotranspirated. 22 % percolated through the soil matrix. The result is very close to the partition in Jokioinen climate.


Plot
Time Series Plot Output
Leachate concentration (mg/m3) at 1.60 m
2.00e-06
1.50e-06
1.00e-06
5.00e-07
0.00e+00
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days
Plot
Time Series Plot Output
Leaching (mg/m2)
2.00e-07
1.50e-07
1.00e-07
5.00e-08
0.00e+00
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days
Plot
Time Series Plot Output
Percolation (mm/d)
15
10
5
0
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days
Plot
Time Series Plot Output
Percolation (mm)
1500
1000
500
0
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days
Plot
Time Series Plot Output
Soil store (ug/kg) (0-10 cm)
4
3
2
1
0
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days
Plot
Depth Plot Output
Day number 3650
Depth (cm)
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160
0.0 0.2 0.4 0.6 0.8 1.0
Soil store (ug/kg)

Metribuzin simulation

Simulation 9: Jokioinen clay + Jokioinen climate

```
Compound : Metribuzin (Source = User-defined)
Soil : Jokioinen Clay1 (Source = User-defined)
Profile depth : 1.50 m
Groundwater at 1.5 m

Risk assessment : Average-case
Subsoil degradation : Proportional to organic carbon

Weather data : Jokioinen 1978-1999
Simulation from 19780101 to 19871231

Year  1  : Potato :          0.35 kg/hectare on day  155
Year  2  : Potato :          No applications
Year  3  : Potato :          0.35 kg/hectare on day  155
Year  4  : Potato :          No applications
Year  5  : Potato :          0.35 kg/hectare on day  155
Year  6  : Potato :          No applications
Year  7  : Potato :          0.35 kg/hectare on day  155
Year  8  : Potato :          No applications
Year  9  : Potato :          0.35 kg/hectare on day  155
Year 10  : Potato :          No applications
```

WATER BALANCE (mm)		PESTICIDE BALANCE (mg/ m^2)	
Precipitation	6360	Applied amount	175
Evapotranspiration	2660	Dissipated	141.71
Change in storage	60	Stored	11.73
Percolation	2490	Leached	0.35
Drainage	0	Lost to drains	0.00
Runoff	1150	Lost to runoff	21.20

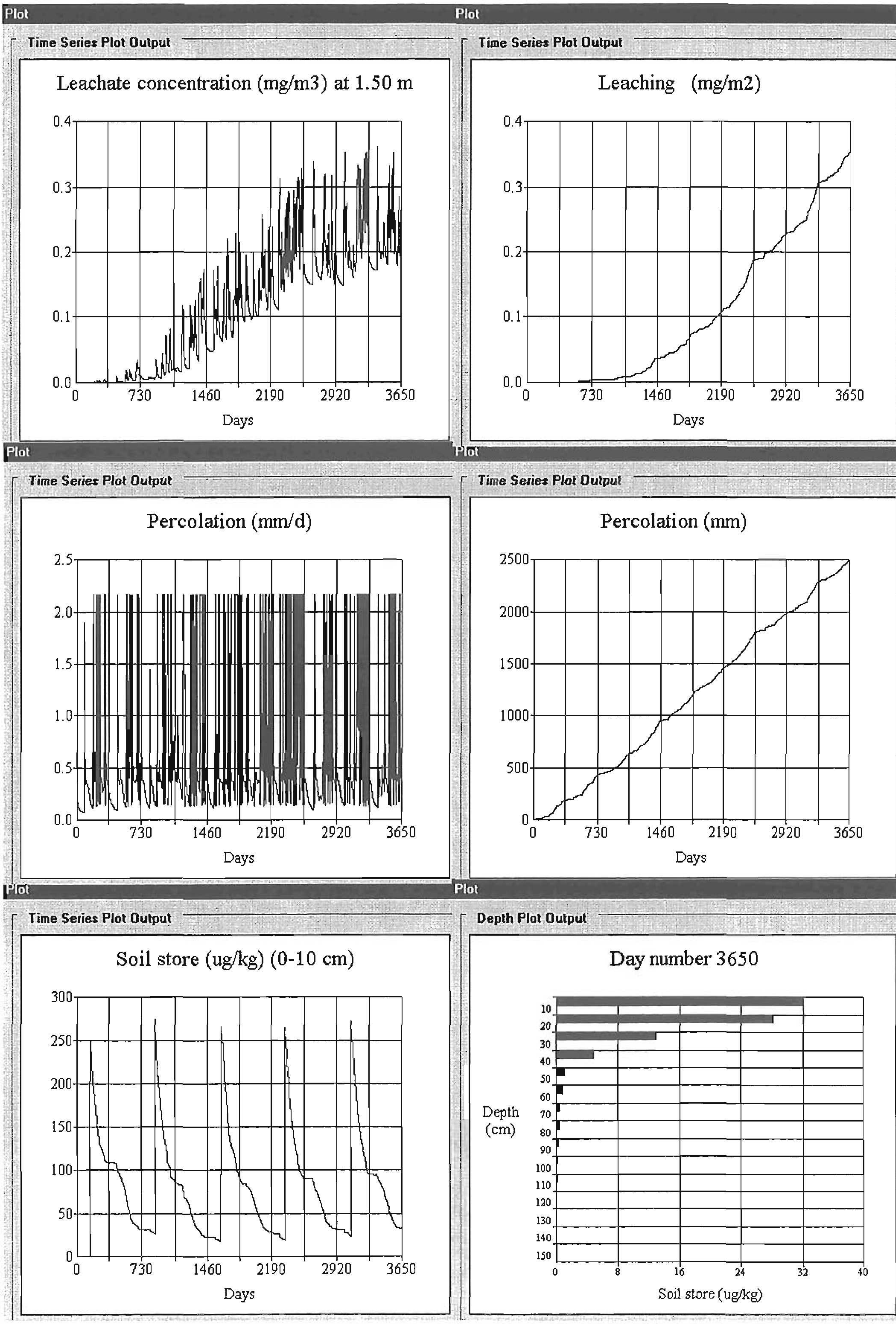
Pesticide balance

Leachate concentrations in groundwater (150 cm, fixed) were quite low for metribuzin but kept rising for the first 9 years. The concentration exceeded 0.1 µg/l in the fourth year of simulation, but a balancing trend could be observed on the tenth year. however, a longer simulation should be conducted in order to find out the trend for continuous use. The leachate concentrations exceeded the drinking water quality stardard (0.1 µg/l) clearly in the latter half of the simulation period. Surprisingly trace amounts of pesticide could be observed in 150 cm depth already in the first year, very soon after the first application, which is probably due to macropore flow. Very little of the applied amount leached into the groundwater but 12 % lost to runoff. 81 % dissipated.

Possibly due to the high leachability of the substance the concentrations in the plough layer decreased rapidly, and kept approximately on the same level after each application. Thus, no accumulation can be observed in the simulation results. Despite of this, it appears that the soil storage remains at the same level only, if the pesticide is not used in consecutive years.

Water balance

The scenario was simulated without drainage. 42 % of the precipitation was evapotranspirated. 39 % percolated through the soil. The share of runoff was much higher in potato cultivation than in oats (see tribenuron methyl simulation).


Plot
Time Series Plot Output
Leachate concentration (mg/m3) at 1.50 m
0.4
0.3
0.2
0.1
0.0
0
730
1460
2190
2920
3650
Days
Plot
Time Series Plot Output
Leaching (mg/m2)
0.4
0.3
0.2
0.1
0.0
0
730
1460
2190
2920
3650
Days
Plot
Time Series Plot Output
Percolation (mm/d)
2.5
2.0
1.5
1.0
0.5
0.0
0
730
1460
2190
2920
3650
Days
Plot
Time Series Plot Output
Percolation (mm)
2500
2000
1500
1000
500
0
0
730
1460
2190
2920
3650
Days
Plot
Time Series Plot Output
Soil store (ug/kg) (0-10 cm)
300
250
200
150
100
50
0
0
730
1460
2190
2920
3650
Days
Plot
Depth Plot Output
Day number 3650
Depth
(cm)
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
0
8
16
24
32
40
Soil store (ug/kg)

Simulation 10: Jokioinen Clay2 soil + Jokioinen climate

```
Compound : Metribuzin (Source = User-defined)
Soil : Jokioinen Clay2 (Source = User-defined)
Profile depth : 1.90 m
Groundwater at 1.9 m

Risk assessment : Average-case
Subsoil degradation : Proportional to organic carbon

Weather data : Jokioinen 1978-1999
Simulation from 19780101 to 19871231

Year  1  : Potato :        0.35 kg/hectare on day  155
Year  2  : Potato :        No applications
Year  3  : Potato :        0.35 kg/hectare on day  155
Year  4  : Potato :        No applications
Year  5  : Potato :        0.35 kg/hectare on day  155
Year  6  : Potato :        No applications
Year  7  : Potato :        0.35 kg/hectare on day  155
Year  8  : Potato :        No applications
Year  9  : Potato :        0.35 kg/hectare on day  155
Year 10  : Potato :        No applications
```

WATER BALANCE (mm)		PESTICIDE BALANCE (mg/ m^2)	
Precipitation	6360	Applied amount	175
Evapotranspiration	2520	Dissipated	140.50
Change in storage	60	Stored	12.76
Percolation	2650	Leached	1.84
Drainage	0	Lost to drains	0.00
Runoff	1130	Lost to runoff	19.90

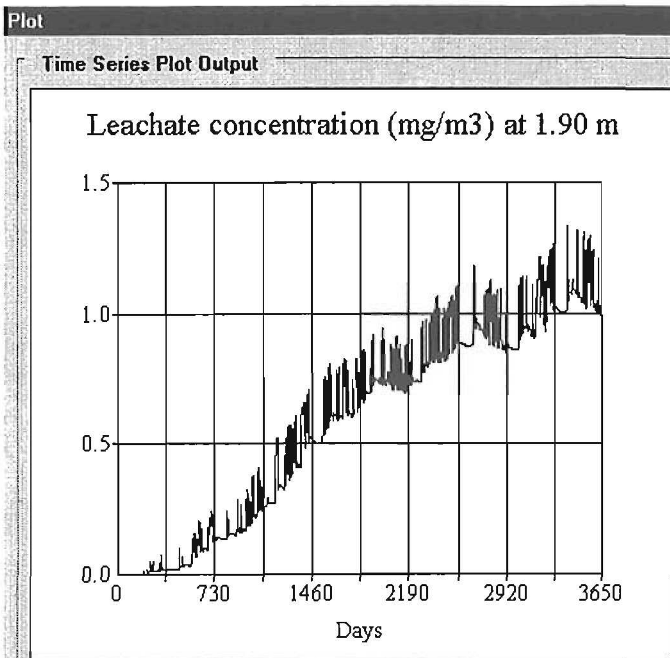
Pesticide balance

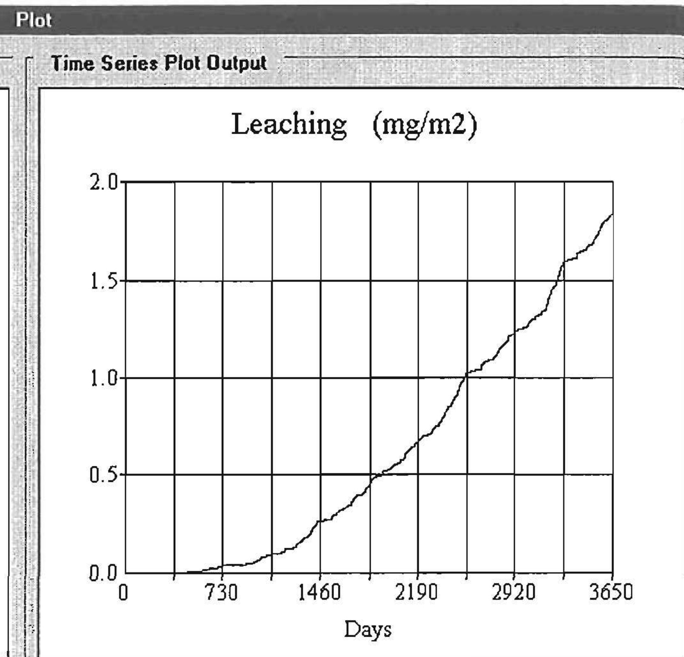
Leachate concentrations in groundwater (190 cm, fixed) were quite high (> 1 μg/l) in the end of the simulation period after rising for the first 9 years. The leachate concentrations exceeded clearly the drinking water quality values (0.1 μg/l) and threat the drinking water quality. The significance of the saturated conductivity can be seen in this example, as the the share of leached pesticide is manyfold compared to Clay1, though the groundwater level 40 cm deeper. Metribuzin leached into the groundwater already in the first year of use. 1 % of the applied amount was leached into the groundwater and 11 % lost to runoff. 80 % dissipated.

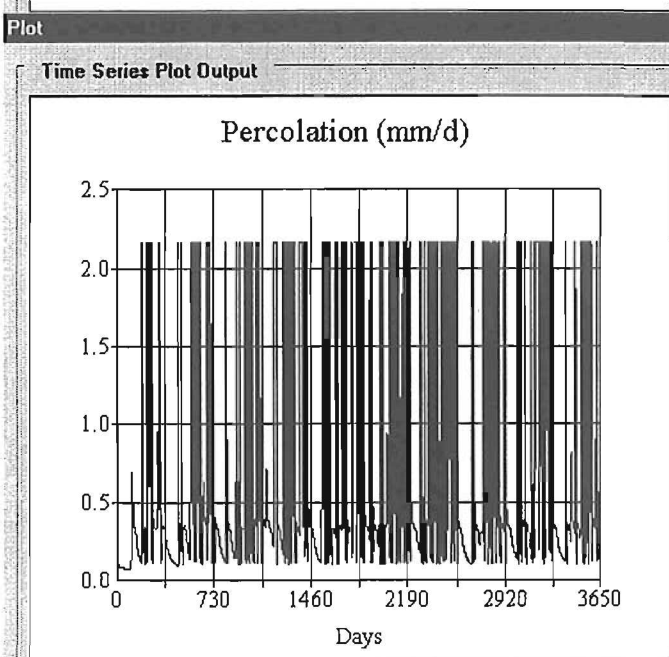
Possibly due to the high leachability of the substance the concentrations in soil decreased rapidly, though were about 100-fold compared to the concentrations of tribenuron methyl in the period following the pesticide application. Metribuzine was present in all the soil layers, concentrations decreasing towards the bottom. It appears that the soil storage remains at the same level, if the pesticide is used according to the instructions of use, not in consecutive years.

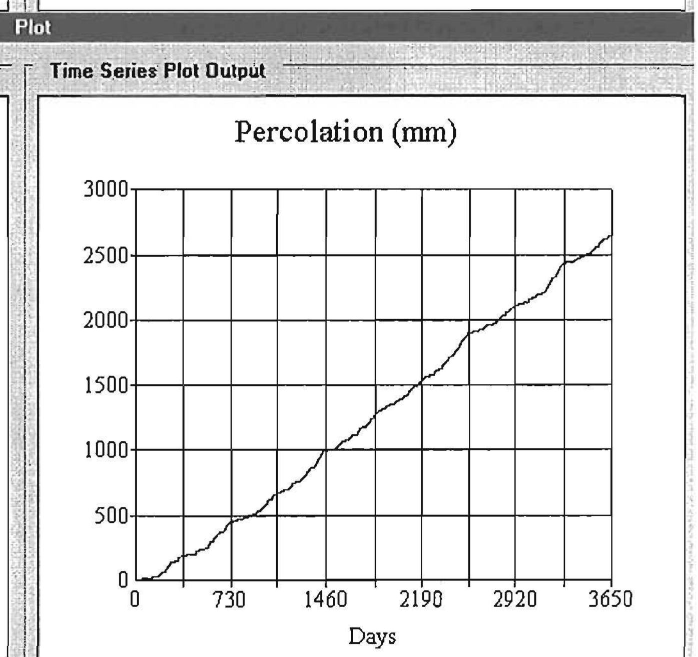
Water balance

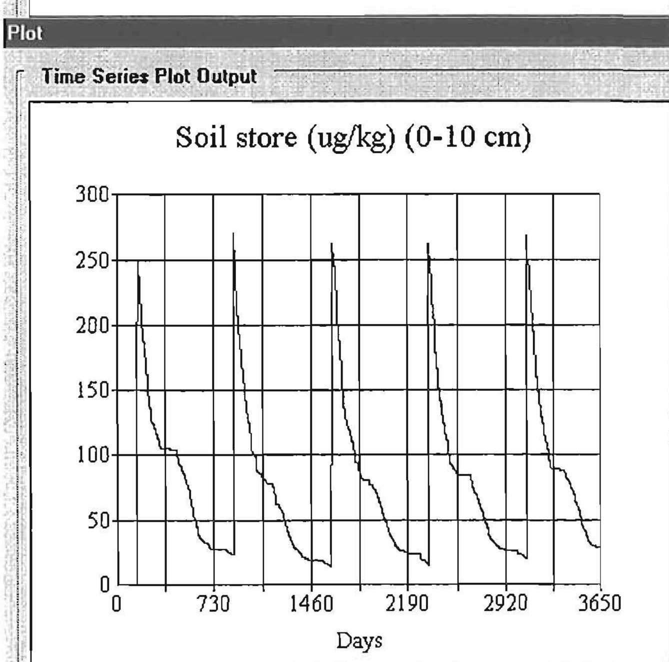
The scenario was simulated without drainage. 40 % of the precipitation was evapotranspirated. 42 % percolated through the soil. The share of runoff was much higher in potato cultivation than in oats (see tribenuron methyl simulation).

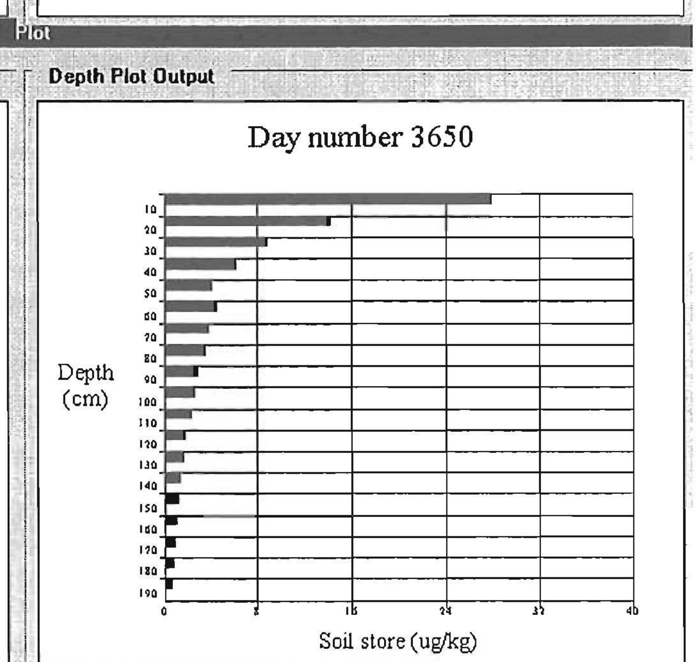

Plot
Time Series Plot Output
Leachate concentration (mg/m3) at 1.90 m
1.5
1.0
0.5
0.0
0
730
1460
2190
2920
3650
Days


Plot
Time Series Plot Output
Leaching (mg/m2)
2.0
1.5
1.0
0.5
0.0
0
730
1460
2190
2920
3650
Days


Plot
Time Series Plot Output
Percolation (mm/d)
2.5
2.0
1.5
1.0
0.5
0.0
0
730
1460
2190
2920
3650
Days


Plot
Time Series Plot Output
Percolation (mm)
3000
2500
2000
1500
1000
500
0
0
730
1460
2190
2920
3650
Days


Plot
Time Series Plot Output
Soil store (ug/kg) (0-10 cm)
300
250
200
150
100
50
0
0
730
1460
2190
2920
3650
Days


Plot
Depth Plot Output
Day number 3650
Depth (cm)
Soil store (ug/kg)

Simulation 11: Pälkäne 02 soil + Jokioinen climate

```
Compound : Metribuzin (Source = User-defined)
Soil : Pälkäne 02 (Source = User-defined)
Profile depth : 1.60 m
Groundwater at 1.6 m

Risk assessment : Average-case
Subsoil degradation : Proportional to organic carbon

Weather data : Jokioinen 1978-1999
Simulation from 19780101 to 19871231
Year  1  : Potato :        0.35 kg/hectare on day  155
Year  2  : Potato :        No applications
Year  3  : Potato :        0.35 kg/hectare on day  155
Year  4  : Potato :        No applications
Year  5  : Potato :        0.35 kg/hectare on day  155
Year  6  : Potato :        No applications
Year  7  : Potato :        0.35 kg/hectare on day  155
Year  8  : Potato :        No applications
Year  9  : Potato :        0.35 kg/hectare on day  155
Year  10 : Potato :        No applications
```

WATER BALANCE (mm)		PESTICIDE BALANCE (mg/ m^2)	
Precipitation	6360	Applied amount	175.00
Evapotranspiration	3720	Dissipated	144.35
Change in storage	80	Stored	22.81
Percolation	2560	Leached	7.84
Drainage	0	Lost to drains	0.00
Runoff	0	Lost to runoff	0.00

Pesticide balance

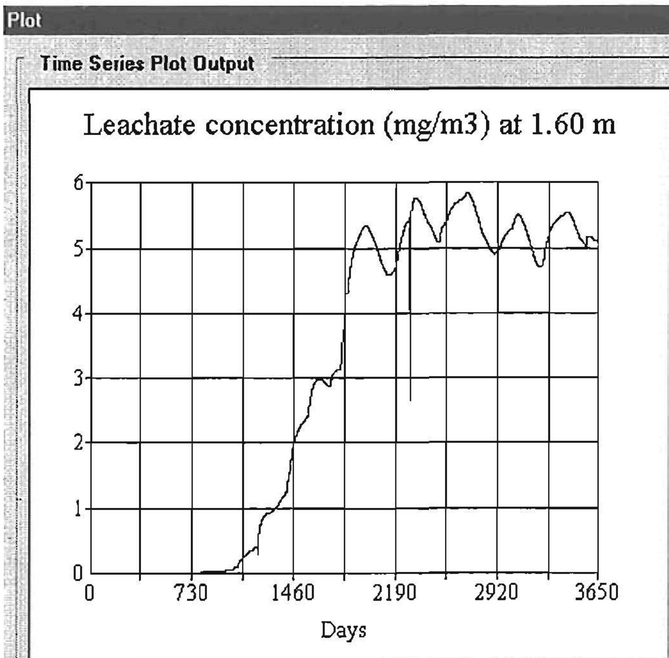
Leachate concentrations in groundwater (160 cm, fixed) were very high and rose until year 6. The leachate concentrations balanced in year 6 and remained at approximately 5 μg/l until the end of simulation. The leaching below 160 cm layer started approximately 2 years after the start of use.

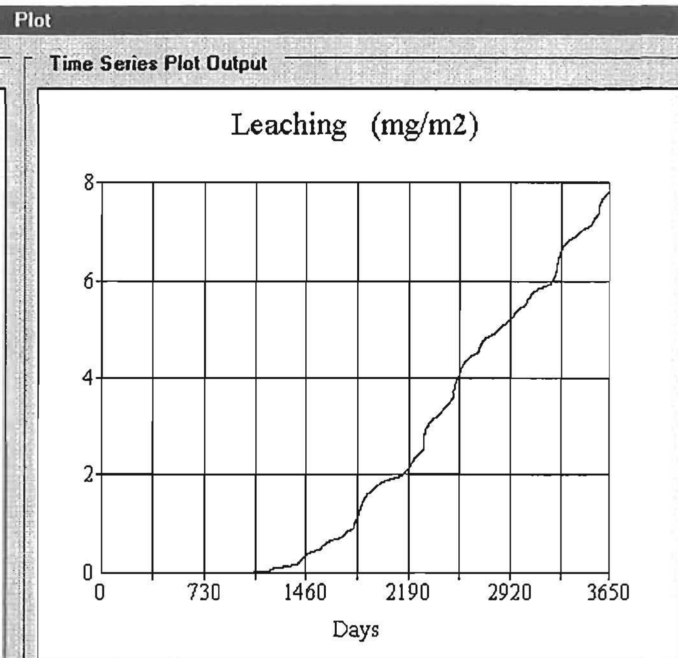
The leachate concentrations exceeded clearly the drinking water quality values (0.1 μg/l) and threat the drinking water quality. Totally, 4.5 % of the applied amount was leached into the groundwater but none lost to runoff. Surprisingly, as Pälkäne soil is more permeable than Jokioinen soil used in previous simulation and the groundwater level is higher, the substance entered the groundwater slower. The high permeability can be seen in the lack of runoff.

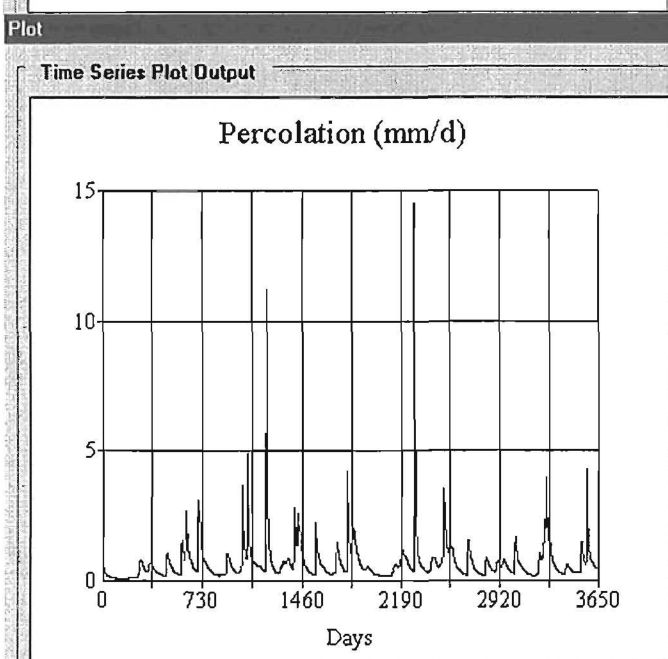
It appears that the soil storage in the plough layer remains at the same level year after year, if the pesticide is not used in consecutive years. However, the depth plot reveals the pesticide not only dissipating but also gradually getting into deeper layers where the degradation is slower. It would have been important to continue the simulation to see whether the high concentrations in top soil layers eventually would affect the groundwater concentrations. 82 % of the applied substance dissipated.

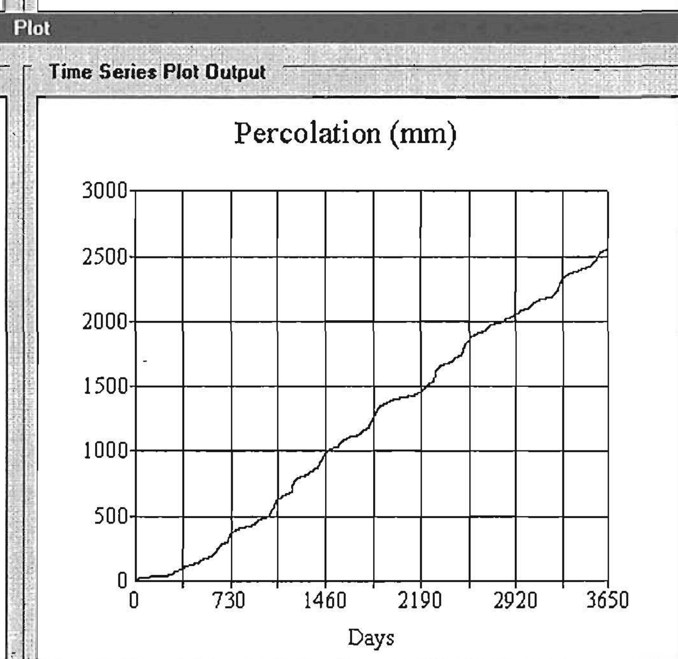
Water balance

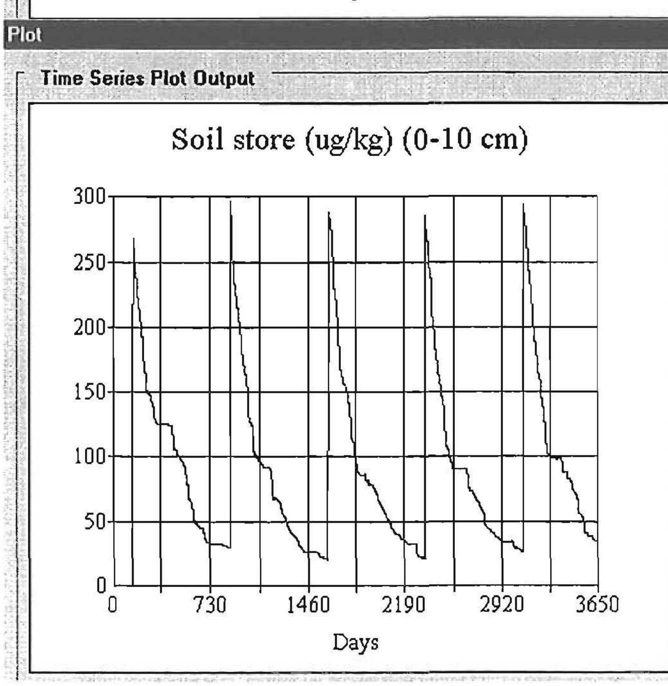
The scenario was simulated without drainage. 58 % of the precipitation was evapotranspirated. 40 % was percolated through the soil. Unlike with Jokioinen Clay2 soil, where the share of runoff was much higher in potato cultivation than in oats (see tribenuron methyl simulation), there was no calculated runoff in this scenario.

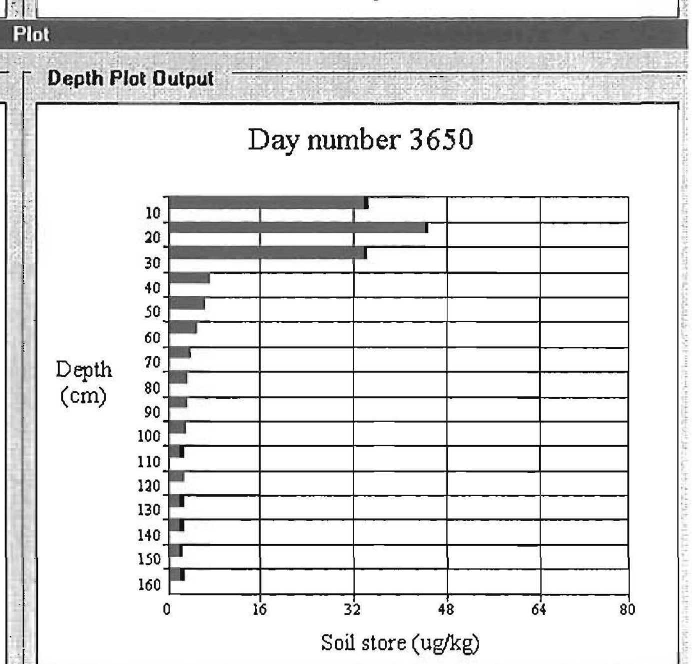

Plot
Time Series Plot Output
Leachate concentration (mg/m3) at 1.60 m
0 1 2 3 4 5 6
0 730 1460 2190 2920 3650
Days


Plot
Time Series Plot Output
Leaching (mg/m2)
0 2 4 6 8
0 730 1460 2190 2920 3650
Days


Plot
Time Series Plot Output
Percolation (mm/d)
0 5 10 15
0 730 1460 2190 2920 3650
Days


Plot
Time Series Plot Output
Percolation (mm)
0 500 1000 1500 2000 2500 3000
0 730 1460 2190 2920 3650
Days


Plot
Time Series Plot Output
Soil store (ug/kg) (0-10 cm)
0 50 100 150 200 250 300
0 730 1460 2190 2920 3650
Days


Plot
Depth Plot Output
Day number 3650
Depth (cm)
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160
0 16 32 48 64 80
Soil store (ug/kg)

Simulation 12: Västerby soil + Jokioinen climate

Compound : Metribuzin (Source = User-defined)
Soil : VÄSTERBY (Source = MARKDATA)
Profile depth : 1.50 m
Groundwater at 1.5 m

Risk assessment : Average-case
Subsoil degradation : Proportional to organic carbon

Weather data : Jokioinen 1978-1999
Simulation from 19780101 to 19871231

Year	1	: Potato :	0.35 kg/hectare on day 155
Year	2	: Potato :	No applications
Year	3	: Potato :	0.35 kg/hectare on day 155
Year	4	: Potato :	No applications
Year	5	: Potato :	0.35 kg/hectare on day 155
Year	6	: Potato :	No applications
Year	7	: Potato :	0.35 kg/hectare on day 155
Year	8	: Potato :	No applications
Year	9	: Potato :	0.35 kg/hectare on day 155
Year	10	: Potato :	No applications

WATER BALANCE (mm)		PESTICIDE BALANCE (mg/m^2)	
Precipitation	6360	Applied amount	175.00
Evapotranspiration	3240	Dissipated	114.79
Change in storage	55	Stored	18.31
Percolation	2620	Leached	31.70
Drainage	0	Lost to drains	0.00
Runoff	445	Lost to runoff	10.20

Pesticide balance

Leachate concentrations in groundwater (150 cm, fixed) were very high and rose until the last year of simulation. The concentration seemed to level at 16-17 µg/l. The leaching into the groundwater started very soon after the start of use. The leachate concentrations exceeded clearly the drinking water quality values (0.1 µg/l) and threat the drinking water quality.

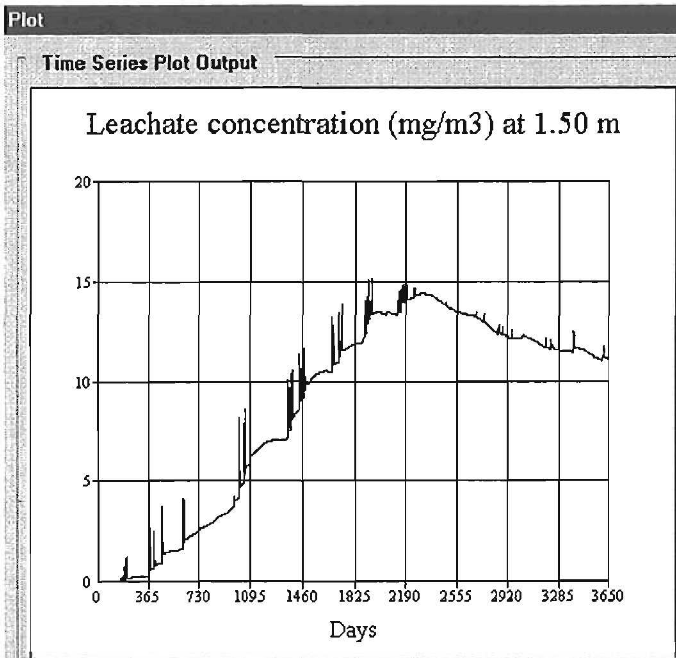
Totally, 18 % of the applied amount during the simulation period was leached into the groundwater and 6 % was lost to runoff. Probably, the fast entry of pesticide into the groundwater owes to the presence of macropores, as the soil is heavy clay.

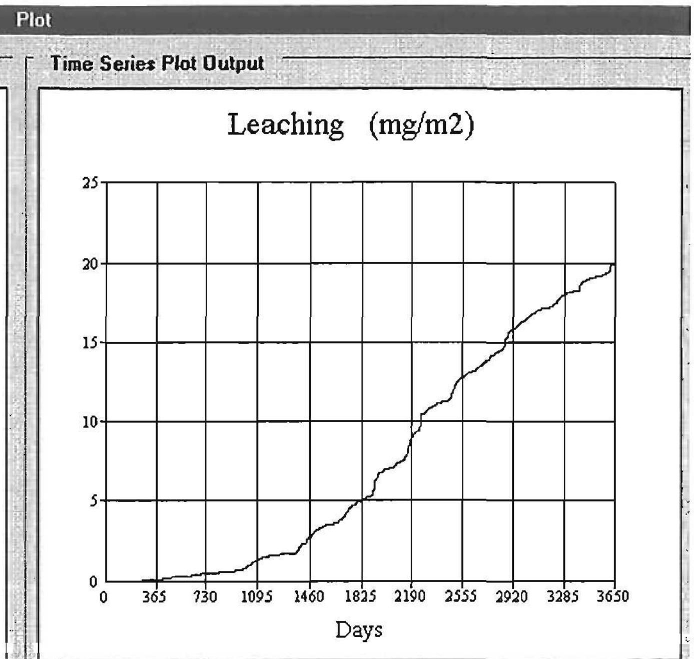
It appears that the soil storage remains in the plough layer at the same level, if the pesticide is used according to the instructions of use, not in consecutive years. The depth plot reveals the pesticide not only dissipating (66 %) but also gradually getting into deeper layers where the degradation is slower. The concentrations in deeper soil layers were very high compared to Finnish soils. Thus the pesticide can be found all through the soil matrix in considerable concentrations (5-9 µg/kg). The soil store also explains the levelling of the pesticide concentration in leaching.

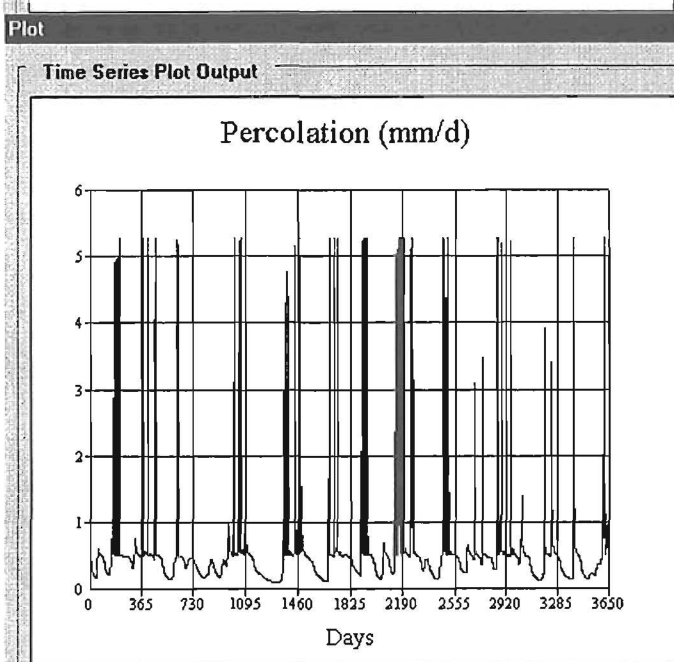
Water balance

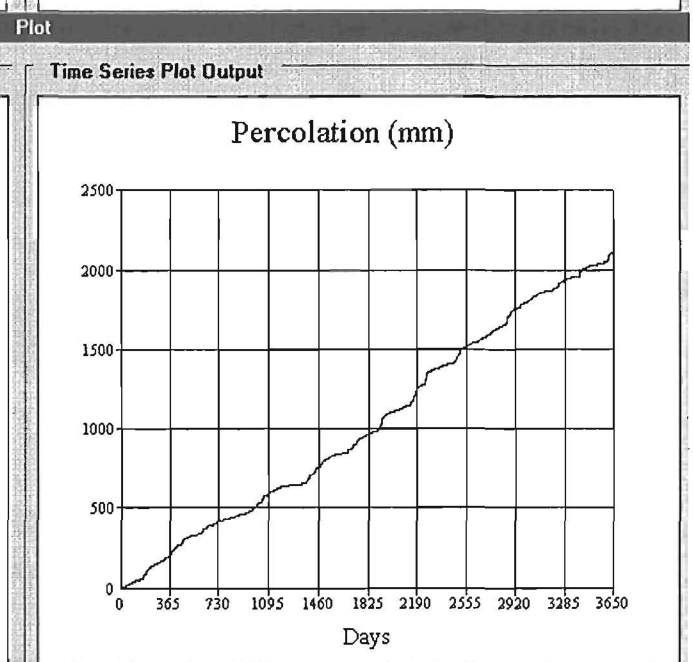
The scenario was simulated without drainage. 51 % of the precipitation was evapotranspirated. 41 % percolated through the soil.

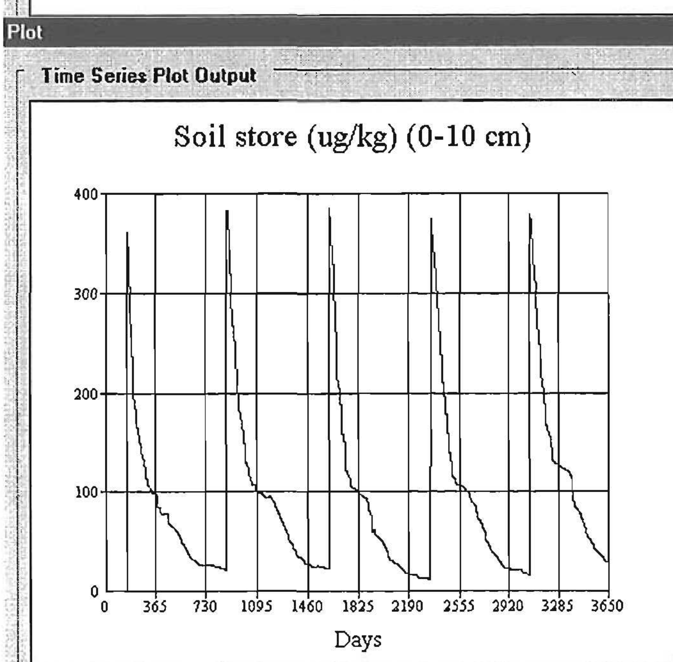
All in all, the pesticide leaches deeper so fast, that there is no time for dissipation.

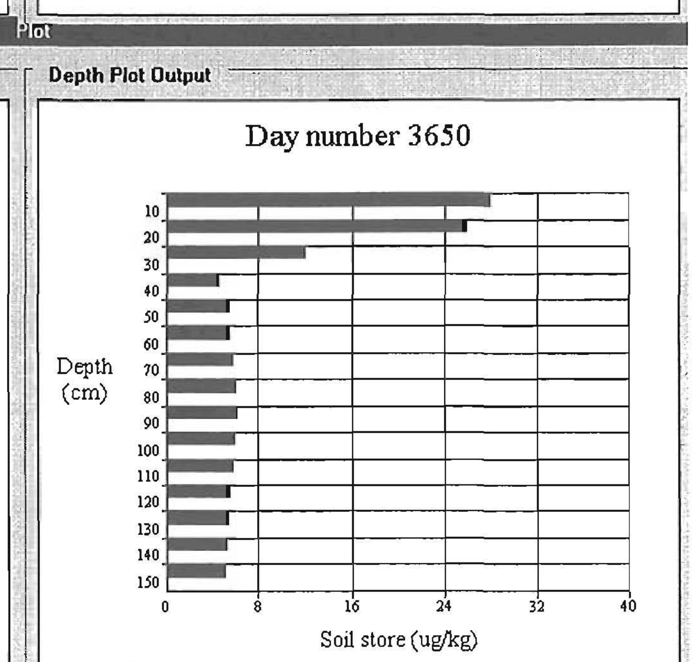

Plot
Time Series Plot Output
Leachate concentration (mg/m3) at 1.50 m
0
5
10
15
20
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Time Series Plot Output
Leaching (mg/m2)
0
5
10
15
20
25
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Time Series Plot Output
Percolation (mm/d)
0
1
2
3
4
5
6
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Time Series Plot Output
Percolation (mm)
0
500
1000
1500
2000
2500
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Time Series Plot Output
Soil store (ug/kg) (0-10 cm)
0
100
200
300
400
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Depth Plot Output
Day number 3650
Depth (cm)
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
0 8 16 24 32 40
Soil store (ug/kg)

Simulation 13: Västerby soil + Uppsala climate

```
Compound : Metribuzin (Source = User-defined)
Soil : VÄSTERBY (Source = MARKDATA)
Profile depth : 1.50 m
Groundwater at 1.5 m

Risk assessment : Average-case
Subsoil degradation : Proportional to organic carbon

Weather data : Uppsala
Simulation from 19610101 to 19701231

Year  1  : Potato :        0.35 kg/hectare on day  155
Year  2  : Potato :        No applications
Year  3  : Potato :        0.35 kg/hectare on day  155
Year  4  : Potato :        No applications
Year  5  : Potato :        0.35 kg/hectare on day  155
Year  6  : Potato :        No applications
Year  7  : Potato :        0.35 kg/hectare on day  155
Year  8  : Potato :        No applications
Year  9  : Potato :        0.35 kg/hectare on day  155
Year 10  : Potato :        No applications
```

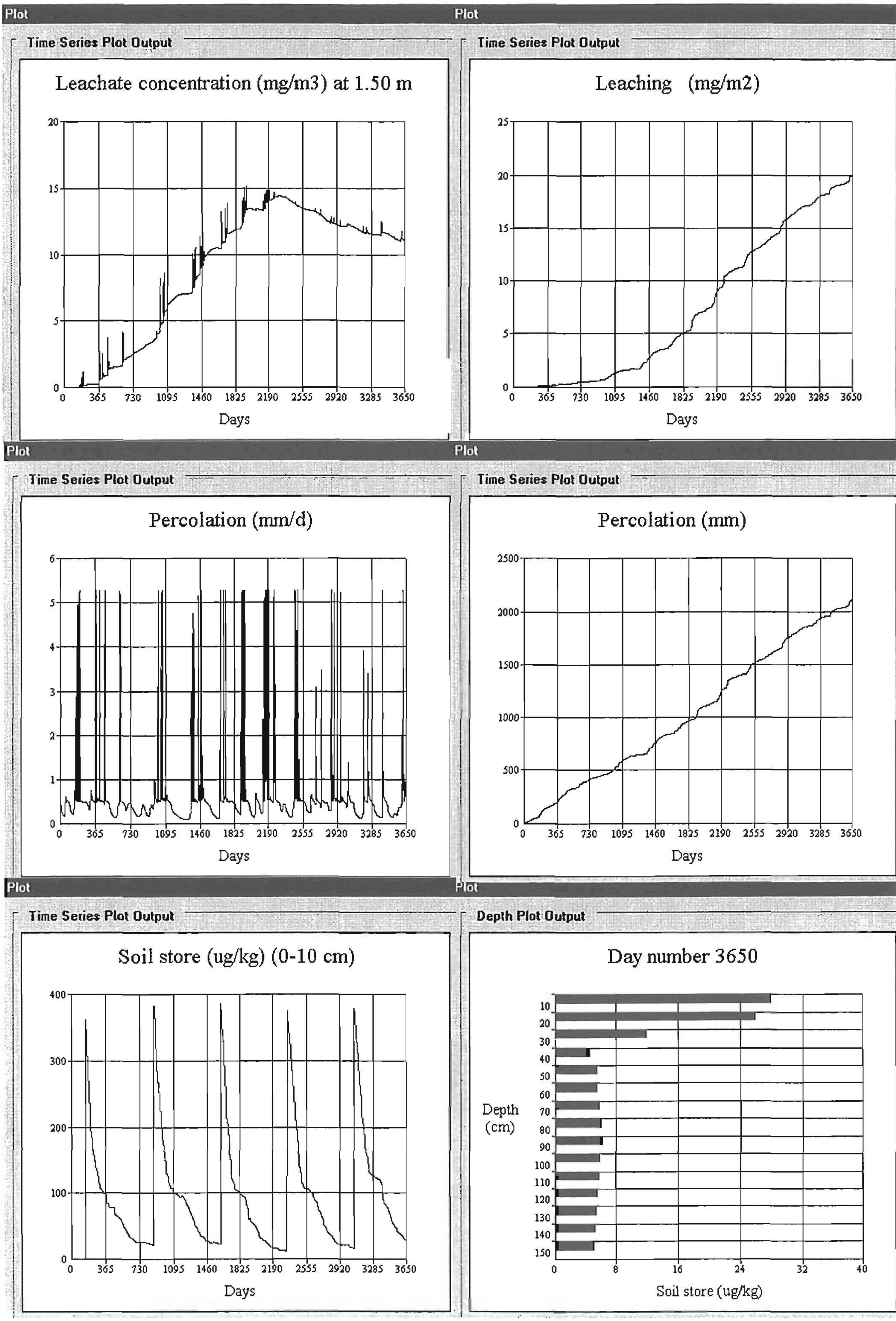
WATER BALANCE (mm)		PESTICIDE BALANCE (mg/ m^2)	
Precipitation	4900	Applied amount	175.00
Evapotranspiration	2440	Dissipated	131.97
Change in storage	33	Stored	15.30
Percolation	2120	Leached	20.10
Drainage	0	Lost to drains	0.00
Runoff	307	Lost to runoff	7.63

PESTICIDE BALANCE

The leachate concentration started rising already in the first year. Metribuzine concentration grew steadily until year 7, when it started decreasing. The total leached amount was 11 % of the addition. However, the soil store was higher in the plough layer, as the concentrations in deeper compartments were generally a bit lower than with Jokioinen climate. Also in this case, the prohibition of use in consecutive years gave the soil enough time to dissipate the pesticide bound and thus the concentrations in the topsoil were approximately the same every year and there seemed to be no increasing cumulation. However, each year the winter time concentrations in top soil were higher than before.
With Uppsala climate the amount of metribuzine dissipated was a bit higher than with Jokioinen climate (132 mg/m2 and 113 mg/m2, respectively).

WATER BALANCE

50 % of the water was evapotranspirated. 43 % percolated through the soil matrix.


Plot
Time Series Plot Output
Leachate concentration (mg/m3) at 1.50 m
Days
Plot
Time Series Plot Output
Leaching (mg/m2)
Days
Plot
Time Series Plot Output
Percolation (mm/d)
Days
Plot
Time Series Plot Output
Percolation (mm)
Days
Plot
Time Series Plot Output
Soil store (ug/kg) (0-10 cm)
Days
Plot
Depth Plot Output
Day number 3650
Depth (cm)
Soil store (ug/kg)

Simulation 14: Jokioinen Clay1 + Uppsala

```
Compound : Metribuzin (Source = User-defined)
Soil : Jokioinen Clay1 (Source = User-defined)
Profile depth : 1.50 m
Groundwater at 1.5 m

Risk assessment : Average-case
Subsoil degradation : Proportional to organic carbon

Weather data : Uppsala
Simulation from 19610101 to 19701231

Year  1  : Potato :         0.35 kg/hectare on day  155
Year  2  : Potato :         No applications
Year  3  : Potato :         0.35 kg/hectare on day  155
Year  4  : Potato :         No applications
Year  5  : Potato :         0.35 kg/hectare on day  155
Year  6  : Potato :         No applications
Year  7  : Potato :         0.35 kg/hectare on day  155
Year  8  : Potato :         No applications
Year  9  : Potato :         0.35 kg/hectare on day  155
Year  10 : Potato :         No applications
```

WATER BALANCE (mm)		PESTICIDE BALANCE (mg/ m^2)	
Precipitation	4900	Applied amount	175.00
Evapotranspiration	2060	Dissipated	150.78
Change in storage	27	Stored	9.24
Percolation	2040	Leached	0.09
Drainage	0	Lost to drains	0.00
Runoff	774	Lost to runoff	14.90

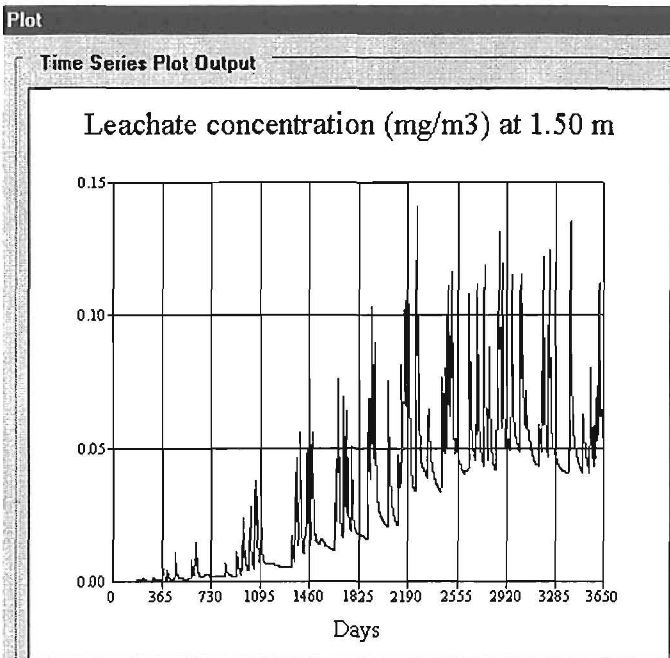
PESTICIDE BALANCE

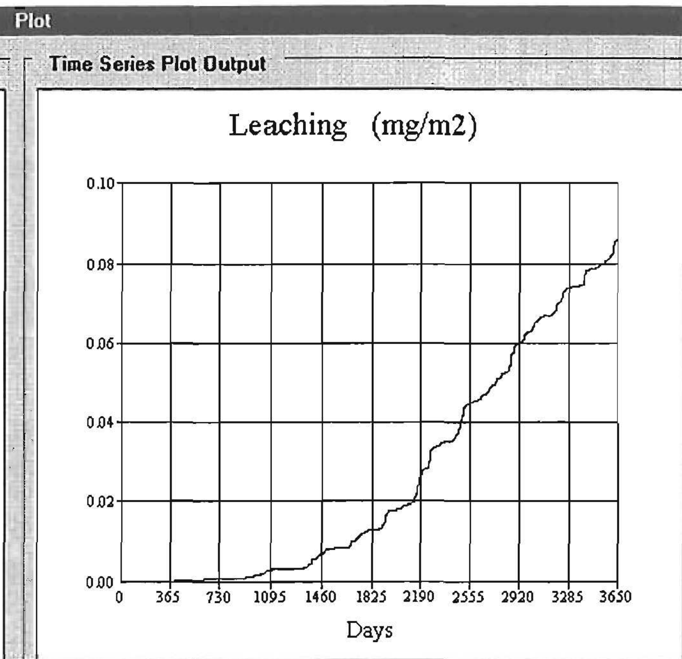
The substance started leaching soon also in this case. Metribuzine concentration grew steadily until year 9, but was still very low, 0.05 µg/l. However, the undegraded share of substance appears to have stuck on soil plough layer, as the concentrations are very high. Also in this case, the use of metribuzin every other year gave the soil enough time to dissipate the pesticide bound and thus the concentrations in the topsoil were approximately the same every year and there was very little increase in concentrations preceding the new application.

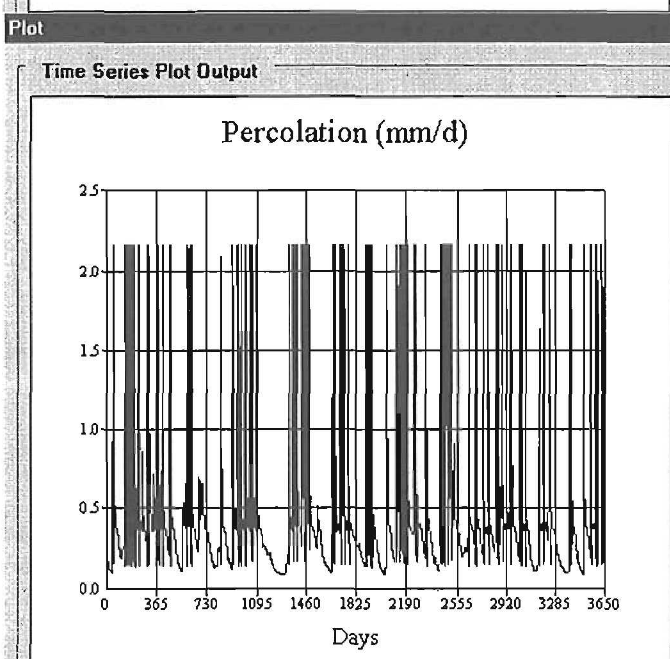
With Uppsala climate the amount of metribuzine dissipated was a bit higher than with Jokioinen climate (151 mg/m2 and 142 mg/m2, respectively).

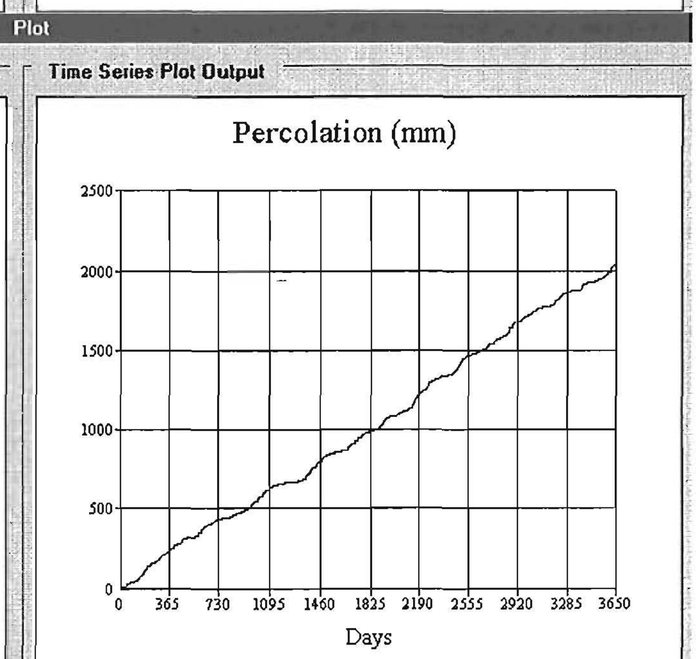
WATER BALANCE

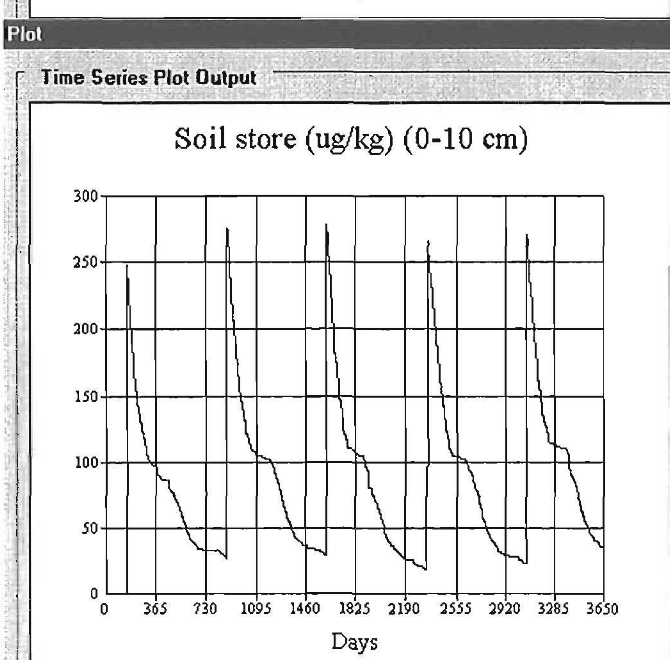
42 % of the water was evapotranspirated. 42 % percolated through the soil matrix.

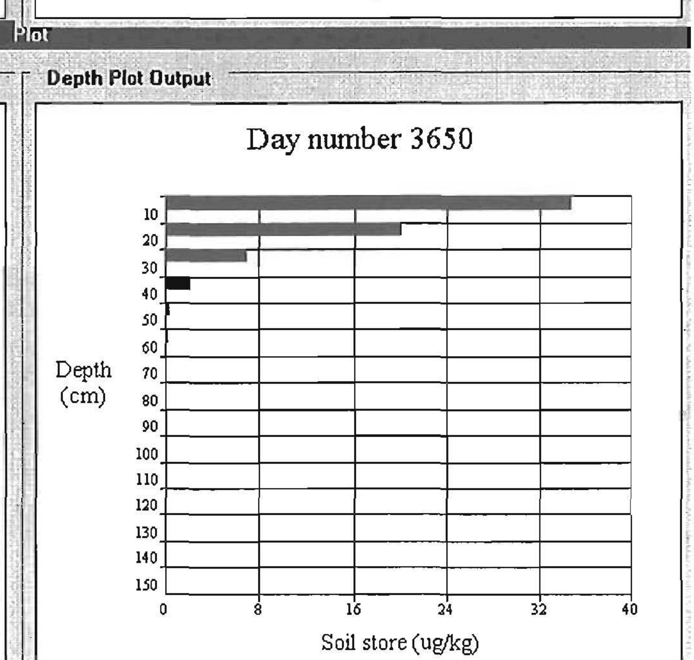

Plot
Time Series Plot Output
Leachate concentration (mg/m3) at 1.50 m
0.15
0.10
0.05
0.00
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Time Series Plot Output
Leaching (mg/m2)
0.10
0.08
0.06
0.04
0.02
0.00
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Time Series Plot Output
Percolation (mm/d)
2.5
2.0
1.5
1.0
0.5
0.0
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Time Series Plot Output
Percolation (mm)
2500
2000
1500
1000
500
0
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Time Series Plot Output
Soil store (ug/kg) (0-10 cm)
300
250
200
150
100
50
0
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Depth Plot Output
Day number 3650
Depth (cm)
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
0 8 16 24 32 40
Soil store (ug/kg)

Simulation 15: Jokioinen Clay2 + Uppsala

```
Compound : Metribuzin (Source = User-defined)
Soil : Jokioinen Clay2 (Source = User-defined)
Profile depth : 1.90 m
Groundwater at 1.9 m

Risk assessment : Average-case
Subsoil degradation : Proportional to organic carbon

Weather data : Uppsala
Simulation from 19610101 to 19701231

Year  1  : Potato :          0.35 kg/hectare on day  155
Year  2  : Potato :          No applications
Year  3  : Potato :          0.35 kg/hectare on day  155
Year  4  : Potato :          No applications
Year  5  : Potato :          0.35 kg/hectare on day  155
Year  6  : Potato :          No applications
Year  7  : Potato :          0.35 kg/hectare on day  155
Year  8  : Potato :          No applications
Year  9  : Potato :          0.35 kg/hectare on day  155
Year  10 : Potato :          No applications
```

WATER BALANCE (mm)		PESTICIDE BALANCE (mg/m^2)	
Precipitation	4900	Applied amount	175.00
Evapotranspiration	1950	Dissipated	151.32
Change in storage	47	Stored	9.67
Percolation	2170	Leached	0.61
Drainage	0	Lost to drains	0.00
Runoff	733	Lost to runoff	13.40

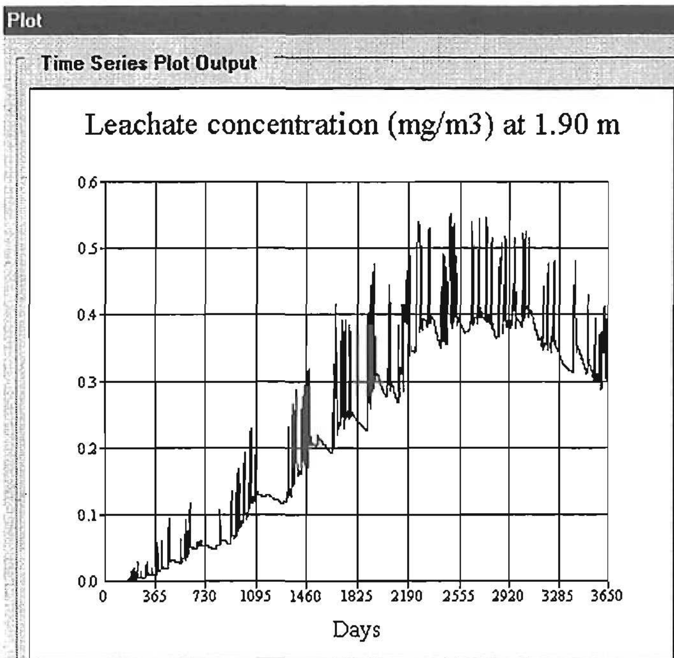
PESTICIDE BALANCE

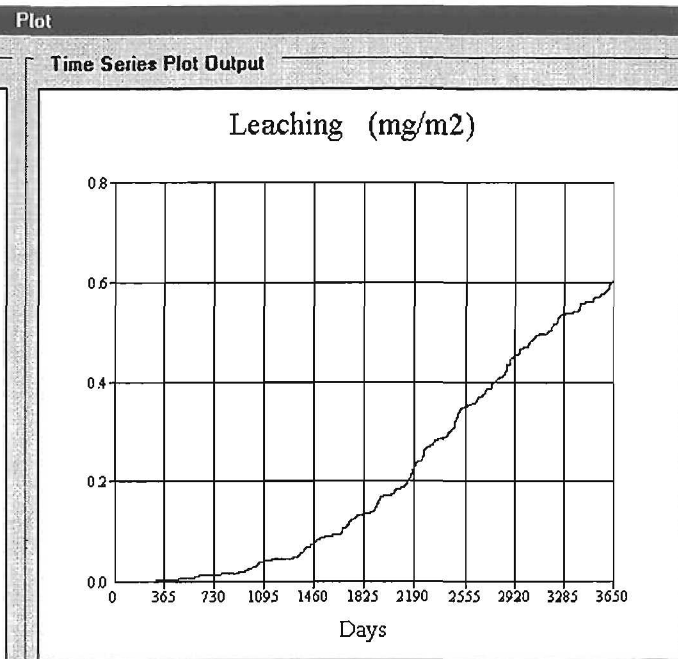
The substance leached soon after the first application. Metribuzine concentration grew steadily until year 7, and was 0.4 μg/l. In year 9 the concentration started decreasing. The total leached amount was less than 0.5 % of the addition. The undegraded share of substance, however, appears to have stuck on soil plough layer, as the concentrations are higher than with Jokioinen climate. Also in this case, the use of metribuzin every other year gave the soil enough time to dissipate the pesticide bound and thus the concentrations in the topsoil were approximately the same every year and there was very little increase in concentrations preceding the new application.

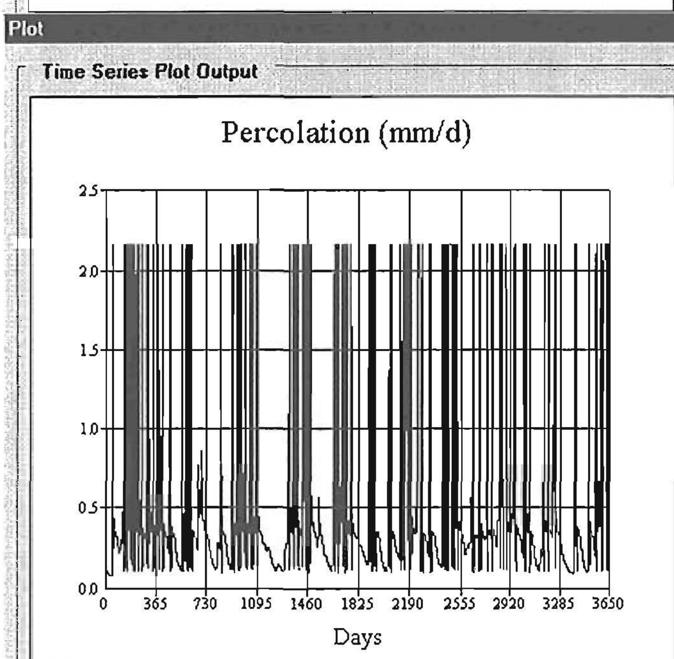
With Uppsala climate the amount of metribuzine dissipated was a bit higher than with Jokioinen climate (151 mg/m2 and 141 mg/m2, respectively). Compared to Clay1, the leaching was again higher and thanks to the higher saturated conductivity, runoff a little smaller.

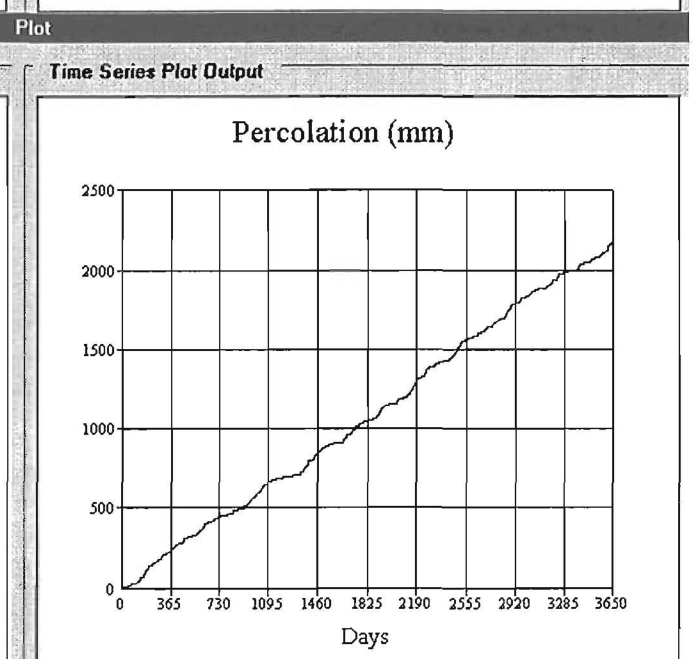
WATER BALANCE

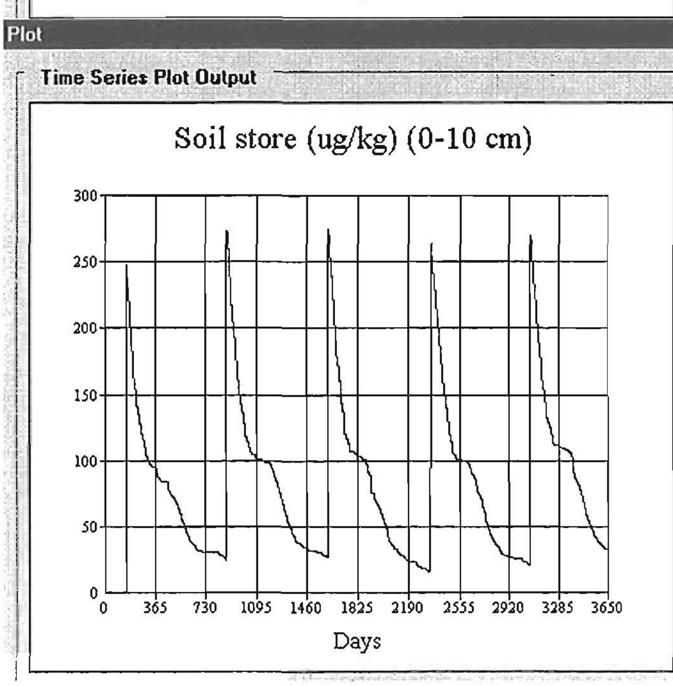
40 % of the water was evapotranspirated. 44 % percolated through the soil matrix.

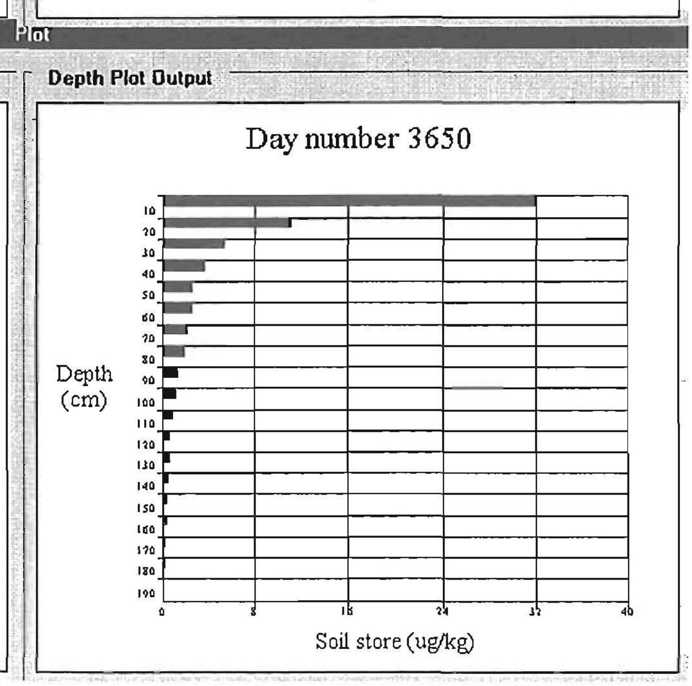

Plot
Time Series Plot Output
Leachate concentration (mg/m3) at 1.90 m
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Time Series Plot Output
Leaching (mg/m2)
0.0
0.2
0.4
0.6
0.8
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Time Series Plot Output
Percolation (mm/d)
0.0
0.5
1.0
1.5
2.0
2.5
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Time Series Plot Output
Percolation (mm)
0
500
1000
1500
2000
2500
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Time Series Plot Output
Soil store (ug/kg) (0-10 cm)
0
50
100
150
200
250
300
0 365 730 1095 1460 1825 2190 2555 2920 3285 3650
Days


Plot
Depth Plot Output
Day number 3650
Depth (cm)
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190
0 8 16 24 32 40
Soil store (ug/kg)

Simulation 16: Pälkäne 02 + Uppsala

Compound : Metribuzin (Source = User-defined)
Soil : Pälkäne 02 (Source = User-defined)
Profile depth : 1.60 m
Groundwater at 1.6 m

Risk assessment : Average-case
Subsoil degradation : Proportional to organic carbon

Weather data : Uppsala
Simulation from 19610101 to 19701231

Year 1 : Potato : 0.35 kg/hectare on day 155
Year 2 : Potato : No applications
Year 3 : Potato : 0.35 kg/hectare on day 155
Year 4 : Potato : No applications
Year 5 : Potato : 0.35 kg/hectare on day 155
Year 6 : Potato : No applications
Year 7 : Potato : 0.35 kg/hectare on day 155
Year 8 : Potato : No applications
Year 9 : Potato : 0.35 kg/hectare on day 155
Year 10 : Potato : No applications

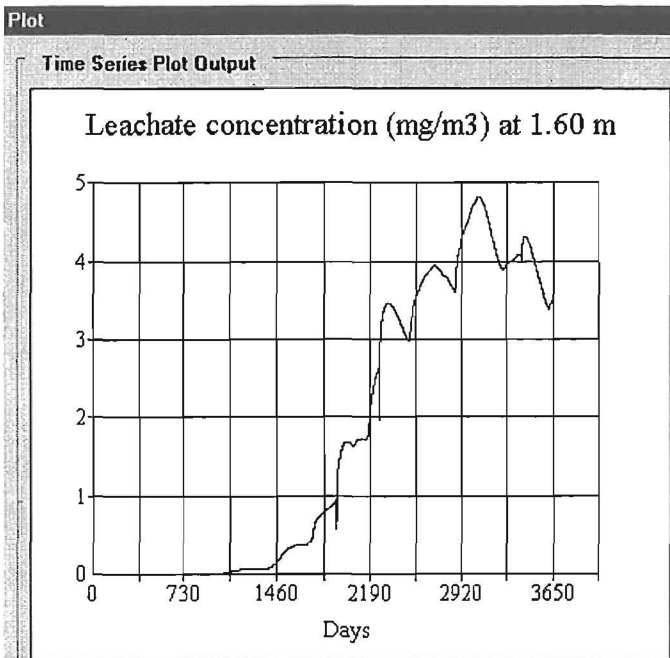
WATER BALANCE (mm)		PESTICIDE BALANCE (mg/ m^2)	
Precipitation	4900	Applied amount	175.00
Evapotranspiration	2690	Dissipated	151.99
Change in storage	60	Stored	19.13
Percolation	2150	Leached	3.88
Drainage	0	Lost to drains	0.00
Runoff	0	Lost to runoff	0.00

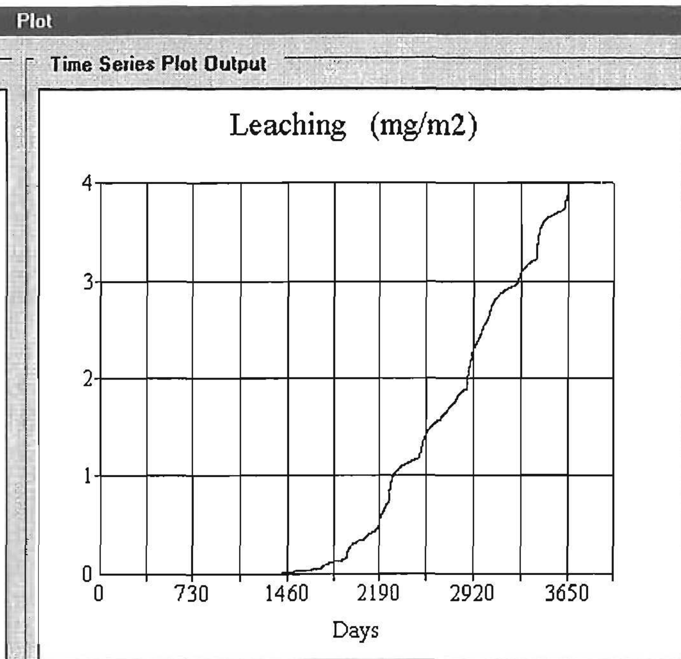
PESTICIDE BALANCE

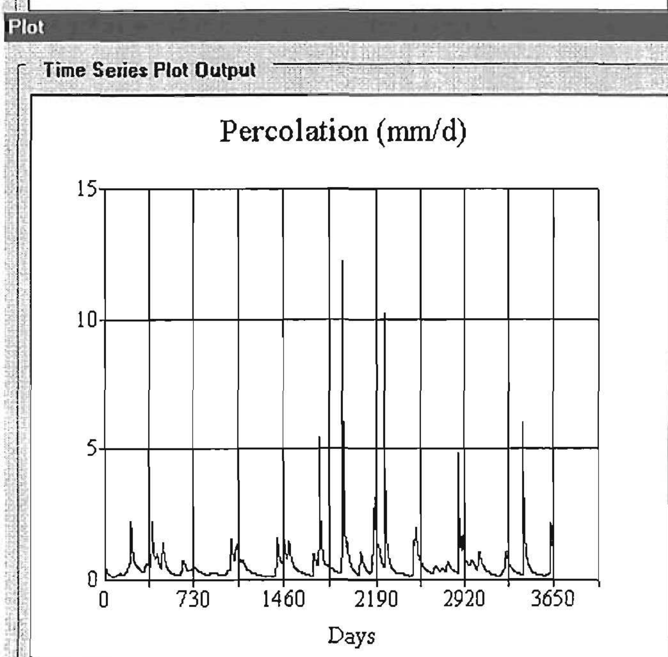
The substance started leaching below 160 cm layer in year 3. Metribuzine concentration grew steadily until year 7, when it started decreasing. The total leached amount was only 2 % of the addition. The soil store was high in the plough layer, and the substance was degraded for the most in it ((87 %). Also in this case, the use of metribuzine only every two years gave the soil enough time to dissipate the pesticide bound and thus the concentrations in the topsoil remained approximately the same every year and there seemed to be no increasing cumulation. However, each year the winter time concentrations in top soil were higher than before.
With Uppsala climate the amount of metribuzine dissipated was a bit higher than with Jokioinen climate (152 mg/m2 and 144 mg/m2, respectively).

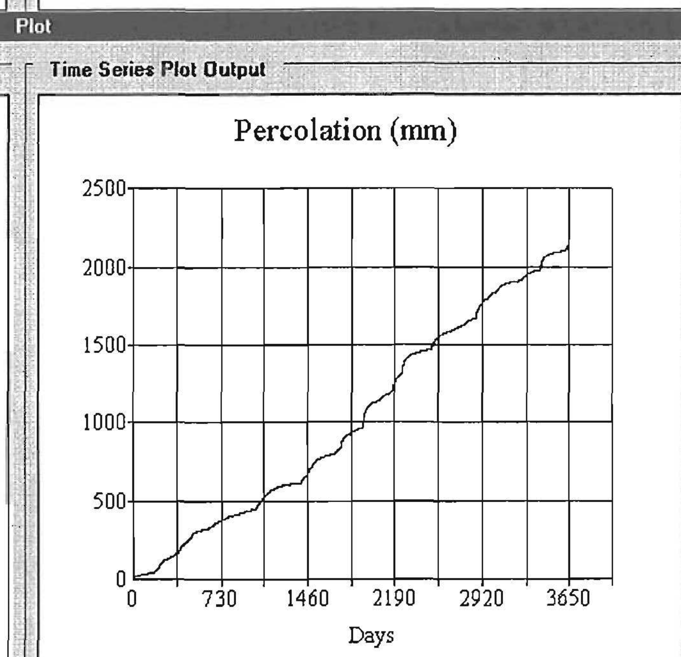
WATER BALANCE

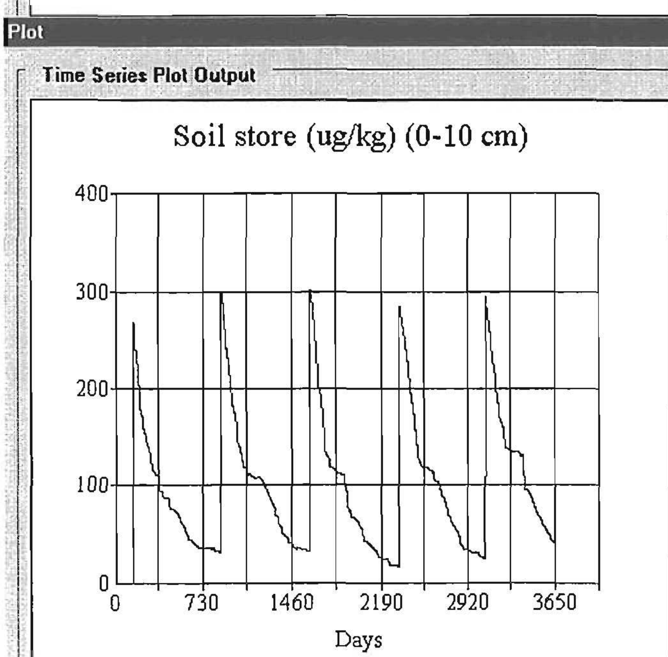
55 % of the water was evapotranspirated. 44 % percolated through the soil matrix.

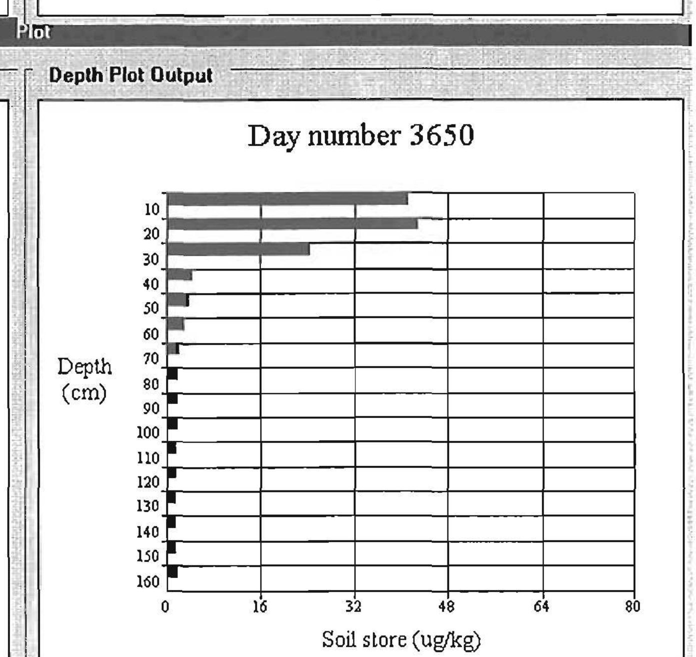

Plot
Time Series Plot Output
Leachate concentration (mg/m3) at 1.60 m
5
4
3
2
1
0
0
730
1460
2190
2920
3650
Days


Plot
Time Series Plot Output
Leaching (mg/m2)
4
3
2
1
0
0
730
1460
2190
2920
3650
Days


Plot
Time Series Plot Output
Percolation (mm/d)
15
10
5
0
0
730
1460
2190
2920
3650
Days


Plot
Time Series Plot Output
Percolation (mm)
2500
2000
1500
1000
500
0
0
730
1460
2190
2920
3650
Days


Plot
Time Series Plot Output
Soil store (ug/kg) (0-10 cm)
400
300
200
100
0
0
730
1460
2190
2920
3650
Days


Plot
Depth Plot Output
Day number 3650
Depth (cm)
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
0
16
32
48
64
80
Soil store (ug/kg)

Ethofumesate simulation

Simulation 17: Jokioinen Clay1 soil + Jokioinen climate

Compound : Ethofumesate (Source = User-defined)
Soil : Jokioinen Clay1 (Source = User-defined)
Profile depth : 1.50 m
Groundwater at 1.5 m

Risk assessment : Average-case
Subsoil degradation : Proportional to organic carbon

Weather data : Jokioinen 1978-1999
Simulation from 19780101 to 19831231

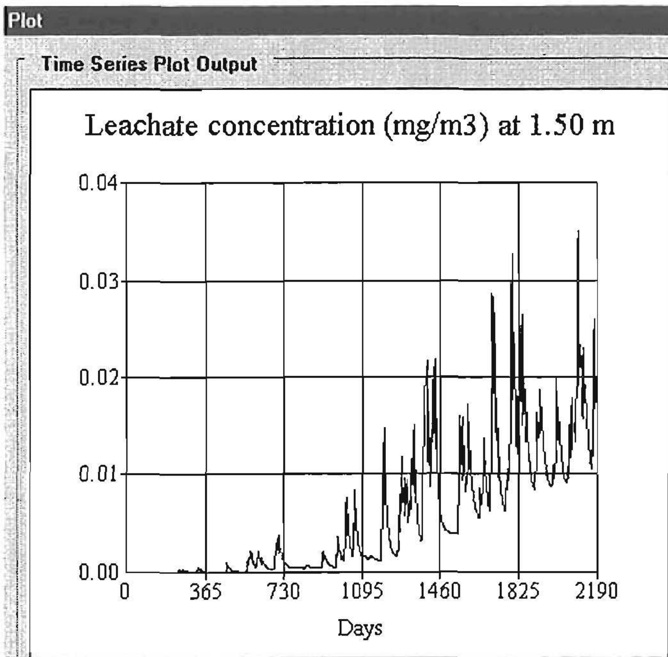
Year 1	: Sugar beet :	0.18 kg/hectare on day 131
		0.28 kg/hectare on day 149
		0.28 kg/hectare on day 177
Year 2	: Sugar beet :	No applications
Year 3	: Sugar beet :	0.18 kg/hectare on day 131
		0.28 kg/hectare on day 149
		0.28 kg/hectare on day 177
Year 4	: Sugar beet :	No applications
Year 5	: Sugar beet :	0.18 kg/hectare on day 131
		0.28 kg/hectare on day 149
		0.28 kg/hectare on day 177
Year 6	: Sugar beet :	No applications

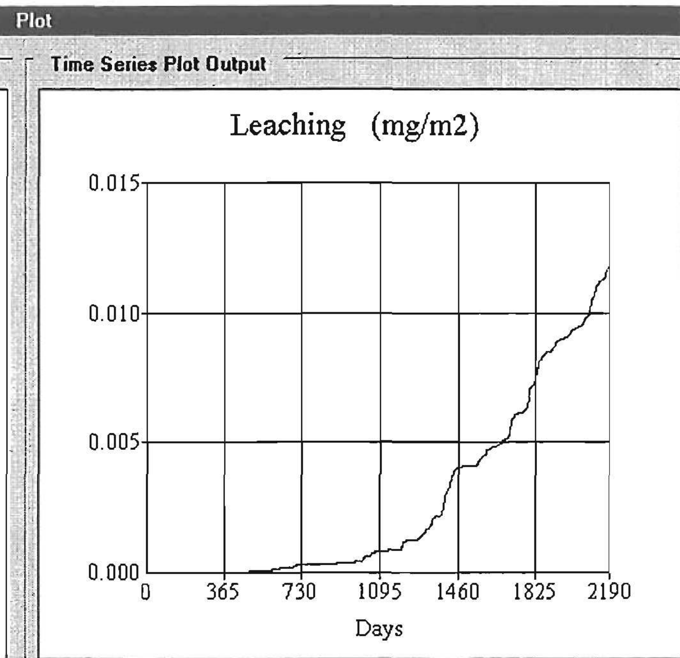
WATER BALANCE (mm)		PESTICIDE BALANCE (mg/ m²)	
Precipitation	3760	Applied amount	222
Evapotranspiration	1540	Dissipated	189.54
Change in storage	78	Stored	15.65
Percolation	1470	Leached	0.01
Drainage	0	Lost to drains	0.00
Runoff	680	Lost to runoff	16.80

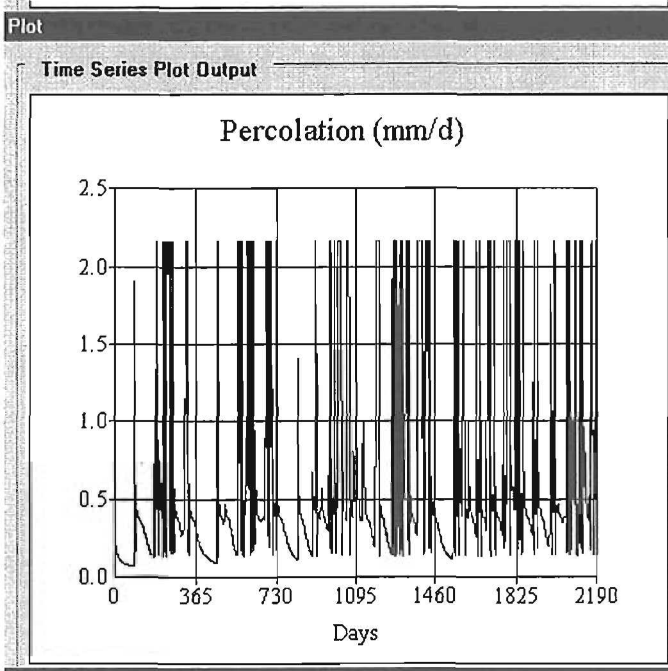
Pesticide balance
Leachate concentrations were low and the share of leached ethofumesate very low. However, traces of substance appeared in the groundwater level very soon after the first application, which is probably due to preferential flow in macropores.

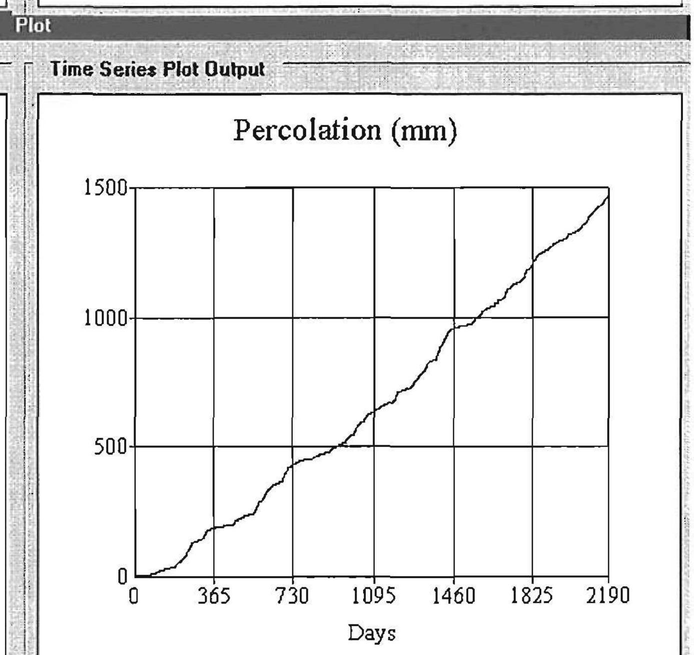
8 % of the substance was lost to runoff, and an approximately equal amounbt stored in soil. The concentrations in the top 10 cm of the plough layer appeared to be approximately at the same level before each application, thanks to the application restricted to every two years. In the end of the simulation period, the soil storage was about 65 µg / kg top soil (10 cm layer).

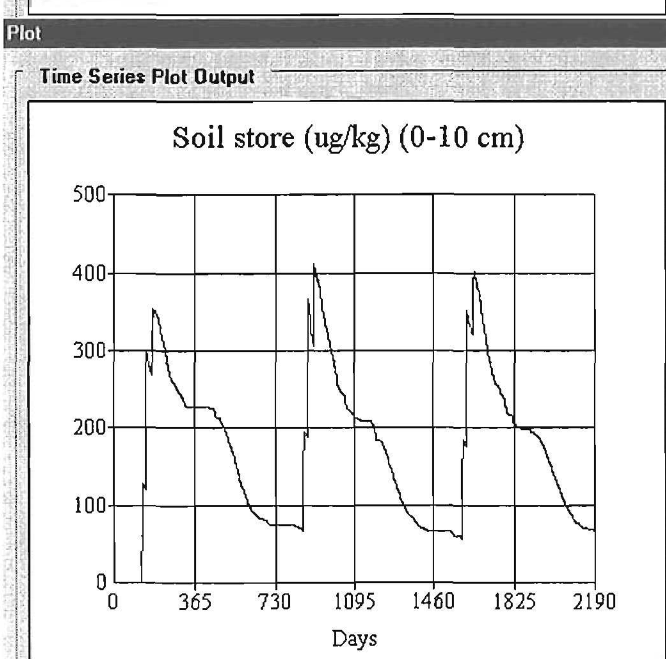
Water balance
The scenario was simulated without drainage. 41 % of the precipitation was evapotranspirated. 39 % percolated through the soil. About 18 % was lost to runoff.

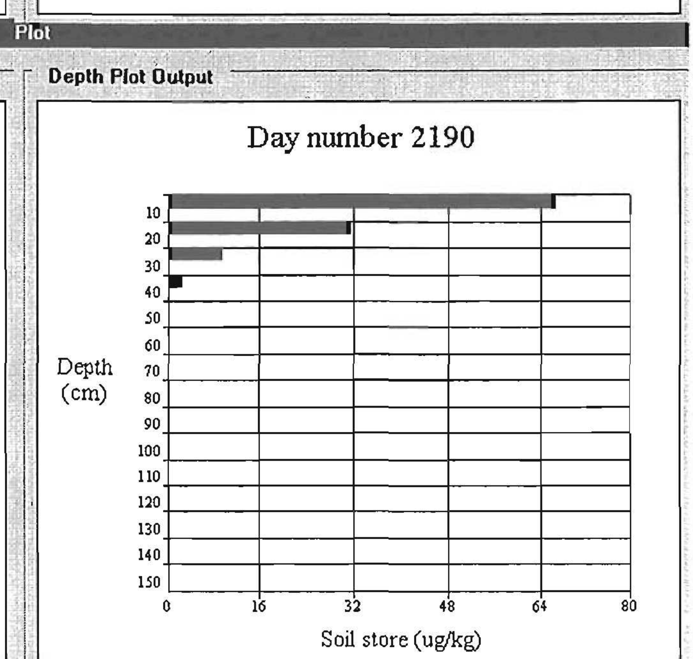

Plot
Time Series Plot Output
Leachate concentration (mg/m3) at 1.50 m
0.04
0.03
0.02
0.01
0.00
0 365 730 1095 1460 1825 2190
Days


Plot
Time Series Plot Output
Leaching (mg/m2)
0.015
0.010
0.005
0.000
0 365 730 1095 1460 1825 2190
Days


Plot
Time Series Plot Output
Percolation (mm/d)
2.5
2.0
1.5
1.0
0.5
0.0
0 365 730 1095 1460 1825 2190
Days


Plot
Time Series Plot Output
Percolation (mm)
1500
1000
500
0
0 365 730 1095 1460 1825 2190
Days


Plot
Time Series Plot Output
Soil store (ug/kg) (0-10 cm)
500
400
300
200
100
0
0 365 730 1095 1460 1825 2190
Days


Plot
Depth Plot Output
Day number 2190
Depth (cm)
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
0 16 32 48 64 80
Soil store (ug/kg)

Simulation 18: Jokioinen Clay2 soil + Jokioinen climate

```
Compound : Ethofumesate (Source = User-defined)
Soil : Jokioinen Clay2 (Source = User-defined)
Profile depth : 1.90 m
Groundwater at 1.9 m

Risk assessment : Average-case
Subsoil degradation : Proportional to organic carbon

Weather data : Jokioinen 1978-1999
Simulation from 19780101 to 19831231

Year  1  : Sugar beet :     0.18 kg/hectare on day  131
                            0.28 kg/hectare on day  149
                            0.28 kg/hectare on day  177
Year  2  : Sugar beet :     No applications
Year  3  : Sugar beet :     0.18 kg/hectare on day  131
                            0.28 kg/hectare on day  149
                            0.28 kg/hectare on day  177
Year  4  : Sugar beet :     No applications
Year  5  : Sugar beet :     0.18 kg/hectare on day  131
                            0.28 kg/hectare on day  149
                            0.28 kg/hectare on day  177
Year  6  : Sugar beet :     No applications
```

WATER BALANCE (mm)		PESTICIDE BALANCE (mg/ m²)	
Precipitation	3760	Applied amount	222
Evapotranspiration	1460	Dissipated	188.57
Change in storage	78	Stored	16.78
Percolation	1550	Leached	0.25
Drainage	0	Lost to drains	0.00
Runoff	672	Lost to runoff	16.40

Pesticide balance

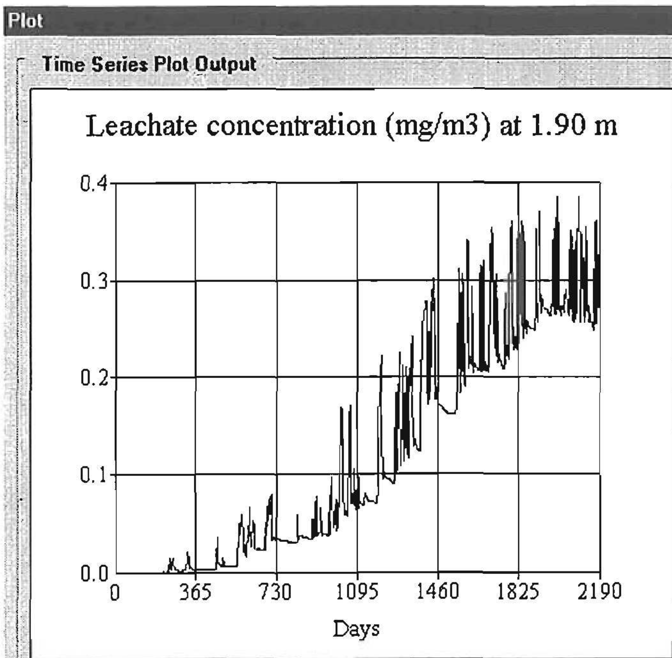
Leachate concentration peaks into the groundwater (190 cm, fixed) exceeded the drinking water quality standard level in the 3rd year of use. On the 4th year the concentrations were permanently above the level and appeared to be rising until year six. Traces of substance appeared in the groundwater level very soon after the first application.

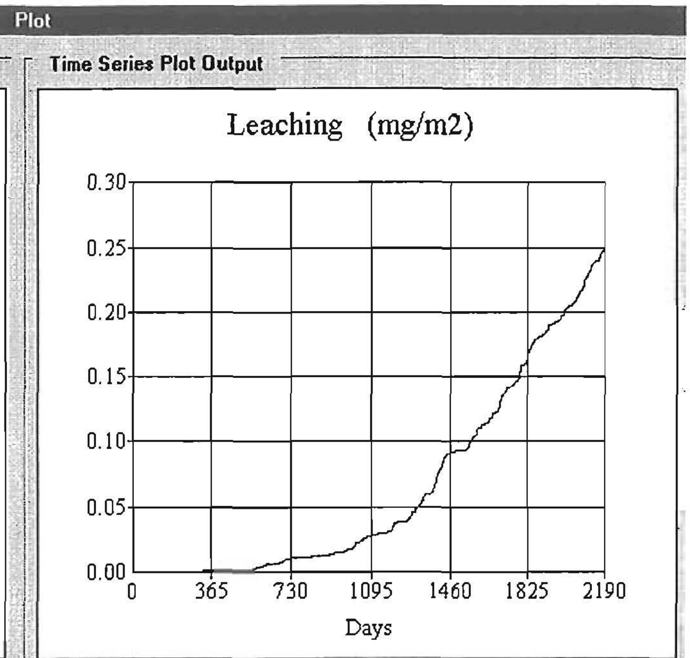
The cumulative leaching in the six year period was 0.25 mg/m2, which represents about 0.1 % of the applied total amount. 7 % of the substance was lost to runoff. The concentrations in the top 10 cm of the plough layer appeared to be approximately at the same level before each application, thanks to the application every two years. In the end of the simulation period, the soil storage was about 60 μg / kg top soil (10 cm layer).

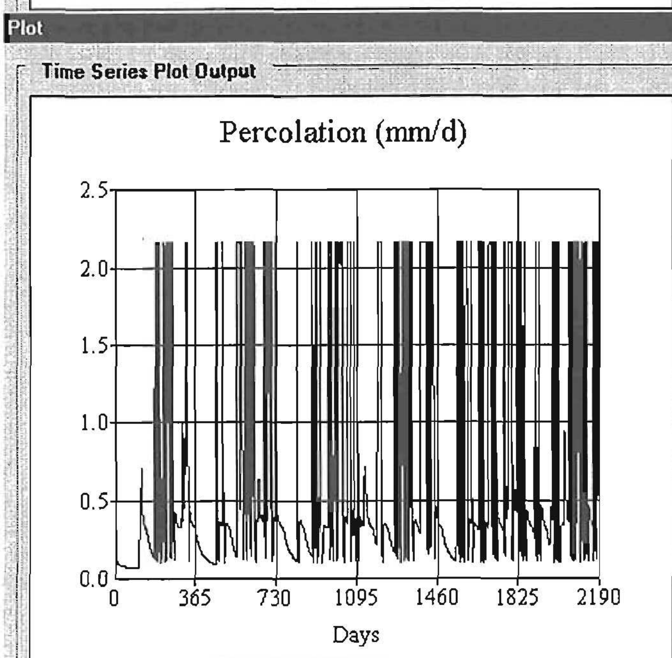
As expected, the leaching with Clay2 was higher, though small in general, and runoff in turn lower. This can be explained with the permeability: percolated amount of precipitation in clay2 is somewhat higher.

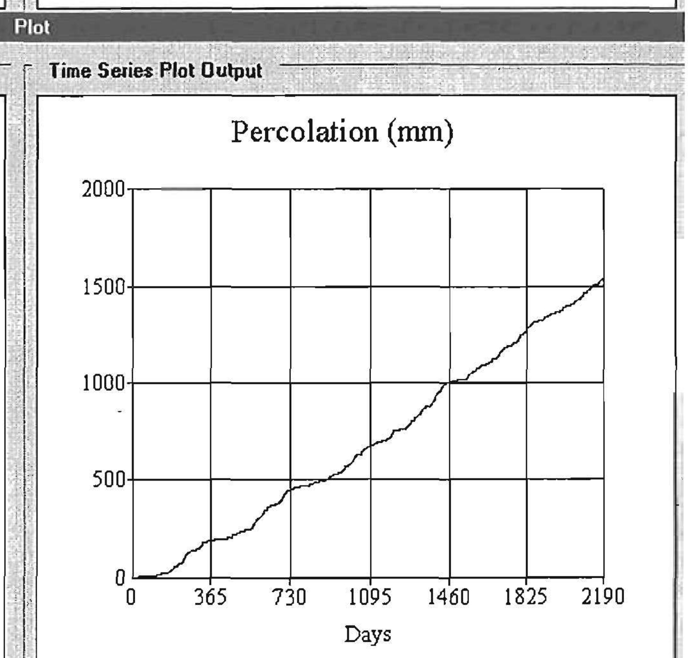
Water balance

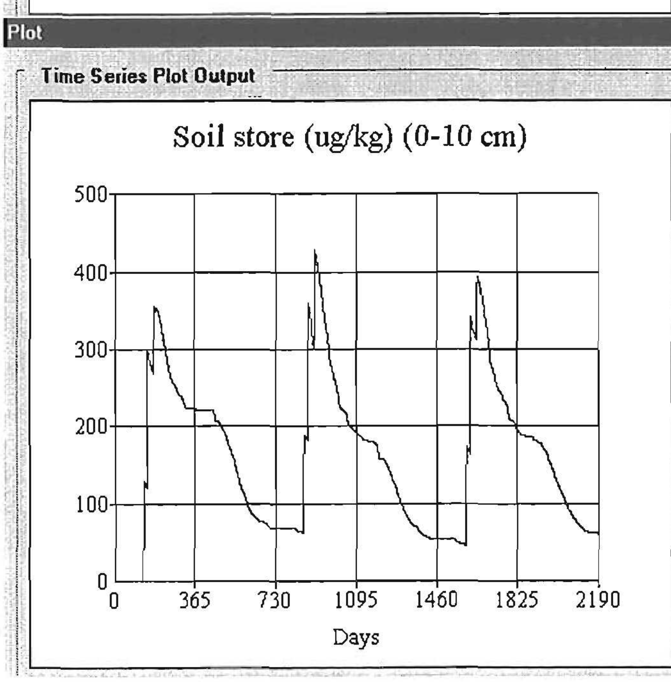
The scenario was simulated without drainage. 39 % of the precipitation was evapotranspirated. 41 % percolated through the soil. About 18 % was lost to runoff.

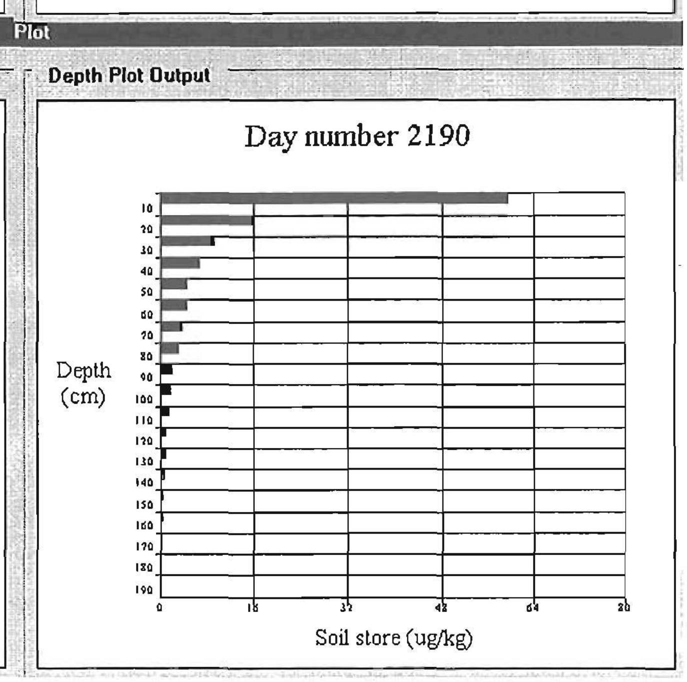

Plot
Time Series Plot Output
Leachate concentration (mg/m3) at 1.90 m
0.4
0.3
0.2
0.1
0.0
0
365
730
1095
1460
1825
2190
Days


Plot
Time Series Plot Output
Leaching (mg/m2)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
365
730
1095
1460
1825
2190
Days


Plot
Time Series Plot Output
Percolation (mm/d)
2.5
2.0
1.5
1.0
0.5
0.0
0
365
730
1095
1460
1825
2190
Days


Plot
Time Series Plot Output
Percolation (mm)
2000
1500
1000
500
0
0
365
730
1095
1460
1825
2190
Days


Plot
Time Series Plot Output
Soil store (ug/kg) (0-10 cm)
500
400
300
200
100
0
0
365
730
1095
1460
1825
2190
Days


Plot
Depth Plot Output
Day number 2190
Depth (cm)
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
Soil store (ug/kg)

Simulation 19: Pälkäne 02 soil + Jokioinen climate

```
Compound : Ethofumesate (Source = User-defined)
Soil : Pälkäne 02 (Source = User-defined)
Profile depth : 1.60 m
Groundwater at 1.6 m

Risk assessment : Average-case
Subsoil degradation : Proportional to organic carbon

Weather data : Jokioinen 1978-1999
Simulation from 19780101 to 19831231

Year  1  : Sugar beet :      0.18 kg/hectare on day  131
                             0.28 kg/hectare on day  149
                             0.28 kg/hectare on day  177
Year  2  : Sugar beet :      No applications
Year  3  : Sugar beet :      0.18 kg/hectare on day  131
                             0.28 kg/hectare on day  149
                             0.28 kg/hectare on day  177
Year  4  : Sugar beet :      No applications
Year  5  : Sugar beet :      0.18 kg/hectare on day  131
                             0.28 kg/hectare on day  149
                             0.28 kg/hectare on day  177
Year  6  : Sugar beet :      No applications
```

WATER BALANCE (mm)		PESTICIDE BALANCE (mg/m^2)	
Precipitation	3760	Applied amount	222
Evapotranspiration	2170	Dissipated	191.31
Change in storage	110	Stored	30.56
Percolation	1480	Leached	0.13
Drainage	0	Lost to drains	0.00
Runoff	0	Lost to runoff	0.00

PESTICIDE BALANCE

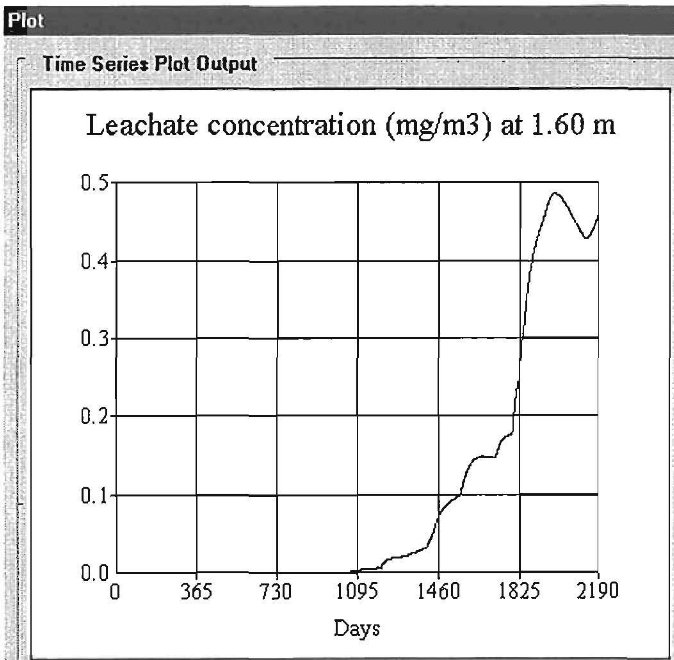
It took almost three years (day 1000) until the leachate concentration started notably rising. The concentration rose stadily after that, exceeding drinking water quality standard after day 1500. There was a very dramatic winter time rise in leachate concentration around day 1800. At the same time the percolation increased, which explains the high leaching in year 6.

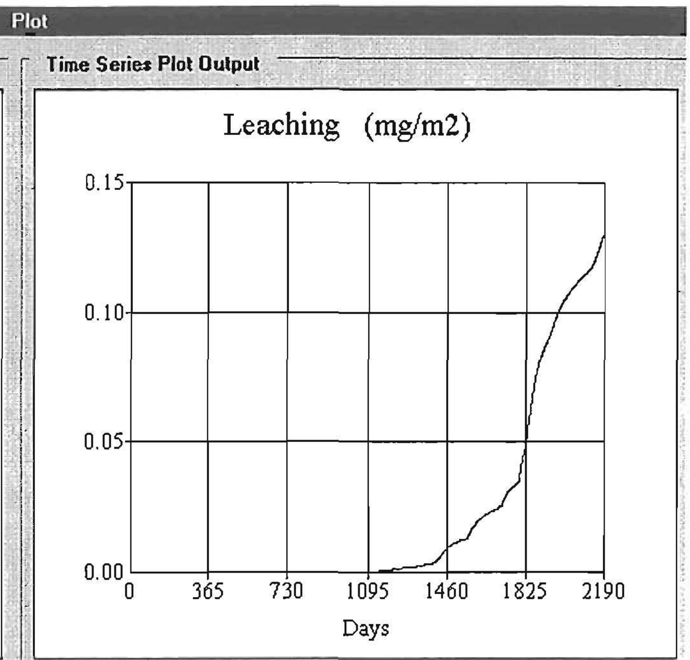
Some accumulation in the top soil occurred. After each application the soil concentrations were higher than previously. At the time of the application, the soil store was approximately 100 µg/kg (10 cm layer top soil), rising to 400 µg/kg after application. In the end of year 6, high concentrations of ethofumesate were observed in the plough layer. Smaller amounts of ethofumesate were seen up to 140 cm.

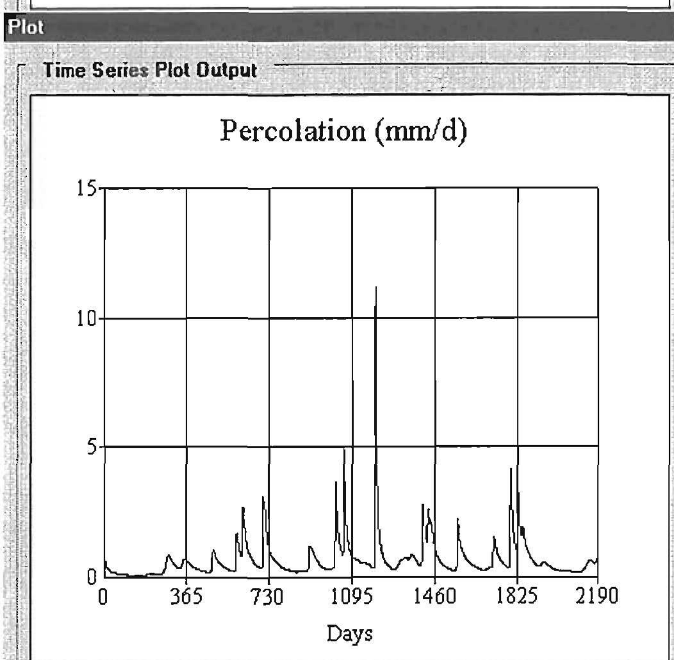
The total leached amount was very low, less than 1 % of the addition. However, the soil store was quite high in the plough layer (14 % of the addition). 86 % of the substance dissipated during the simulation period. The increase in leaching was alarming and would definitely have required a longer modelling period.

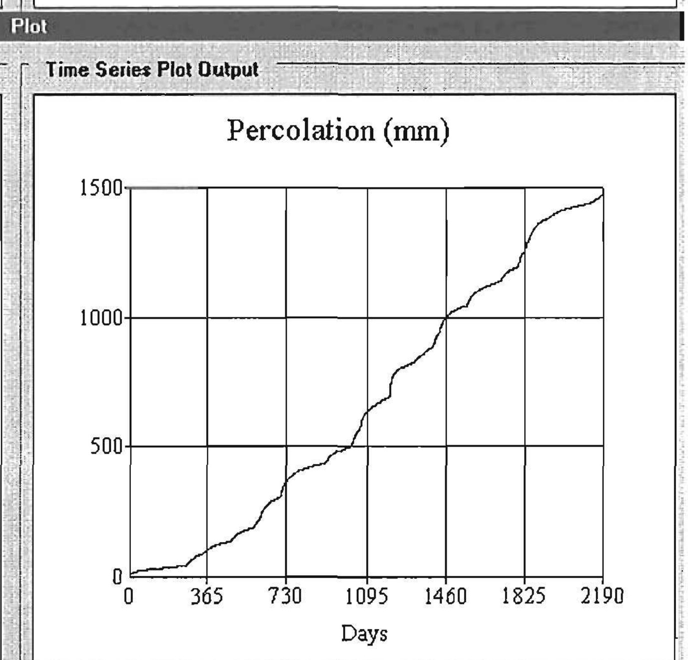
WATER BALANCE

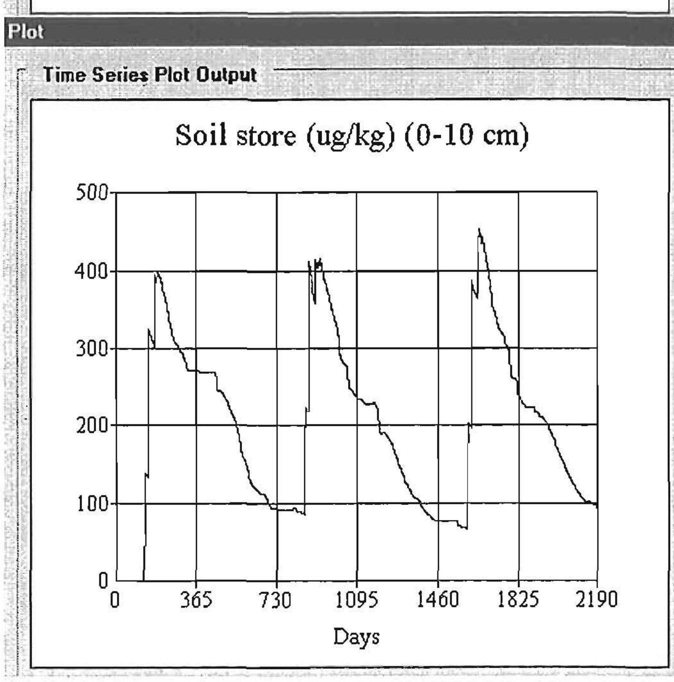
58 % of the water was evapotranspirated. 39 % percolated through the soil matrix which, surprisingly, is less than with the Jokioinen clay soil.

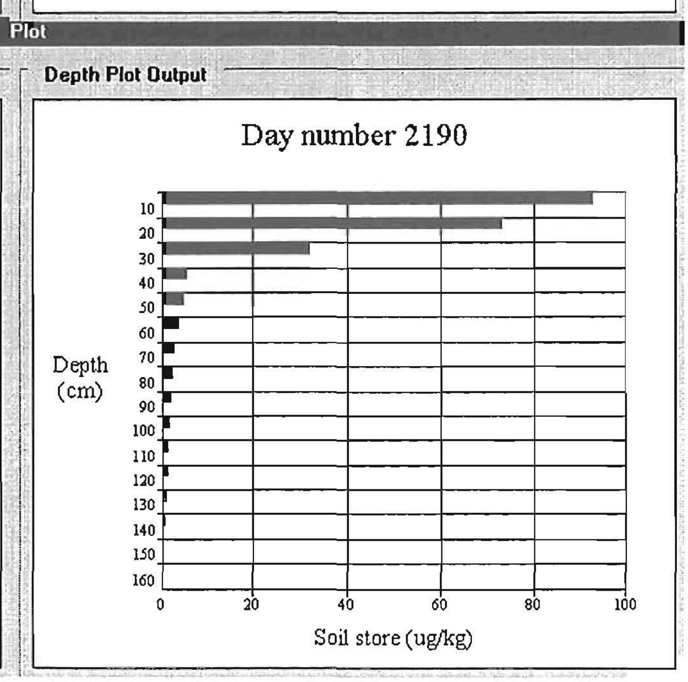

Plot
Time Series Plot Output
Leachate concentration (mg/m3) at 1.60 m
0.5
0.4
0.3
0.2
0.1
0.0
0
365
730
1095
1460
1825
2190
Days


Plot
Time Series Plot Output
Leaching (mg/m2)
0.15
0.10
0.05
0.00
0
365
730
1095
1460
1825
2190
Days


Plot
Time Series Plot Output
Percolation (mm/d)
15
10
5
0
0
365
730
1095
1460
1825
2190
Days


Plot
Time Series Plot Output
Percolation (mm)
1500
1000
500
0
0
365
730
1095
1460
1825
2190
Days


Plot
Time Series Plot Output
Soil store (ug/kg) (0-10 cm)
500
400
300
200
100
0
0
365
730
1095
1460
1825
2190
Days


Plot
Depth Plot Output
Day number 2190
Depth (cm)
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
0
20
40
60
80
100
Soil store (ug/kg)

Simulation 20: Västerby soil + Jokioinen climate

```
Compound : Ethofumesate (Source = User-defined)
Soil : VÄSTERBY (Source = MARKDATA)
Profile depth : 1.50 m
Groundwater at 1.5 m

Risk assessment : Average-case
Subsoil degradation : Proportional to organic carbon

Weather data : Jokioinen 1978-1999
Simulation from 19780101 to 19831231

Year  1  : Sugar beet :     0.18 kg/hectare on day  131
                            0.28 kg/hectare on day  149
                            0.28 kg/hectare on day  177
Year  2  : Sugar beet :     No applications
Year  3  : Sugar beet :     0.18 kg/hectare on day  131
                            0.28 kg/hectare on day  149
                            0.28 kg/hectare on day  177
Year  4  : Sugar beet :     No applications
Year  5  : Sugar beet :     0.18 kg/hectare on day  131
                            0.28 kg/hectare on day  149
                            0.28 kg/hectare on day  177
Year  6  : Sugar beet :     No applications
```

WATER BALANCE (mm)		PESTICIDE BALANCE (mg/m^2)	
Precipitation	3760	Applied amount	222
Evapotranspiration	1880	Dissipated	170.12
Change in storage	78	Stored	25.08
Percolation	1570	Leached	16.10
Drainage	0	Lost to drains	0.00
Runoff	232	Lost to runoff	10.70

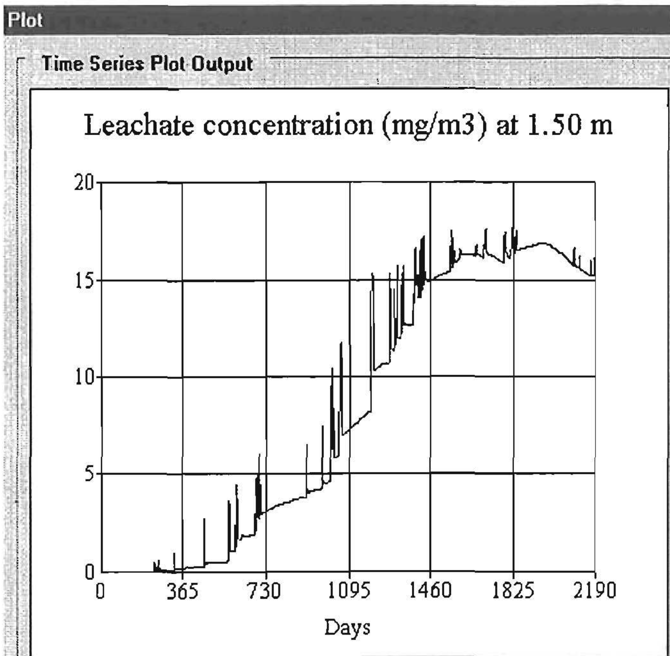
PESTICIDE BALANCE

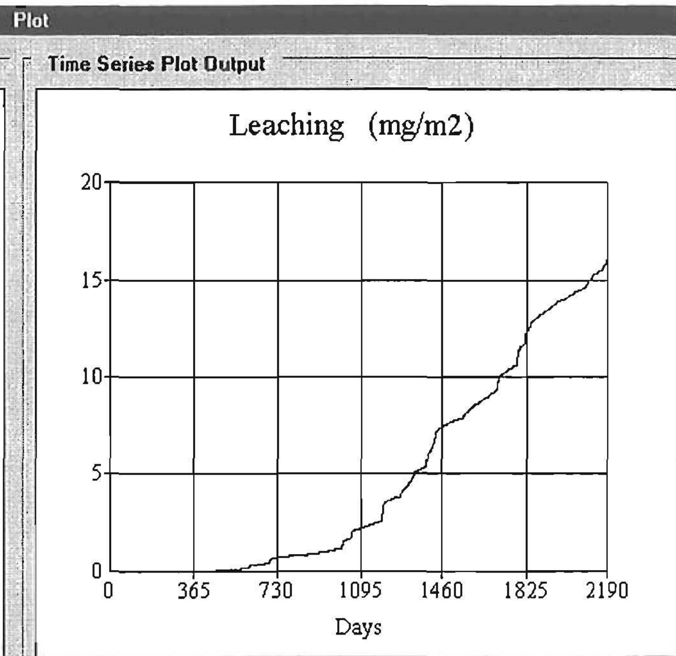
The leachate concentration started rising already in the first year and pesticide entered groundwater very soon. Ethofumesate concentration grew steadily in the following 3 years and the concentrations were very high compared to the drinking water quality standard. In year 5 the leached concentration appeared to level.

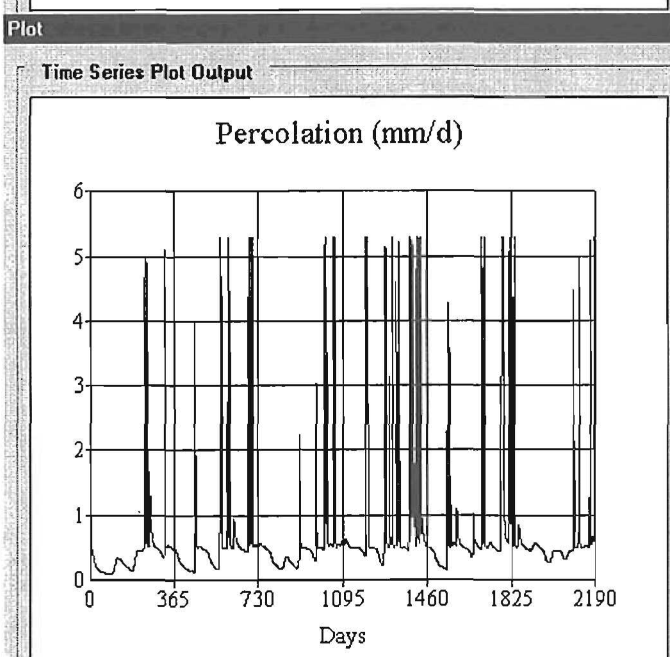
Total leached amount was 4 % of the addition. However, the soil store was quite high in the plough layer, though somewhat lower than with Jokioinen and Pälkäne soils. Each year, there was approximately 50 μg/kg pesticide in soil at the time of new addition. The levels of ethofumesate in deeper soil layers were very high compared to Finnish soils.

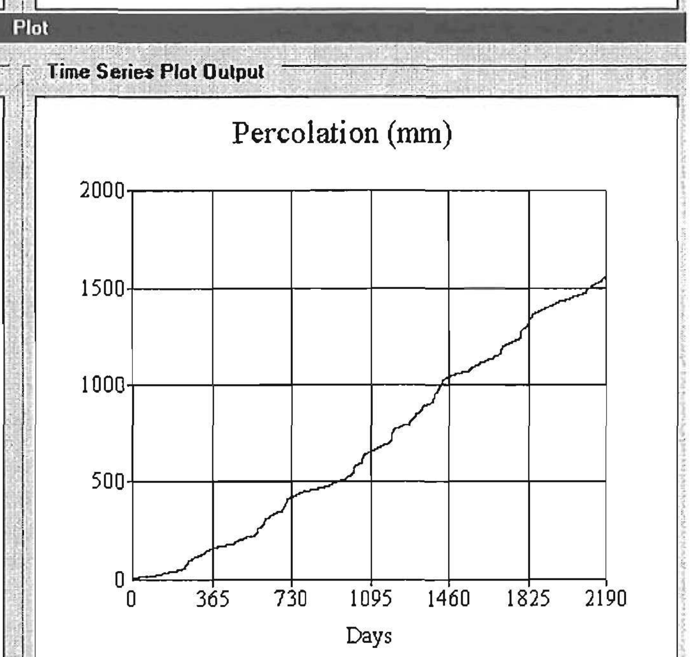
WATER BALANCE

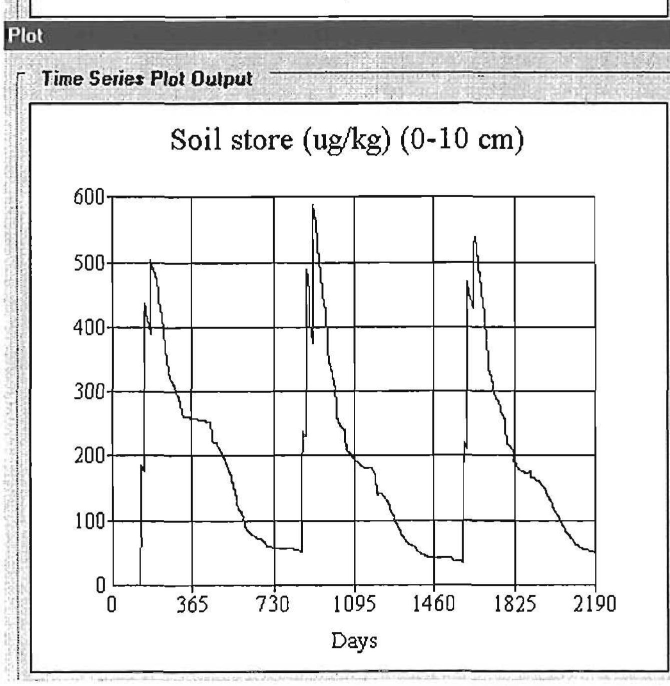
50 % of the water was evapotranspirated. 42 % percolated through the soil matrix. 6 % escaped as surface runoff.

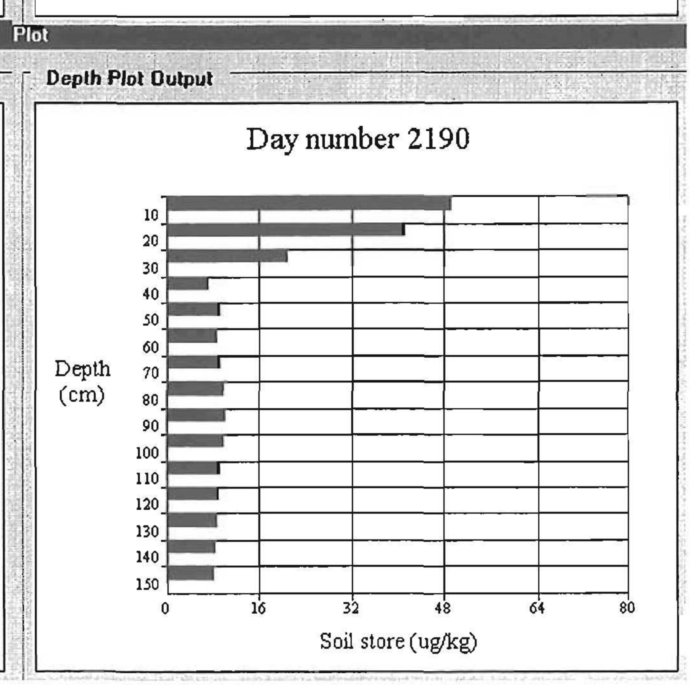

Plot
Time Series Plot Output
Leachate concentration (mg/m3) at 1.50 m
20
15
10
5
0
0 365 730 1095 1460 1825 2190
Days


Plot
Time Series Plot Output
Leaching (mg/m2)
20
15
10
5
0
0 365 730 1095 1460 1825 2190
Days


Plot
Time Series Plot Output
Percolation (mm/d)
6
5
4
3
2
1
0
0 365 730 1095 1460 1825 2190
Days


Plot
Time Series Plot Output
Percolation (mm)
2000
1500
1000
500
0
0 365 730 1095 1460 1825 2190
Days


Plot
Time Series Plot Output
Soil store (ug/kg) (0-10 cm)
600
500
400
300
200
100
0
0 365 730 1095 1460 1825 2190
Days


Plot
Depth Plot Output
Day number 2190
Depth (cm)
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
0 16 32 48 64 80
Soil store (ug/kg)

Simulation 21: Västerby soil + Uppsala climate

```
Compound : Ethofumesate (Source = User-defined)
Soil : VÄSTERBY (Source = MARKDATA)
Profile depth : 1.50 m
Groundwater at 1.5 m

Risk assessment : Average-case
Subsoil degradation : Proportional to organic carbon

Weather data : Uppsala
Simulation from 19610101 to 19661231

Year  1  : Sugar beet :     0.18 kg/hectare on day  131
                            0.28 kg/hectare on day  149
                            0.28 kg/hectare on day  177
Year  2  : Sugar beet :     No applications
Year  3  : Sugar beet :     0.18 kg/hectare on day  131
                            0.28 kg/hectare on day  149
                            0.28 kg/hectare on day  177
Year  4  : Sugar beet :     No applications
Year  5  : Sugar beet :     0.18 kg/hectare on day  131
                            0.28 kg/hectare on day  149
                            0.28 kg/hectare on day  177
Year  6  : Sugar beet :     No applications
```

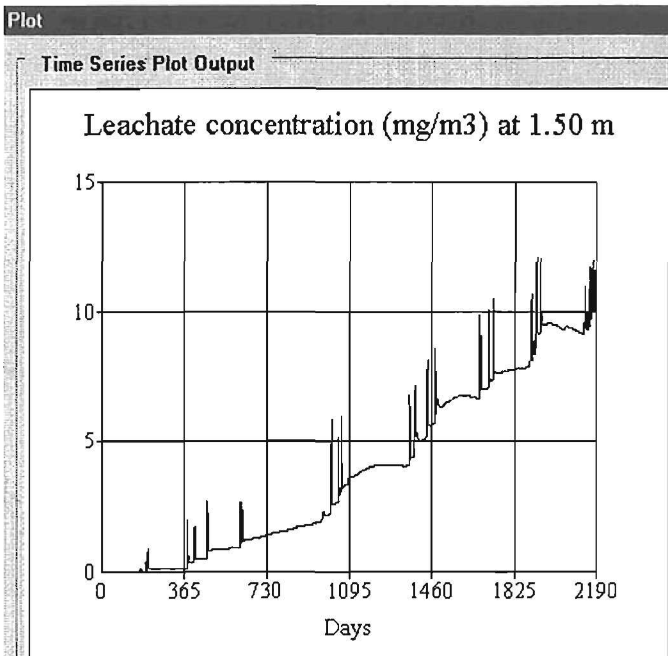
WATER BALANCE (mm)		PESTICIDE BALANCE (mg/m^2)	
Precipitation	2950	Applied amount	222
Evapotranspiration	1430	Dissipated	184.81
Change in storage	72	Stored	21.03
Percolation	1260	Leached	6.16
Drainage	0	Lost to drains	0.00
Runoff	188	Lost to runoff	10.00

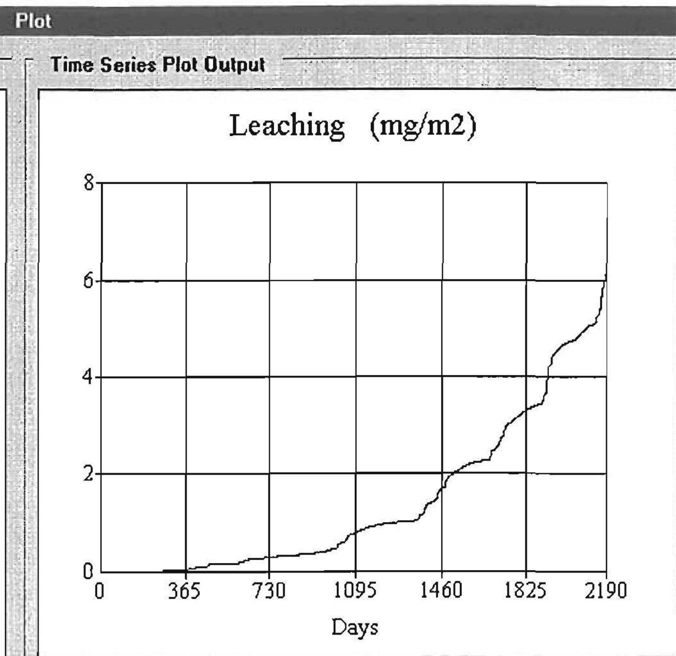
PESTICIDE BALANCE

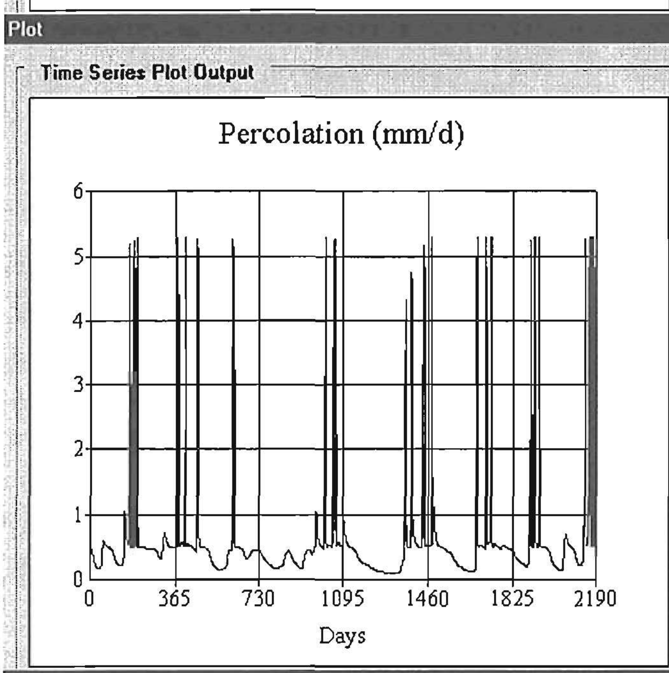
As with Jokioinen climate, ethofumesate entered the groundwater also in this case very soon after the first application. The leachate concentrations were a lot smaller than with Jokioinen climate, and there were fewer high concentration peaks (possibly due to rainfall events). The total leached amount was less than 3 % of the addition, which is about half of the scenario with Jokioinen climate. However, the soil concentrations in top layer of the profile were higher in this scenario until the end of simulation. Interestingly, the end concentrations of the soil profile appear to be much lower than with Jokioinen climate, which can be explained with high leaching concentrations in the same period. Each year the winter time concentrations were approximately at the same level at the time of new addition, though a lot higher than with the Jokioinen climate.
83 % of the substance dissipated. Thus, the lower leaching appears to be explained with higher degradation (compared to same soil with Jokioinen climate) rate and sorption.

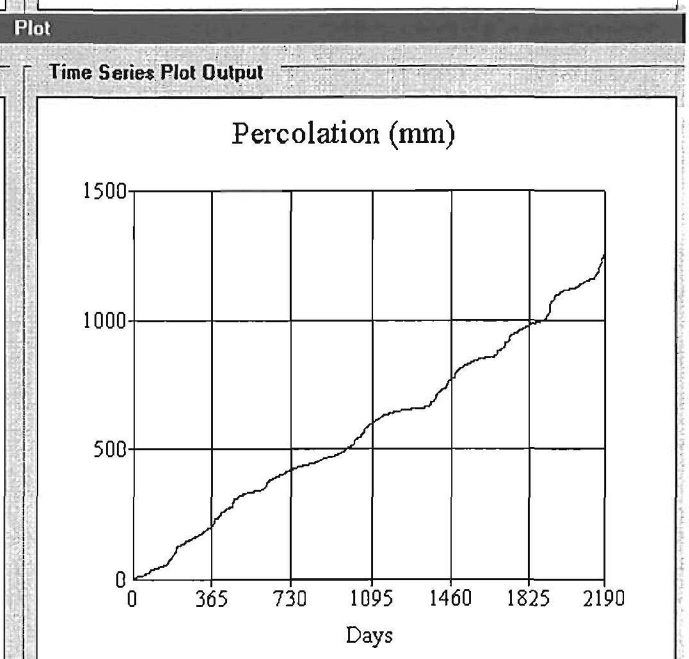
WATER BALANCE

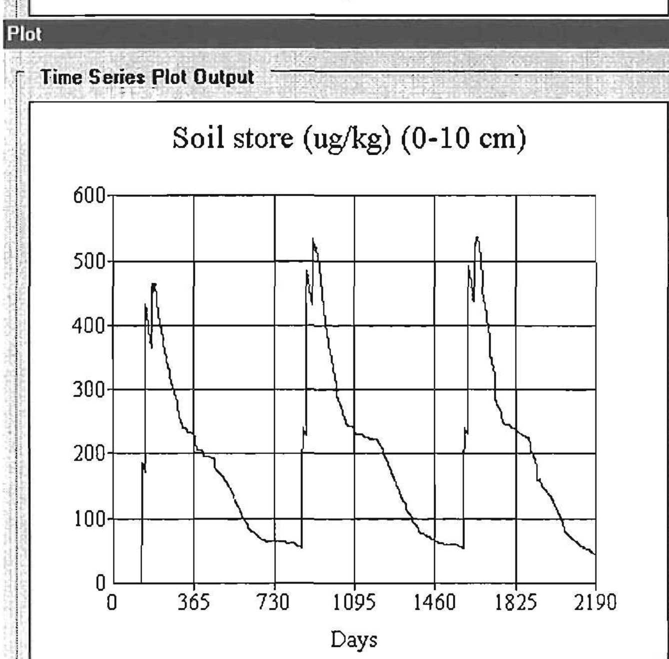
49 % of the water was evapotranspirated. 43 % percolated through the soil matrix.

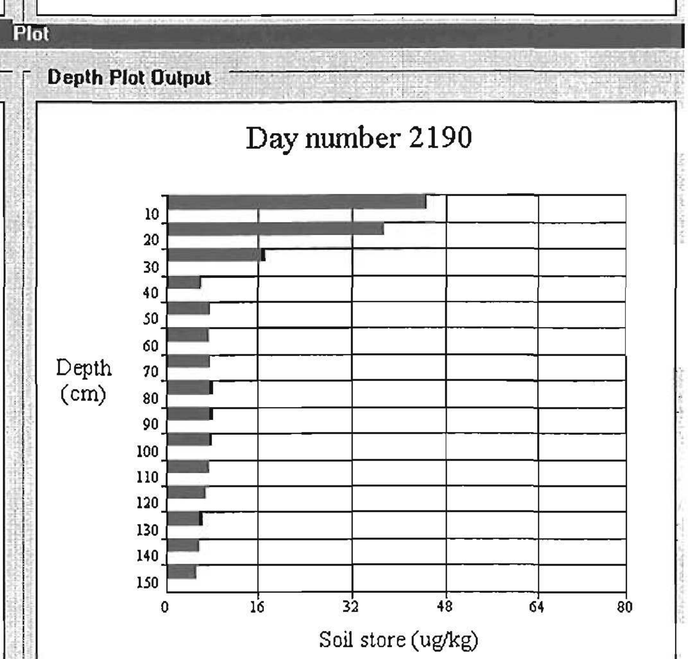

Plot
Time Series Plot Output
Leachate concentration (mg/m3) at 1.50 m
15
10
5
0
0
365
730
1095
1460
1825
2190
Days


Plot
Time Series Plot Output
Leaching (mg/m2)
8
6
4
2
0
0
365
730
1095
1460
1825
2190
Days


Plot
Time Series Plot Output
Percolation (mm/d)
6
5
4
3
2
1
0
0
365
730
1095
1460
1825
2190
Days


Plot
Time Series Plot Output
Percolation (mm)
1500
1000
500
0
0
365
730
1095
1460
1825
2190
Days


Plot
Time Series Plot Output
Soil store (ug/kg) (0-10 cm)
600
500
400
300
200
100
0
0
365
730
1095
1460
1825
2190
Days


Plot
Depth Plot Output
Day number 2190
Depth (cm)
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
0
16
32
48
64
80
Soil store (ug/kg)

Simulation 22: Jokioinen Clay1 + Uppsala

```
Compound : Ethofumesate (Source = User-defined)
Soil : Jokioinen Clay1 (Source = User-defined)
Profile depth : 1.50 m
Groundwater at 1.5 m

Risk assessment : Average-case
Subsoil degradation : Proportional to organic carbon

Weather data : Uppsala
Simulation from 19610101 to 19661231

Year  1  : Sugar beet :      0.18 kg/hectare on day  131
                             0.28 kg/hectare on day  149
                             0.28 kg/hectare on day  177
Year  2  : Sugar beet :      No applications
Year  3  : Sugar beet :      0.18 kg/hectare on day  131
                             0.28 kg/hectare on day  149
                             0.28 kg/hectare on day  177
Year  4  : Sugar beet :      No applications
Year  5  : Sugar beet :      0.18 kg/hectare on day  131
                             0.28 kg/hectare on day  149
                             0.28 kg/hectare on day  177
Year  6  : Sugar beet :      No applications
```

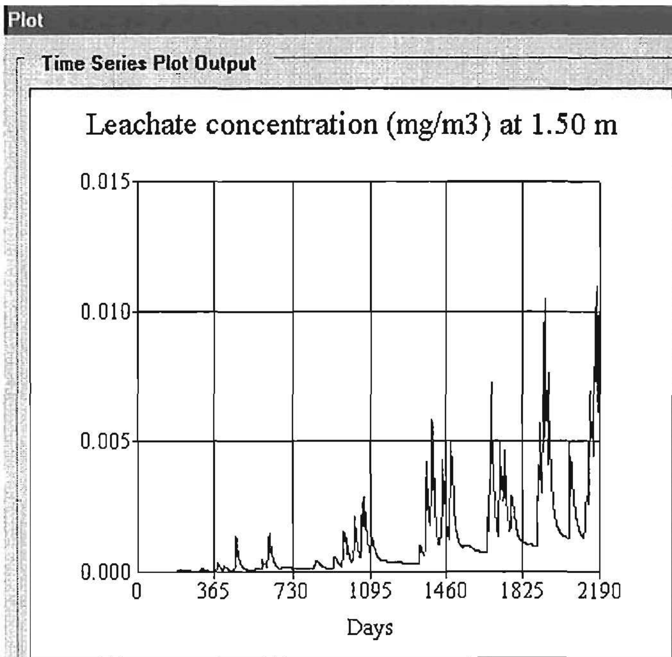
WATER BALANCE (mm)		PESTICIDE BALANCE (mg/ m^2)	
Precipitation	2950	Applied amount	222
Evapotranspiration	1200	Dissipated	195.85
Change in storage	59	Stored	13.95
Percolation	1240	Leached	0.00
Drainage	0	Lost to drains	0.00
Runoff	451	Lost to runoff	12.20

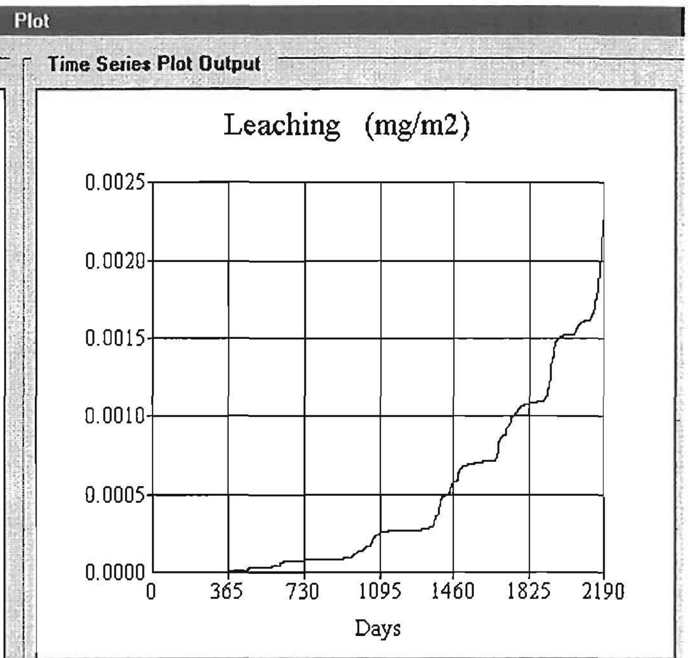
PESTICIDE BALANCE
Traces of substance can be seen in the groundwater zone very soon after the start of use. The leachate concentration generally grew steadily through the simulation period, the concentration peaks being closely related to rainfall peaks: high concentrations were observed together with high percolation. A rise in leaching was seen in the end of simulation period, but the the total leached amount was in spite of it very low.

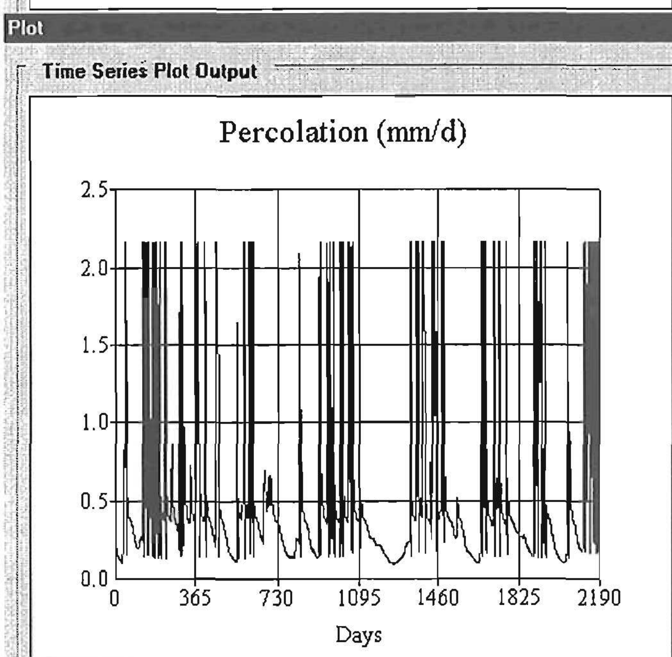
Also in this case, the prohibition of use in consecutive years gave the soil enough time to dissipate the pesticide bound and thus the concentrations in the topsoil were approximately the same every year and there seemed to be no increasing cumulation. However, each year the winter time concentrations in top soil were higher than before, except for the end when the high leaching appeared to wash the topsoil.

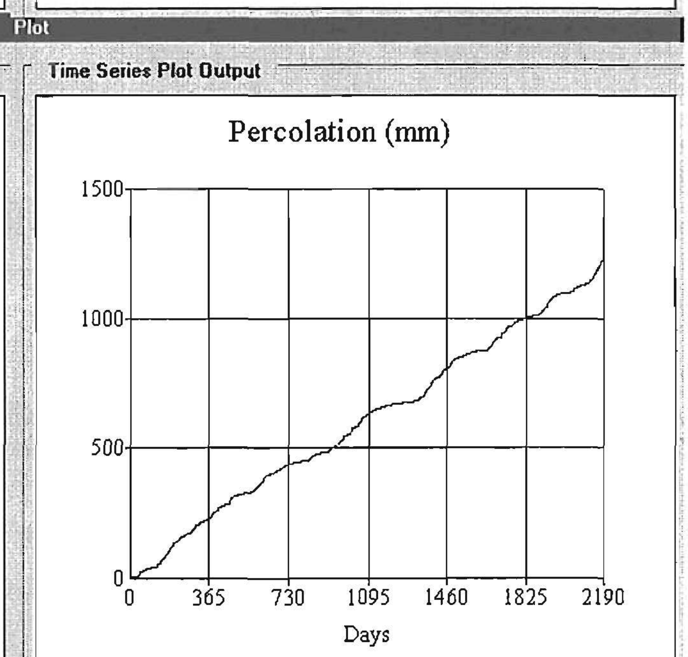
88 % of the applied ethofumesate dissipated, which is a bit more than in scenario with Jokioinen climate.

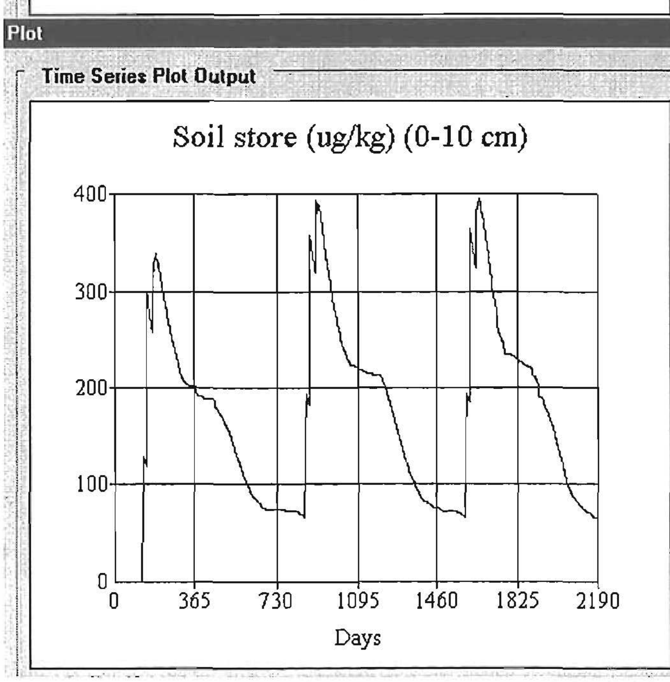
WATER BALANCE
41 % of the water was evapotranspirated. 42 % percolated through the soil matrix. The share of surface runoff was quite high, 15 %.

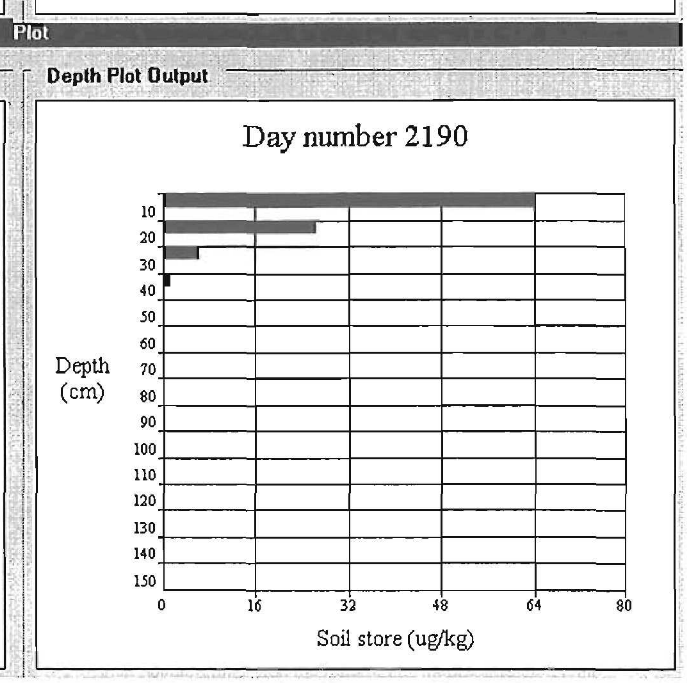

Plot
Time Series Plot Output
Leachate concentration (mg/m3) at 1.50 m
0.015
0.010
0.005
0.000
0
365
730
1095
1460
1825
2190
Days


Plot
Time Series Plot Output
Leaching (mg/m2)
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
0
365
730
1095
1460
1825
2190
Days


Plot
Time Series Plot Output
Percolation (mm/d)
2.5
2.0
1.5
1.0
0.5
0.0
0
365
730
1095
1460
1825
2190
Days


Plot
Time Series Plot Output
Percolation (mm)
1500
1000
500
0
0
365
730
1095
1460
1825
2190
Days


Plot
Time Series Plot Output
Soil store (ug/kg) (0-10 cm)
400
300
200
100
0
0
365
730
1095
1460
1825
2190
Days


Plot
Depth Plot Output
Day number 2190
Depth (cm)
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
0
16
32
48
64
80
Soil store (ug/kg)

Simulation 23: Jokioinen Clay2 Soil + Uppsala climate

```
Compound : Ethofumesate (Source = User-defined)
Soil : Jokioinen Clay2 (Source = User-defined)
Profile depth : 1.90 m
Groundwater at 1.9 m

Risk assessment : Average-case
Subsoil degradation : Proportional to organic carbon

Weather data : Uppsala
Simulation from 19610101 to 19661231

Year  1  : Sugar beet :      0.18 kg/hectare on day  131
                             0.28 kg/hectare on day  149
                             0.28 kg/hectare on day  177
Year  2  : Sugar beet :      No applications
Year  3  : Sugar beet :      0.18 kg/hectare on day  131
                             0.28 kg/hectare on day  149
                             0.28 kg/hectare on day  177
Year  4  : Sugar beet :      No applications
Year  5  : Sugar beet :      0.18 kg/hectare on day  131
                             0.28 kg/hectare on day  149
                             0.28 kg/hectare on day  177
Year  6  : Sugar beet :      No applications
```

WATER BALANCE (mm)		PESTICIDE BALANCE (mg/ m^2)	
Precipitation	2950	Applied amount	222
Evapotranspiration	1130	Dissipated	196.46
Change in storage	85	Stored	14.19
Percolation	1310	Leached	0.05
Drainage	0	Lost to drains	0.00
Runoff	425	Lost to runoff	11.30

PESTICIDE BALANCE

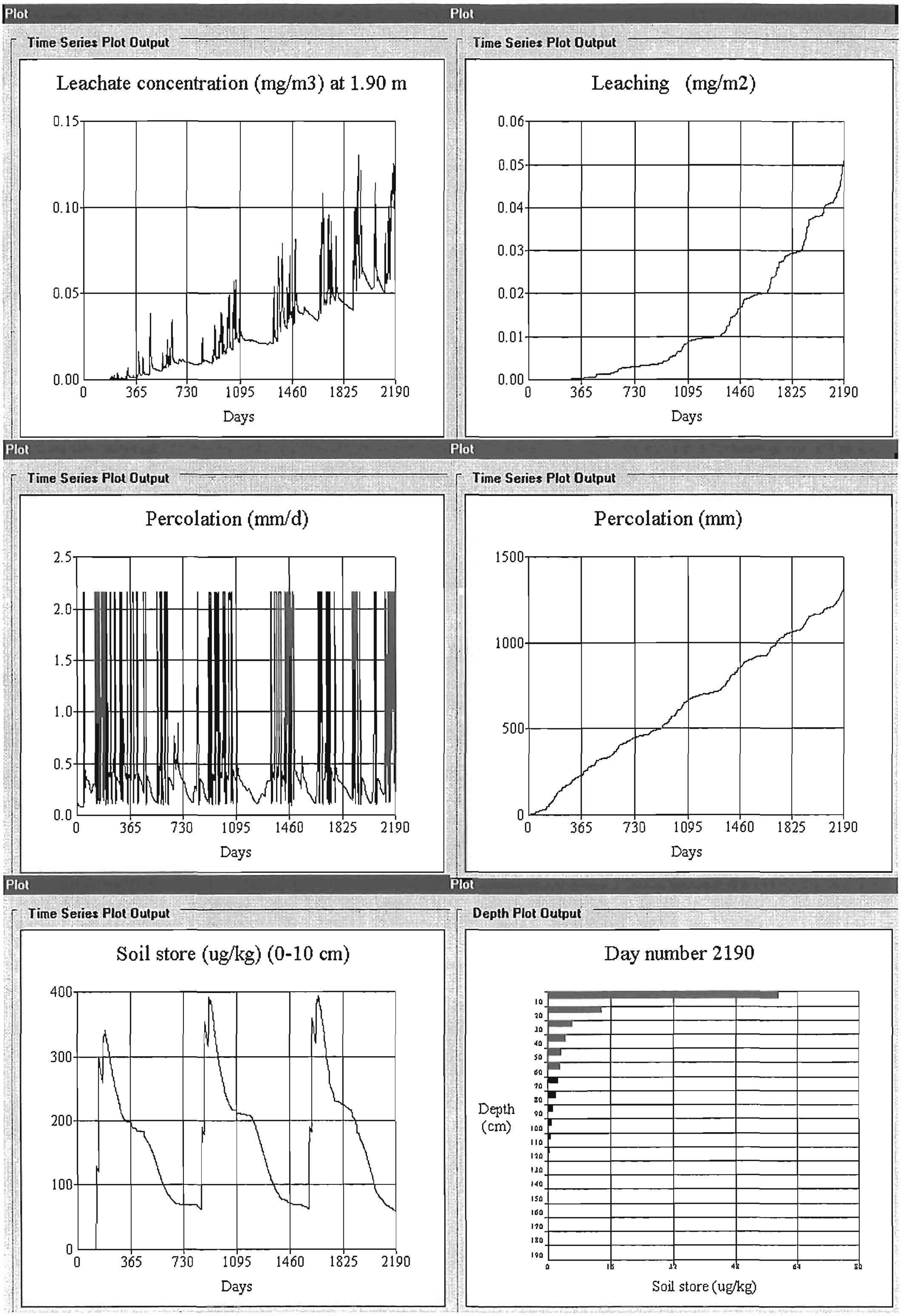
The substance leached into the groundwater soon after the start of use. The leachate concentration generally grew steadily through the simulation period, the concentration peaks depending on rainfall: high concentrations were observed together with high percolation. A rise in leaching was seen in the end of simulation period, but the the total leached amount was in spite of it very low.

Also in this case, the prohibition of use in consecutive years gave the soil enough time to dissipate the pesticide bound and thus the concentrations in the topsoil were approximately the same every year and there seemed to be no increasing cumulation. However, each year the winter time concentrations in top soil were higher than before, except for the end when the high leaching appeared wash the topsoil.

89 % of the applied ethofumesate dissipated, which is a bit more than in scenario with Jokioinen climate.

WATER BALANCE

38 % of the water was evapotranspirated. 44 % percolated through the soil matrix. The share of surface runoff was quite high, 14 %.


Plot
Time Series Plot Output
Leachate concentration (mg/m3) at 1.90 m
0.15
0.10
0.05
0.00
0 365 730 1095 1460 1825 2190
Days
Plot
Time Series Plot Output
Leaching (mg/m2)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0 365 730 1095 1460 1825 2190
Days
Plot
Time Series Plot Output
Percolation (mm/d)
2.5
2.0
1.5
1.0
0.5
0.0
0 365 730 1095 1460 1825 2190
Days
Plot
Time Series Plot Output
Percolation (mm)
1500
1000
500
0
0 365 730 1095 1460 1825 2190
Days
Plot
Time Series Plot Output
Soil store (ug/kg) (0-10 cm)
400
300
200
100
0
0 365 730 1095 1460 1825 2190
Days
Plot
Depth Plot Output
Day number 2190
Depth
(cm)
Soil store (ug/kg)

Simulation 24: Pälkäne 02 + Uppsala

```
Compound : Ethofumesate (Source = User-defined)
Soil : Pälkäne 02 (Source = User-defined)
Profile depth : 1.60 m
Groundwater at 1.6 m

Risk assessment : Average-case
Subsoil degradation : Proportional to organic carbon

Weather data : Uppsala
Simulation from 19610101 to 19661231

Year  1  : Sugar beet :      0.18 kg/hectare on day  131
                             0.28 kg/hectare on day  149
                             0.28 kg/hectare on day  177
Year  2  : Sugar beet :      No applications
Year  3  : Sugar beet :      0.18 kg/hectare on day  131
                             0.28 kg/hectare on day  149
                             0.28 kg/hectare on day  177
Year  4  : Sugar beet :      No applications
Year  5  : Sugar beet :      0.18 kg/hectare on day  131
                             0.28 kg/hectare on day  149
                             0.28 kg/hectare on day  177
Year  6  : Sugar beet :      No applications
```

WATER BALANCE (mm)		PESTICIDE BALANCE (mg/ m^2)	
Precipitation	2950	Applied amount	222
Evapotranspiration	1570	Dissipated	193.84
Change in storage	120	Stored	28.14
Percolation	1260	Leached	0.02
Drainage	0	Lost to drains	0.00
Runoff	0	Lost to runoff	0.00

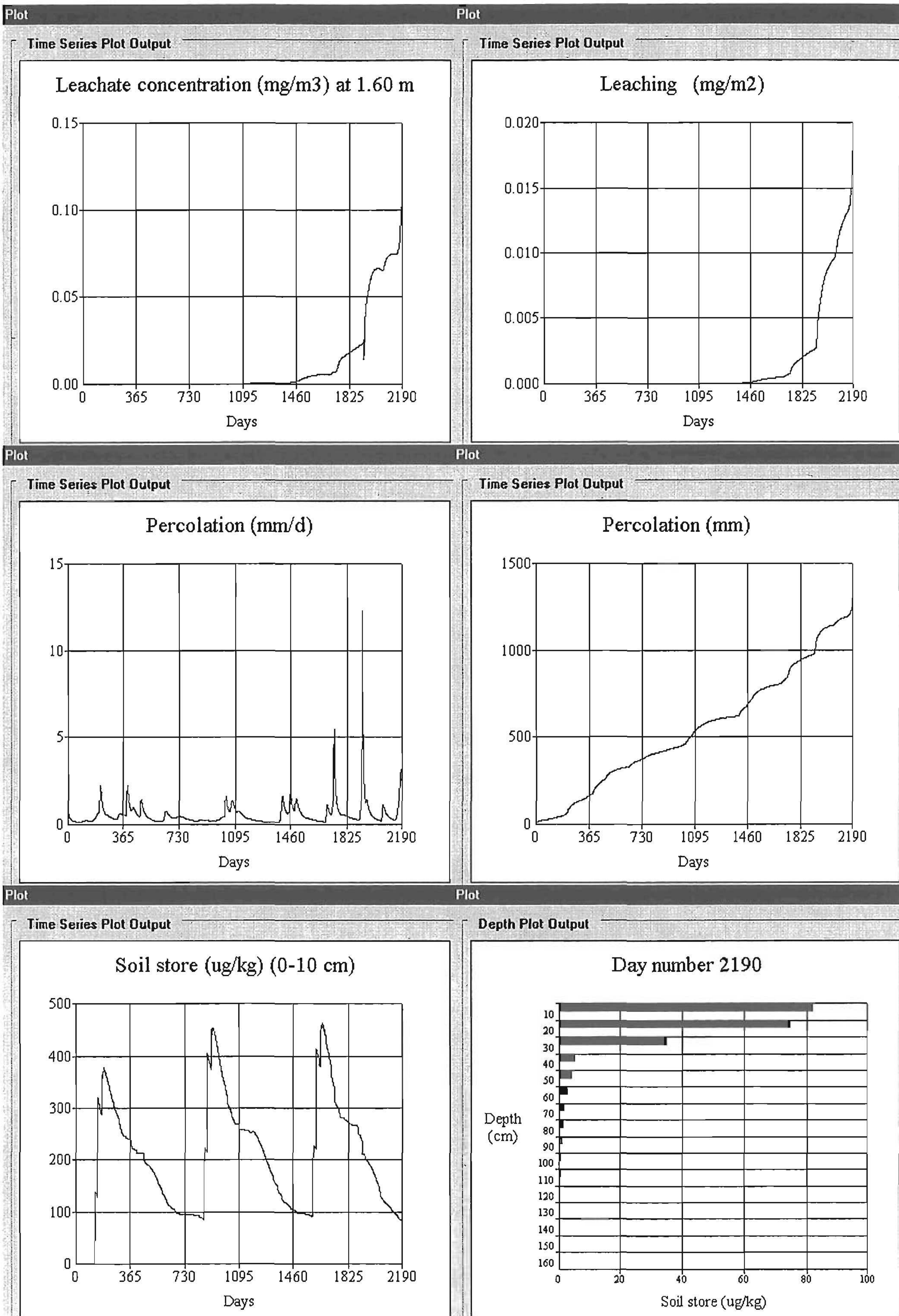
PESTICIDE BALANCE

Again, it took almost three years until substance was leached into the groundwater. The drinking water quality limit 0.1 µg/l did not exceed until in the very end of simulation when the substance appeared to start leaching a bit more. Top soil concentrations were once again highest of all soil scenarios, which explains the little leaching (<<1 %).

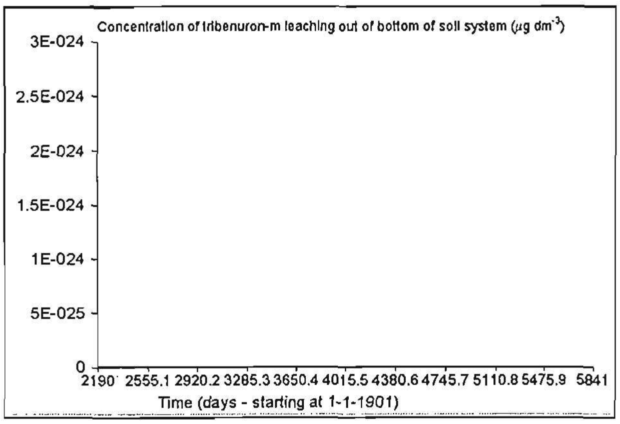
Also in this case, the prohibition of use in consecutive years gave the soil enough time to dissipate the pesticide bound and thus the concentrations in the topsoil were approximately the same every year and there seemed to be no increasing accumulation. However, each year after the application the winter time concentrations in top soil were higher than before.

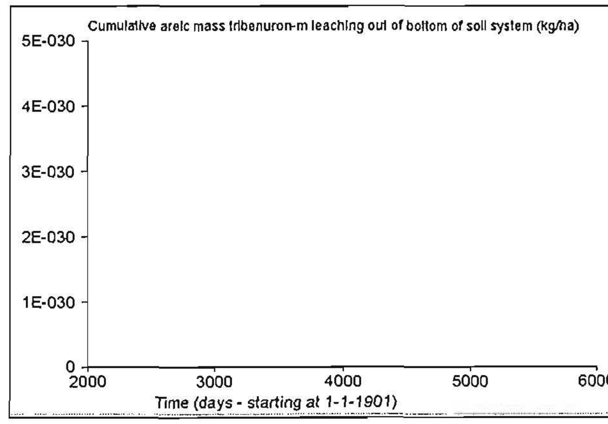
WATER BALANCE

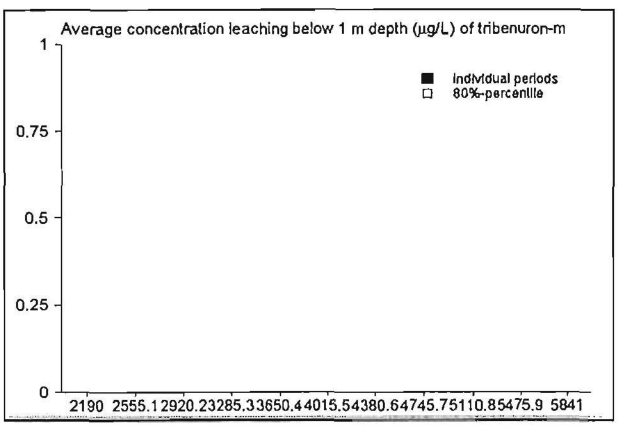
53 % of the water was evapotranspirated. 43 % percolated through the soil matrix. There was no surface runoff, as the soil was very permeable.

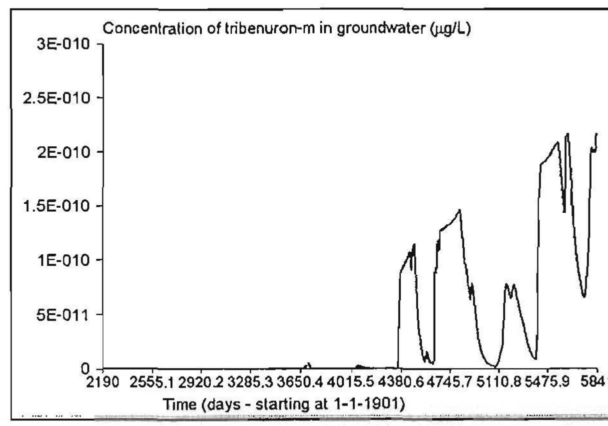

Plot
Time Series Plot Output
Leachate concentration (mg/m3) at 1.60 m
0.15
0.10
0.05
0.00
0 365 730 1095 1460 1825 2190
Days
Plot
Time Series Plot Output
Leaching (mg/m2)
0.020
0.015
0.010
0.005
0.000
0 365 730 1095 1460 1825 2190
Days
Plot
Time Series Plot Output
Percolation (mm/d)
15
10
5
0
0 365 730 1095 1460 1825 2190
Days
Plot
Time Series Plot Output
Percolation (mm)
1500
1000
500
0
0 365 730 1095 1460 1825 2190
Days
Plot
Time Series Plot Output
Soil store (ug/kg) (0-10 cm)
500
400
300
200
100
0
0 365 730 1095 1460 1825 2190
Days
Plot
Depth Plot Output
Day number 2190
Depth (cm)
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160
0 20 40 60 80 100
Soil store (ug/kg)

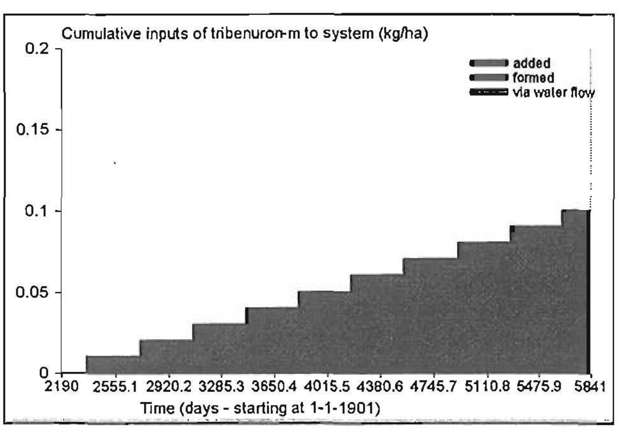
Tribenuron-methyl (PESTLA + FOCUS scenario Jokioinen)

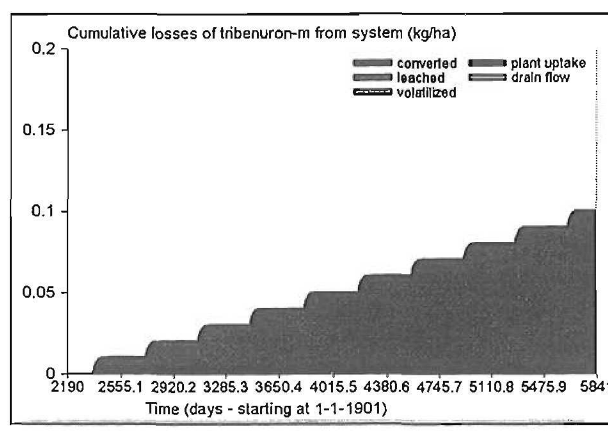


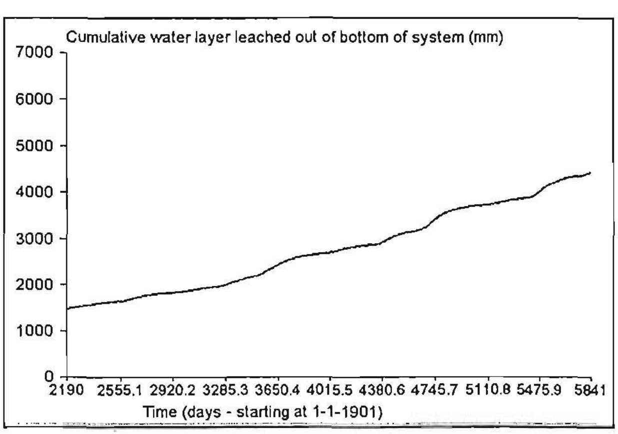


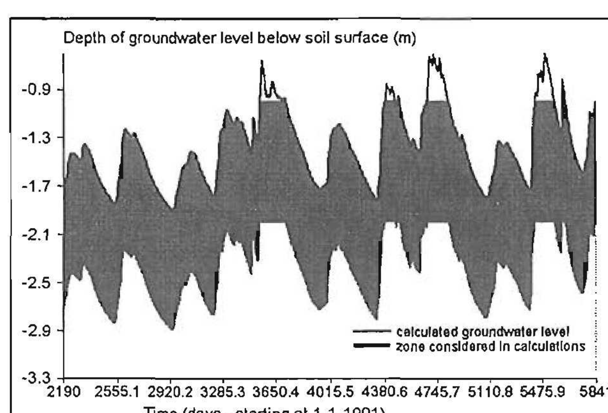




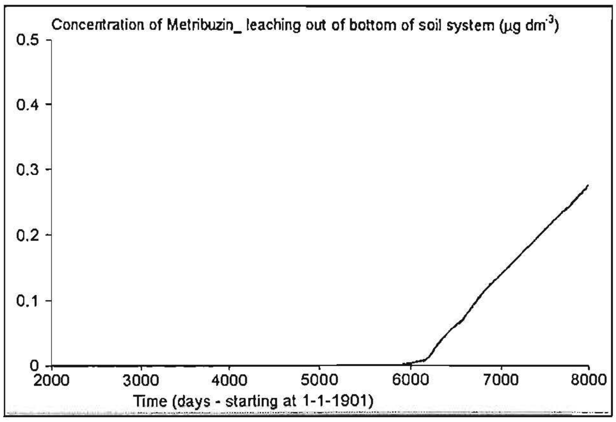


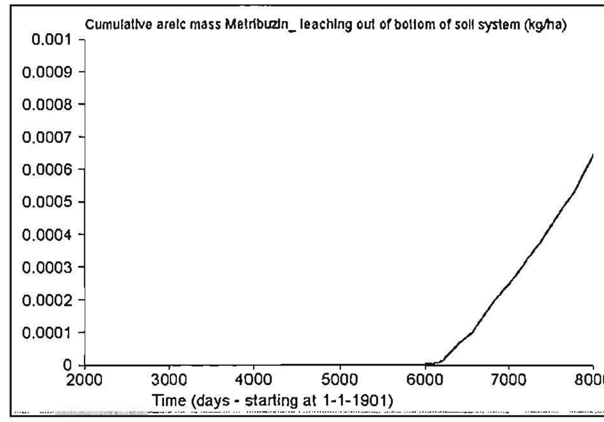


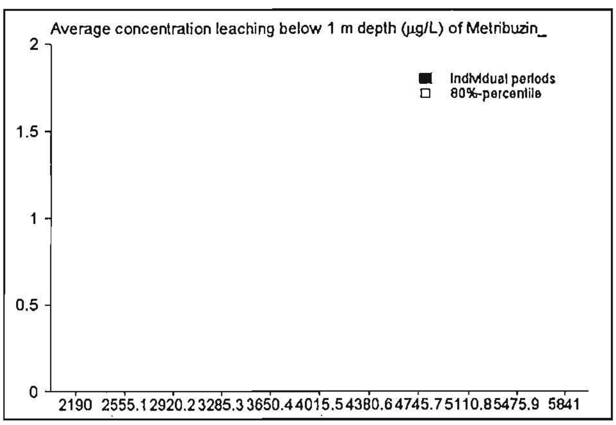


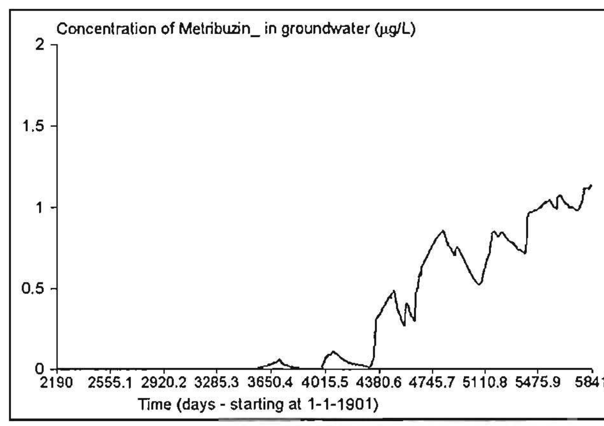


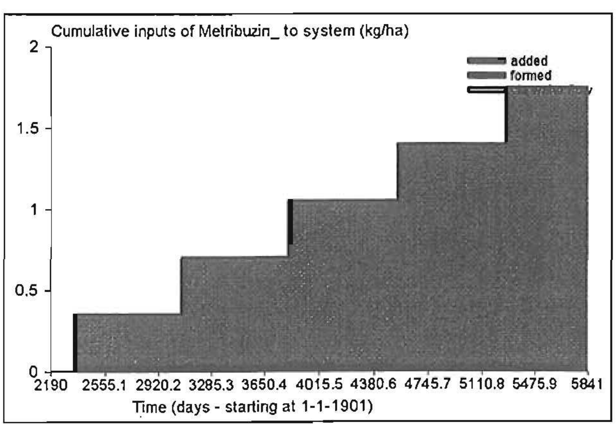
Metribuzin (PESTLA + FOCUS scenario Jokioinen)

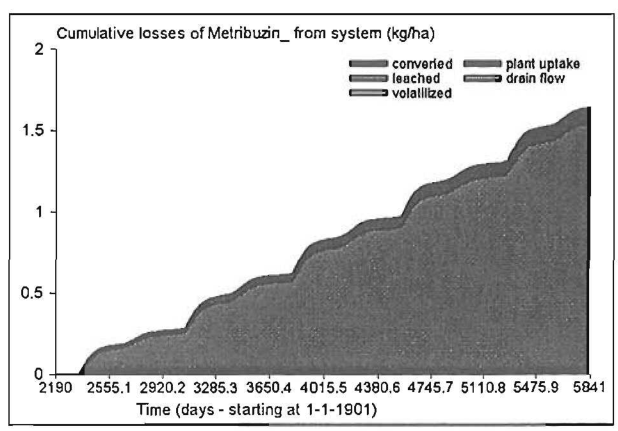


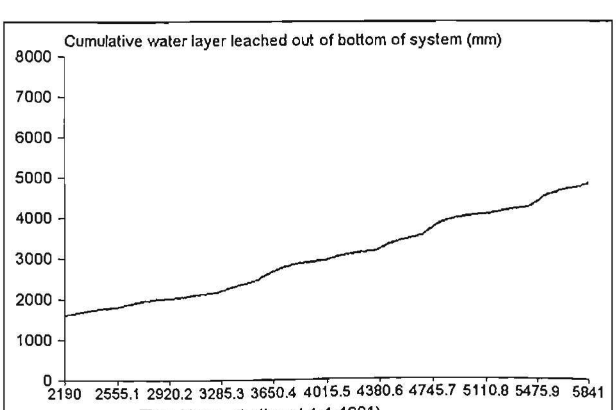


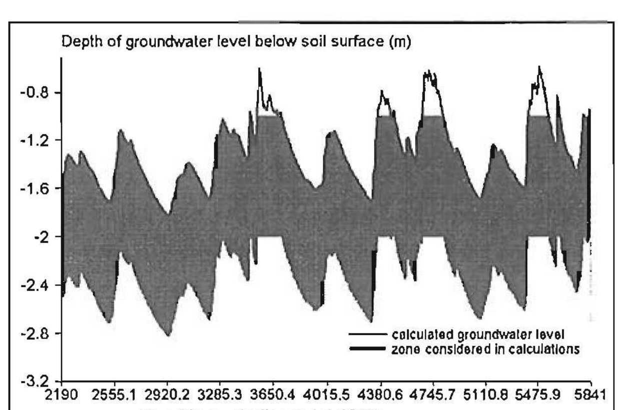




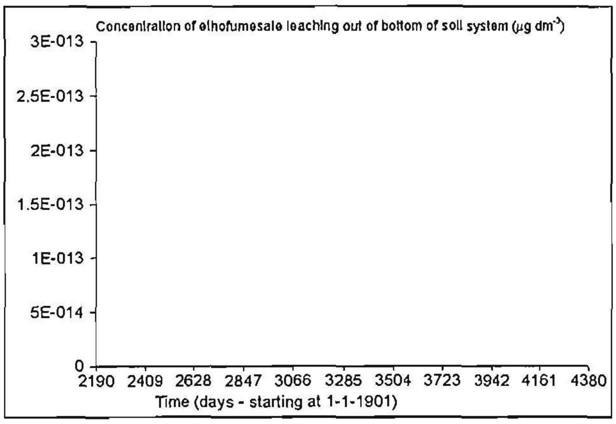


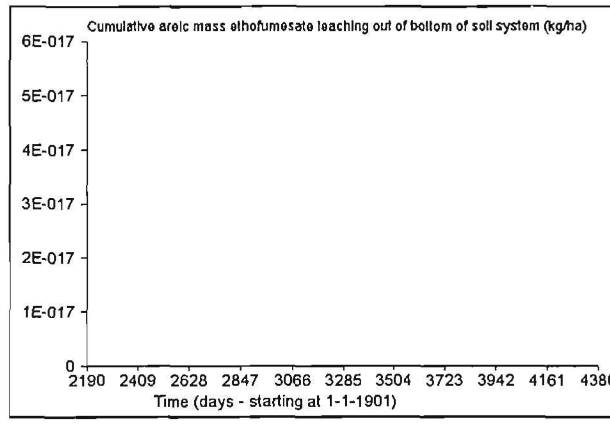


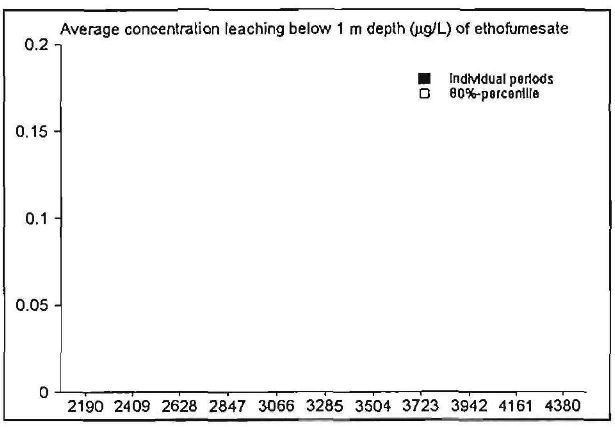


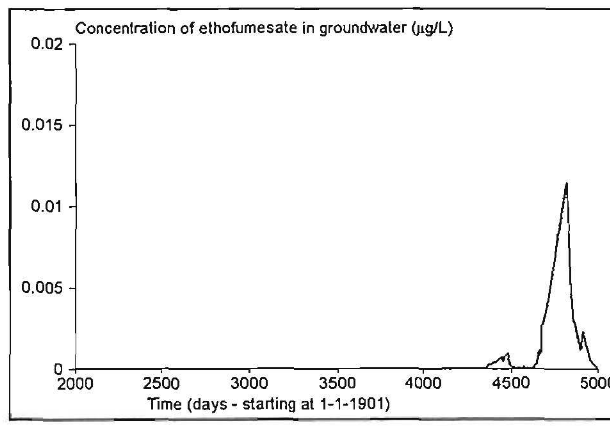


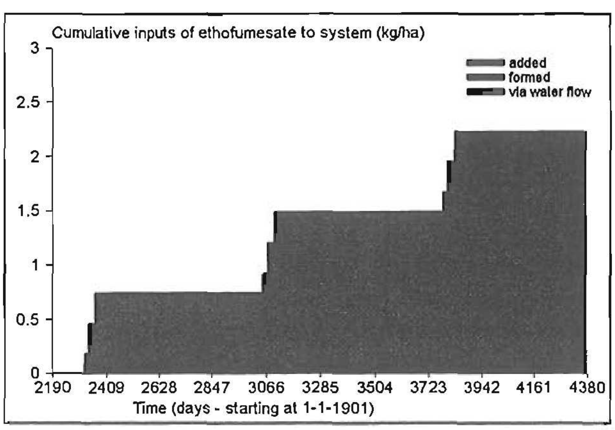
Ethofumesate (PESTLA + FOCUS scenario Jokioinen)

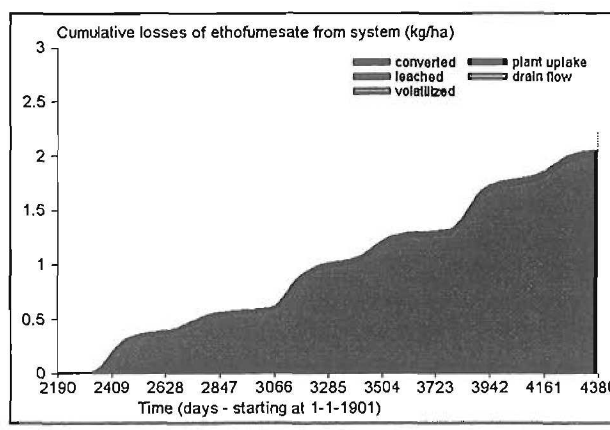


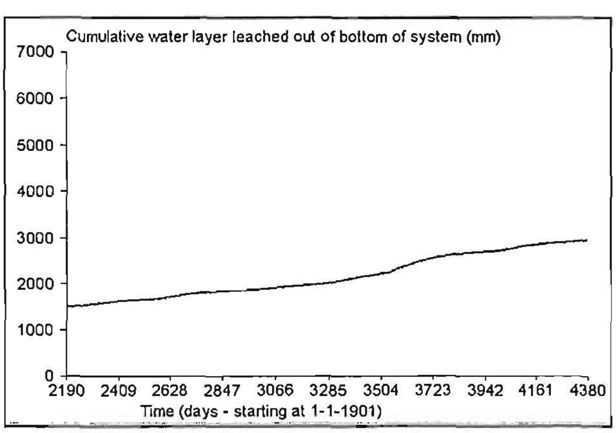


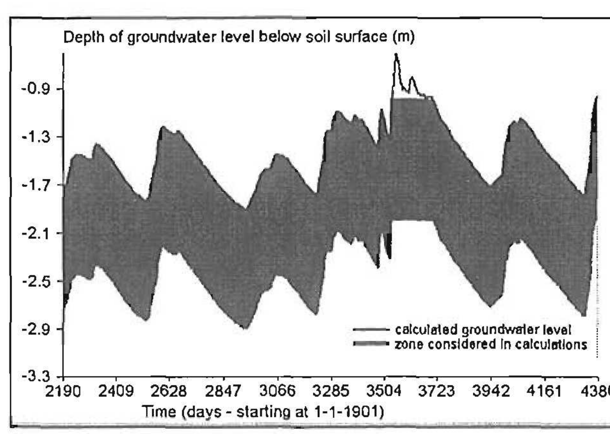












KUVAILULEHTI

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Julkaisun päivämäärä
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Tekijä(t) (toimielimestä: nimi, puheenjohtaja, sihteeri)
Timo Seppälä, Suomen ympäristökeskus
Markku Yli-Halla, Maa-ja elintarviketalouden tutkimuskeskus (MTT)

Julkaisun nimi (myös ruotsinkielinen)
Torjunta-aineiden pohjavesihuuhtoutumismallien käyttö riskinarvioinnissa Suomessa - väliraportti
Riskvärdering av grundvattenkontamination: modellering av bekämpningmedels rörlighet – mellanrapport

Julkaisun laji

Toimeksiantaja

Toimielimen asettamispvm

Julkaisun osat

Tiivistelmä

Torjunta-aineiden riskinarvionti yhdentyy EU:ssa. Samalla torjunta-aineiden käyttäytymistä ympäristössä simuloivien mallien painoarvo riskinarvioinnissa kasvaa. EU (FOCUS-työryhmä) on valmistellut neljälle pohjavesihuuhtoutumis-mallille yhdeksän skenaariota, joita tullaan käyttämään torjunta-aineiden yhteisessä riskinarvioinnissa. Tässä julkaisussa tarkastellaan Suomen olosuhteita edustavan EU-skenaarion ominaisuuksia sekä esitellään alustavat omat, suomalai-siin oloihin paremmin sopivat kansalliset skenaariot yhdelle huuhtoutumismallille (MACRO-DB). Lisäksi julkaisussa on vertailtu EU:n yhteiseen riskinarviointimenettelyyn tarkoitetun mallin sekä kansalliseen riskinarviointiin kaavaillun mallin antamia tuloksia kolmelle torjunta-aineelle (metributsiini, etofumesaatti ja tribenuroni-metyyli).

Suomen oloissa tärkeitä tekijöitä torjunta-aineiden pohjavesiin huuhtoutumisen kannalta ovat maaperän oikovirtaukset makrohuokosissa, alhainen lämpötila, sadannan jakautuminen vesi- ja lumisateeseen sekä roudan vaikutukset maaperän hydrologiaan (mm. halkeilu ja veden jäätyminen). Alustavien tulosten perusteella kansalliseen käyttöön tarkoitetulla MACRO-DB skenaariolla torjunta-aineet huuhtoutuvat pohjavesiin enemmön kuin FOCUS-skenaariot ja niillä käytettävät mallit osoittavat. Lisäksi Jokioisten ilmastossa torjunta-aineet hajoavat mallinnuksen mukaan hitaammin kuin esimerkiksi tutkimuksessa käytetyssä Uppsalan ilmastossa.

Suomen muusta Euroopasta poikkeavien ympäristö- ja maatalousolojen takia kansallisten huuhtoutumisskenaarioiden valmistelua tulee jatkaa, jotta voidaan varmistaa pohjavesiä uhkaavien torjunta-aineiden löytyminen valmisteita hyväksyttäessä siinä missä turvalliset käyttökohteetkin. Tämä edellyttää useiden eri maatyyppien käyttöä mallinnuksessa.

Asiasanat (avainsanat)
Torjunta-aineet, huuhtoutuminen, kulkeutuminen, pohjavesi, mallit, riskinarviointi, ympäristönsuojelu, MACRO-DB, PESTLA, FOCUS

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Riskvärdering och godkännande av bekämpningsmedel sker i allt större omfattning i samording I Europeiska Unionen. Modellering av spridning och förekomst av bekämpningsmedel för allt viktigare roll i den europeiska riskvärdering. En europeisk arbetsgrupp (FOCUS groundwater working group) har utvecklat nio skenarier som kommer att användas för modelleringen av grundvattenkontamination. FOCUS skenarie Jokioinen representerar den nordligaste jordbruksområde i Europa. Faktorer som har en viktig betydelse för utlakning av bekämpningsmedel från jord till grundvatten i finska naturen är makroporflöde, låg temperatur, nederbörd i form av vatten och snö, samt effekter av tjäle på jordens hydrologi. Vi har utvecklat 2 preliminära nationella skenarier som tillämpar bättre för finländska klimat, natur- och jordbruks-förhållanden än Jokioinen skenarie. De nationella skenarierna är utvecklade för MACRO-DB modellen som anses bäst simulera utlakning av bekämpningsmedel i de finländska förhållanden. MACRO-DB modellerar makroporflöde vilket inte gör de andra FOCUS modellerna. Jokioinen skenarie är utvecklade för modellen PESTLA och kan inte köras i MACRO_DB. I rapporten jämförs simuleringsresultat av Jokioinen skenarie med de nationella skenarier. I modelleringarna har man använt tre olika bekämpningsmedel (metribuzin, ethofumesat och tribenuron-metyl). Enligt resultaten leder den nationella skenarien i MACRO_DB till större grundvattenkontamination än Jokioinen skenarie med PESTLA. Resultaten visar vikten att vidare utveckla nationella skenarier som är skärskilt anpassade till finska förhållanden för att upptäcka bekämpningsmedel som potentiellt kan kontaminera grundvattnet och också att kunna hitta riskfri användning. Modellering måste vara gjort med många olika jordtyper.

Sakord (nyckelord)
Bekämpningsmedel, urlakning, mobilitet, grundvatten, modellering, risk avvärdering, miljöskydd, MACRO-DB, PESTLA, FOCUS

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Pesticide groundwater leaching modelling in risk assessment in Finland - interim report

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Abstract

Pesticide approval and risk assessment are moving from national level to EU level. In the European risk assessment the role of pesticide fate modelling is increasing. European Union (FOCUS Groundwater working group) has prepared 9 scenarios for four groundwater leaching models that will be used in the common EU level risk assessment. This publication deals with the European FOCUS scenario representing the Northern region (Jokioinen) and presents provisional national pesticide risk assessmment scenarios, which cover the Finnish climatic and soil in more depth. These scenarios are prepared for MACRO-DB. In addition, the publication compares the leaching of three herbicides (metribuzin, ethofumesate and tribenuron-methyl) in Jokioinen FOCUS scenario modelled with PESTLA with the results of the prepared national scenarios modelled with MACRO-DB.

In Finnish conditions the most important factor contributing to the pesticide leaching into groundwater are preferential flow in the macropores of some soils, low temperature, precipitation falling as rain or snow depending on air temperature, soil groundfrost and its effects on soil hydrology (cracks and water freeze). According to the provisional results obtained in this modelling excercise, the leaching was higher in national scenarios with MACRO-DB than in the European FOCUS scenario Jokioinen and PESTLA. In addition, in the Jokioinen climate the pesticides modelled degraded slower than in Uppsala climate used for comparison.

Because of the Finnish environmental and agricultural properties being so different from the rest of the EU the preparation of national scnearios should be continued in the future, in order to assure identifying pesticides and conditions that pose threat to groundwaters in the course of pesticide risk assessment and product approval, as well as the safe uses. This requires use of several soil types and approaches in modelling.

Keywords
Pesticides, leaching, mobility, groundwater, modelling, risk assessment, environmental protection, MACRO-DB, PESTLA, FOCUS

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