FAO PESTICIDE DISPOSAL SERIES 8

Assessing soil contamination

A reference manual

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Introduction

Improper storage of (obsolete) agrochemicals often leads to pesticides being spilled in the surroundings of the storage site, where they seep into the soil or are dispersed by wind. In some cases pesticide spillage has been going on for many years. Such spillage may cause serious soil or groundwater contamination. When soil and groundwater are contaminated, crops, livestock and drinking-water may become affected and, when they are consumed by human beings, health risks may occur.

This manual aims to help the user determine if pesticide spills have caused soil or groundwater contamination and, if so, whether or not that contamination implies risks for human health.

Not every spill of pesticides implies health risks. Some important factors determining the risks of a spill are:

- the characteristics of the stored pesticides; some pesticides are more toxic than others, some degrade rapidly into harmless compounds, while others are more persistent;
- how much of a pesticide has been spilled and how long the spillage has been occurring. It takes time for contamination to reach the high levels at which health risks may occur.

Taking these and other relevant aspects into account, this manual provides users with a simple method for reaching three conclusions:

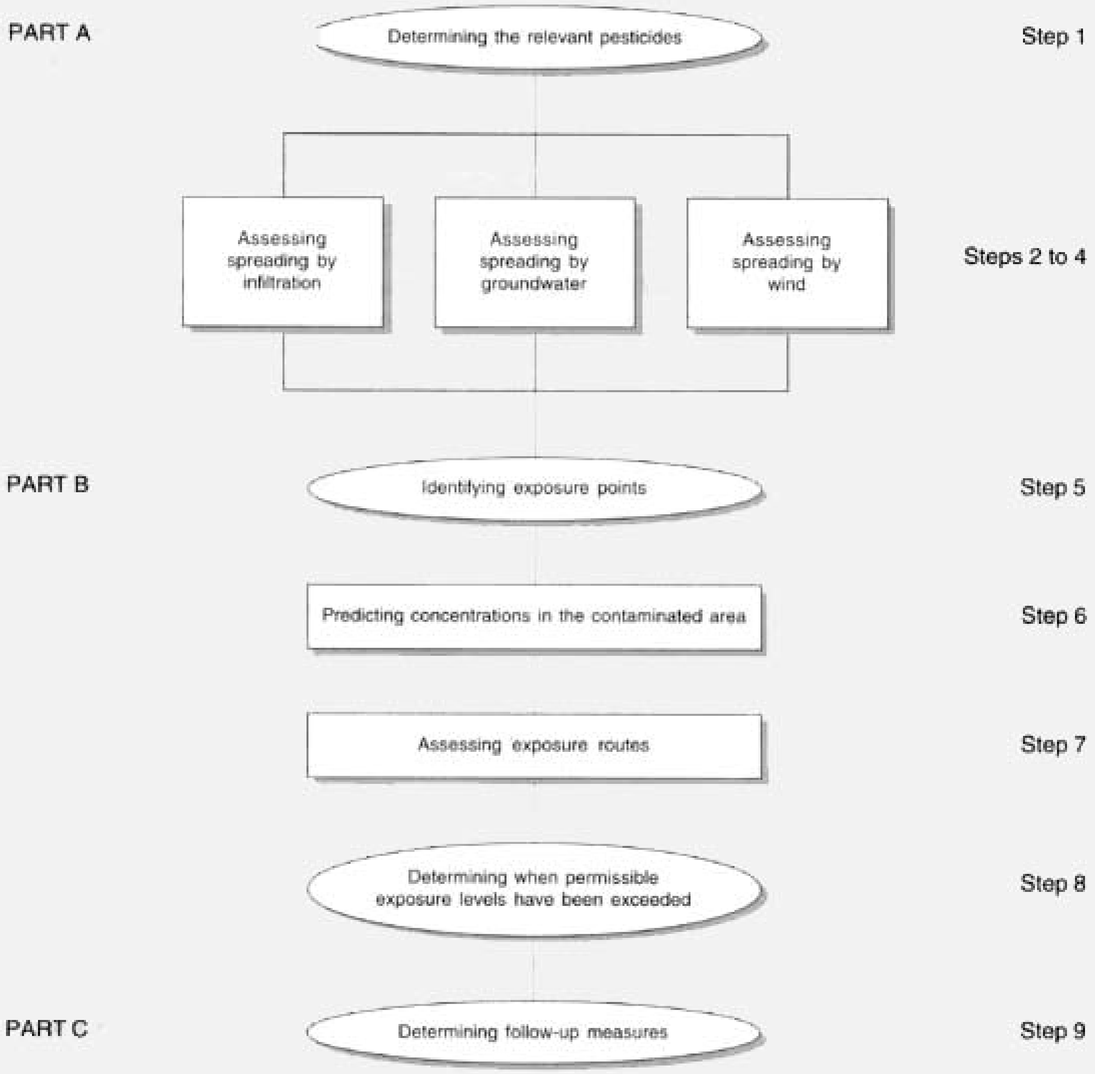
- whether it is likely that the soil or groundwater in the surroundings of the storage facility is contaminated;
- whether such a possible contamination is causing risks for human beings;
- what measures can be taken to reduce these risks.

Note that this manual does not deal with the health risks related to the *use or handling* of pesticides or those that occur *at the storage site* itself. Instead it discusses contamination and health risks outside the storage site, caused by distribution of pesticides in the surroundings.

HOW TO USE THIS MANUAL

The manual consists of a main text and appendixes. The main text describes the steps to be taken to predict whether spillage of pesticides has caused soil or groundwater contamination to such an extent that health risks have occurred. It consists of a series of tables, decision trees and short explanations and is intended for use by storekeepers and those officials responsible for pesticides management. The appendixes provide background information on the subjects dealt with in the main text and are more scientific.

The manual is divided into three parts. Part A helps the user determine whether the area around the store is contaminated and, if so, the size of the contaminated area. Part B helps the user determine whether this contamination has a health impact on human beings. Part C describes the measures to be taken when the contamination poses health risks. Each part describes the information needed to reach conclusions. The user should provide some of this information. The rest can be determined by using the graphs and formulas in the manual.



Steps for assessing the risks of improperly stored pesticides

PART A
Assessing contamination

Distribution of pesticides into the environment

Areas become contaminated because pesticides escape out of the store into the environment. This can take place in various ways:

- pesticides may infiltrate the soil;
- they may be carried away by wind;
- they may be spread by runoff;
- they may leach out into the groundwater and subsequently spread underground, eventually entering rivers or lakes.

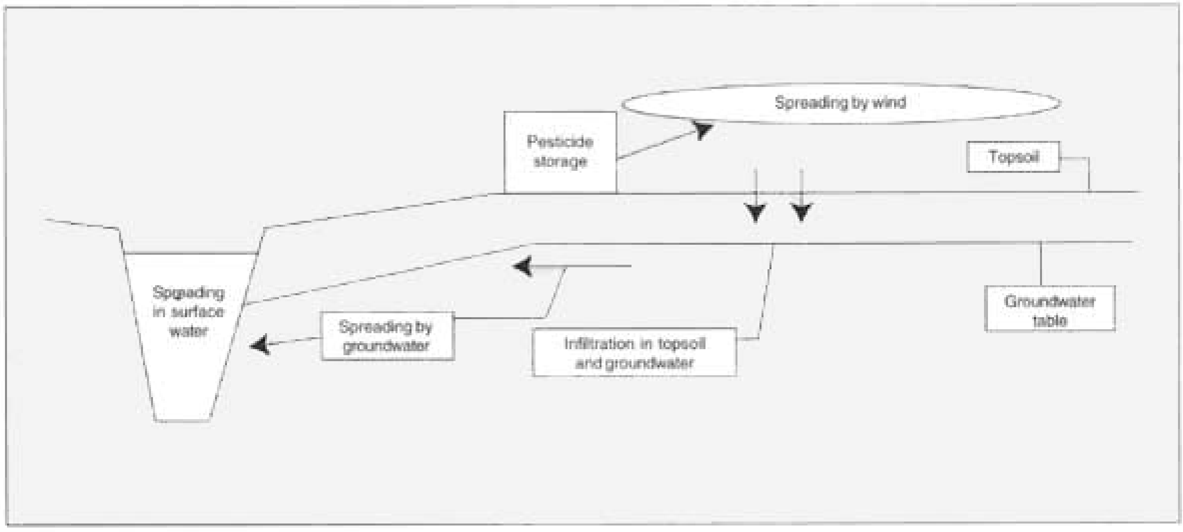
The most important ways of spreading are infiltration (of the soil or towards the groundwater) and dispersal by wind. Distribution of pesticides by runoff should be considered a form of infiltration. (Runoff may be taken into account by assessing the places where runoff has concentrated and deposited the pesticides and subsequently considering this to be a place where infiltration has occurred.)

Distribution by wind contaminates the surface of the area surrounding the site. Distribution by infiltration contaminates the soil below the storage site and may lead to contamination of the groundwater and eventually, after further distribution, to contamination of surface water (e.g. lakes and rivers).

The following figure summarizes these distribution possibilities. Step 2 describes the two most important distribution routes and explains how to calculate the size of the affected area. It also presents a methodology for calculating the concentrations to be expected in the contaminated area.

Four steps need to be taken in order to determine the area that is contaminated:

- Step 1 determines which of the pesticides that have been spilled are relevant, i.e. may have caused contamination.
- Step 2 determines whether these relevant pesticides have infiltrated the soil and, if so, to what depth.
- Step 3 determines whether the relevant pesticides have leached into the groundwater and, if so, which area around the store will have contaminated groundwater.
- Step 4 determines whether the relevant pesticides have been distributed by the wind and if so, which area around the store is contaminated.



Distribution of contaminants from a store into the environment

Step 1
Determining the relevant pesticides

First, use Table 1.1 to list all pesticides that have been spilled.

TABLE 1.1

Pesticides (see Note) (chemical name)	Amount spilled (estimate)

Note: When the pesticides that have been spilled are known, consult Appendix 3, which describes nearly 40 common (obsolete) pesticides and gives information relevant to later parts of this manual. Pesticides not included in that appendix may be found in the literature listed in Appendix 9. When pesticides cannot be identified, take a sample as described in Part C - Checking and send it to a chemical laboratory for testing.

Second, using Table 1.2, determine which of the spilled pesticides are “relevant”. Not all pesticides that have inadvertently entered the environment are harmful to the extent that they cause contamination and an impact on human health. Therefore, a distinction must be made between those pesticides that are likely to cause contamination (relevant pesticides) and those that are not (not relevant pesticides).

Relevant pesticides are pesticides that have been spilled in considerable quantities and that are not readily degrading. The rate of degradation is expressed in half-life, or as DT_{50} in soil. (See Appendix 5 for a description.) When the half-life of a pesticide (its DT_{50} value) is less than six months, the pesticide may be considered as readily degradable and therefore not relevant. The likelihood of the occurrence of health risks caused by leakage of such a pesticide is negligible. Apart from the degradation rate, the amount of spilled pesticide is also important. Spillages of less than 100 litres, or 100 kg, are considered too small to cause health risks through contamination.

TABLE 1.2

A Pesticides spilled (name)	B Quantity > 100 kg. or 0.1 m ? (yes/no)	C DT_{50}-soil (refer to Appendix 3)	D DT_{50} > 1/2 year? (yes/no)	E Pesticide relevant? (yes, if answers in columns B and D are both yes otherwise no)

Conclusion

Are some of the spilled pesticides to be considered relevant? **Yes/No**

If No, stop. If yes, list the relevant pesticides in Table 1.3 and proceed with steps 2–6 *for each individual pesticide that was considered relevant*.

TABLE 1.3

Relevant pesticides	Amount spilled

Step 2
Assessing contamination caused by infiltration

Differentiate between pesticides stored in the open and those stored under a roof.

When in the open:

- For highly mobile pesticides, the subsoil is contaminated to the groundwater level or to a layer of low porosity.
- For moderately mobile pesticides, the subsoil is contaminated to the groundwater level or to a layer of moderate or low porosity.

- For slightly mobile pesticides, only the topsoil (the upper 0.5 metres) will be contaminated.

When under a roof:

- If considerable amounts of liquid pesticides (> 0.1 m^3) have been spilled, pesticide mobility is very high and soil porosity is high, then contamination may extend to deep below the soil surface.
- If considerable amounts of liquid pesticides (> 0.1 m^3) have been spilled, pesticide mobility is high and soil porosity is moderate or high, then contamination may extend to a depth of a few metres below the soil surface.
- In all other cases, only the topsoil (0–0.5 metres) will be contaminated.

ASSESSING THE PESTICIDE CONCENTRATION IN THE SOIL

Infiltration of pesticides into the soil applies to liquids and solids. (Note that infiltration may also occur at sites where pesticides have been accumulating, due to runoff, for instance, or to loading and unloading.) Liquid pesticides will drain into the soil and dissolve in the soil moisture. Solid pesticides will usually first spread from the store on to the soil surface (e.g. by wind or runoff) and may subsequently also infiltrate the soil, after being dissolved in rainwater. Either way, pesticides will always dilute with the soil moisture. The concentration of the pesticide in the soil, therefore, is the concentration of the pesticide in the soil moisture. The maximum pesticide concentration in the soil depends on the solubility of the pesticide in water (see Appendix 2).

Use Tables 2.1 and 2.2 to calculate the concentration of the pesticide in the soil. The concentration is abbreviated as C_0.

$$\begin{cases} if \quad \dfrac{L}{R \times A} \leq S \quad then \quad C_0 = \dfrac{L}{R \times A} \\ if \quad \dfrac{L}{R \times A} > S \quad then \quad C_0 = S \end{cases}$$

TABLE 2.1

Relevant pesticide	Indicate M = amount spilled (kg or litres)	Indicate or estimate T = period of spillage (years)	Calculate L = annual load of pesticides infiltrating (L = M/T) (kg/year)

TABLE 2.2

Relevant pesticide	Use L = annual load (kg/year)	Indicate R = annual rainfall (m/year)	Estimate A = area of spill (m^2)	Indicate S = solubility in water (kg/m^3) (see Appendix 3)	Calculate L/(R × A) (kg/m^3)

Step 3
Assessing contamination in groundwater

ASSESSING THE LIKELIHOOD OF SPILLAGES REACHING THE GROUNDWATER

In general terms, one can assume that spills of pesticides that have infiltrated the soil will eventually reach the groundwater, unless characteristics of the pesticides or the site make that unlikely. Characteristics that could influence the leaching of pesticides into the groundwater include the amount of rainfall, soil drainage, the depth of the groundwater, the type of storage, the given pesticide's mobility and its degradation.

Use Table 3.1 to predict the transport of pesticides towards the groundwater.

Using Table 3.1 will lead to one of two conclusions: the spilled pesticides will reach the groundwater or they will not. If they will not, this means that leakages will not cause the groundwater to become contaminated. Nevertheless, it is wise to take one or a few groundwater samples to check the accuracy of the prediction. (See Part C - Checking.) If it is concluded that the spilled pesticides *will* reach the groundwater, the next step is to determine how far the contamination has spread. This is dealt with in the following section.

DETERMINING THE PESTICIDE CONCENTRATION IN THE GROUNDWATER

The distribution downstream of pesticides in the groundwater aquifer creates an area where the groundwater is contaminated. If the groundwater is used for drinking or irrigation, or if it discharges into a river or lake whose water is used for drinking or irrigation, it is important to know the concentrations of the contaminants in the water. This may be done by calculating the groundwater concentration C_1 at a point where the pesticide enters the aquifer. To carry out this calculation, data are needed about the geohydrology of the storage site. These data are usually available from hydrologists at the given country's Ministry of Agriculture or Water Resources department.

Now calculate the concentration in the groundwater under the spot where spillage has occurred.

$$\begin{cases} if \quad \dfrac{R\times\sqrt{A}}{q\times b}\leq 1 \quad then \quad C_1 = C_0\times\dfrac{R\times\sqrt{A}}{q\times b} \\ if \quad \dfrac{R\times\sqrt{A}}{q\times b} > 1 \quad then \quad C_1 = C_0 \end{cases}$$

TABLE 3.1

Number	Input data	Value	Conclusion
1	Depth of groundwater	<2 m	Groundwater always reached
		<5 m	Proceed with 2
		>5 m	Proceed with 2
2	Amount of pesticides spilled	>100 litres or 100 kg	Proceed with 3
		>100 litres or 100 kg	Groundwater never reached, unless groundwater close to

			surface (< 2 m)
3	Pesticides stored in a closed or half-open store? (see Table I in Appendix 1)	Yes	Groundwater never reached, unless groundwater <5 m
		No	Proceed with 4
4	Time period since start of spillage	< 1 year	Groundwater never reached, unless pesticide mobility high
		> 1 year	Proceed with 5
5	Annual rainfall	> 2000 mm	Groundwater always reached
		=< 2000 mm	Proceed with 6
6	Pesticide mobility (see Appendix 3)	High	Groundwater always reached
		Low	Proceed with 7
7	Degradation (see Appendix 3)	High (DT_{50} soil < 10 days)	Groundwater never reached
		Low (DT_{50} soil > 10 days)	Groundwater always reached

TABLE 3.2

Input data	Dimension	Value
Determine hydraulic gradient (i)		
• use groundwater level measurements or groundwater contour maps	No dimension	
Determine hydraulic conductivity (K) - use Table 3.3	m/day	
Calculate q (specific groundwater discharge) $q = K \times i \times 365$	m/year	
Estimate A (surface area of the place where spillage has occurred) $A = \text{length} \times \text{width}$	m^2	
Determine R (annual rainfall)	m/year	
Calculate $R \times \sqrt{A}/q \times b$ (assume b=1 m)	No dimension	
C_0 (calculated in Step 2 of Appendix 1)	kg/m^3	

TABLE 3.3

Typical values for the hydraulic conductivity of various unconsolidated deposits and rocks

Type of material	K (m/day)
Unconsolidated deposits	
Gravel	1000
Clean sand	100
Silty sand	10
Silt Loess	1
Glacial till	0.1
Unweathered marine clay	0.001
Shale	0.0001

Rocks	
Karst limestone	1000
Permeable basalt	100
Fractured igneous and metamorphic rocks	100
Limestone and dolomite without karst	10
Sandstone without fractures	10
Unfractured igneous and metamorphic rocks	0.00001

Note: Once the pesticide has reached the groundwater table, it is assumed that it will instantly mix with the upper part of the saturated zone. This mixing zone near the water-table zone has an unknown thickness b. For practical purposes, assume that b=1.0 m. Furthermore, it is assumed that the aquifer is polluted over the entire width of the storage facility. The latter is assumed to be √ A.

Step 4
Determining distribution by wind

ASSESSING THE RATE OF EMISSION OF PESTICIDES OUT OF THE STORE

Distribution by wind usually takes place only over relatively short distances, in the order of tens of metres. Dust may be spread over a larger area by strong winds, but the amount of material blown far away will then be small.

To determine the spreading of pesticides by wind, it is necessary first to determine whether or not the relevant pesticides can be distributed by wind.

Only if pesticides are available as powder may the distribution of them by wind take place.

Second, the characteristics of the store have to be determined. To do so, the following parameters must be known:

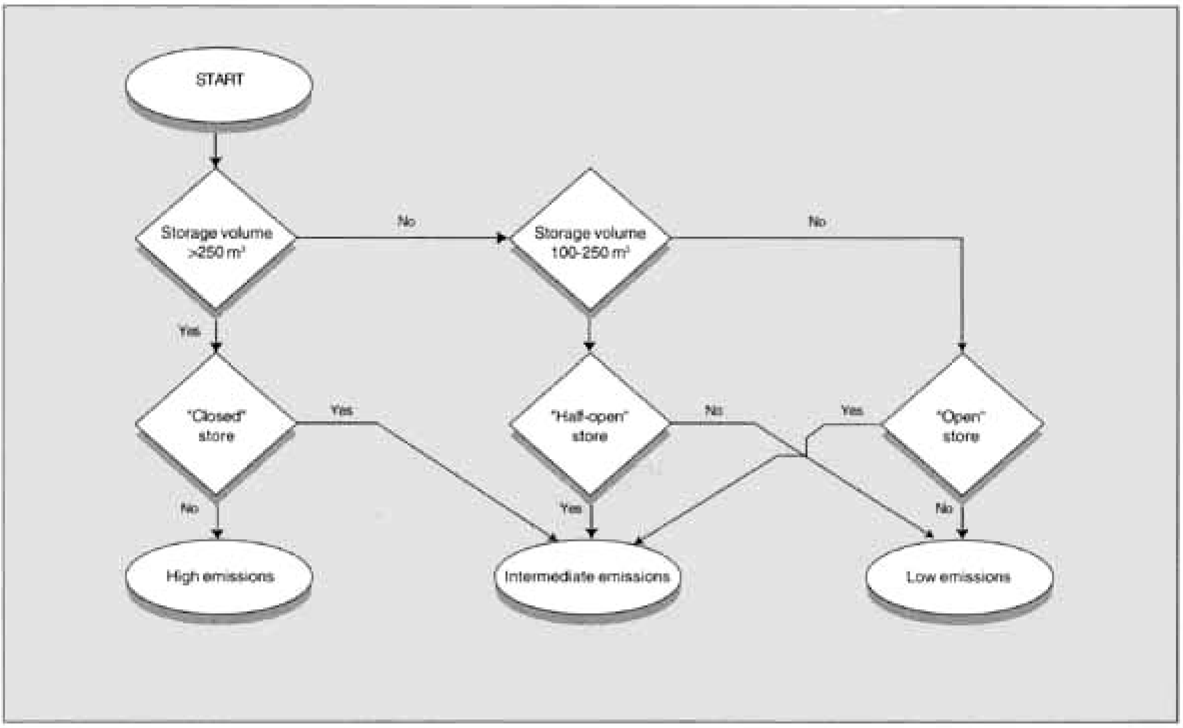
- the volume of the store (length × width × height);
- the “openness” of the store (if walls extend to the roof, the store is considered “closed”; if there are no walls at all, the store is considered “open”; and a store with large ventilation openings or broken windows is considered “half-open”).

TABLE 4.1

Relevant pesticides	Powder? (yes/no)

Next it is necessary to determine whether or not emissions from the store are likely to be high (see Figure).

Use the outcome of this decision tree in Step 6, which helps users determine the concentrations in the area contaminated by the depositing of pesticides by wind.



Decision tree determining the likelihood of distribution by wind

PART B
Identifying possible human health risks through contamination

Introduction

In Part A an assessment was made to determine whether spillages of pesticides caused contamination of soil or groundwater. In Part B it will be determined whether this contamination poses a potential risk to human health. If there are risks, measures must be taken to reduce them. These measures are described below in Part C. If no risks exist, the contamination can be ignored because it will have no effect on the health of humans. Either way, it is wise to take one or more samples to check whether the outcome predicted in this manual corresponds to the real concentrations in the soil and groundwater at the site. How to carry out such checks is described in Part C.

As in Part A, Part B includes several steps that must be taken in order to determine whether contamination poses risks to human health. Step 5 assesses whether there are points in the neighbourhood of the store where humans are exposed to the contamination. Such “exposure points” may be a house or a well, that is, places that are frequently visited or used by people. Step 6 determines the pesticide concentrations that can be expected at the exposure sites. Step 7 assesses how people are exposed. That is, it determines the exposure routes between contamination and humans. Finally, Step 8 determines whether the concentrations exceed the “permissible exposure levels” - the levels of contamination that are still considered safe for humans.

Step 5
Identifying exposure points

EXPOSURE POINTS IN THE AREA WHERE GROUNDWATER IS CONTAMINATED

Objects vulnerable to contamination by pesticides via groundwater are wells, springs, rivers, lakes, reservoirs and ponds. Draw up a list of all the vulnerable objects in the immediate surroundings of the store, within a radius of 300 metres.

TABLE 5.1

Possible exposure points (groundwater)	Distance to store (m)

Not all possible exposure points, however, are at risk of becoming contaminated. Determine the risk by taking the following steps:

- Determine the *principal direction of groundwater flow*. In the absence of groundwater level measurements, use the direction of steepest descent of the regional topography.
- Determine the *downstream quadrant* by drawing two lines at an angle of 45° to the principal direction of groundwater flow, as shown in Figure 5.1.
- Check if any exposure points or vulnerable objects are located inside the downstream quadrant. Mark these objects as “at risk”.

Wells and springs are so-called *point sinks*. If a point sink is located outside the downstream quadrant, it may still be at risk of becoming contaminated.

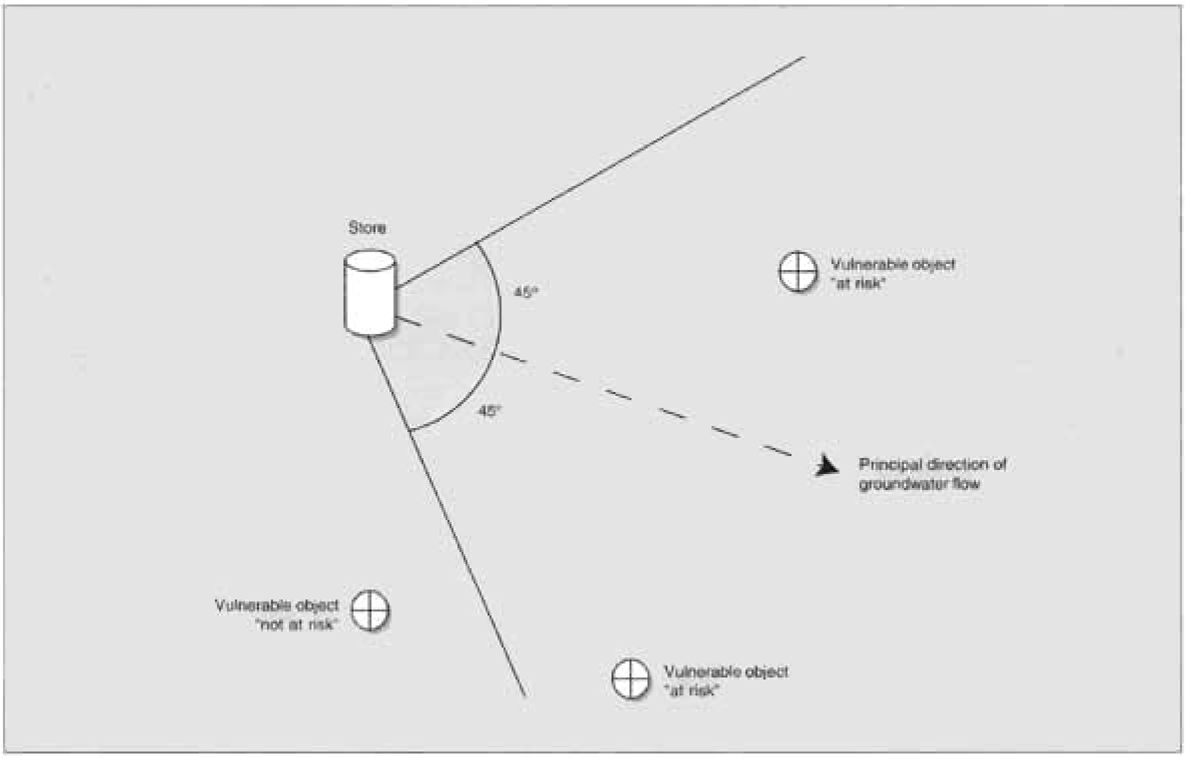


FIGURE 5.1
Delineation of the downstream quadrant

Calculate the *radius of influence* (r) of all point sinks with the following formula:

$$r = \frac{Q}{2 \times q \times D}$$

For each point sink, check if its radius of influence overlaps with the downstream quadrant, as shown in Figure 5.2. If this is the case, then mark this point sink as “at risk”.

Repeat these steps for all vulnerable objects identified as “at risk” and list all relevant objects in Table 5.2.

TABLE 5.2

Relevant exposure points (groundwater)	Distance from store (m)

EXPOSURE POINTS IN THE AREA WHERE TOPSOIL IS CONTAMINATED BY WIND

Objects vulnerable to contamination via wind are objects where humans stay for prolonged periods of time, such as houses, schools, meeting places and work areas. Crops and livestock also need to be considered as vulnerable objects since human beings consume them. List all the vulnerable objects in the immediate surroundings of the store, within a radius of 300 metres.

TABLE 5.3

Relevant exposure points (groundwater)	Distance from store (m)

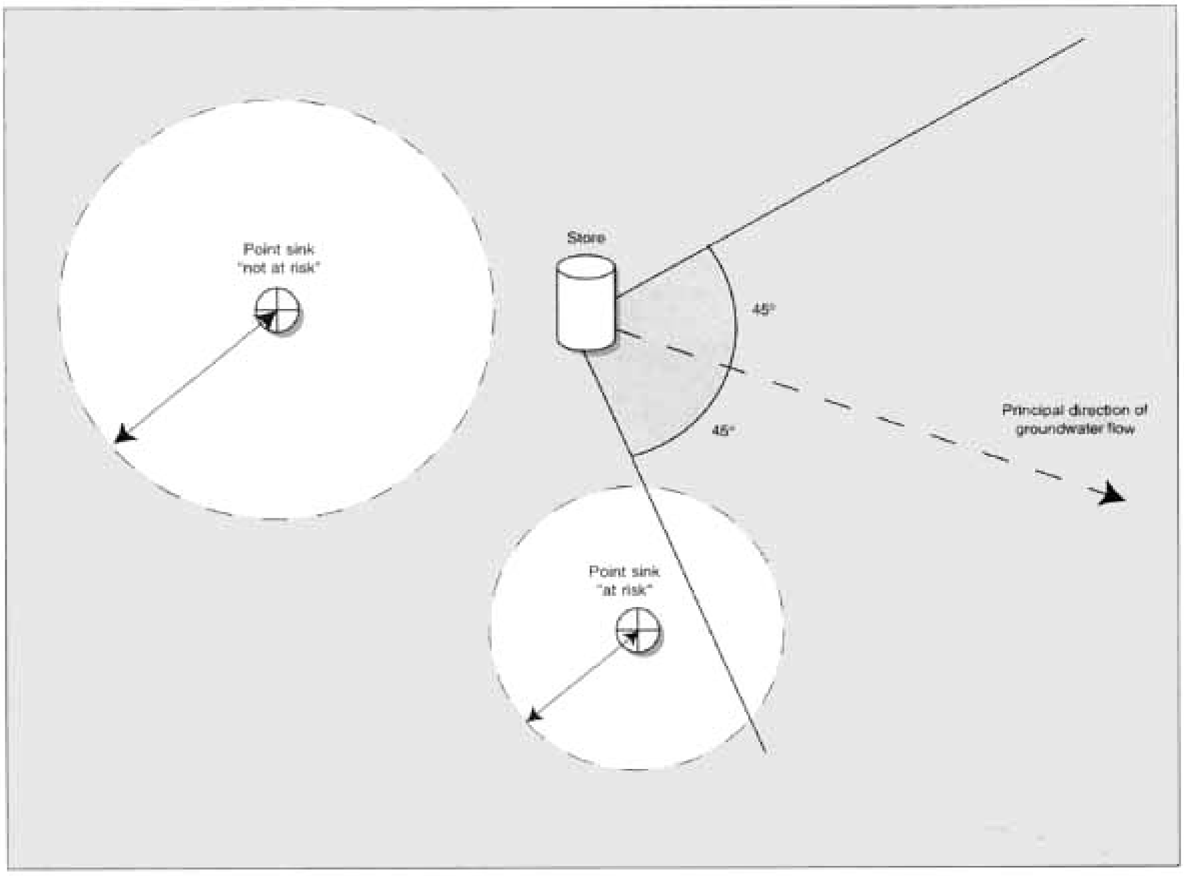


FIGURE 5.2
Delineation of the radius of influence of point sinks

Step 6
Predicting concentrations at the exposure points

POINTS EXPOSED TO GROUNDWATER CONTAMINATION

The calculation of the concentrations at the exposure points is described below. (See Appendix 7.)

Calculate the relative distance (d) between the storage site and each exposure point.

Note that once the dissolved pesticide has reached the groundwater it is assumed that it is transported horizontally in a straight line towards a vulnerable object at risk. The dissolved pesticide moves with the groundwater in a so-called *dispersion front*.

TABLE 6.1

Input	Dimension	Value
Log K_{oc} - ask geohydrologist	Log(ml/g)	
Calculate constant (a) $a = \log K_{oc} - 3$	No dimension	
Calculate retardation (R) $R = 0.3 + 2 \times 10^a$	No dimension	
Retrieve q (groundwater discharge) - refer to Table 3.2	M/year	
Determine T (time since start of spillage)	Years	
Calculate s (horizontal distance travelled by the centre of mass of the dispersion front) $s = q/R \times T$	Metre	
Measure the distance between storage and exposure point (x)	Metre	
Calculate relative distance (d) $d = x/s$	Metre	

Note: The calculation of the retardation factor (R) is based upon a formation with sufficient porosity (approximately 0.3) and extremely low organic matter content (≤ 0.1 percent). These are the types of formations most vulnerable to contamination by pesticides.

- Repeat the steps in Table 6.1 for all exposure points and list the results in Table 6.2, differentiating between wells, springs and rivers on the one hand and lakes and reservoirs on the other (within a 300-metre distance).
- Calculate concentrations in exposure points (e.g. wells, springs, rivers, ponds).

The contamination of the groundwater from pesticide leaching will gradually decrease as contaminated water mixes with clean water in the aquifer. First, calculate a mixing ratio. The concentration at the exposure point is calculated by multiplying the mixing factor with the original concentration below the storage site, corrected with a correction factor. See Table 6.3 and Figure 6.1.

TABLE 6.2

Exposure point (wells, springs or rivers)	Relative distance (d)
Exposure points (lakes, reservoirs)	

Calculate the mixing ratio (m_g) of a well, spring or river with discharge Q:

$$\begin{cases} if \quad \frac{R \times A}{Q} \leq 1 \quad then \quad m_g = \frac{R \times A}{Q} \\ if \quad \frac{R \times A}{Q} > 1 \quad then \quad m_g = 1 \end{cases}$$

The larger the distance from the pollution source, the more the pesticide will be spread out through the aquifer, as a result of *hydrodynamic dispersion*. Ignore any dispersion perpendicular to the principal direction of flow of the groundwater, which in most cases will be small. Furthermore, it is assumed that the dispersion is equal to 10 percent of the distance (x) to the vulnerable object.

Use these assumptions to calculate a correction factor (f_g) that takes into account hydrodynamic dispersion. This correction factor has been plotted in Figure 6.1 as a function of the relative distance travelled by the centre of mass of the dispersion front. Use this figure to look up the value for f_g corresponding with the relative distance d.

Use the following formula to calculate the pesticide concentration (C_g) in a well, spring or river:

$C_g = C_1 \times f_g \times m_g$

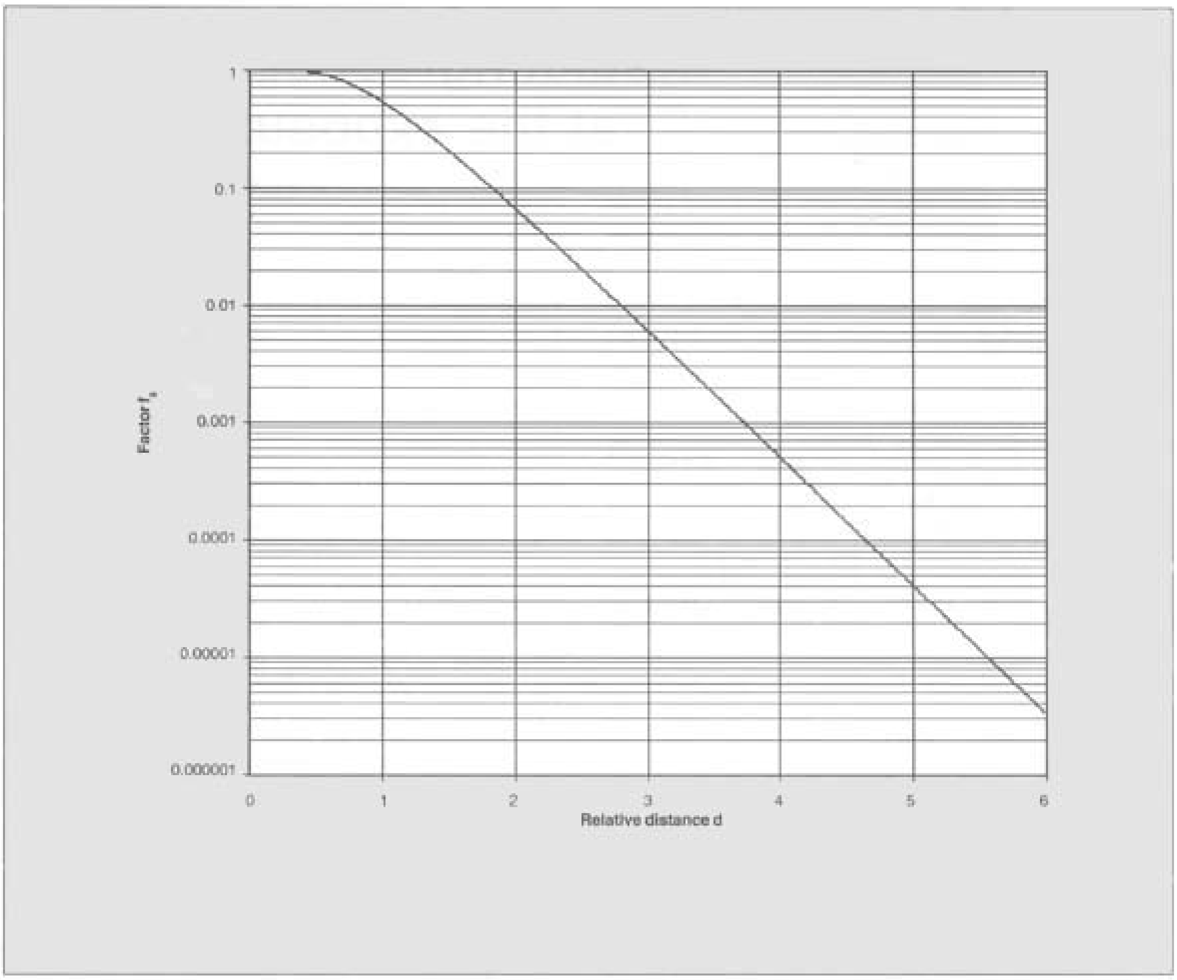


FIGURE 6.1
The correction factor f_g as a function of the relative distance d

When a store is situated on the border of a lake or other large reservoir, calculate the concentration by calculating the mixing ratio (m_s) of a lake, reservoir or pond with water volume V:

$$\begin{cases} if \quad \frac{R \times A \times T}{V} \leq 1 \quad then \quad m_s = \frac{R \times A \times T}{V} \\ if \quad \frac{R \times A \times T}{V} > 1 \quad then \quad m_s = 1 \end{cases}$$

Again, the larger the distance from the pollution source, the more the pesticide will be spread out through the aquifer, as a result of hydrodynamic dispersion. The assumption is that the pesticide will accumulate in the surface water body until the maximum concentration C_1 has been reached.

Use these assumptions to calculate a correction factor (f_s) for surface water that takes into account hydrodynamic dispersion. This correction factor has been plotted in Figure 6.2 as a function of the relative distance travelled by the centre of mass of the dispersion front. Use this figure to look up the value for f_s corresponding to the relative distance d.

Use the following formula to calculate the pesticide concentration (C_s) in the lake, reservoir or pond:

$C_s = C_1 \times f_s \times m_s$

After calculating the concentration at each of the identified exposure points, list the results in Table 6.3.

POINTS EXPOSED TO CONTAMINATION BY WIND

The distribution of pesticides by wind causes the deposition of pesticide dust on an area around the storage site. The fact that an area is contaminated by pesticide dust does not automatically mean that that area poses risks to human health.

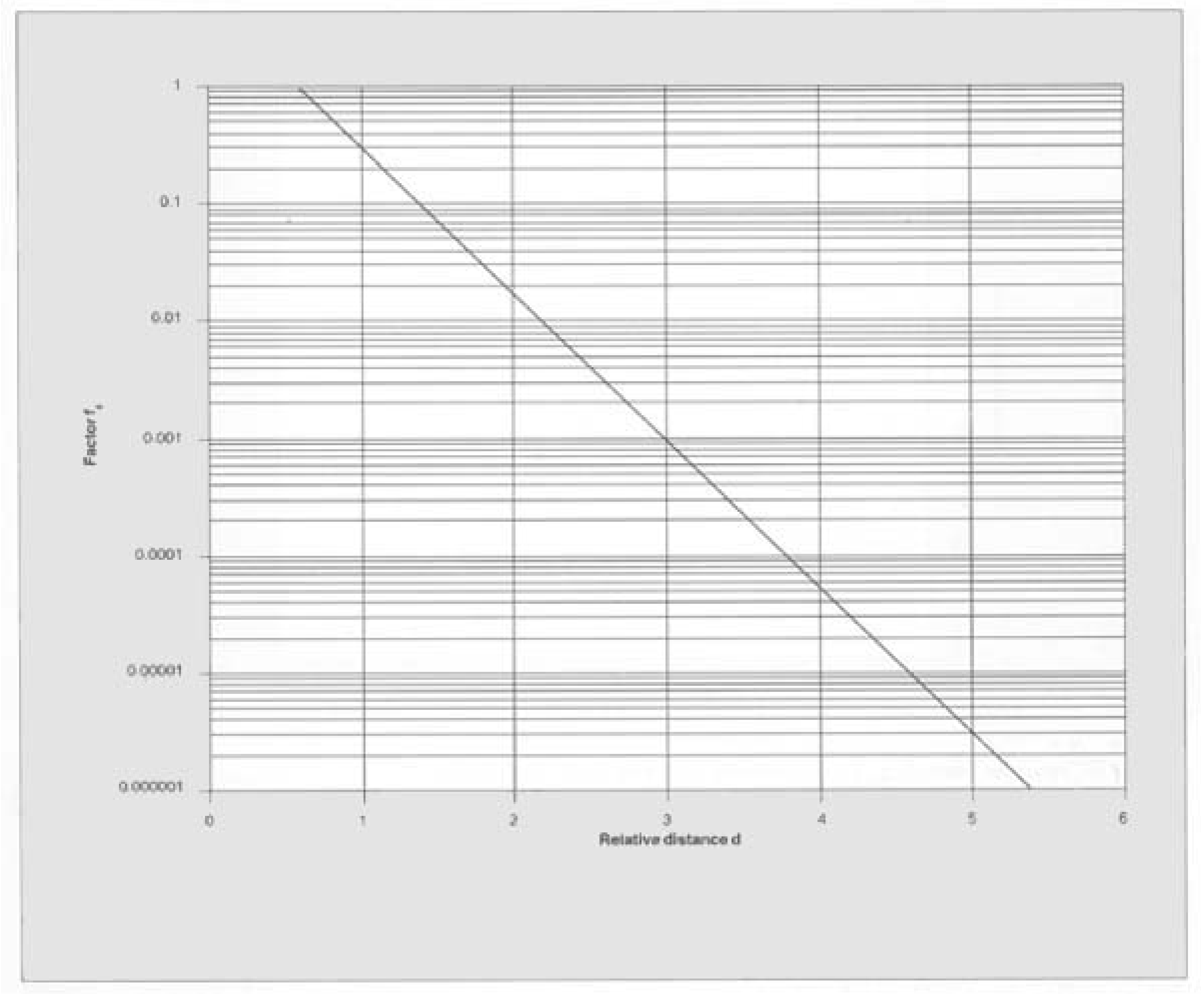


FIGURE 6.2
The correction factor f_s as a function of the relative distance d

TABLE 6.3

Exposure point	Concentration

TABLE 6.4

Pesticide	Permissible concentration (direct contact)

Concentrations may be too low to cause effects. Therefore, it is important to determine which concentrations are still permissible (i.e. which do not cause any health effects) and which are not. The permissible concentrations for direct contact and for the consumption of vegetables, livestock products or drinking-water may be found in Appendix 3 (these concentrations apply also to pesticides distributed by wind).

Note that whether or not a concentration is high enough to cause health risks is calculated by means of risk assessment computer models. The model used to create this manual (Csoil) is scientifically proven and internationally accepted. More information is given in Appendix 6.

Use Table 6.4 to fill in the values.

Figures 6.3 through 6.5 show the pesticide concentrations that can be found in the area around the store. This applies to all directions. Thus, a circle can be drawn around the store to indicate the area affected by wind. In fact, this is a worst-case scenario. By drawing a circle it is assumed that the prevailing wind blows in all directions. (A prevailing wind direction was used in the wind distribution model used to create Figures 6.3 through 6.5. It was assumed that 25 percent of the time the wind blew in the prevailing wind direction.)

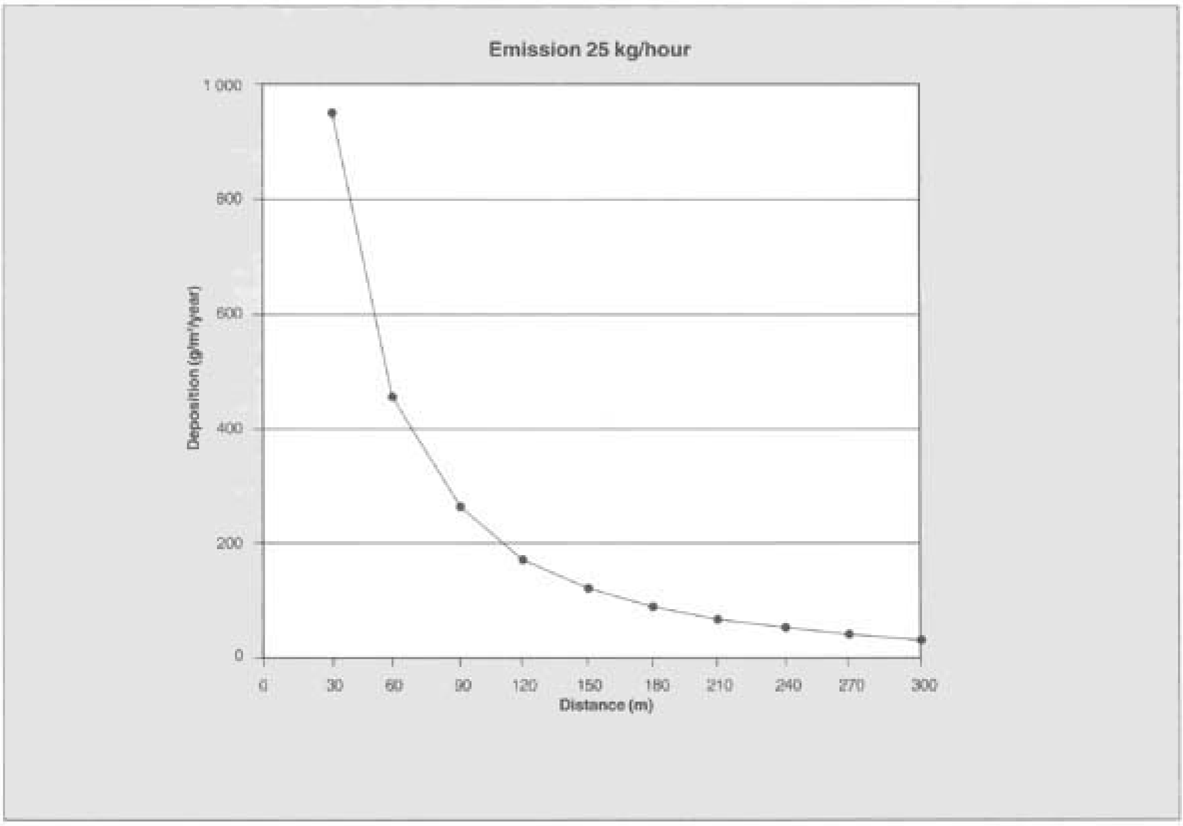


FIGURE 6.3
Graph to determine spreading of contaminants by wind (high emissions)

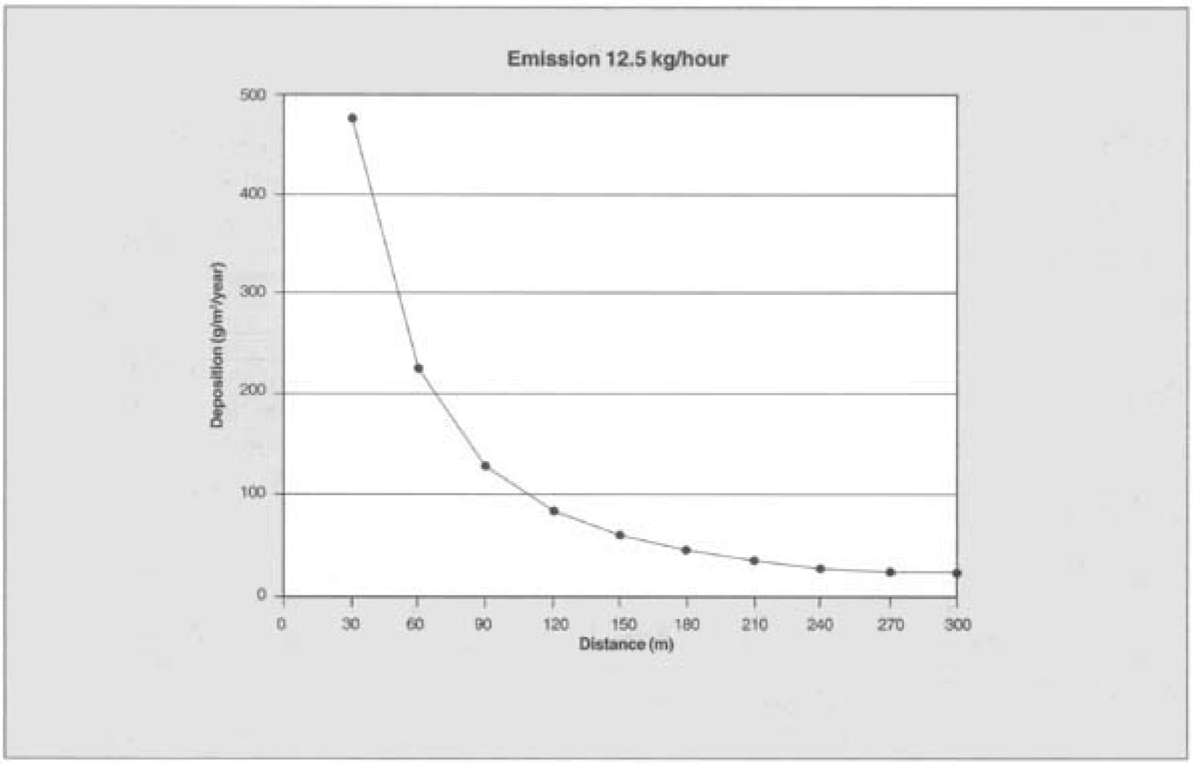


FIGURE 6.4
Graph to determine spreading of contaminants by wind (intermediate emission)

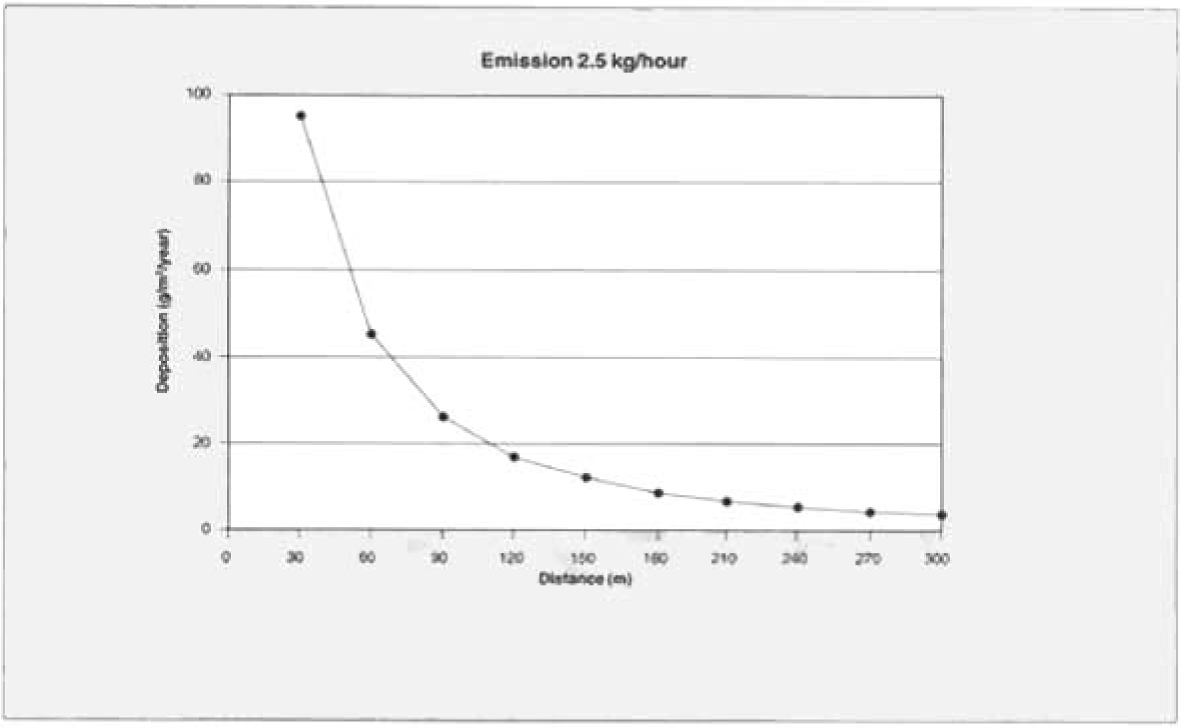


FIGURE 6.5
Graph to determine spreading of contaminants by wind (low emissions)

Now that the permissible concentrations for the relevant pesticides are known, the area within which these concentrations are exceeded can be identified. A standard wind distribution model has been used to this end. The results are presented in Figures 6.3, 6.4 and 6.5 (one for each rate of emission, as determined in Step 4). More information about the model and the parameters used in the calculations is given in Appendix 6.

Now, with the help of Figure 4.1 (assessing the rate of emission), Table 6.4 (the permissible concentrations), and Figures 6.3 through 6.5 (relation concentration and distance), the deposition of pesticides at exposure points may be determined.

Step 7
Identifying exposure routes

To assess whether humans might be affected by contamination (a process called “risk assessment”) one must first identify the routes by which humans can be affected. Human exposure is divided into two pathways, direct and indirect exposure.

Direct exposure will occur from direct contact with soil. This is possible from:

- ingestion of soil;
- dermal contact with soil;
- inhalation of soil particles.

In these cases only the contamination of topsoil is relevant. Direct exposure to a contamination in deeper soil layers is only relevant should one start digging.

Indirect exposure is possible by various different pathways. These pathways are:

- consumption of crops, vegetables or fruits from a contaminated area;
- ingestion of animal products, such as meat, milk and fish;
- ingestion of contaminated drinking water.

Not all exposure routes will always be applicable. For instance, if no crops are grown in the contaminated area, the exposure route “ingestion of contaminated vegetables or fruits” is not applicable and therefore not relevant. Use Table 7.1 to list only the relevant exposure routes. In order to identify relevant exposure routes take into consideration the following:

Soil

- Are humans living within the contaminated area?
- Are schools or hospitals situated within the contaminated area?
- Are crops for human consumption being grown in the contaminated area?
- Do cattle graze within the contaminated area?

Water

- Is water being drunk?
- Is water being used for irrigation?
- Is water being used for fishing?
- Is water being used regularly for bathing, washing (clothes, food, dishes, etc.) or swimming?

Proceed with Step 8, but only for the relevant exposure routes.

TABLE 7.1

Exposure points		Relevant exposure route	
Wells		Drinking-water	
Springs		Irrigation water	
Rivers		Fishing	
Lakes		Water used for bathing/washing/swimming	
Reservoirs			
Ponds			
Houses		Direct contact	
Schools		Consumption of crops, vegetables or fruit	
Meeting places			
Hospitals			

Step 8
Determining when permissible exposure levels have been exceeded

International bodies such as the World Health Organization (WHO) generally define the health risks to humans by chemicals as Acceptable Daily Intake (ADI). The ADI value indicates the maximum quantities of a given chemical that human beings can absorb in a day without showing any signs of illness.

PERMISSIBLE EXPOSURE LEVELS FOR GROUNDWATER

The consumption of contaminated groundwater may pose risks to human health. Consumption of groundwater with pesticide concentrations lower than the permissible concentrations, however, will not pose risks to human health. Of course, the permissible concentration is different for each pesticide and for each exposure route. Consult Appendix 3 for the permissible concentrations, also called exposure levels. Use Table 8.1 to compare these levels with the predicted concentrations (refer to Table 6.3) to determine whether or not permissible concentrations have been exceeded.

PERMISSIBLE EXPOSURE LEVELS FOR WIND

When pesticides are distributed by wind, they may contaminate the soil around the storage area. Direct contact with contaminated soil (e.g. soil ingestion, dermal contact) or indirect contact (consumption of fruits or vegetables cultivated on a contaminated site) may pose risks to human health, but only when permissible concentrations have been exceeded.

For contamination caused by wind, the permissible deposition is also important. Appendix 3 provides the permissible concentrations, depending on the relevant exposure route. To calculate the permissible deposition, calculate the number of hours during which total deposition occurred (N_d) as follows:

N_d = M / average emission level

where:

N_d - number of hours during which total deposition occurred [hours]

M - total amount spilled (see Table 2.3) [kg or litres]

average emission level - see Step 4 [kg/hour]

Calculate the permissible deposition as follows:

permissible deposition = (permissible concentration × 0.5 × 365 × 24) / emission hours [g/m2/year]

Once the permissible deposition is known, compare it with the predicted deposition (Step 6) to determine whether the predicted concentrations exceed the permissible exposure levels.

TABLE 8.1

Exposure point	Exposure route	Predicted concentration	Permissible exposure level	Permissible levels exceeded? (yes/no)

PART C
Determining follow-up measures

Step 9
Checking

The previous steps predict the extent of contamination and the risks associated with it. Before taking actions that are often expensive it is wise to check whether the predictions made using this manual, based on generic rules and models, are true for the specific site and conditions.

Two questions must be asked:

- Are the types of pesticides found in the soil or groundwater the same as those predicted?
- Are the concentrations of those pesticides the same as those predicted?

Step 9 describes what needs to be done to answer these two questions and what needs to be done if the results are different from those predicted.

CHECKING IN THE FIELD

Take samples from the soil and groundwater and have them analysed in a chemical laboratory. It is important, however, that the samples are taken in the right manner and in the right places, otherwise the results will be unreliable and therefore useless for checking purposes.

Where to sample

The places where sampling will be *most useful* are those places where humans are most exposed to the soil or water. These include wells used for drinking-water (by humans or cattle), fields used for agriculture (in particular the growing of vegetables) and the topsoil near houses or schools. Of course, a sampling spot should be within the parameters of contamination predicted by the manual. In selecting these spots, it is essential to take into account the prevailing wind direction and the direction of groundwater flow. Take the samples downwind or downstream (the groundwater flow direction will normally be known by the given country's Ministry of Agriculture, Land Use Planning or Water Supply department). Sample those spots that are nearest to where the obsolete pesticides have been stored.

Sampling is *not useful* when contamination by other activities may have occurred. Examples of unsuitable spots are roads, areas where other waste has been stored, areas near factories and spots where wastewater is discharged.

How to sample water

The sampling of groundwater is not difficult. Fill a clean bottle, preferably of glass, with water. As a rule, sample one litre.

How to sample soil

Aim. To obtain soil samples by employing a uniform, high-quality method.

Principle. Soil excavated during boring should be sampled in such a manner that the sample obtained is sufficiently representative of the soil layer concerned and that the contaminant concentrations have not suffered evaporation or contamination caused by the packaging or the sampling equipment.

Three main types of soil samples should be distinguished:

1. *Undisturbed soil samples*. Split-spoon samplers, thin-wall tube samplers and core barrels can be used to obtain undisturbed soil samples. The sampling tubes are pressed, hammered or rotated into the soil and can be shipped to the laboratory or subsampled in the field. Undisturbed sampling is recommended for the analysis of volatile compounds.
2. *Semi-undisturbed soil samples*. Undisturbed drill cuttings can be obtained by using gouges or piston samplers. The exposed surface of the cuttings can be removed with a spatula and the inner cuttings can be placed immediately in a sampling jar.
3. *Disturbed samples*. The soil samples obtained by using edelman augers and solid-stem augers will be moderately disturbed during the drilling activities but in most cases can be used for chemical analysis purposes. The exposed surface of the cuttings can be removed with a spatula and the inner cuttings can be collected in a sampling jar. It should be noted that high-quality samples of the shallow soil could be obtained by excavating profile pits, using a spatula to take samples directly from the pit walls.

TABLE 9.1

Survey of sample quantities and data on the filtration and preservation of groundwater samples in the field

Analysis	Bottle		To be topped up	Filtr	Preservation		
	Volume (litre)	Colour			Agent	Amount	Holding time
Aromatic solvents, chlorinated solvents, volatile chlorobenzenes	0.25	Green	Yes		HNO_3 pH<2	0.2 ml	7 days
Chlorophenols, phenols (GC)	0.5	Green	Yes				24 h
Chromium VI	0.5	Green	Yes				24 h
Cyanide	0.25	Green	Yes	Yes	N_aOH pH=12	0.25 ml	24 h
BOX	1	Green	Yes				48 h
Phenols (volatile)	0.25	Green	Yes		H_3PO_4 pH<4 $CuSO_4$	3 drops 0.25 g	24 h
GC-MS volatile	1	Green	Yes				24 h
GC-MS semivolatiles	1	Green	Yes				24 h
Mercury	0.25	White	No	Yes	HNO_3 pH<1 $K_3Cr_2O_7$	2 ml 0.05 g	1 month
Heavy metals	0.25	White	No	Yes	HNO_3pH<2	0.2 ml	1 month

Non-volatile chlorobenzenes	1	Green	Yes		HNO_3pH<2	0.75 ml	7 days
Nitrophenols	1	Green	Yes				24 h
Oil (GC)	0.5	Green	Yes		HNO_3 or HCl pH<2		7 days
Organophosphorus pesticides, organonitrogen pesticides	1	Green	Yes				24 h
PAH (polycyclic aromatic hydrocarbons)	1	Green	Yes		HNO_3 pH<2	0.75 ml	24 h
PCB_s, organochlorine pesticides	1	Green	Yes				7 days
Vinyl chloride*	0.02	White	No				ASAP (24 h)
Volatile hydrocarbons (C_4-G_4)	0.5	Green	Yes		HNO_3 pH<2	0.4 ml	7 days
VOX	0.25	Green	Yes		HNO_3 pH<2	0.2 ml	7 days
Water-soluble solvents and acrylates (headspace)	0.25	Green	Yes				24 h

* Prescription used by Tauw Laboratory: inject 15 ml of sample into a 20-ml headspace phial; deliver three phials for each well.

Equipment required:

- plastic foil;
- latex gloves;
- sampling jars with screw lids;
- spatula;
- split-spoon samplers, thin-wall tube samplers, core barrels;
- cooling boxes.

General procedures:

- Wear gloves during sampling to prevent contaminated soil from coming into contact with your hands.
- Always use HDPE or PE foil to store samples and equipment.
- Sampling must be done for each different type of soil (based on texture and organic matter content) and for different degrees of contamination (based on sensory observations), and normally 50 cm at most of excavated material may be collected per sampling jar.

When volatile components are to be analysed:

- *Important:* Samples must be taken directly and without delay from the boring system and stored under cool conditions in order to avoid contaminant losses due to volatilization.
- The sample jars must be kept closed as much as possible in between filling phases.
- Each sampling jar must be filled to its limit. Clean the screw thread and the lid of each jar, and screw the lid on tightly to lower the chance of the contaminants' evaporating.

When non-volatile components are to be analysed:

- Samples of 50 cm drilling depth should be taken from the boring system and placed in order on plastic foil.
- Soil sampled with a piston sampler must be placed on foil or in a PVC gully in one long strip. To measure the boring, place a tape measure next to the strip of soil.

Note that direct sampling from the boring system generally reduces the representativeness of the sample in comparison with sampling from a foil. In the case of volatile contaminants, however, this effect is negligible compared with the effects of volatilization.

Instructions for filling a jar:

- Collect the soil that is the least “smeared” by using a spatula or the lid of the sampling jar. Scrape the soil into the sampling jar using the inside (to avoid contact with the ink) of the sampling jar's lid.
- When sampling clay and loam, break off pieces of clay by hand (wearing clean latex gloves!) or cut the soil with a spatula.
- To ensure that the mass of soil in the sampling jar is representative of the section from which it was taken, check that the locations of the subsamples were proportionally distributed over that section.
- Each sampling jar must be filled to its limit. Clean the screw thread and the lid of each jar, and screw the lid on tightly.

Coding of soil samples. The jars containing the soil samples should be marked with the following data: site name, bore hole number, section depth and date of sampling.

Storage and shipment of soil samples. For the duration of the fieldwork, sampling jars and sampling tubes filled with soil must be stored at a location that is as cool as possible (approximately 2–4°C) and protected from sunlight. The soil samples must be transported to the laboratory as soon as possible after the fieldwork is completed.

Note that cuttings and samples not kept for analysis should be stored and disposed of in agreement with the responsible site manager.

Holding time. The holding time of soil samples is limited due to volatilization and biodegradation. A sample should be extracted in the laboratory within the holding time. The holding times are summarized in Table 9.2.

Reporting. Enter in the bore log the codes marked on the sampling jars and the depths at which the samples were taken. At the completion of the fieldwork, enter in the boring order form the total number of soil samples taken.

How to analyse the samples

All samples need to be analysed for the presence of the pesticides that were predicted in the manual, as well as for the presence of harmful pesticides other than those predicted. Since there are many hundreds of different pesticides, however, checking all of them would be far too expensive. A good solution is to request that the laboratory screen the samples for the five to ten pesticides that show the highest concentrations. Most laboratories are able to carry out this screening with the help of gas chromotography-mass spectrometry (GC-MS) or atomic absorption (AAS) equipment.

WHAT TO DO IF RESULTS ARE DIFFERENT FROM THOSE PREDICTED

Concentrations are lower than predicted

The manual predicts the contamination and risks caused by improper pesticide storage based on a worst-case scenario. This means that the manual predicts a contaminated area as wide as realistically possible and assumes that the pesticide concentrations are as high in this entire area as the highest concentration predicted.

In reality, concentrations will be smaller based on prevailing wind or water distribution patterns. Therefore, during checking, concentrations lower than those predicted will often be found. In this case, ignore the results of the check and proceed as if the predicted values had been found. Or, sample and analyse again to confirm the first analysis. If the results of the second sample are also lower than the predicted values, use the average results of the samples rather than the values predicted with this manual.

TABLE 9.2

Holding time for soil samples

Parameters	Holding time
Solvents	24 h
VOX	24h
Phenols	24 h
Chlorinated pesticides and PCB	7 days
EOX/AOX	48 h
TPH	24 h
PAH	7 days
Chromium VI	48 h
Mercury (total)	15 days
Metals	unlimited

Concentrations are higher than predicted

If the concentrations found through sampling and analysis are higher than those predicted with the manual, it is important to repeat the sampling and analysis, since the results of one sample are considered to be reliable only if confirmed by a second sample. If the second sample also shows higher-than-predicted values, take the average of the two sample results, rather than the values predicted with the manual. If the second sample is lower than the predicted one, either take the predicted value, or sample for a third time.

Step 10
Measures for addressing contamination

DISPOSING OF OBSOLETE PESTICIDES

When deteriorated packaging of obsolete pesticides has caused contamination to occur, measures (sometimes simple, sometimes elaborate and expensive) must be taken to prevent further damage.

First, the cause of the problem (improperly stored pesticides) needs to be addressed. The pesticides, their deteriorated packaging and the severely contaminated soil must be packed in proper containers.

To prevent a recurrence of the problem, the pesticides need to be removed and treated properly, which generally means incinerated in a dedicated waste incinerator. Some types of pesticides may be incinerated also in cement kilns, provided that those kilns are managed properly. This solution, however, is still the subject of debate.

DISPOSING OF CONTAMINATED SOIL OR GROUNDWATER

Measures may also be necessary to treat the area that has been contaminated by the pesticides. There are three basic types of measures:

- removing the contamination (e.g. excavation of soil, pumping-up of groundwater);
- containing the contamination (e.g. covering contaminated soil with buildings, asphalt or another impermeable layer, and preventing contaminated groundwater from flowing downstream);
- preventing human contact with the contamination (e.g. covering the contamination with clean soil, fencing-off contaminated areas, closing contaminated wells).

Removing the contamination also means that the material removed needs to be put somewhere else. Contaminated soil is usually disposed of in a controlled landfill, whereas contaminated groundwater is treated (contamination is removed) and then discharged. Landfilling should be avoided as much as possible. Note that *in-situ* measures (e.g. treating the contamination at the spot without removing it) are generally not possible with obsolete pesticides because of their characteristics (low degradation, low volatility, low leachability). More modern pesticides generally degrade much more easily.

For soil contaminated with organochlorine pesticides such as HCH, on-site biological treatment may be a cost-effective alternative. The treatment includes an initial phase in which the soil is covered with a layer of water to which nutrients are added. This stimulates anaerobic biological degradation. Subsequently, the soil is laid to dry and is ploughed or turned over, in order to stimulate aerobic biological activity. The treatment may take a few years but is relatively cheap.

Generally speaking, removing contamination is more expensive than containing it, which in turn is more expensive than taking protective measures. On the other hand, removing it is a more final solution (all contamination is gone), whereas containment measures must be maintained forever. Protective measures are effective only for as long as they are maintained, which may be difficult to ensure over a longer period.

WHICH MEASURES TO TAKE

The choice of measures depends on the seriousness of the contamination (whether contamination poses risks and whether those risks are high; the higher the risks, the longer-lasting the solution must be). It also depends on the vulnerability of the surroundings: a higher level of contamination may be more acceptable in industrial areas than in agricultural or residential areas. It also depends on the budgets available for direct investments and recurring costs. Also important is whether measures are needed for the immediate protection of human beings only or to prevent contamination from spreading and causing damage in the future.

When choosing which measures to take, the following guidelines apply:

- If the topsoil is contaminated and poses risks to human beings, removing it is recommended.
- If the topsoil is contaminated but does not pose risks, measures, strictly speaking, are not necessary. For psychological reasons (i.e. for the peace of mind of the area's inhabitants), protection measures may be recommended.
- Expensive measures (removal, containment) are necessary only when risks are considerable and the control of protective measures is not likely to be strict.
- If the subsoil is contaminated, removal is often not necessary since the topsoil will prevent human contact with it; to prevent further contamination towards and via the groundwater, containment measures are recommended (e.g. by sealing off the surface, thus preventing rainwater from transporting contamination from the subsoil to the groundwater).
- If the groundwater is contaminated and poses risks to humans, removal of it is recommended. If the obsolete pesticides that caused the contamination are removed, their removal may have to continue for as long as the body of water remains contaminated. Protective measures are also recommended, especially in poorer countries, but need strict control to be effective.
- If the groundwater is contaminated but does not pose risks, and the improperly stored pesticides have been repacked or removed, no measures are needed. The site should be monitored (e.g. samples taken from wells once a year) to determine whether contamination is recurring.

APPENDIX 1
Field format for assessing soil contamination

Step 1
Determining the relevant pesticides

Use Table A to list all the pesticides that have been spilled at the site.

TABLE A

Pesticides (chemical name)	Amount spilled (in kg or litres) (estimate)

Now use Table B to determine which of the spilled pesticides are relevant.

TABLE B

A Pesticide spilled (name)	B Quantity > 100 kg or 100 litres? (yes/no)	C DT_{50} soil (refer to Appendix 3)	D $DT_{50} > 60$ days? (yes/no)	E Pesticide relevant? (yes, if responses in column B and D are yes: otherwise, no)

Conclusion

Are some of the spilled pesticides to be considered relevant? **Yes/No**

If yes, list the relevant pesticides in Table C and proceed with steps 2 through 6 *for each pesticide considered relevant.*

TABLE C

Relevant pesticide	Amount spilled

Step 2
Assessing contamination caused by infiltration

Use Tables D and E to calculate C_0 (the concentration of the pesticide in the soil at the point of the spillage).

TABLE D

Relevant pesticide	Indicate M = amount spilled (kg or litres)	Indicate or estimate T = period of spill (years)	Calculate L = annual load of pesticides infiltrating (L = M/T) (kg/year)

TABLE E

Relevant pesticide	Use L = annual load (kg/year)	Indicate R = annual rainfall (m/year)	Estimate A = area of spill (m^2)	Indicate S = solubility in water (kg/m^2) (see Appendix 3)	Calculate L/(R × A) (kg/m^3)

$$\begin{cases} \text{if} \quad \dfrac{L}{R \times A} \leq S \quad \text{then} \quad C_0 = \dfrac{L}{R \times A} \\ \text{if} \quad \dfrac{L}{R \times A} > S \quad \text{then} \quad C_0 = S \end{cases}$$

Conclusion

C_0 pesticide = ……kg/m^3

Step 3
Assessing contamination in groundwater

Use Table F to predict the transport of pesticides towards the groundwater.

TABLE F

Number	Input data	Value	Conclusion
1	Depth of groundwater	<2 m	Groundwater always reached
		<5 m	Proceed with 2
		>5 m	Proceed with 2
2	Amount of pesticides spilled	>100 litres or 100 kg	Proceed with 3
		<100 litres or 100 kg	Groundwater never reached, unless groundwater close to surface (<2 m)
3	Pesticides stored in a closed or half-open store? (see Table I in Appendix 1)	Yes	Groundwater never reached, unless groundwater <5 m
		No	Proceed with 4
4	Time period since start of spillage	< 1 year	Groundwater never reached, unless pesticide mobility high
		> 1 year	Proceed with 5
5	Annual rainfall	>2000 mm	Groundwater always reached
		=<2000 mm	Proceed with 6
6	Pesticide mobility (see Appendix 3)	High	Groundwater always reached
		Low	Proceed with 7
7	Degradation (see Appendix 3)	High (DT_{50} soil < 10 days)	Groundwater never reached
		Low (DT_{50} soil > 10 days)	Groundwater always reached

Conclusion

Groundwater always reached. Proceed with Step 3.

Groundwater never reached. Proceed to Step 4.

Now use table G to determine C_1, the pesticide concentration in the groundwater.

TABLE G

Input data	Dimension	Value
Determine hydraulic gradient (i)		
- use groundwater level measurements or groundwater contour maps	No dimension	
Determine hydraulic conductivity (K) - use Table 3.4	m/day	
Calculate q (specific groundwater discharge)		
$q = K \times i \times 365$	m/year	
Estimate A (surface area of the place where spillage has occurred)		
$A = \text{length} \times \text{width}$	m^2	
Determine R (annual rainfall)	m/year	
Calculate $R \times \sqrt{A} / q \times b$		
(assume b = 1 m)	No dimension	
C_0 (calculated in Step 2 of Appendix 1)	kg/m^3	

$$\begin{cases} if \quad \dfrac{R \times \sqrt{A}}{q \times b} \leq 1 \quad then \quad C_1 = C_0 \times \dfrac{R \times \sqrt{A}}{q \times b} \\ if \quad \dfrac{R \times \sqrt{A}}{q \times b} > 1 \quad then \quad C_1 = C_0 \end{cases}$$

Conclusion

C_1 pesticide = …… kg/m^3

Step 4

Determining distribution by wind

Use Table H to determine whether the relevant pesticides can be distributed by wind.

TABLE H

Relevant pesticides	Powder? (yes/no)

Conclusion

Since the relevant pesticide is not available as a powder, distribution by wind will not take place.

Since the relevant pesticide is available as a powder, distribution by wind may take place.

Now use Table I to characterize the store.

TABLE I

Calculate the volume of the store (length × width × height in meters)		
Indicate the openness of the store	Walls extend to the roof	Closed
	No walls	Open
	Large ventilation openings or broken windows	Half-open

Conclusion

The store is considered closed.

The store is considered half-open.

The store is considered open.

Now use Figure A determine whether or not emissions from the store are likely to be high.

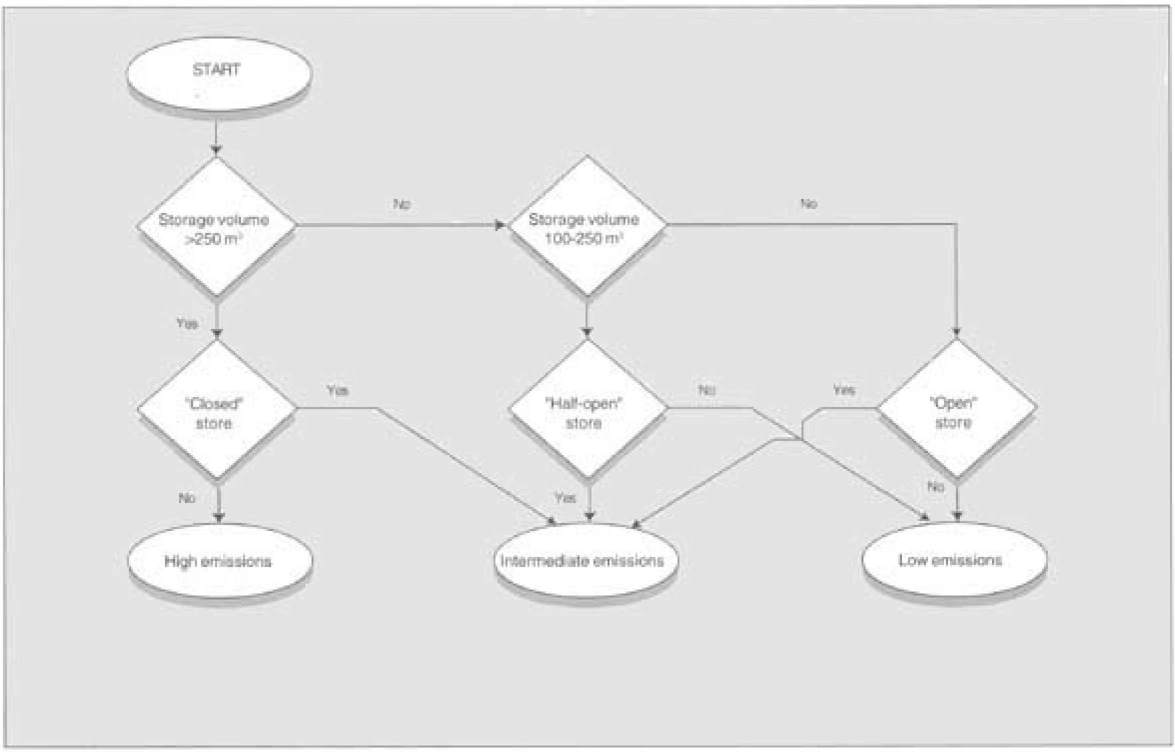


FIGURE A
Decision tree determining the likelihood of distribution by wind

Conclusion

High emission have occurred at the site.

Intermediate emissions have occurred at the site.

Low emissions have occurred at the site.

Step 5
Identifying exposure points

GROUNDWATER

Draw up a list of vulnerable objects in the immediate surroundings of the store (within a radius of 300 metres) that might be influenced by groundwater contamination. Objects vulnerable to contamination by pesticides via groundwater are wells, springs, rivers, lakes, reservoirs and ponds.

TABLE J

Possible exposure points (groundwater)	Yes?	Distance from the store (m)
Wells		
Springs		
Rivers		
Lakes		
Reservoirs		
Ponds		
Other		

Determine the principal direction of groundwater flow. In the absence of groundwater level measurements, use the direction of steepest descent of the regional topography.

Subsequently, determine the downstream quadrant by drawing two lines at an angle of 45° with the principal direction of groundwater flow, as shown in Figure B.

Check if any exposure points or vulnerable objects are located inside the downstream quadrant. Mark these objects as “at risk”.

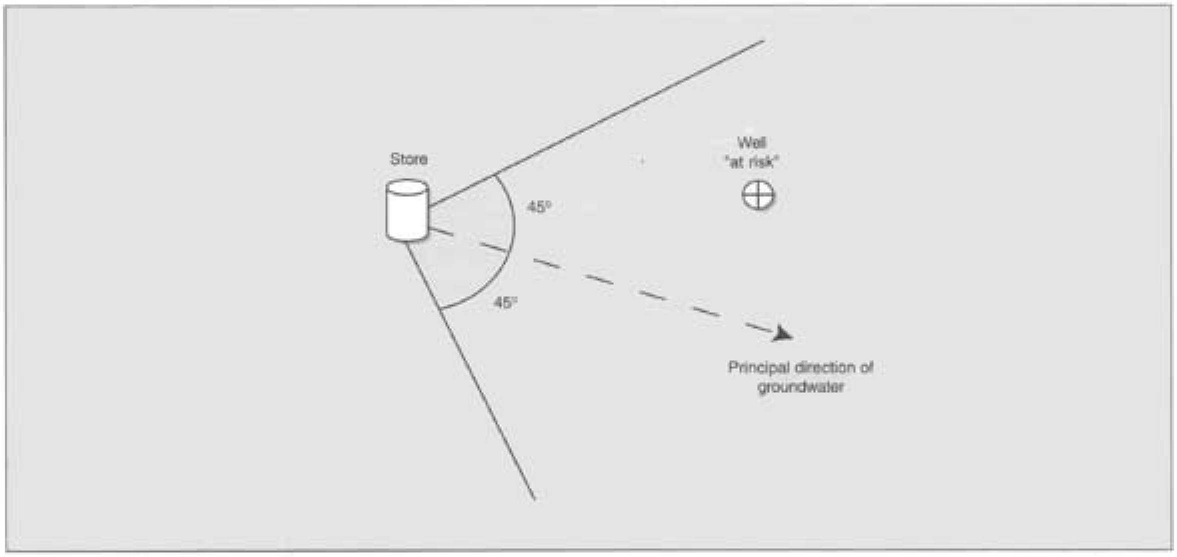


FIGURE B
Delineation of the downstream quadrant

Conclusion

There are no relevant points exposed to groundwater contamination.

Identified exposure points are .... at .... metres from the store.

WIND

Use Table K to list the vulnerable objects in the immediate surroundings of the store (within a radius of 300 metres) where the topsoil might be contaminated by wind.

TABLE K

Possible exposure points (wind)	Yes?	Distance from the store (m)
Houses		
Schools		
Meeting places		
Hospitals		

Conclusion

There are no relevant points exposed to contamination by wind.

Identified exposure points are .... at .... metres from the store.

Step 6

Predicting concentrations at the exposure points

POINTS EXPOSED TO GROUNDWATER CONTAMINATION

First, use Table L to calculate the relative distance (d) for each relevant pesticide.

TABLE L

Input	Dimension	Value
Log K_{oc} - ask geohydrologist	Log(ml/g)	
Calculate constant (a) $A = \log K_{oc} - 3$	No dimension	
Calculate retardation (r) $R = 0.3 + 2 \times 10^a$	No dimension	
Retrieve q (groundwater discharge) - refer to Table G	m/year	
Determine T (time since start of spillage) - refer to Table D	Years	
Calculate s (horizontal distance travelled by the centre of mass of the dispersion front) $s = (Q/R) \times T$	Metres	
Measure the distance between storage and exposure point (x) - refer to Table J	Metres	
Calculate relative distance (d) $d = x/s$	Metres	
Is one of the exposure points a well, spring or river? If yes, indicate discharge Q	m^3/year	
Is one of the exposure points a lake, reservoir or pond? If yes, indicate volume V	m^3	

If one of the exposure points is a well, spring or river, calculate the mixing ratio m_g. If other exposure points are lakes, reservoirs or ponds, calculate the mixing ratio m_s. See page 53.

$$\begin{cases} if \quad \dfrac{R \times A}{Q} \leq 1 \quad then \quad m_g = \dfrac{R \times A}{Q} \\ if \quad \dfrac{R \times A}{Q} > 1 \quad then \quad m_g = 1 \end{cases}$$

pesticide: (R × A)/Q = ...

The mixing ratio m_g pesticide = ...

Now calculate a correction factor (f_g) that takes into account hydrodynamic dispersion. Use Figure C to look up the value for f_g corresponding to the relative distance d (calculated in Table L).

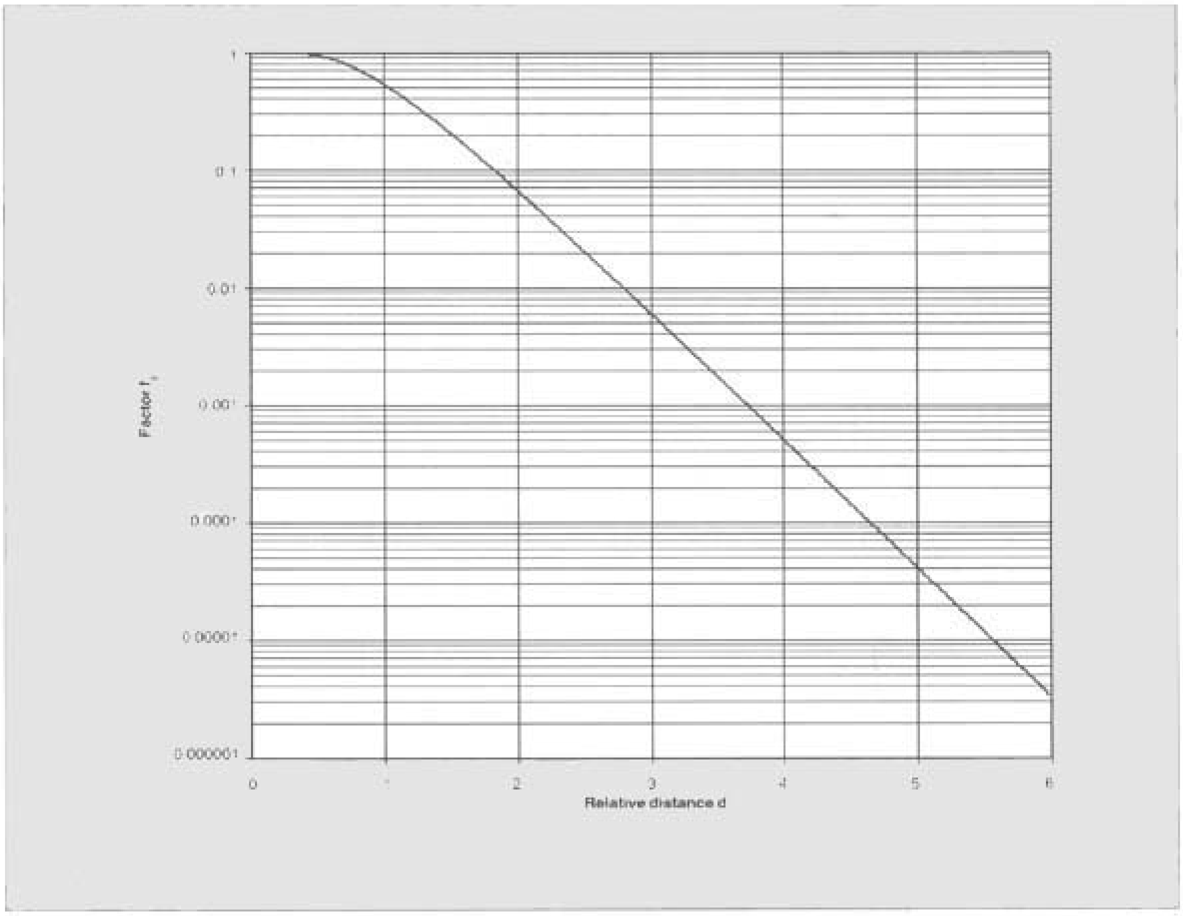


FIGURE C
The correction factor f_g as a function of the relative distance d

f_g pesticide = ...

Next, use Table M to calculate concentrations at the relevant exposure points (C_g).

TABLE M

Pesticide	C_1 =	f_g =	m_g =	$C_g = C_1 \times f_g \times m_g =$ …… kg/m^3
Pesticide	C_1 =	f_g =	m_g =	$C_g = C_1 \times f_g \times m_g =$ …… kg/m^3
Pesticide	C_1 =	f_g =	m_g =	$C_g = C_1 \times f_g \times m_g =$ …… kg/m^3
Pesticide	C_1 =	f_g =	m_g =	$C_g = C_1 \times f_g \times m_g =$ …… kg/m^3

Conclusion

The calculated concentration of pesticides in the well/spring/river (C_g) is $C_g = C_1 \times f_g \times m_g$ = ... kg/m^3 × 1 000 000 = ... μg/l. Notrelevant. There are no relevant points exposed to groundwater contamination.

For a lake, reservoir or pond with water volume V, calculate the mixing ratio (m_s):

$$\begin{cases} if \quad \dfrac{R \times A \times T}{V} \leq 1 \quad then \quad m_s = \dfrac{R \times A \times T}{V} \\ if \quad \dfrac{R \times A \times T}{V} > 1 \quad then \quad m_s = 1 \end{cases}$$

pesticide: R × A/Q = ...

The mixing ratio m_g pesticide = ...

Then, calculate a correction factor (f_s) that takes into account hydrodynamic dispersion. Use Figure D to look up the value for f_s corresponding to the relative distance d (calculated in Table L).

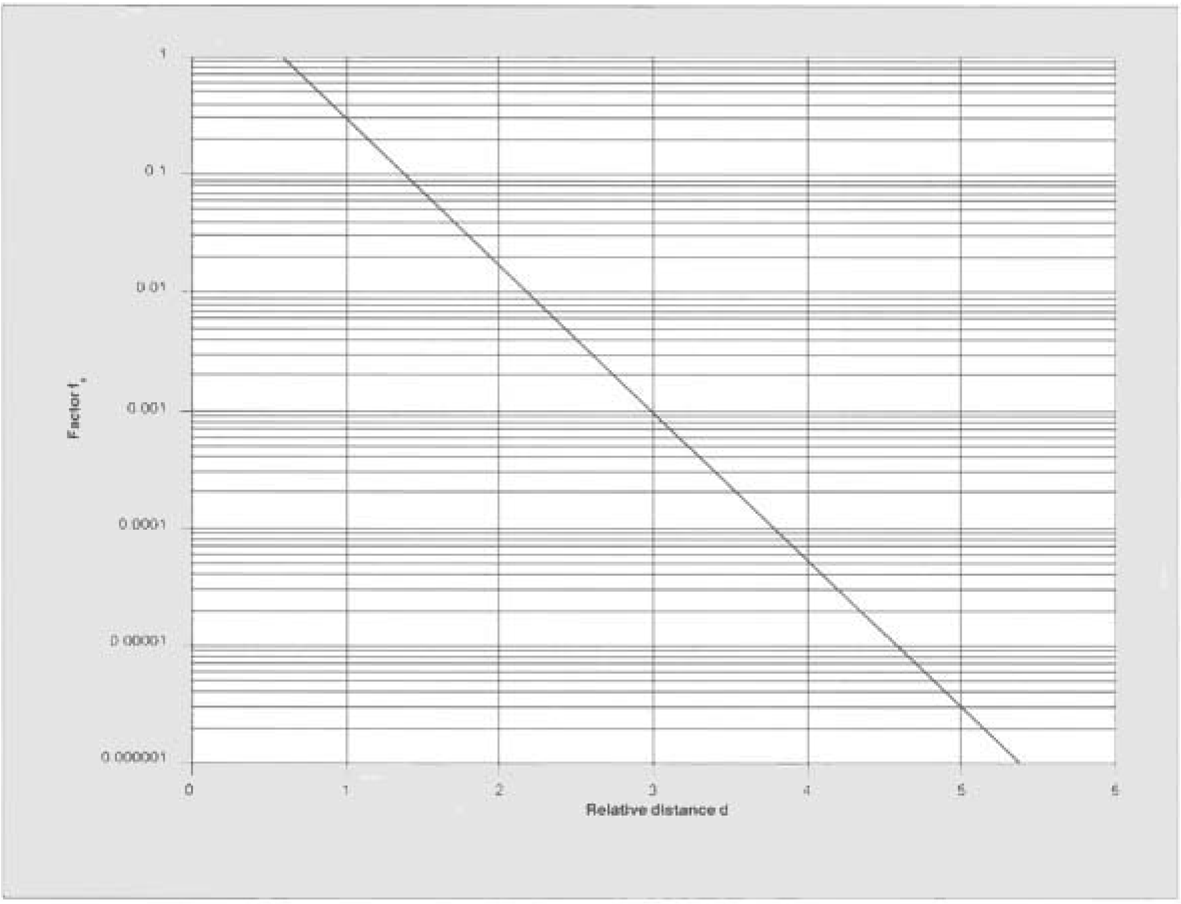


FIGURE D
The correction factor f_s as a function of the relative distance d

f_s pesticide = ...

Next, use Table N to calculate concentrations at the relevant exposure points (C_s).

TABLE N

Pesticide	C_1 =	f_s =	m_s =	$C_s = C_l \times f_s \times m_s$ = …… kg/m^3
Pesticide	C_1 =	f_s =	m_s =	$C_s = C_l \times f_s \times m_s$ = …… kg/m^3
Pesticide	C_1 =	f_s =	m_s =	$C_s = C_l \times f_s \times m_s$ = …… kg/m^3
Pesticide	C_1 =	f_s =	m_s =	$C_s = C_l \times f_s \times m_s$ = …… kg/m^3

Conclusion

The calculated concentration of pesticides in the lake/reservoir/pond (C_s) is $C_s = C_l \times f_s \times m_s$ = ... kg/m^3 × 1 000 000 = ...µg/l. Not relevant. There are no relevant points exposed to groundwater contamination.

POINTS EXPOSED TO CONTAMINATION BY WIND

In Step 4 (Figure A) the level of emissions by wind were determined (as high, intermediate or low). Now use Figure E, F or G to determine the deposition at the exposure points.

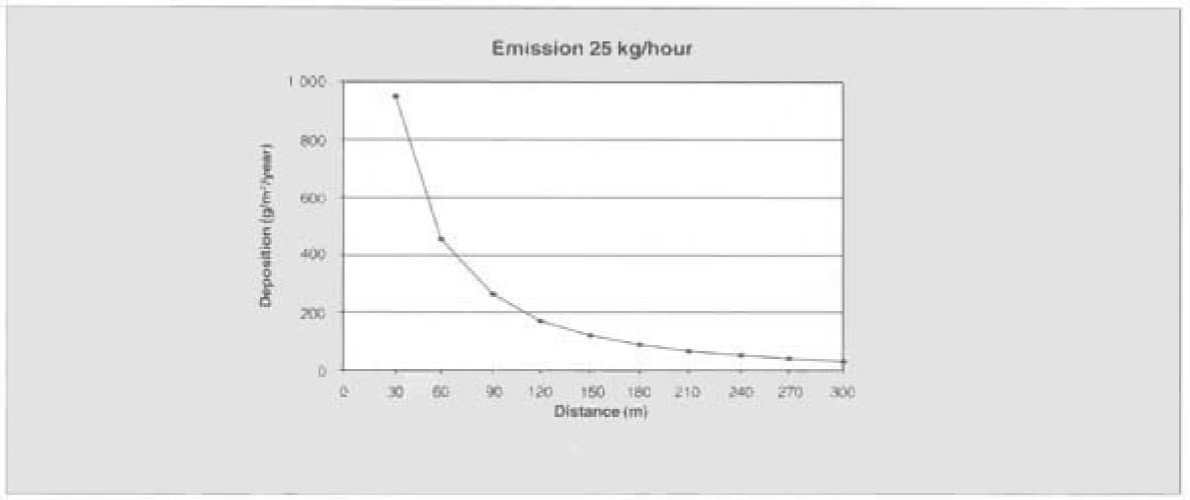


FIGURE E

High emission

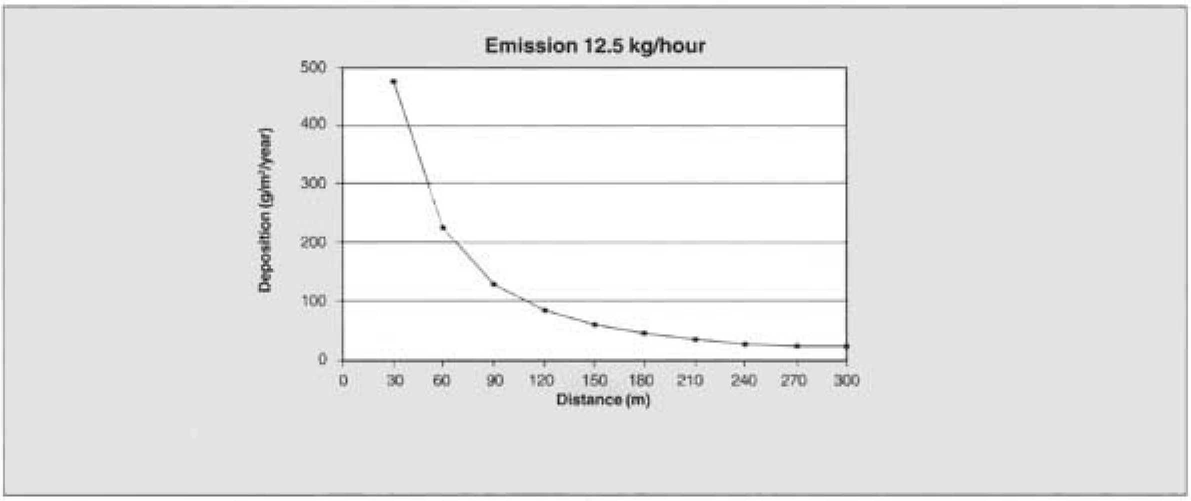


FIGURE F

Intermediate emission

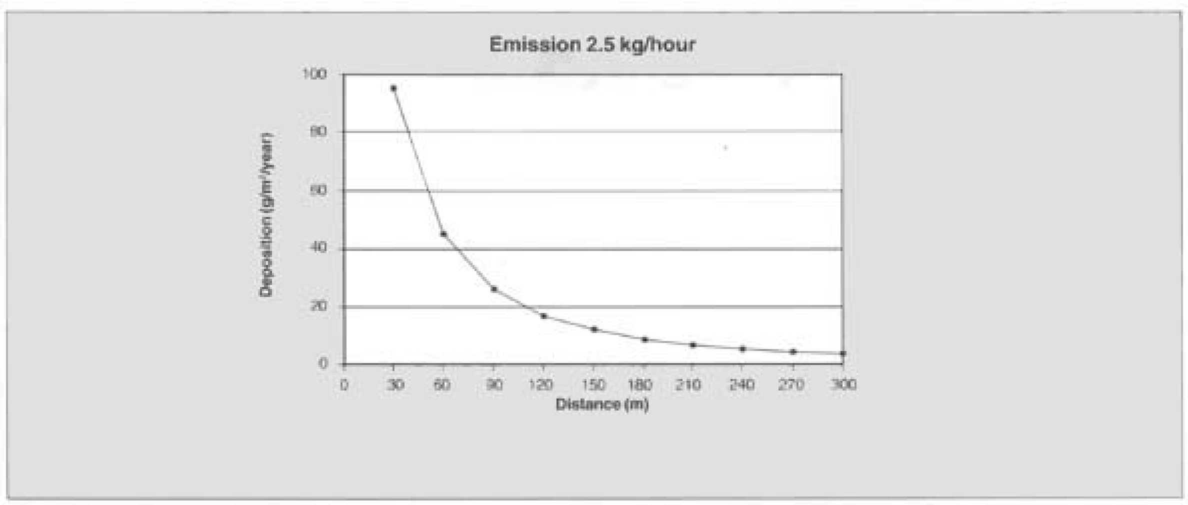


FIGURE G
Low emission

Conclusion

The expected deposition at the exposure points (based on Figure E,F or G) at .... metres from the store is .... g/m²/year. Not relevant. There are no relevant points exposed to wind contamination.

Step 7
Identifying exposure routes

Use Table O to choose the relevant exposure routes.

TABLE O

Exposure points		Relevant exposure route	
Wells		Drinking-water	
Springs		Irrigation water	
Rivers		Fishing	
Lakes		Water used for bathing/washing/swimming	
Reservoirs			
Ponds			
Houses		Direct contact	
Schools		Consumption of crops, vegetables or fruit	
Meeting places			
Hospitals			

Conclusion

The relevant exposure route at the location for .... is .... Proceed with Step 8.

There are no relevant points exposed to groundwater contamination.

There are no relevant points exposed to wind contamination.

Step 8
Determining when permissible exposure levels have been exceeded

PERMISSIBLE EXPOSURE LEVELS FOR GROUNDWATER

Use Table P to compare the predicted concentrations found in Step 6 with the permissible concentrations.

TABLE P

Exposure point	Exposure route	Predicted concentration (µg/l)	Permissible exposure level (µg/l) (see Appendix 3)	Permissible levels exceeded? (yes/no)

Conclusion

The permissible exposure level for .... (full exposure route) is exceeded for .... (name of pesticide). Contamination poses risks to human health.

The permissible exposure level for .... (full exposure route) is not exceeded for .... (name of pesticide).

Not relevant. There are no relevant points exposed to groundwater contamination

PERMISSIBLE EXPOSURE LEVELS FOR WIND

With the help of Appendix 3, select the permissible concentrations for the relevant exposure routes. List them in Table Q.

TABLE Q

Relevant pesticide	Relevant exposure route	Use permissible concentration (direct contact) (mg/kg dm)

Next use Table R to determine the permissible deposition.

TABLE R

Indicate total amount of spilled pesticides (see Table A) in kg or litres	.... kg or litres
Choose average emission level (see Step 4)	25 kg/hour (high)
	12.5 kg/hour (intermediate)
	2.5 kg/hour (low)
Calculate duration of deposition: total amount spilled ÷ average emission level	.... hours
Calculate permissible deposition:	
permissible deposition = (permissible concentration × 0.5 × 365 × 24)/emission hours	$g/m^2/year$

Use Table S to compare the actual deposition found in Step 6 with the permissible deposition.

TABLE S

Exposure point	Exposure route	Predicted deposition ($g/m^2/year$) (see Step 6)	Permissible deposition ($g/m^2/year$) (see Table Q)	Permissible levels exceeded? (yes/no)

Conclusion

The deposition .... metres from the store is below the permissible deposition level.

The deposition .... metres from the store is above the permissible deposition level. Contamination of the topsoil poses risks to human health.

Step 9
Determining follow-up measures

Use Table T to determine which situation applies.

TABLE T

Predicted result	Predicted result to be checked?	Protective measures recommended? (yes/no)	Remediation recommended? (yes/no)
Topsoil is contaminated and poses risks to human health	Yes	Yes	Yes
Topsoil is contaminated but does not pose risks	Yes	Not necessary but may be taken for psychological reasons	No
Groundwater is contaminated and poses risks to human health	Yes	Yes	Yes
Groundwater is contaminated but does not pose risks	Yes	No	No

Conclusion

Follow-up measures are needed.

Follow-up measures are not needed.

Field format for assessing soil contamination: Example 1

Description of a storage site with obsolete pesticides[1]

A large quantity of obsolete pesticides, mainly DDT, received from a European government but never used has been stored at this site, presumably since the 1960s. Although the obsolete pesticides have been properly stored since 1996, they were poorly stored before then. The DDT was originally packed in sacks and plastic, and the store consisted of a corrugated iron roof placed over four wooden poles. There were no walls. A farmhouse is situated nearby, at a distance of around 80 metres. The total amount of DDT stored is estimated at about 25 tons in powder form.

STEP 1
DETERMINING THE RELEVANT PESTICIDES

Use Table A to list all pesticides that have been spilled at the site.

TABLE A

Pesticide (chemical name)	Amount spilled (in kg or litres) (estimate)
DDT	**25 000**

Second, use Table B to determine which of the spilled pesticides are relevant.

TABLE B

A Pesticides spilled (names)	B Quantity > 100 kg. or 0.1 m? (yes/no)	C DT_{50} -soil (refer to Appendix 3)	D DT_{50} >50 days? (yes/no)	E Pesticide relevant? (yes, if answers in columns B and D are both yes: otherwise no)
DDT	**Yes**	**4–30 years**	**Yes**	**Yes**

[1] Data in boldface type are the responses for this hypothetical store.

Conclusion

Are some of the spilled pesticides to be considered relevant? Yes/~~No~~

If yes, list the relevant pesticides in Table C and proceed with steps 2 through 6 for each pesticide considered relevant.

TABLE C

Relevant pesticides	Amount spilled
DDT	**25 000 kg**

STEP 2
ASSESSING CONTAMINATION CAUSED BY INFILTRATION

Use Tables D and E to calculate C_0 (the concentration of the pesticide in the soil at the point of the spillage).

TABLE D

Relevant pesticide	Indicate M = amount spilled (kg or litres)	Indicate or estimate T = period of spillage (years)	Calculate L = annual load of pesticides infiltrating (L = M/T) (kg/year)
DDT	**25 000**	**30**	**833**

TABLE E

Relevant pesticide	Use L = annual load (kg/year)	Indicate R = annual rainfall (m/year)	Estimate A = area of spillage (m^2)	Indicate S = solubility in water (kg/m^3) (see Appendix 3)	Calculate L/(R × A) (kg/m^3)
DDT	**833**	**2.0**	**50**	**0.0033**	**8.3**

$$\begin{cases} if \quad \frac{L}{R \times A} \leq S \quad then \quad C_0 = \frac{L}{R \times A} \\ if \quad \frac{L}{R \times A} > S \quad then \quad C_0 = S \end{cases}$$

8.3>0.0033 = > C_o = S

Conclusion

C_o pesticide = 0.0033 kg/m^3

STEP 3
ASSESSING CONTAMINATION IN GROUNDWATER

Use Table F to predict the transport of pesticides towards the groundwater.

TABLE F

Number	Input data	Value	Conclusion
1	Depth of groundwater	<2 m	Groundwater always reached
		<5 m	Proceed with 2
		>5 m	**Proceed with 2**
2	Amount of pesticides spilled	**>100 litres or 100 kg**	**Proceed with 3**
		<100 litres or 100 kg	Groundwater never reached, unless groundwater close to surface (<2 m)
3	Pesticides stored in a closed or half-open store? (see Table I in Appendix 1)	Yes	Groundwater never reached, unless groundwater <5 m
		No	**Proceed with 4**
4	Time period since start of spillage	<1 year	Groundwater never reached, unless pesticide mobility high
		>1 year	**Proceed with 5**
5	Annual rainfall	>2000 mm	Groundwater always reached
		=<2000 mm	**Proceed with 6**
6	Pesticide mobility (see Appendix 3)	High	Groundwater always reached
		Low	**Proceed with 7**
7	Degradation (see Appendix 3)	High (DT_{50} soil<10 days)	Groundwater never reached
		Low (DT_{50} soil > 10 days)	**Groundwater always reached**

Conclusion

Groundwater always reached. Proceed with step 3.

~~Groundwater never reached. Proceed with Step 4.~~

Now use Table G to determine C_1, the pesticide concentration in the groundwater.

TABLE G

Input data	Dimension	Value
Determine hydraulic gradient (i)		
-use groundwater level measurements or groundwater contour maps	No dimension	**0.001**
Determine hydraulic conductivity (K) - use Table 3.4	m/day	**10**
Calculate q (specific groundwater discharge)		
q = K × i × 365	m/year	**3.65**
Estimate A (surface area of the place where spillage has occurred)		
A = length × width	m^2	**50**
Determine R (annual rainfall)	m/year	**2**
Calculate R × √A/q × b		
(assume b = 1 m)	No dimension	**3.8**
C_o (calculated in Step 2 of Appendix 1)	kg/m^3	**0.0033**

$$\begin{cases} if \quad \frac{R\times\sqrt{A}}{q\times b}\leq 1 \quad then \quad C_1 = C_0\times\frac{R\times\sqrt{A}}{q\times b} \\ if \quad \frac{R\times\sqrt{A}}{q\times b}>1 \quad then \quad C_1 = C_0 \end{cases}$$

R × √A /q × b = 3.8 > 1, then $C_1 = 0.0033$

Conclusion

C_1 pesticide = 0.0033 kg/m^3

STEP 4
DETERMINING DISTRIBUTION BY WIND

First, use Table H to determine whether the relevant pesticides can be distributed by wind.

TABLE H

Relevant pesticides	Powder? (yes/no)
DDT	**yes**

Conclusion

~~Since the relevant pesticide is not available as a powder, distribution by wind will not take place.~~

Since the relevant pesticide is available as a powder, distribution by wind may take place.

Next, use Table I to characterize the store.

TABLE I

Calculate the volume of the store (length × width × height in meters)	12 × 4 × 2.5	120 m^3
Indicate the openness of the store	Walls extend to the roof	Closed
	No walls	**Open**
	Large ventilation openings or broken windows	Half-open

Conclusion

~~The store is considered closed.~~

~~The store is considered half-open.~~

The store is considered open.

Now use Figure A to determine whether or not emissions from the store are likely to be high.

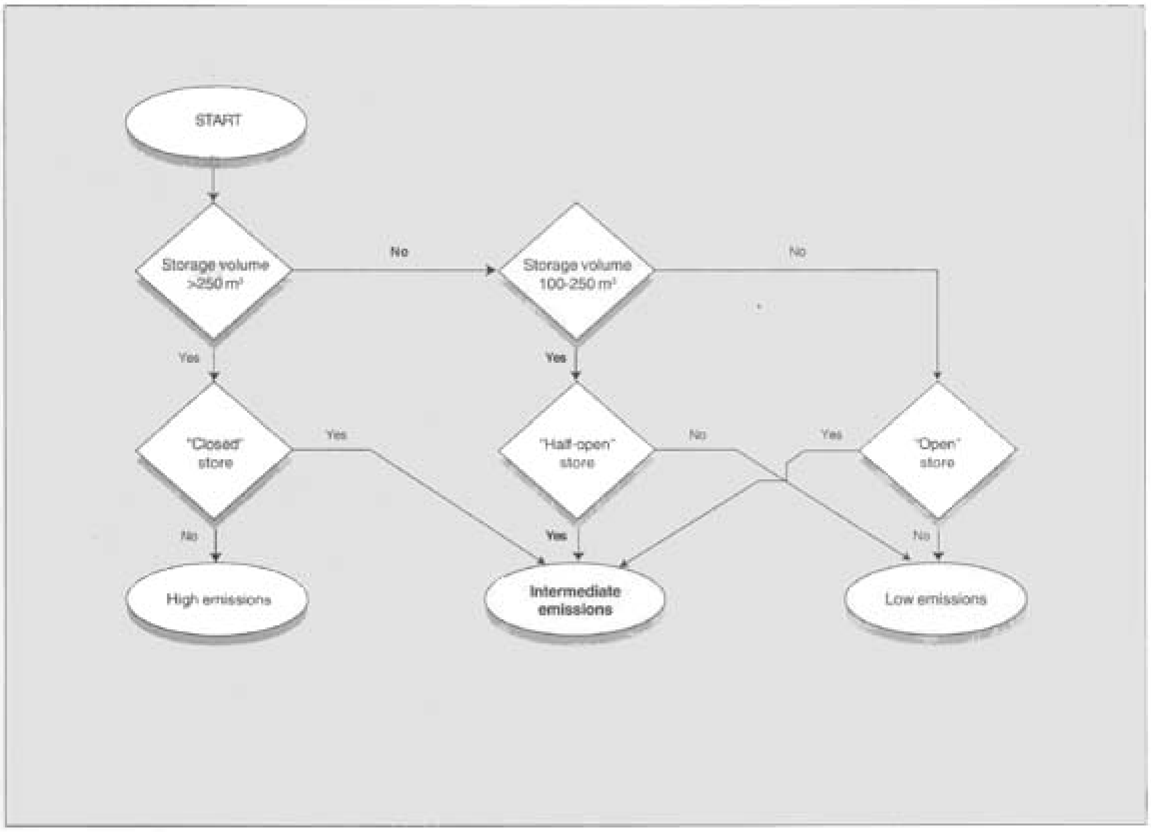


FIGURE A
Decision tree determining emission by wind

Conclusion

~~High emissions have occurred at the site.~~

Intermediate emissions have occurred at the site.

~~Low emissions have occurred at the site.~~

STEP 5
IDENTIFYING EXPOSURE POINTS

Groundwater

Draw up a list of vulnerable objects in the immediate surroundings of the store (within a radius of 300 metres) that might be influenced by groundwater contamination. Objects vulnerable to contamination by pesticides via groundwater are wells, springs, rivers, lakes, reservoirs and ponds.

TABLE J

Possible exposure points (groundwater)	Yes?	Distance from the store (m)
Wells		
Springs		
Rivers		
Lakes		
Reservoirs		
Ponds		
Other		

Determine the *principal direction of groundwater flow*. In the absence of groundwater level measurements, use the direction of steepest descent of the regional topography.

Subsequently, determine the *downstream quadrant* by drawing two lines atr an angle of 45° with the principal direction of groundwater flow, as shown in Figure B.

Check if any exposure points or vulnerable objects are located inside the downstream quadrant. Mark these objects as “at risk”.

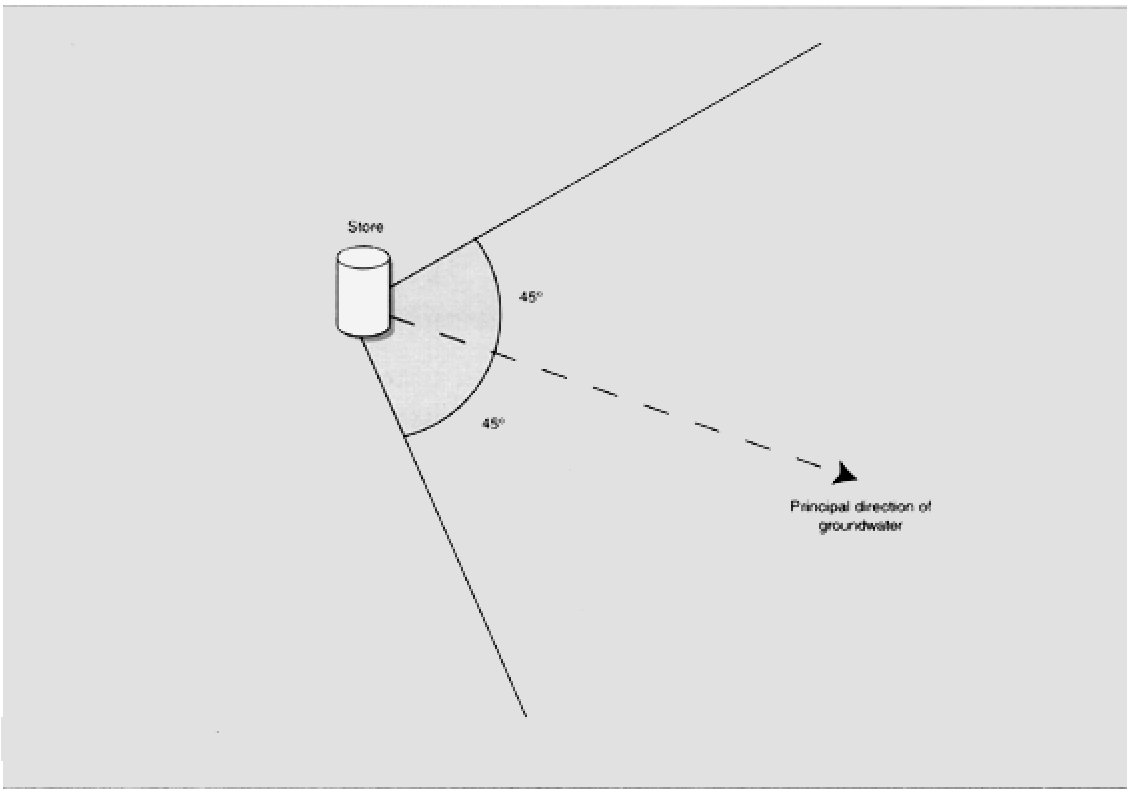


FIGURE B
Delineation of the downstream quadrant

Conclusion

There are no relevant points exposed to groundwater contamination.

~~Identified exposure points are …… at …… metres from the store.~~

Wind

Use Table K to list the vulnerable objects in the immediate surroundings of the store (within a radius of 300 metres) where the topsoil might be contaminated by wind.

TABLE K

Possible exposure points (wind)	Yes?	Distance from the store (m)
Houses	**X**	**80**
Schools		
Meeting places		
Hospitals		

Conclusion

~~There are no relevant points exposed to contamination by wind.~~

Identified exposure points are houses 80 metres from the store.

STEP 6
PREDICTING CONCENTRATIONS AT THE EXPOSURE POINTS

Points exposed to groundwater contamination

First use Table L to calculate the relative distance (d) for each relevant pesticide.

TABLE L

Input	Dimension	Value
Log K_{oc} - ask geohydrologist	Log (ml/g)	
Calculate constant (a) $A = \log K_{oc} - 3$	No dimension	
Calculate retardation (r) $R = 0.3 + 2 \times 10^{a}$	No dimension	
Retrieve q (groundwater discharge) - refer to Table G	m/year	
Determine T (time passed since start of spillage) - refer to Table D	Years	
Calculate s (horizontal distance travelled by the centre of mass of the dispersion front) $s = (Q/R) \times T$	Metres	
Measure the distance between storage and exposure point (x) - refer to Table J	Metres	
Calculate relative distance (d) $d = x/s$	Metres	
Is one of the exposure points a well, spring or river? If yes, indicate discharge Q	m^3/year	
Is one of the exposure points a lake, reservoir or pond? If yes, indicate volume V	m^3	

If one of the exposure points is a well, spring or river, calculate the mixing ratio m_g. If other exposure points are lakes, reservoirs or ponds, calculate the mixing ratio m See page 53.

$$\begin{cases} if \quad \dfrac{R \times A}{Q} \leq 1 \quad then \quad m_g = \dfrac{R \times A}{Q} \\ if \quad \dfrac{R \times A}{Q} > 1 \quad then \quad m_g = 1 \end{cases}$$

pesticide: (R × A)/Q = ...

The mixing ratio m_g pesticide = ...

Now calculate a correction factor (f_g) that takes into account hydrodynamic dispersion. Use Figure C to look up the value for f_g corresponding with the relative distance d (calculated in Table L).

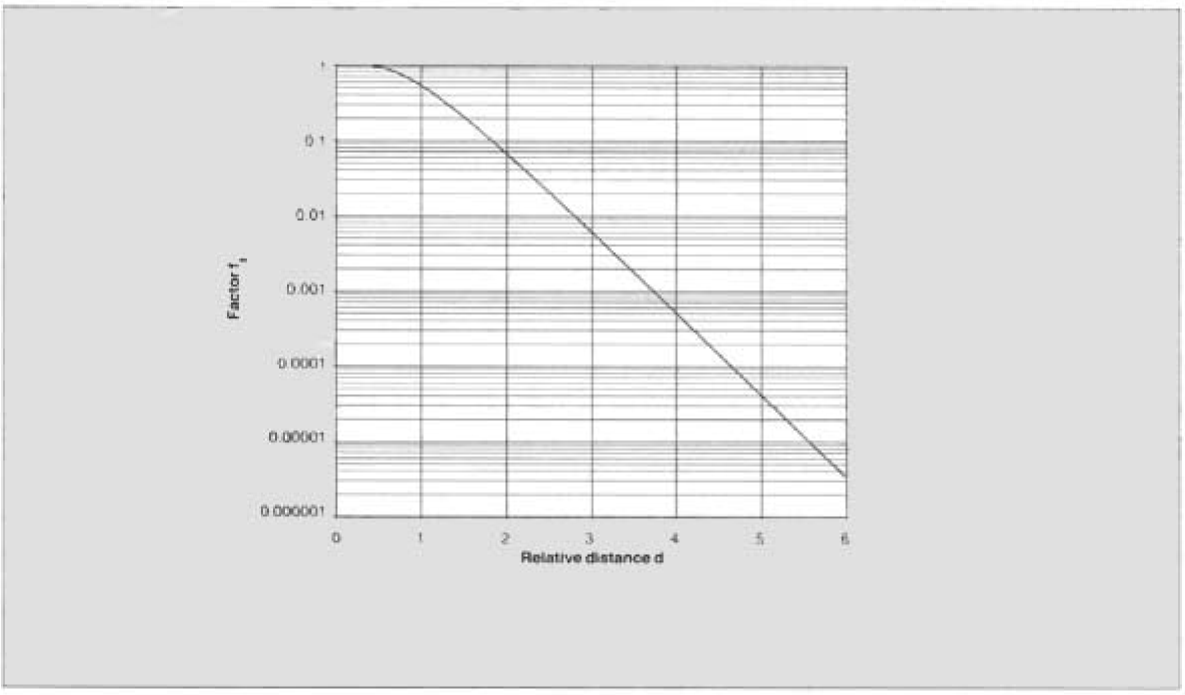


FIGURE C
The correction factor f_g as a function of the relative distance d

f_g pesticide = ...

Next, use Table M to calculate the concentrations at the relevant exposure points (C_g).

TABLE M

Pesticide	C_1=	f_g=	m_g=	$C_g = C_1 \times f_g \times m_g$ = …… kg/m³
Pesticide	C_1=	f_g=	m_g=	$C_g = C_1 \times f_g \times m_g$ = …… kg/m³
Pesticide	C_1=	f_g=	m_g=	$C_g = C_1 \times f_g \times m_g$ = …… kg/m³
Pesticide	C_1=	f_g=	m_g=	$C_g = C_1 \times f_g \times m_g$ = …… kg/m³

Conclusion

~~The calculated concentration of pesticides in the well/spring/river (C_g) is $C_g = C_1 \times f_g \times m_g$ = ... kg/m³ 1 000 000 = ... ug/l.~~

Not relevant. There are no relevant points exposed to groundwater contamination.

For a lake, reservoir or pond with water volume V, calculate the mixing ratio (m_s):

$$\begin{cases} if \quad \dfrac{R \times A \times T}{V} \leq 1 \quad then \quad m_s = \dfrac{R \times A \times T}{V} \\ if \quad \dfrac{R \times A \times T}{V} > 1 \quad then \quad m_s = 1 \end{cases}$$

pesticide: R × A/Q = ...

The mixing ratio m_g pesticide = ...

Then, calculate a correction factor (f_s) that takes into account hydrodynamic dispersion. Use Figure D to look up the value for f_s corresponding with the relative distance d (calculated in Table L).

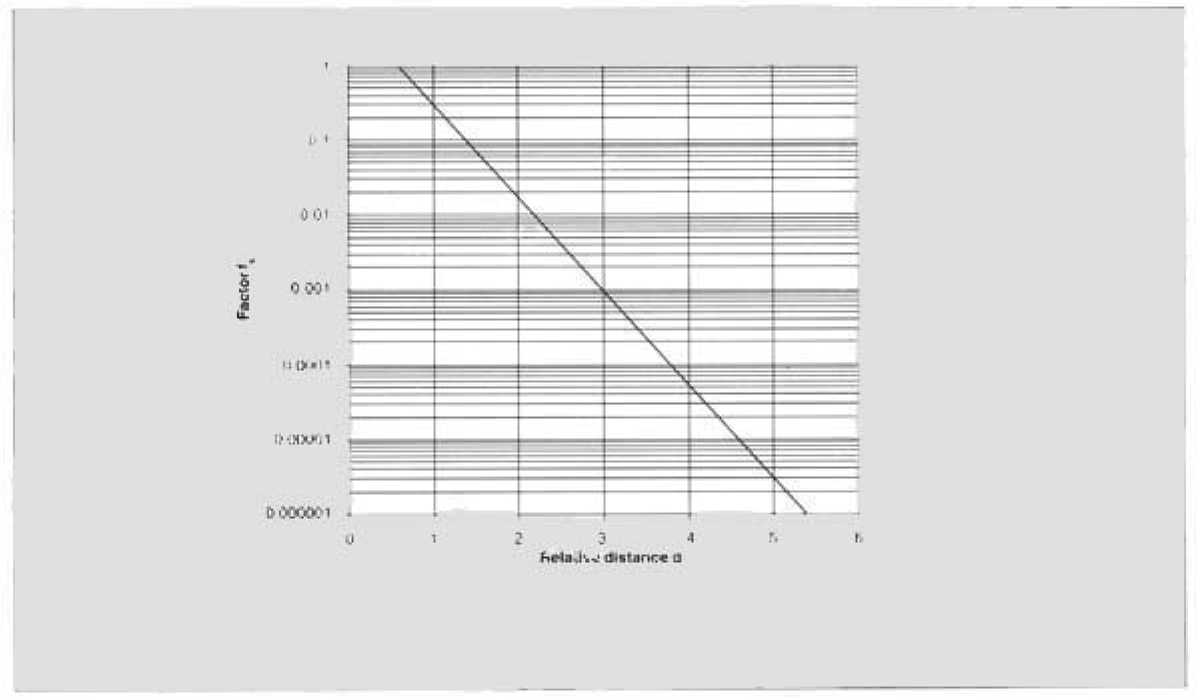


FIGURE D
The correction factor f_s as a function of the relative distance d

f_s pesticide = ...

Next, use Table N to calculate concentrations at the relevant exposure points (C_s).

TABLE N

Pesticide	C_1=	f_s=	m_s=	$C_s = C_1 \times f_s \times m_s$ = ... kg/m^3
Pesticide	C_1=	f_s=	m_s=	$C_s = C_1 \times f_s \times m_s$ = ... kg/m^3
Pesticide	C_1=	f_s=	m_s=	$C_s = C_1 \times f_s \times m_s$ = ... kg/m^3
Pesticide	C_1=	f_s=	m_s=	$C_s = C_1 \times f_s \times m_s$ = ... kg/m^3

Conclusion

~~The calculated concentration of pesticides in the well/spring/river (C_s) is $C_s = C_1 \times f_s \times m_s$ = ... kg/m^3 1 000 000 = ... ug/l.~~

Not relevant. There are no relevant points exposed to groundwater contamination.

Points exposed to contamination by wind

In Step 4 (Figure A) the level of emissions by wind were determined (as high, intermediate or low). Now use Figure E, F or G to determine the deposition at the exposure points.

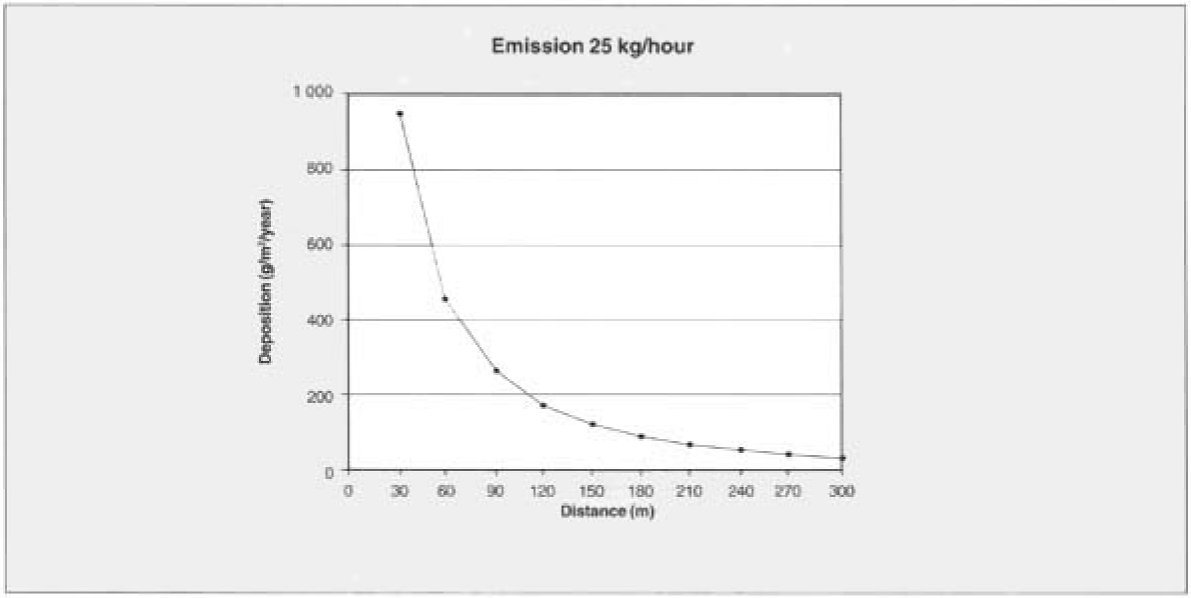


FIGURE E
High emission

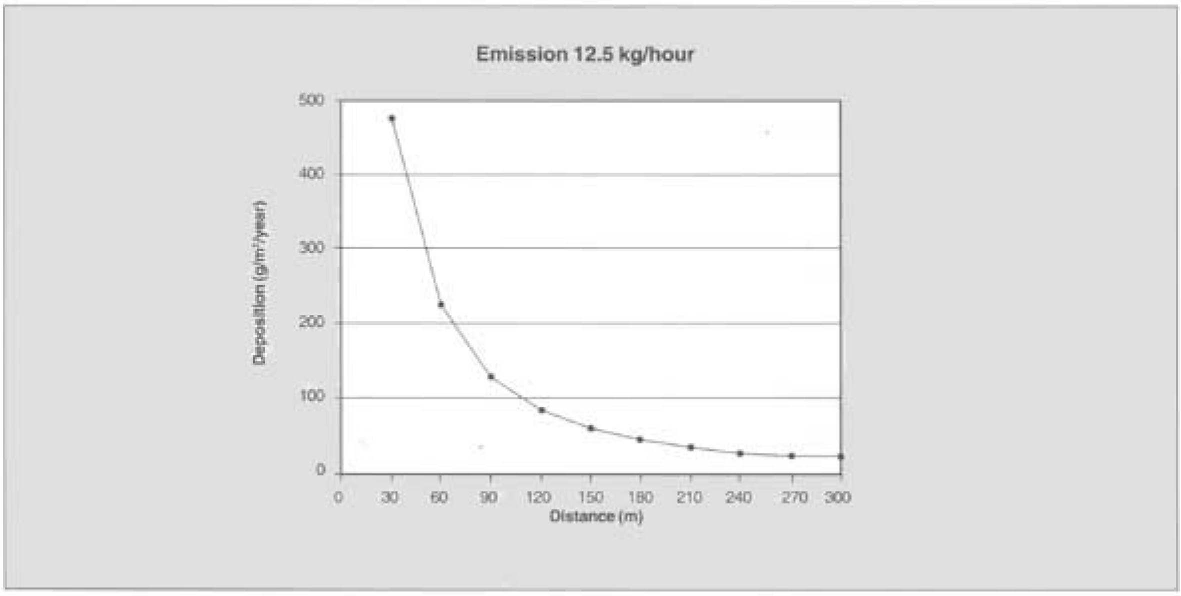


FIGURE F
Intermediate emission

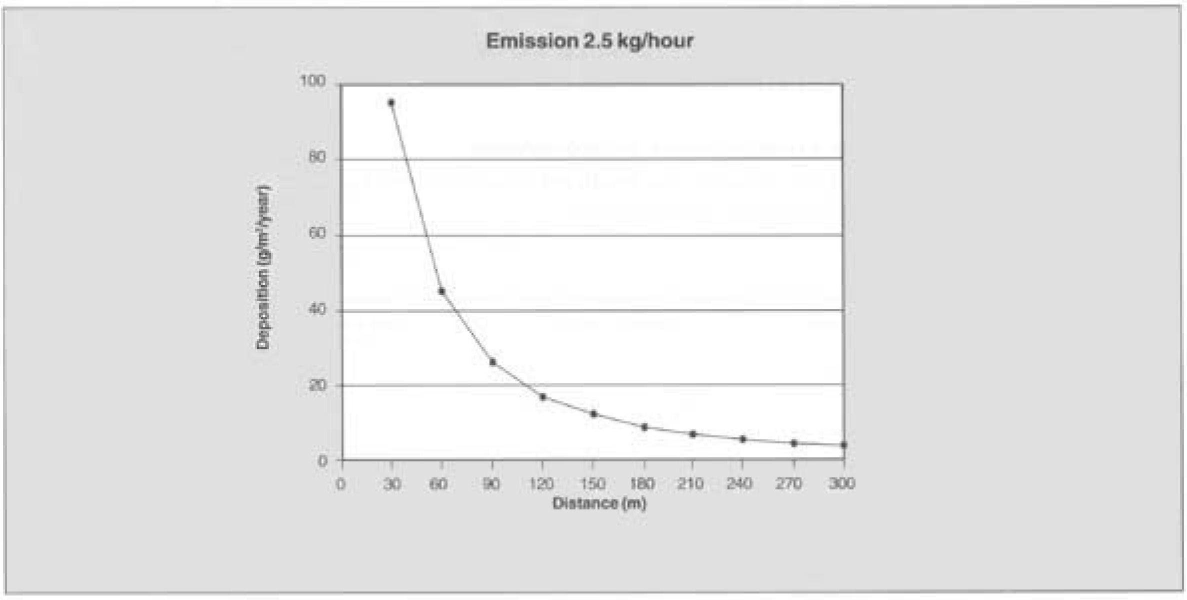


FIGURE G
Low emission

Conclusion

The expected deposition at the exposure points (based on Figure E, F or G) at the distance of 80 metres from the store is 150 g/m²/year.

~~Not relevant. There are no relevant points exposed to wind contamination.~~

STEP 7
IDENTIFYING EXPOSURE ROUTES

Use Table O to choose the relevant exposure routes.

TABLE O

Exposure points		Relevant exposure route	
Wells		Drinking-water	
Springs		Irrigation water	
Rivers		Fishing	
Lakes		Water used for bathing/washing/swimming	
Reservoirs			
Ponds			
Houses	X	Direct contact	X
Schools		Consumption of crops, vegetables or fruit	
Meeting places			
Hospitals			

Conclusion

The relevant exposure route at the location for houses is direct contact. Proceed with Step 8.

There are no relevant points exposed to groundwater contamination.

~~There are no relevant points exposed to wind contamination.~~

STEP 8
DETERMINING WHEN PERMISSIBLE EXPOSURE LEVELS HAVE BEEN EXCEEDED

Permissible exposure levels for groundwater

Use Table P to compare the predicted concentrations found in Step 6 with the permissible concentrations.

TABLE P

Exposure point	Exposure route	Predicted concentration (ug/l)	Permissible exposure level (ug/l) (see Appendix 3)	Permissible levels exceeded? (yes/no)

Conclusion

~~The permissible exposure level for .... (full exposure route) is exceeded for .... (name of pesticide). Contamination poses risks to human health.~~

~~The permissible exposure level for .... (full exposure route) is not exceeded for .... (name of pesticide).~~

Not relevant. There are no relevant points exposed to groundwater contamination

Permissible exposure levels for wind

With the help of Appendix 3, select the permissible concentrations for the relevant exposure routes. List them in Table Q.

TABLE Q

Relevant pesticide	Relevant exposure route	Use permissible concentration (direct contact) (mg/kg dm)
DDT	**Direct contact**	**10 000**

Next use Table R to determine the permissible deposition.

TABLE R

Indicate total amount of spilled pesticides (see Table A) in kg or litres	**25 000** kg
Choose average emission level (see Step 4)	25 kg/hour (high)
	12.5 kg/hour (intermediate)
	2.5 kg/hour (low)
Calculate duration of deposition: total amount spilled ÷ average emission level	**25 000/12.5 = 2 000 hours**
Calculate permissible deposition: permissible deposition = (permissible concentration × 0.5 × 365 × 24)/ emission hours	**permissible deposition = (10 000 × 0.5 × 365 × 24)/ 2 000 = 21 900 g/m^2/year**

Use Table S to compare the actual deposition found in Step 6 with the permissible deposition.

TABLE S

Exposure point	Exposure route	Predicted deposition (g/m^2/year) (see Step 6)	Permissible deposition (g/m^2/year) (see Table Q)	Permissible levels exceeded? (yes/no)
House	**Direct contact**	**150**	**21 900**	**No**

Conclusion

The deposition at 80 metres from the store is below the permissible deposition level.

~~The deposition .... metres from the store is above the permissible deposition level. Contamination of the topsoil poses risks to human health.~~

STEP 9
DETERMINING FOLLOW-UP MEASURES

Use Table T to determine which situation applies.

TABLE T

Predicted result	Predicted result to be checked?	Protective measures recommended? (yes/no)	Remediation recommended? (yes/no)
Topsoil is contaminated and poses risks to human health	Yes	Yes	Yes
Topsoil is contaminated but does not poses risks	**Yes**	**Not necessary but may be taken for psychological reasons**	**No**
Groundwater is contaminated and poses risks to human health	Yes	Yes	Yes
Groundwater is contaminated but does not pose risks	Yes	No	No

Conclusion

~~Follow up measures are needed.~~

Follow-up measures are not needed.

Field format for assessing soil contamination: Example 2

Description of a storage site with obsolete pesticides[2]

A vast range of used materials such as cars, tyres, desks, typewriters, barrels and batteries are stored at the ministerial depot Dar es Salaam. Outside this depot are also “obsolete” pesticides. The current supplies are stored inside.

The building in which the pesticides are stored is made of brick. The floor is of concrete and without drains or raised edges. Liquids could flow from the floor directly into the soil. The roofing material seems intact, since there are no leaks.

The supply is stored three pallets high, placing excessive weight on many of the boxes on the bottom pallets, thus increasing the risk of collapse. This could damage the primary packing material, creating a potential risk of spillages onto other packaging and on the floor. There is no first-in-first-out system, meaning that new supplies are being stacked onto old supplies, a system that could produce obsolete supplies.

Outside the building is a three-metre-long covering made of corrugated metal sheets. Under it are obsolete supplies and usable pesticides (boxes in Clingfilm) that cannot be stored inside. Among the pesticides are tyres, batteries, etc. There is no flooring, only sand.

Some of the pesticides are covered with canvas. Under this canvas are also broken jerrycans from which liquid has spilled or evaporated, leaving a solid substance. Over time, the jerrycans have become brittle and cracked.

A possible soil contamination by pesticides could not be established. There is, however, a quantity of oil on the soil.

The depot lies in the vicinity of a residential area and a market, and there is a well 100 metres from the building.

STEP 1
DETERMINING THE RELEVANT PESTICIDES

Use Table A to list all the pesticides that have been spilled at the site.

TABLE A

Pesticide (chemical name)	Amount spilled (estimate)
Atrazine	**200 litres**
Dimethoate	**400 litres**
Fenitrothion	**100 litres**

[1] Data in boldface type are the responses for this hypothetical store.

Now use Table B to determine which of the spilled pesticides are relevant.

TABLE B

A Pesticides spilled (name)	B Quantity > 100 kg. or 0.1 m ? (yes/no)	C DT_{50} -soil (refer to Appendix 3)	D DT > 60 days? (yes/no)	E Pesticide relevant? (yes, if answers in columns B and D are both yes; otherwise no)
Atrazine	**Yes**	**60–150**	**Yes**	**Yes**
Dimethoate	**Yes**	**4–122**	**Yes**	**Yes**
Fenitrothion	**Yes**	**4–54**	**No**	**No**
.				

Conclusion

Are some of the spilled pesticides to be considered relevant? Yes/~~No~~

If yes, list the relevant pesticides in Table C and proceed with Steps 2 through 6 *for each pesticide considered relevant.*

TABLE C

Relevant pesticides	Amount spilled
Atrazine	**200 litres**
Dimethoate	**400 litres**

STEP 2
ASSESSING CONTAMINATION CAUSED BY INFILTRATION

Use Tables D and E to calculate C_0 (the concentration of the pesticide in the soil at the point of the spillage).

TABLE D

Relevant pesticide	Indicate M = amount spilled (kg or litres)	Indicate or estimate T = period of spillage (years)	Calculate L = annual load of pesticides infiltrating (L = M/T) (kg/year)
Atrazine	**200**	**10**	**20**
Dimethoate	**400**	**10**	**40**

TABLE E

Relevant pesticide	Use L = annual load (kg/year)	Indicate R = annual rainfall (m/year)	Estimate A = area of spillage (m^2)	Indicate S = solubility in water (kg/m^3) (see Appendix 3)	Calculate L/(R × A) (kg/m^3)
Atrazine	**20**	**2.0**	**10**	**0.03**	**1**
Dimethoate	**40**	**2.0**	**30**	**0.025**	**0.7**

$$\begin{cases} if \quad \frac{L}{R \times A} \leq S \quad then \quad C_0 = \frac{L}{R \times A} \\ if \quad \frac{L}{R \times A} > S \quad then \quad C_0 = S \end{cases}$$

atrazine: 1> 0.03 => C_0 = S
dimethoate: 0.7> 0.025 => C_0 = S

Conclusion

C_0 atrazine = 0.03 kg/m^3

C_0 dimethoate = 0.025 kg/m^3

STEP 3
ASSESSING CONTAMINATION IN GROUNDWATER

Use Table F to predict the transport of pesticides towards the groundwater.

TABLE F

Number	Input data	Value	Conclusion
1	Depth of groundwater	<2 m	Groundwater always reached
		<5 m	**Proceed with 2**
		>5 m	Proceed with 2
2	Amount of pesticides spilled	**> 100 litres or 100 kg**	**Proceed with 3**
		< 100 litres or 100 kg	Groundwater never reached unless groundwater close to surface (< 2 m)
3	Pesticides stored in a closed or half-open store? (see Table I in Appendix 1)	**Yes**	**Groundwater never reached**, **unless groundwater <5 m**
		No	Proceed with 4
4	Time period since start of spillage	<1 year	Groundwater never reached, unless pesticide mobility high
		>1 year	Proceed with 5

5	Annual rainfall	>2 000 mm	Groundwater always reached
		=<2 000 mm	Proceed with 6
6	Pesticide mobility (see Appendix 3)	High	Groundwater always reached
		Low	Proceed with 7
7	Degradation (see Appendix 3)	High (DT_{50} soil <10 days)	Groundwater never reached
		Low (DT_{50} soil > 10 days)	Groundwater always reached

Conclusion

Groundwater reached because groundwater is <5 metres. Proceed with Step 3.

~~Groundwater never reached. Proceed to Step 4.~~

Now use Table G to determine C_1, the pesticide concentration in the groundwater.

TABLE G

Input data	Dimension	Value
Determine hydraulic gradient (i)		
- use groundwater level measurements or groundwater contour maps	No dimension	**0.001**
Determine hydraulic conductivity (K) - use Table 3.4	m/day	**10**
Calculate q (specific groundwater discharge) $q = K \times i \times 365$	m/year	**3.65**
Estimate A (surface area of the place where spillage has occurred)		**Atrazine: 10**
A = length × width	m^2	**Dimethoate: 30**
Determine R (annual rainfall)	m/year	**2**
Calculate $R \times \sqrt{A}/q \times b$ (assume b = 1 m)	No dimension	**Atrazine: 1.73** **Dimethoate: 3.00**
C_0 (calculated in Step 2 of Appendix 1)	kg/m^3	**Atrazine: 0.03** **Dimethoate: 0.025**

$$\begin{cases} if \quad \dfrac{R \times \sqrt{A}}{q \times b} \leq 1 \quad then \quad C_1 = C_0 \times \dfrac{R \times \sqrt{A}}{q \times b} \\ if \quad \dfrac{R \times \sqrt{A}}{q \times b} > 1 \quad then \quad C_1 = C_0 \end{cases}$$

atrazine: $(R \times \sqrt{A})/(q \times b) = 1.73 > 1$, then $C_1 = 0.03$
dimethoate: $(R \times \sqrt{A})/(q \times b) = 3.00 > 1$, then $C_1 = 0.025$

Conclusion

C_1 atrazine = 0.03 kg/m^3

C_1 dimethoate = 0.025 kg/m^3

STEP 4
DETERMINING DISTRIBUTION BY WIND

First, use Table H to determine whether the relevant pesticides can be distributed by wind.

TABLE H

Relevant pesticides	Powder? (yes/no)
Atrazine	**No**
Dimethoate	**No**

Conclusion

Since the relevant pesticide is not available as a powder, distribution by wind will not take place.

~~Since the relevant pesticide is available as a powder, distribution by wind may take place.~~

Next, use Table I to characterize the store.

TABLE I

Calculate the volume of the store (length × width × height in meters)		
Indicate the openness of the store	Walls extend to the roof	Closed
	No walls	Open
	Large ventilation openings or broken windows	Half-open

Conclusion

The store is considered closed.

The store is considered half-open.

The store is considered open.

Now use Figure A to determine whether or not emissions from the store are likely to be high.

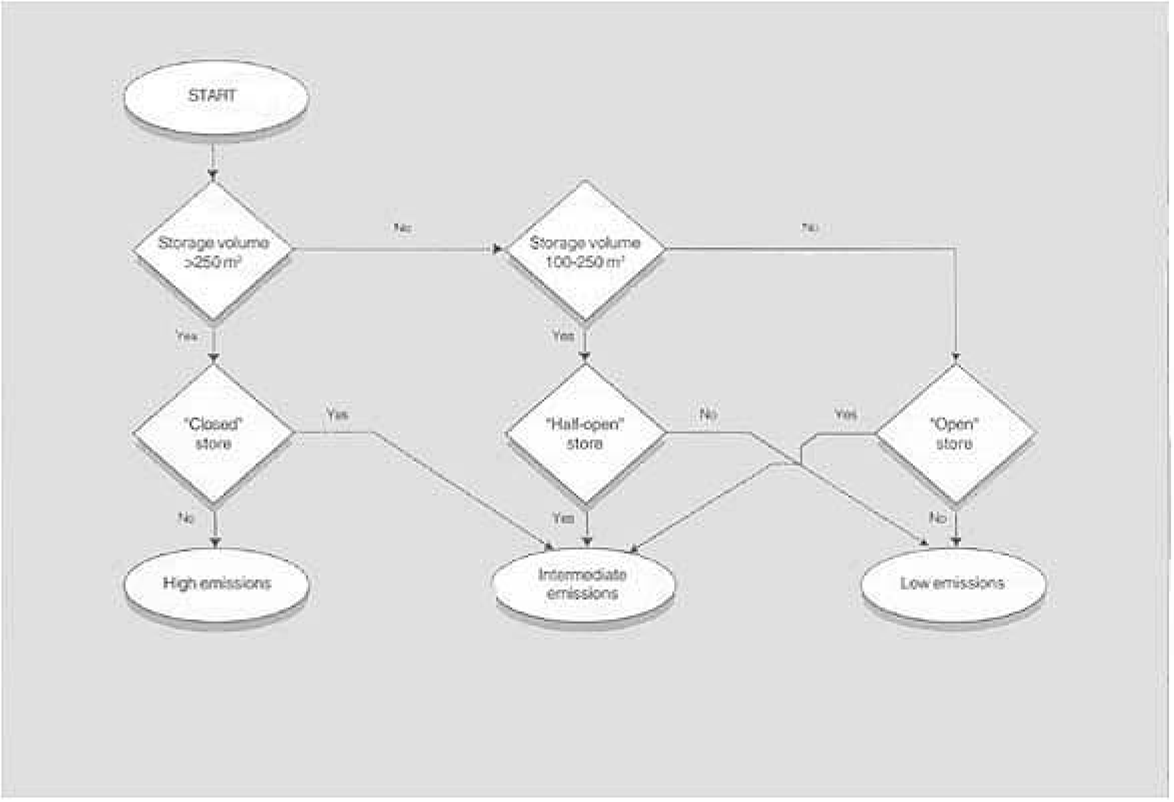


FIGURE A
Decision tree determining emission by wind

Conclusion

High emissions have occurred at the site.

Intermediate emissions have occurred at the site.

Low emissions have occurred at the site.

STEP 5
IDENTIFYING EXPOSURE POINTS

Groundwater

Draw up a list of vulnerable objects in the immediate surroundings of the store (within a radius of 300 metres) that might be influenced by groundwater contamination. Objects vulnerable to contamination by pesticides via groundwater are wells, springs, rivers, lakes, reservoirs and ponds.

TABLE J

Possible exposure points (groundwater)	Yes?	Distance from the store (m)
Wells	X	100
Springs		
Rivers		
Lakes		
Reservoirs		
Ponds		
Other		

Determine the *principal direction of groundwater flow*. In the absence of groundwater level measurements, use the direction of steepest descent of the regional topography.

Subsequently, determine the *downstream quadrant* by drawing two lines at an angle of 45° with the principal direction of groundwater flow, as shown in Figure B.

Check if any exposure points or vulnerable objects are located inside the downstream quadrant. Mark these objects as “at risk”.

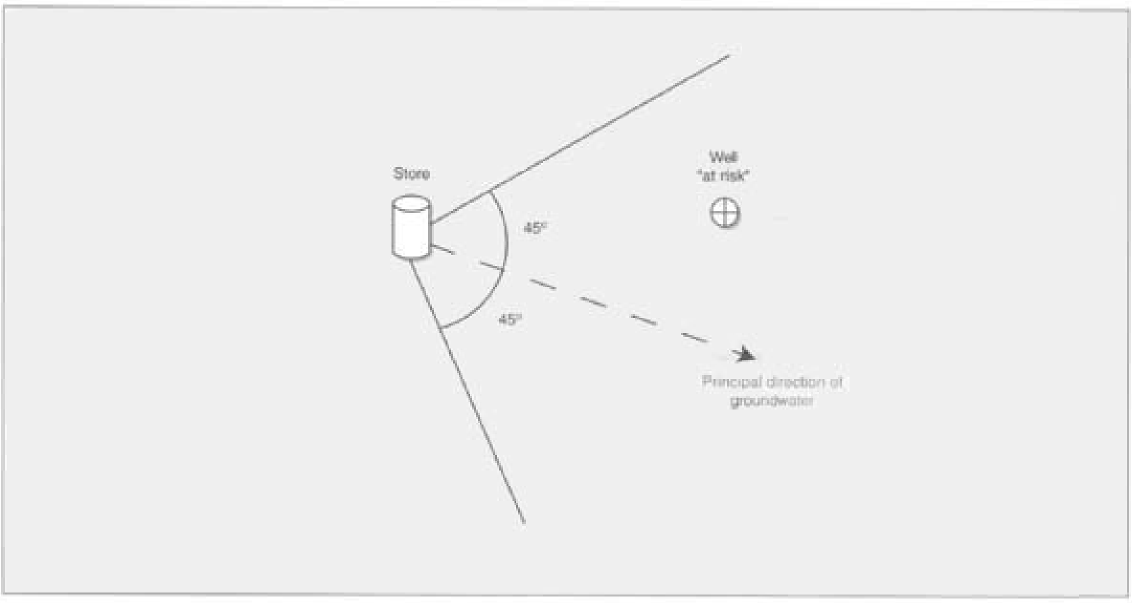


FIGURE B
Delineation of the downstream quadrant

Conclusion

~~There are no relevant points exposed to groundwater contamination.~~

Identified exposure point is a well 100 metres from the store.

Wind

Use Table K to list the vulnerable objects in the immediate surroundings of the store (within a radius of 300 metres) where the topsoil might be contaminated by wind.

TABLE K

Possible exposure points (wind)	Yes?	Distance from the store (m)
Houses		
Schools		
Meeting places		
Hospitals		

Conclusion

There are no relevant points exposed to contamination by wind.

~~Identified exposure points are .... at .... metres from the store.~~

STEP 6
PREDICTING CONCENTRATIONS AT THE EXPOSURE POINTS

Points exposed to groundwater contamination

First, use Table L to calculate the relative distance (d) for each relevant pesticide.

TABLE L1

Atrazine

Input	Dimension	Value
Log K_{oc} - ask geohydrologist	Log(ml/g)	**0.19**
Calculate constant (a) $A = \log K_{oc} - 3$	No dimension	**-2.81**
Calculate retardation (r) $R = 0.3 + 2 \times 10^{a}$	No dimension	**R = 0.3**
Retrieve q (groundwater discharge) - refer to Table G	m/year	**3.65**
Determine T (time passed since start of spillage) - refer to Table D	Years	**10**
Calculate s (horizontal distance travelled by the centre of mass of the dispersion front) $s = (q/r) \times T$	Metres	**122**
Measure the distance between storage and exposure point (x) - refer to Table J	Metres	**100**
Calculate relative distance (d) $d = x/s$	Metres	**0.8**
Is one of the exposure points a well, spring or river? If yes, indicate discharge q	m^3/year	**2 000**
Is one of the exposure points a lake, reservoir or pond? If yes, indicate volume V	m^3	

TABLE L2

Dimethoate

Input	Dimension	Value
Log K_{oc} - ask geohydrologist	Log(ml/g)	**1**
Calculate constant (a) A = log K_{oc} - 3	No dimension	**- 2**
Calculate retardation (r) $R = 0.3 + 2 \times 10^{a}$	No dimension	**R = 0.32**
Retrieve q (groundwater discharge) - refer to Table G	m/year	**3.65**
Determine T (time passed since start of spillage) - refer to Table D	Years	**10**
Calculate s (horizontal distance travelled by the centre of mass of the dispersion front) s = (q/r) × T	Metres	**114**
Measure the distance between storage and exposure point (x) - refer to Table J	Metres	**100**
Calculate relative distance (d) d = x/s	Metres	**0.9**
Is one of the exposure points a well, spring or river? If yes, indicate discharge Q	m^3/year	**2 000**
Is one of the exposure points a lake, reservoir or pond? If yes, indicate volume V	m^3	

If one of the exposure points is a well, spring or river, calculate the mixing ratio m_g. If other exposure points are lakes, reservoirs or ponds, calculate the mixing ratio m_s. See page 53.

$$\begin{cases} if \quad \frac{R \times A}{Q} \leq 1 \quad then \quad m_g = \frac{R \times A}{Q} \\ if \quad \frac{R \times A}{Q} > 1 \quad then \quad m_g = 1 \end{cases}$$

atrazine: R × A/Q = (2 × 10) / 2000 = 0.01 dimethoate: R × A/Q = 2 × 30 / 2000 = 0.03

The mixing ratio m_g atrazine = 0.01 The mixing ratio m_g dimethoate = 0.03

Now calculate a correction factor (f_g) that takes into account hydrodynamic dispersion. Use Figure C to look up the value for f_g corresponding with the relative distance d (calculated in Table L).

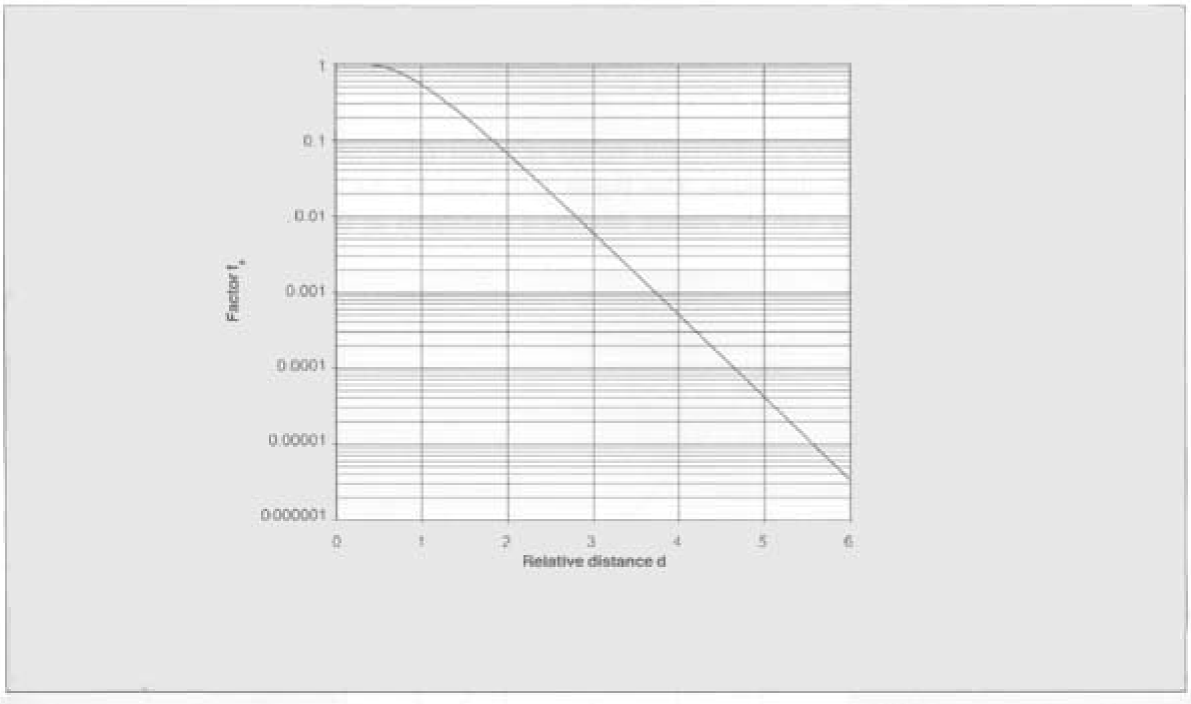


FIGURE C
The correction factor f_g as a function of the relative distance d

f_g atrazine = 0.7

f_g dimethoate = 0.6

Next, use Table M to calculate concentrations at the relevant exposure points (C_g).

TABLE M

Atrazine	**$C_1 = 0.003$**	**$f_g = 0.7$**	**$m_g = 0.01$**	$C_g = C_l \times f_g \times m_g =$ **0.00021 kg/m^3**
Dimethoate	**$C_1 = 0.025$**	**$f_g = 0.6$**	**$m_g = 0.03$**	$C_g = C_l \times f_g \times m_g =$ **0.00045 kg/m^3**
Pesticide	$C_1 =$	$f_g =$	$m_g =$	$C_g = C_l \times f_g \times m_g =$ .... kg/m^3
Pesticide	$C_1 =$	$f_g =$	$m_g =$	$C_g = C_l \times f_g \times m_g =$ .... kg/m^3

Conclusion

The calculated concentration of atrazine in the well (C_g) is $C_g = C_1 \times f_g \times m_g = 0.00021$ kg/m^3 × 1 000 000 = 210 µg/l.
The calculated concentration of dimethoate in the well (C_g) is $C_g = C_1 \times f_g \times m_g = 0.00045$ kg/m^3 × 1 000 000 = 450 µg/l.

~~Not relevant. There are no relevant points exposed to groundwater contamination.~~

For a lake, reservoir or pond with water volume V, calculate the mixing ratio (m_s):

$$\begin{cases} if \quad \dfrac{R \times A \times T}{V} \leq 1 \quad then \quad m_s = \dfrac{R \times A \times T}{V} \\ if \quad \dfrac{R \times A \times T}{V} > 1 \quad then \quad m_s = 1 \end{cases}$$

pesticide: R × A/Q = ...

The mixing ratio m_g pesticide = ...

Then calculate a correction factor (f_s) that takes into account hydrodynamic dispersion. Use Figure D to look up the value for f_s corresponding with the relative distance d (calculated in Table L).

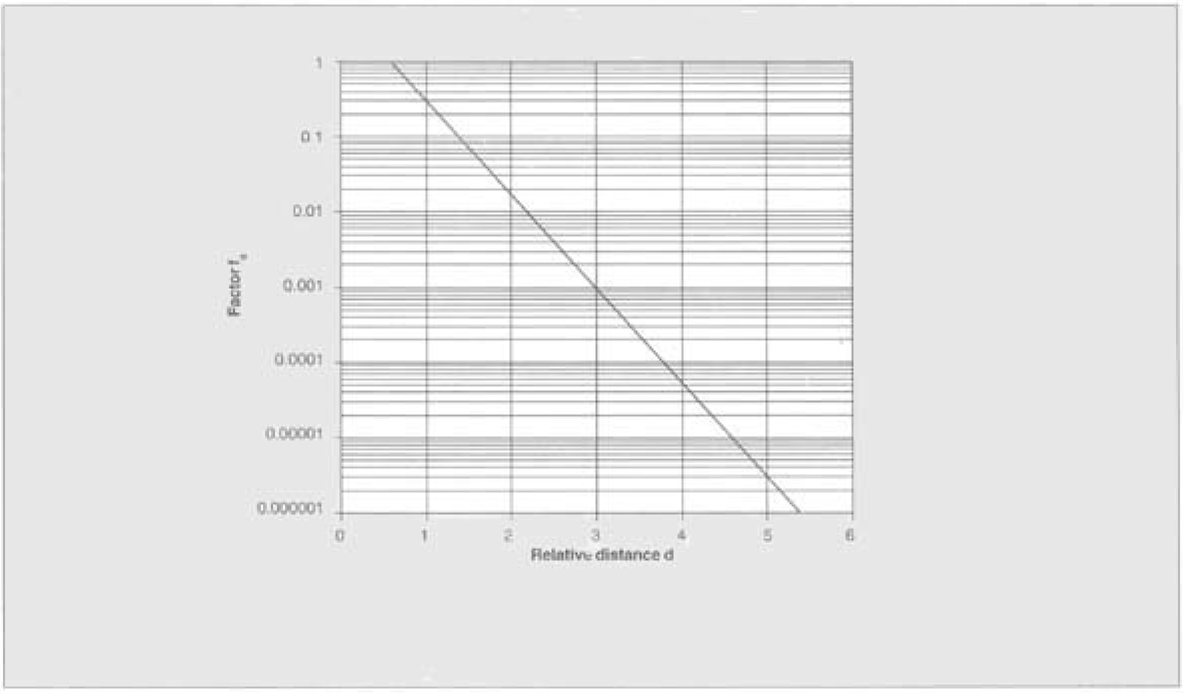


FIGURE D
The correction factor f_s as a function of the relative distance d

f_s pesticide = ...

Next, use Table N to calculate the concentrations at the relevant exposure points (C_s).

TABLE N

Pesticide	C_1 =	f_s =	m_s =	$C_s = C_1 \times f_s \times m_s$ = …… kg/m³
Pesticide	C_1 =	f_s =	m_s =	$C_s = C_1 \times f_s \times m_s$ = …… kg/m³
Pesticide	C_1 =	f_s =	m_s =	$C_s = C_1 \times f_s \times m_s$ = …… kg/m³
Pesticide	C_1 =	f_s =	m_s =	$C_s = C_1 \times f_s \times m_s$ = …… kg/m³

Conclusion

~~The calculated concentration of pesticides in the lake/reservoir/pond (C_s) is $C_s = C_1 \times f_s \times m_s$ = ... kg/m^3 × 1 000 000 = ... µg/l.~~

Not relevant. There are no relevant points exposed to groundwater contamination.

Points exposed to contamination by wind

In Step 4 (Figure A) the level of emissions by wind were determined (as high, intermediate or low). Now use Figure E, F or G to determine the deposition at the exposure points.

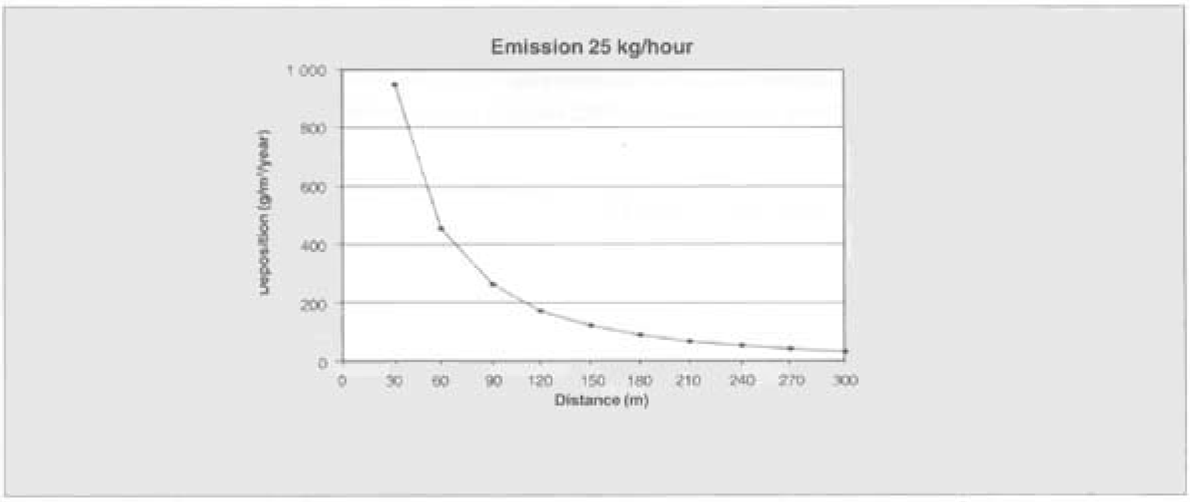


FIGURE E
High emission

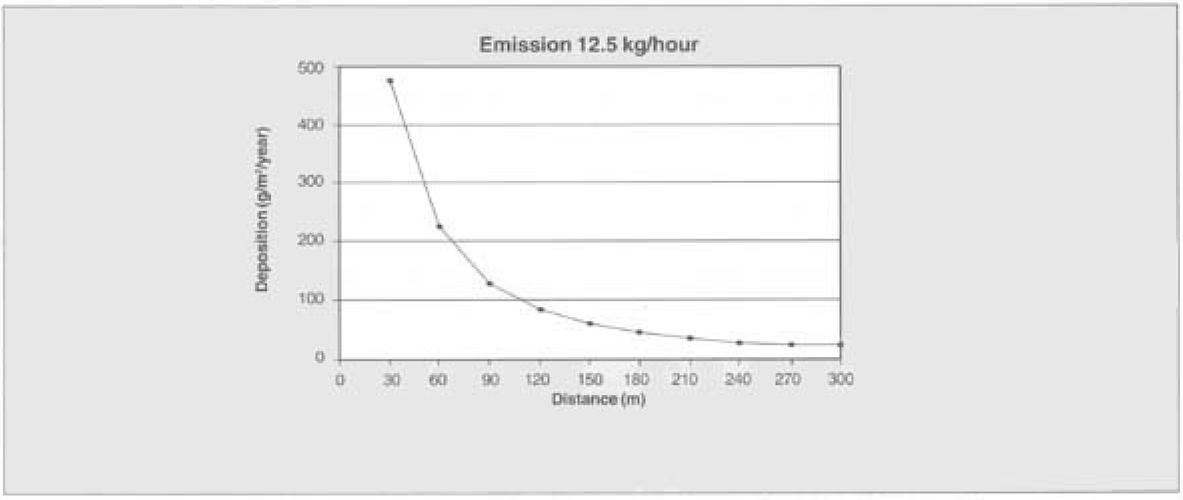


FIGURE F
Intermediate emission

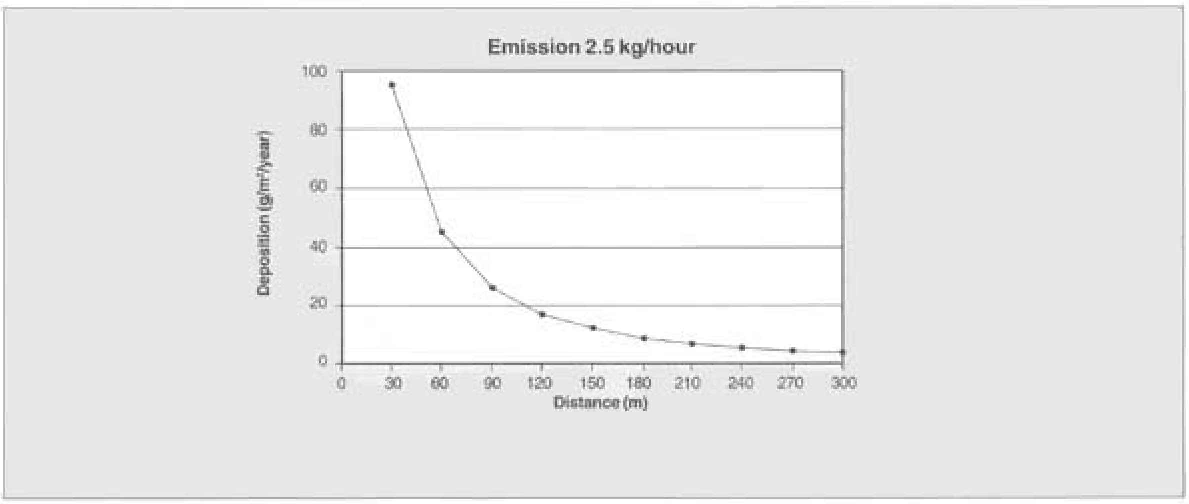


FIGURE G
Low emission

Conclusion

~~The expected deposition at the exposure points (based on Figure E, F or G) .... metres from the store is .... g/m²/year.~~

Not relevant. There are no relevant points exposed to wind contamination.

STEP 7
IDENTIFYING EXPOSURE ROUTES

Use Table O to find the relevant exposure routes.

TABLE O

Exposure points		Relevant exposure route	
Wells	X	Drinking-water	X
Springs		Irrigation water	
Rivers		Fishing	
Lakes		Water used for bathing/washing/swimming	
Reservoirs			
Ponds			
Houses		Direct contact	
Schools		Consumption of crops, vegetables or fruit	
Meeting places			
Hospitals			

Conclusion

The relevant exposure route at the location for a well is drinking-water. Proceed with Step 8.

~~There are no relevant points exposed to groundwater contamination.~~ There are no relevant points exposed to wind contamination.

STEP 8
DETERMINING WHEN PERMISSIBLE EXPOSURE LEVELS HAVE BEEN EXCEEDED

Permissible exposure levels for groundwater

Use Table P to compare the predicted concentrations found in Step 6 with the permissible concentrations.

TABLE P1

Atrazine

Exposure point	Exposure route	Predicted concentration (µg/l)	Permissible exposure level (µg/l) (see Appendix 3)	Permissible levels exceeded? (yes/no)
Well	**drinking-water**	**210**	**100**	**Yes**

TABLE P2

Dimethoate

Exposure point	Exposure route	Predicted concentration (µg/l)	Permissible exposure level (µg/l) (see Appendix 3)	Permissible levels exceeded? (yes/no)
Well	**drinking-water**	**450**	**200**	**Yes**

Conclusion

The permissible exposure level for drinking-water is exceeded for atrazine and dimethoate. Contamination poses risks to human health.

~~The permissible exposure level for .... (full exposure route) is not exceeded for .... (name of pesticide).~~

~~Not relevant. There are no relevant points exposed to groundwater contamination~~

Permissible exposure levels for wind

Consult Appendix 3 to find the permissible concentrations for the relevant exposure routes. List them in Table Q.

TABLE Q

Relevant pesticide	Relevant exposure route	Use permissible concentration (direct contact) (mg/kg dm)

Next, use Table R to determine the permissible deposition.

TABLE R

Indicate total amount of spilled pesticides (see Table A) in kg or litres	…… kg
Choose average emission level (see Step 4)	25 kg/hour (high)
	12.5 kg/hour (intermediate)
	2.5 kg/hour (low)
Calculate duration of deposition:	
total amount spilled ÷ average emission level	…… hours
Calculate permissible deposition:	
permissible deposition = (permissible concentration × 0.5 × 365 × 24)/ emission hours	g/m^2/year

Use Table S to compare the actual deposition found in Step 6 with the permissible deposition.

TABLE S

Exposure point	Exposure route	Predicted deposition (g/m^2/year) (see Step 6)	Permissible deposition (g/m^2/year) (see Table Q)	Permissible levels exceeded? (yes/no)

Conclusion

The deposition .... metres from the store is below the permissible deposition level.

The deposition .... metres from the store is above the permissible deposition level. Contamination of the topsoil poses risks to human health.

STEP 9
DETERMINING FOLLOW-UP MEASURES

Use Table T to determine which situation applies.

TABLE T

Predicted result	Predicted result to be checked?	Protective measures recommended? (yes/no)	Remediation recommended? (yes/no)
Topsoil is contaminated and poses risks to human health	Yes	Yes	Yes
Topsoil is contaminated but does not pose risks	Yes	Not necessary but may be taken for psychological reasons	No
Groundwater is contaminated and poses risks to human health	**Yes**	**Yes**	**Yes**
Groundwater is contaminated but does not pose risks	Yes	No	No

Conclusion

Follow-up measures are needed.

~~Follow-up measures are not needed.~~

APPENDIX 2

Parameters of pesticides that influence processes in the soil

The parameters used to characterize the properties of pesticides are:

Degradation

- persistence
- half-life time DT_{50}
- biodegradation
- hydrolysis
- photolysis

Mobility

- water solubility
- soil-water partition coefficient K_{OC}
- retardation factor R

Bioaccumulation

- octanol-water partition coefficient K_{OW}

DEGRADATION

The organic compounds in soil undergo a lot of change. Most pesticides break down or degrade over time as a result of several chemical and microbiological reactions in soils. Some are broken down by sunlight. These processes result in the final degradation of the compound into the mineral compounds CO_2, H_2O, HCl, SO_2, etc. As they degrade, some pesticides produce intermediate substances (metabolites) whose biological activity may also have environmental significance.

Compounds with an extremely long degradation time are considered *persistent*. Persistent compounds disperse into the environment without undergoing any changes.

The value of the degradation is given by half-life DT_{50}. Half-life DT_{50} is a measure of the amount of time it takes for 50 percent of the parent compound to disappear from soil or water by transformation. The important degradation processes are biological processes (*biodegradation*) and physicochemical processes (*hydrolysis, photolysis*, etc.).

The major degradation products are listed in Appendix 3. Additional remarks are made for the degradation products that are expected to have a significant influence on the environment.

Biodegradation

Biodegradation is the transformation of a substance by micro-organisms. Under environmental conditions, biodegradation can be affected by a number of factors, including the presence of oxygen (aerobic/anaerobic conditions) and nutrients, the population size of the required microorganisms, and the micro-organisms' adaptation.

Hydrolysis

During hydrolysis a compound is split by contact with water, undergoing a chemical reaction in which a part of the molecule of the reacting substance is replaced by an OH group. This process is strongly affected by the acidity of the environment (pH).

Photolysis

Photolysis is the breaking down of a compound as a direct result of irradiation.

MOBILITY

The mobility of a pesticide in water indicates the water's solubility and pesticide sorption (K_{OC}), or retardation factor. When a pesticide enters soil, some of it adheres to soil particles (particularly organic matter) through a process called sorption, and some dissolves and mixes with the soil water.

TABLE A

Classification of degradability in soil (biological and physicochemical transformations)

DT_{50}	Classification
<20	Readily degradable
20–60	Fairly degradable
60–180	Slightly degradable
>180	Very slightly degradable

The organic compounds that dissolve in groundwater move more slowly than groundwater because of sorption to the soil particles. The solubility of a pesticide and its sorption in soil are inversely related: i.e. increased solubility results in less sorption.

Water solubility

Pesticide solubility is an important factor in waste disposal. Solubility can indicate the maximum amount of pesticide in solution in any accidentally contaminated water. The solubility of a compound in water is given in mg/L at 20°C. Compounds with high degrees of solubility are expected to leach into groundwater.

Soil-water partition coefficient K_{OC}

The partition coefficient K_{OC} is defined as the ratio of pesticide concentration in a state of sorption (i.e. adhered to soil particles) and the solution phase (i.e. dissolved in the soil water). Thus, for a given amount of pesticide, the smaller the K_{oc} value, the greater the concentration of the pesticide in solution. Pesticides with a small K_{oc} value are more likely to leach into groundwater than those with a large K_{oc} value.

Sorption for a given pesticide is greater in soils with a higher organic matter content. Thus, pesticide leaching is thought to be slower in those soils than in soils lower in organic matter.

Because of the large range of K_{oc} values, use the logarithm of K_{oc}. A compound's mobility in soil is classified according to Table C.

Retardation factor

The K_{oc} value is used to determine the parameter known as *retardation factor R*. This factor indicates the delay of the pesticide transport rate in comparison with the water rate.

TABLE B

Classification of solubility in water

Solubility	Classification
<0.10	Not soluble
0.1–1	Slightly soluble
1–10	Moderately soluble
10–100	Readily soluble
>100	Highly soluble

TABLE C

Classification of mobility

Log K_{oc}	Classification
<1	Highly mobile
1–2	Mobile
2–3	Moderately mobile
3–4	Slightly mobile
4–5	Hardly mobile
>5	Immobile

BIOACCUMULATION

Bioaccumulation indicates the tendency of a compound to accumulate in organisms. The most useful index for quantifying pesticide bioaccumulation is the partition coefficient K_{OW}.

Octanol-water partition coefficient K_{OW}

The octanol-water partition coefficient K_{OW} is defined as the ratio of the pesticide concentration in two unmixed liquids, octanol and water. The compounds with a high K_{OW} value (i.e. readily soluble in octanol and less soluble in water) accumulate in organisms.

TABLE D

Pesticide categories

Pesticide	Category
	Impact mainly because of high mobility in groundwater (risks owing to spreading)
1,2-dibromoethane(EDB)	
Paraquat	
Pentachlorophenol	
2,4,5-T	
Warfarin	
	Impact mainly because of bioaccumulation, toxicity, high persistency and immobile character (risks owing to direct contact with pesticide or consumption of contaminated fruits or vegetables)
Chlordane	
DDT	
Dieldrin	
Dioxins	
Furans	
Heptachlor	
Hexabromobiphenyl	
Hexachlorobenzene	
Hexachlorobiphenyl	
Polyaromatic Hydrocarbons (PAHs)	
Polybrominated biphenyls (PBB)	
	Impact because of degradation products
Carbaryl	
Endosulfan	
Malathion	
Mancozeb	
Methamidophos	
Monocrotophos	
	No dominant impact
Aldrin	
Atrazine	
Captafol	
Carbofuran	
Chlorfenvinphos	
Chlorobenzilate	
Diazinon	
Dimethoate	
Dinoseb and dinoseb salts	
Fenitrothion	

Methyl-parathion	
Parathion	
Phosphamidon	
Propoxur	
	Insufficient information
Chlordimeform	
Crocidolite	
Endrin	
Fluoroacetamide	
HCH(mixed isomers)	
Mercuric chloride	
Mirex	
Polychlorinated biphenyls (PCB)	
Polychlorinated terphenyls (PCT)	
Toxaphene	
Tris(2,3-dibromopropyl) phosphate	

APPENDIX 3
Fact sheets on pesticides

Aldrin

Common formulation

$C_{12}H_8Cl_6$

CAS registry number

309-00-2

Use

As an insecticide against soil and cotton insects, turf pests, white grubs and corn root worms.

ALDRIN IN THE ENVIRONMENT

• Mobility

Aldrin is thought to adsorb moderately to soil.

• Degradation

Aldrin residues in soil and plants volatilize from soil surfaces or are slowly transformed into dieldrin in soil. Biodegradation is thought to be slow, and aldrin is thought not to leach. Aldrin is classified as moderately persistent, meaning its half-life in soil ranges from 20–100 days. Photo-oxidization of aldrin is thought to be significant. Photolysis has been observed in water, although the absorption characteristics of aldrin indicate that it should not directly photolyse in the environment to any significant extent.

• Degradation products

The main product of aldrin degradation is dieldrin.

• Volatilization/evaporation

Aldrin residues in water and soil volatilize from the surface. Vapourphase aldrin residues in the atmosphere are thought to react with photochemically generated hydroxyl radicals, with an estimated halflife of 35 minutes.

• Bioaccumulation

Bioaccumulation of aldrin is significant.

• Phytotoxicity

Aldrin is phytotoxic to tomatoes and cucumbers only at application rates many times greater than those recommended. Cabbage is the crop most sensitive to aldrin.

* Most information in Appendix 3 was obtained from the following sources: U.S. National Library of Medicine, Hazardous Substances Databank, 1995; Oregon State University, Extension Toxicology Network (database), 1995; and British Crop Protection Council. The Pesticide Manual, various editions. Other sources can be found in Appendix 9.

PROPERTIES

Aldrin ranges in colour from colourless to dark brown and is a liquid or solid. It is resistant to organic and inorganic bases and to the action of hydrated metal chlorides and mild acids. It is stable up to 200°C and in the pH range 4–8.

TABLE A
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	104	
Vapour pressure		mPa	8.6	
Density		g/cm^3	1.6	
Degradation	DT_{50}soil	Days	20–100	Slightly degradable
Solubility	S_w	mg/1	0.027	Not soluble
Mobility	Log K_{oc}		2.61–4.45	Moderately to slightly mobile
ADI		mg/kg/day	0.0001	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	50	
	Consumption of vegetables	mg/kg dm soil	0.1	
	Consumption of drinking-water	μg/1	2	

Atrazine

Active ingredient

Trazine

Common formulation

$C_8H_{14}ClN_5$

CAS registry number

1912–24–9

Use

As an herbicide to control annual weeds in asparagus fields, forests, grasslands, grass, crops, maize, etc.

ATRAZINE IN THE ENVIRONMENT

• Mobility

Atrazine is thought to maintain high to medium mobility in soil, and should not adsorb readily to sediment. Atrazine adsorbs more readily to muck or clay soils than to soils of a low clay or organic matter content.

• Degradation

Most triazines are very stable in soil and dissipate slowly through degradation by soil microorganisms. Although the half-life of 50 days was reported for laboratory conditions, in practice atrazine persisted in soil for more than four months.

The rate of chemical degradation of atrazine depends strongly on environmental acidity and the presence of catalytic substances. Atrazine may hydrolyse fairly rapidly in either acidic or alkaline environments, yet is strongly resistant to hydrolysis in neutral environments (pH 7). In a neutral environment and at 25°C the half-life of atrazine was calculated to be 1 800 years. In extreme environments, atrazine was completely hydrolysed within three to four days. Hydrolysis in alkaline environments proceeds twice as rapidly as it does in acidic environments.

The rate of hydrolysis is increased drastically by the addition of humic materials. The acidic functional groups of humic materials (in particular hydrogen ions) work as catalytic agents. For example, the half-life of atrazine at pH 4 was 244 days without an additive and 1.73 days in the presence of humic acid.

• Degradation products

The major product of atrazine degradation is 2-chloro-4 amino-6-isopropyloamino-s-trazine.

• Volatilization/evaporation

Atrazine is thought not to volatilize.

• Bioaccumulation

On the base of log K_{ow} atrazine is thought to accumulate moderately in organisms. No bioconcentration was observed after exposing fish to various concentrations of atrazine. None of the fish species bioconcentrates atrazine from water (residue concentration below detectable limits).

• Phytotoxicity

Experiments with applying atrazine to susceptible crops have demonstrated that residual concentrations of less than 0.7 mg/kg in plants do not cause serious damage to the crop.

PROPERTIES

Atrazine is a colourless powder. In its original packing, it is stable for several years, with a slight sensitivity to natural light. It must be kept away from heat, flames and sparks. It is unstable in an acidic or alkaline environment. Spillages can be removed using 10 v/w percent of a NaOH solution.

TABLE B
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	175–176	
Vapour pressure		mPa	0.04	
Density		g/cm^3	1.187	
Degradation	DT_{50}soil	Days	60–150	Slightly Degradable
Solubility	S_w	mg/l	30	Readily soluble
Mobility	Log K_{oc}			Highly mobile
ADI		mg/kg/day	0.005	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	2 500	
	Consumption of vegetables	mg/kg dm soil	1	
	Consumption of drinking-water	µg/l	100	

Captafol

Common formulation

$C_{10}H_9C_{14}NO_2S$

CAS registry number

2425–06–1

Use

As a broad-spectrum protective contact fungicide. It is effective for the control of fungal diseases of plants (except powdery mildews) and is widely used to control foliage and fruit diseases on apples, citrus fruits, potatoes, coffee, etc.
It is also used to reduce losses from wood rot fungi in logs and wood products.

CAPTAFOL IN THE ENVIRONMENT

• Mobility

The values of the adsorption coefficient indicate that captafol is slightly mobile in most soils.

• Degradation

Both biodegradation and hydrolysis may be the major processes causing the loss of captafol from most soils. The experimental estimated half-life of captafol in three soils was estimated to be in the range of 23–55 days. Half-lives of less than three, five and eight days have been reported for nonsterile organic, sandy and clay loam soils, respectively. Captafol does not leach from alkaline soils. The estimated half-life of captafol in a river is 0.3 of a day, primarily due to biodegradation.

- **Degradation products**

No data available.

- **Volatilization/evaporation**

Because of captafol's low vapour pressure, its volatilization from dry and moist soil should be negligible.

- **Bioaccumulation**

The bioaccumulation of captafol in aquatic organisms is not important.

- **Phytotoxicity**

The half-life of captafol sprayed on most crops was less than five days. Residues were below the tolerance limits at the time of harvest. The roots and shoots of plants absorb Captafol and its metabolites. Captafol is also translocated in plant tissue as a result of seed treatment, soil treatment and foliar application. Grapes, apples and citrus fruits have been injured by phytotoxicity under certain weather conditions. Roses have shown injury at high rates of application.

PROPERTIES

Captafol forms colourless to yellow crystals. It hydrolyses in aqueous emulsions or suspensions. It hydrolyses rapidly in acidic and alkaline media.

TABLE C
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	160–162	
Vapour pressure		mPa	Negligible	
Density		G/cm^3	-	
Degradation	DT$_{50}$ soil	Days	23–55	Fairly degradable
Solubility	S$_w$	mg/1	1.4	Moderately soluble
Mobility	Log K$_{OC}$		3.32	Slightly mobile
ADI		mg/kg/day	0.004	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	2 000	
	Consumption of vegetables	mg/kg dm soil	2	
	Consumption of drinking-water	µg/l	80	

Carbaryl

Common formulation

$C_{12}H_{11}NO_2$

CAS registry number

63–25–2

Use

As an insecticide to control insects on citrus fruits, fruit, cotton, forests, lawns, shade trees and other crops.

CARBARYL IN THE ENVIRONMENT

- **Mobility**

Based on its moderate soil sorption coefficient, carbaryl exhibits moderate mobility.

- **Degradation**

Carbaryl has low persistence in soil. Its degradation is mostly due to sunlight and bacterial action. The rate of photolysis at the soil surface depends on the soil water content. Carbaryl has a half-life of 7–14 days in sandy loam soil, and 14–28 days in clay loam soil. It hydrolyses relatively rapidly in moist alkaline soil, but only slowly in acidic soil.

Release to soil results in rapid hydrolysis at pH values of seven and above (half-life 10.5 days, 1.8 days and 2.5 hours at a pH of seven, eight and nine, respectively). In surface water, carbaryl may degrade due to bacteria and through hydrolysis. The half-life varies greatly depending on water acidity. Hydrolysis in acidic water is slow (halflife 1 500 days at pH 5).

- **Degradation products**

The major degradation products are 3-hydroxycarbofuran. 3-ketocarbofuran and carbofuran phenol.

- **Volatilization/evaporation**

Evaporation of the compound is very slow.

- **Bioaccumulation**

Bioaccumulation is thought to be not significant.

- **Phytotoxicity**

Degradation of carbaryl in crops occurs by hydrolysis inside the plants. It has a short residual life of less than two weeks.

PROPERTIES

Carbaryl forms colourless to light tan crystals. It is stable in the presence of heat, light and acids. It is subject to hydrolysis.

TABLE D
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	142	
Vapour pressure		mPa	<5.3	
Density		g/cm^3	1.232	
Degradation	DT_{50}soil	Days	17–28	Readily/ fairly degradable
Solubility	S_w	mg/1	40	Readily soluble
Mobility	Log K_{OC}		2.5	Moderately mobile
ADI		mg/kg/day	0.01	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	5 000	
	Consumption of vegetables	mg/kg dm soil	5	
	Consumption of drinking-water	µg/l	200	

Carbofuran

Common formulation

$C_{12}H_{15}NO_3$

CAS registry number

1563–66–2

Use

As a broad-spectrum carbamate pesticide. It is used against the soil and foliar pests of fields, fruits, vegetables and forest crops.

CARBOFURAN IN THE ENVIRONMENT

- **Mobility**

Carbofuran has high to very high mobility in soil.

- **Degradation**

There are reported half-lives for carbofuran disappearance from soil of 2–86 days for flooded soils and 26–110 days for field soil. Chemical hydrolysis and microbial degradation appear to be important degradation processes for this compound in both soil and aquatic systems. Chemical hydrolysis of carbofuran is thought to occur more rapidly in alkaline than in acidic or neutral environments. Carbofuran exhibits enhanced biodegradation in soils previously treated with this pesticide. Direct photolysis and photo-oxidation (via hydroxyl radicals) may contribute to carbofuran's removal from natural water. Half-lives for the degradation of carbofuran in river, lake, and sea water samples that were irradiated with sunlight were approximately 2, 6 and 12 hours, respectively. The rate of degradation of carbofuran increases as the application rate decreases, the clay and organic matter content of the soil decreases, the pH increases, and the moisture content of the soil increases.

- **Degradation products**

The major metabolites of carbofuran degradation in soil are 3-hydroxycarbofuran, 3-ketocarbofuran and carbofuran phenol.

- **Volatilization/evaporation**

Volatilization from soil surfaces is thought to be not significant. If released into the atmosphere, carbofuran should exist in both the vapour and particulate phases in the ambient atmosphere based on a measured vapour pressure of 4.85 × 10-6 mm Hg at 19°C. Vapourphase carbofuran is degraded in the atmosphere by reaction with photochemically produced hydroxyl radicals, with a half-life of about 13 hours. Particulate phase carbofuran may be physically removed from the air by wet and dry deposition. Direct photolysis may be an important removal process for carbofuran in the atmosphere.

- **Bioaccumulation**

Bioaccumulation of carbofuran in aquatic organisms is not important.

- **Phytotoxicity**

The half-life of carbofuran on crops is about four days when applied to roots, and longer than four days if applied to the leaves.

PROPERTIES

Carbofuran is a crystalline solid. It is stable under neutral or acidic conditions, but unstable in alkaline media.

TABLE E
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	153–154	
Vapour pressure		mPa	2.7	
Density		g/cm^3	1.8	
Degradation	DT_{50}soil	Days	30-117	Moderately degradable
Solubility	S_w	mg/1	320	Readily soluble
Mobility	Log k_{oc}		1.3	Mobile
ADI		mg/kg/day	0.01	

Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	5 000	
	Consumption of vegetables	mg/kg dm soil	1	
	Consumption of drinking-water	µg/l	200	

Chlordane

Common formulation

$C_{10}H_6Cl_8$

CAS registry number

57-74-9

Use

As a persistent insecticide for underground termite control, for homes, gardens and for the control of corn, citrus fruits, vegetables and other crops.

CHLORDANE IN THE ENVIRONMENT

- **Mobility**

Based on field tests, chlordane is thought to be generally immobile or only slightly mobile.

- **Degradation**

Chlordane is highly persistent in soils, with a half-life of about four years. Several studies have found chlordane residues in excess of 10 percent of the initially applied amount ten years or more after application. Sunlight may break down a small amount of the chlordane exposed to light. Chlordane does not chemically degrade and is not subject to biodegradation in soils. Chlordane molecules usually remain adsorbed to clay particles or to soil organic matter in the topsoil layers and slowly volatilize into the atmosphere. Extremely low levels of chlordane, however (0.01 to 0.001 µg/L), have been detected in both ground and surface waters in areas where chlordane was heavily used. Sandy soils allow the passage of chlordane to groundwater.

Chlordane does not degrade rapidly in water. It can exit aquatic systems by adsorbing to sediments or by volatilization.

- **Degradation products**

The photoisomers of chlordane appear to occur under natural conditions. All of these photoisomers are of special significance because to certain animals they are much more toxic than chlordane. Photo-cis-chlordane, which is more biodegradable than cis-chlordane, showed higher bioaccumulation values and therefore may have more significant effects on food chains.

- **Volatilization/evaporation**

Evaporation is the major route of removal from soils. The volatilization half-life of chlordane in lakes and ponds is estimated to be less than ten days. However, adsorption to sediment significantly attenuates the importance of volatilization. Chlordane reacts in the vapour phase with photochemically produced hydroxyl radicals at an estimated half-life rate of six hours, suggesting that this reaction is the dominant chemical removal process.

- **Bioaccumulation**

Chlordane is thought to have a high accumulation in aquatic organisms.

- **Phytotoxicity**

No data are currently available.

PROPERTIES

Technical chlordane is a mixture of at least 23 different components, including chlordane isomers. It is a viscous, colourless or amber liquid. It decomposes in weak alkalis.

TABLE F
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	104–107	
Vapour pressure		mPa	1.3	
Density		g/cm^3	1.6	
Degradation	DT_{50}soil	Years	4	Slightly/ not degradable
Solubility	S_w	mg/l	0.1	Slightly soluble
Mobility	Log K_{OC}		3.9	Slightly mobile
ADI		mg/kg/day	0.0005	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	250	
	Consumption of vegetables	mg/kg dm soil	0.1	
	Consumption of drinking-water	µg/l	10	

Chlordimeform

Common formulation

$C_{10}H_{13}ClN_2$

CAS registry number

6164-98-3

Use

As an acaricide and insecticide. It is also effective in controlling lepidoptera and is used to control eggs and larvae on cotton.

CHLORDIMEFORM IN THE ENVIRONMENT

- **Mobility**

An estimated K_{OC} value of 890 suggests that chlordimeform has moderate mobility in soil.

- **Degradation**

Chlordimeform biodegrades. Biodegradation under anaerobic conditions is slow.

The residue of chlordimeform decreased rapidly after soluble powder or emulsifiable concentrate formulations of the pesticide were applied, but 10 percent remained detectable after 500 days.

- **Degradation products**

The major degradation products are N-dimethylchlordimeform, chloro-o-formotoluidide and chloro-acetotoluide.

- **Volatilization/evaporation**

Based on a measured vapour pressure of 3.6 × 10-4 mm Hg at 25°C, volatilization from soil is not expected. Chlordimeform in vapour phase is degraded in the atmosphere by reaction with photochemically produced hydroxyl radicals with a half-life of about 0.2 of a day.

- **Bioaccumulation**

The bioaccumulation in aquatic organisms should be moderate based on an estimated value of $K_{ow} = 0.11$.

- **Phytotoxicity**

Not applicable.

PROPERTIES

Chlordimeform forms colourless crystals. It hydrolyses in neutral and acidic aquatic media.

TABLE G
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	35	
Vapour pressure		mPa	Not found	
Density		g/cm^3	1.10	
Degradation	DT_{50}soil	Days	93	Slightly degradable
Solubility	S_w	mg/1	270	Highly soluble
Mobility	Log k_{OC}		2.9	Moderately mobile
ADI		mg/kg/day	Not found	
Permissible Concentrations	Human:			
	Direct contact	mg/kg/ dm soil		
	Consumption of vegetables	mg/kg dm soil		
	Consumption of drinking-water	μg/l		

Chlorfenvinphos (Birlane)

Common formulation

$C_{12}H_{14}Cl_3O_4P$

CAS registry number

470-90-6

Use

As an insecticide to control ticks, files and mites on cattle. Also used to control root files and rootworms and as a foliage insecticide to control the Colorado beetle on potatoes and leafhoppers on rice.

CHLORFENVINPHOS IN THE ENVIRONMENT

- **Mobility**

According to a suggested classification, the log K_{oc} value of 2.47 indicates that chlorfenvinphos has medium mobility in soil.

- **Degradation**

If released into soil or water, chlorfenvinphos degrades through biodegradation. The importance of microbial degradation has been demonstrated by various persistence studies that compared degradation rates in sterile versus non-sterile soil. In these studies, the degradation of chlorfenvinphos was much faster in non-sterile than in sterile soil. In one 90-

day field study, chlorfenvinphos did not leach in a sandy loam soil. Typical soil half-lives range roughly from 10 to 45 days.

The aqueous hydrolysis half-life of chlorfenvinphos has been determined to be four days at pH 6. The rate of hydrolysis depends on the acidity of the environment. The hydrolysis half-life at pH 6–8 and at 20°C is approximately 388–483 days.

- **Degradation products**

The degradation products of chlorfenvinphos are dichlorophenacyl chloride, dichloroacetophenone, alpha-chromethyl-2.4-dichlorobenzyl alcohol, 2-hydroxy-4-chlorbenzoic acid and 2.4-dihydrobenzoic acid.

- **Volatilization/evaporation**

Based on vapour pressure and water solubility, chlorfenvinphos is essentially non-volatile in water. If released into the atmosphere, it degrades rapidly in the vapour phase by reaction with photochemically produced hydroxyl radicals (half-life about seven hours). Particulate phase chlorfenvinphos and aerosols released into the air during spray applications of chlorfenvinphos insecticides are removed from the air physically by dry and wet deposition.

- **Bioaccumulation**

Chlorfenvinphos is thought to accumulate moderately in aquatic organisms.

- **Phytotoxicity**

Not applicable.

PROPERTIES

Chlorfenvinphos is a colourless liquid. It is unstable in alkali at 20°C (half-life 1.28 at pH 13). It slowly hydrolyses in water or acid.

TABLE H
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	-19 to -23	
Vapour pressure		mPa	Negligible	
Density		g/cm^3	1.36	
Degradation	DT$_{50}$soil	Days	10–45	Fairly degradable
Solubility	S$_w$	mg/l	145	Highly soluble
Mobility	Log K$_{oc}$	2.47		Moderately mobile
ADI		mg/kg/day	0.002	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	1 000	
	Consumption of vegetables	mg/kg dm soil	0.1	
	Consumption of drinking-water	µg/l	40	

Chlorobenzilate

Common formulation

$C_{16}H_{14}Cl_2O_3$

CAS registry number

510-15-6

Use

To control mites on citrus crops and in beehives. It has a narrow insecticidal use, killing only ticks and mites.

CHLOROBENZILATE IN THE ENVIRONMENT

- **Mobility**

Since chlorobenzilate is practically insoluble in water and adsorbs strongly to soil particles in the upper soil layers, it is thought to exhibit low mobility in soils, and is therefore unlikely to leach into groundwater.

- **Degradation**

Chlorobenzilate has a low persistence in soils. Its half-life in fine sandy soils is 10–35 days after application of 0.5–1.0 ppm. The removal is probably due to microbial degradation. Following a fiveday application of chlorobenzilate to several different citrus groves employing various tillage treatments, the pesticide was not found in subsurface drainage waters, or in surface runoff waters. Chlorobenzilate adsorbs to sediment and suspended particulate material in water. It is thought not to volatilize in water but may be subject to biodegradation.

- **Degradation products**

The product of chlorobenzilate degradation is 4,4 -dichlorobenzophenone.

- **Volatilization/evaporation**

Due to its strong adsorption to soil particles and low vapour pressure, chlorobenzilate is thought not to volatilize from soil and water surfaces.

- **Bioaccumulation**

Chlorobenzilate should not bioconcentrate in aquatic organisms.

- **Phytotoxicity**

Chlorobenzilate is fairly persistent on plant foliage and may be phytotoxic (poisonous) to some plants. It is not absorbed or transported throughout a plant. Chlorobenzilate residues have been found in the peel of citrus fruit. Its half-life in lemon and orange peels ranges from 60 to more than 160 days.

PROPERTIES

Chlorobenzilate is a colourless solid. It has a shelf-life of at least three to five years when stored in a dry place and at minimum storage temperatures.

TABLE I
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	36	
Vapour pressure		mPa	0.12	
Density		g/cm^3	1.28	
Degradation	DT_{50}soil	Days	10–35	Readily to fairly degradable
Solubility	S_w	mg/l	10	Moderately soluble
Mobility	Log K_{oc}		3	Slightly mobile
ADI		mg/kg/day	0.02	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	10 000	
	Consumption of vegetables	mg/kg dm soil	8	
	Consumption of drinking-water	µg/l	400	

DDT

Common formulation

$C_{14}H_9Cl_5$

CAS registry number

50-29-3

Use

As a non-systemic stomach and contact insecticide.

DDT IN THE ENVIRONMENT

- **Mobility**

DDT is not mobile. It adsorbs to soil strongly and should not leach into groundwater.

- **Degradation**

In the soil, DDT is biologically degradable with a half-life of 2 to more than 15 years. Biodegradation is faster in flooded soils and under anaerobic conditions. It is reported to disappear (75 percent to 100 percent) from soil in 4–30 years. DDT hardly hydrolyses: according to reports, its hydrolysis half-life is 12 years.

In water it is subjected to evaporation with an estimated half-life for evaporation of from several to 50 hours. The direct breakdown of a compound by light in an aqueous solution occurs very slowly, with a half-life exceeding 150 years. Indirect photolysis processes (initiated by natural substances) may be an important step in DDT transformations; its half-life then is a few days. Biodegradation in water is generally poor.

- **Degradation products**

Typical metabolic or chemical reduction products are DDE under aerobic conditions, and DDD to DDA under anaerobic conditions.

- **Volatilization/evaporation**

Not relevant.

- **Bioaccumulation**

If DDT is released into water it adsorbs strongly to sediments and significantly bioconcentrates in fish.

- **Phytotoxicity**

Not applicable.

PROPERTIES

DDT forms colourless crystals. It is resistant to destruction by light and oxidation. Dehydrochlorination may occur above 50°C.

TABLE J
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	108	
Vapour pressure		mPa	0.025	
Density			Not found	
Degradation	DT_{50}soil	Years	4–30	Very slightly degradable
Solubility	S_w	mg/l	0.0033	Not soluble
Mobility	Log K_{oc}		6.2	Not mobile
ADI		mg/kg/day	0.02	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	10 000	
	Consumption of vegetables	mg/kg dm soil	1 000	
	Consumption of drinking-water	μg/l	400	

Diazinon

Common formulation

$C_{12}H_{21}N_2O_3PS$

CAS registry number

333-41-5

Use

As an insecticide, mainly applied to fruit trees, horticultural crops, rice, sugar cane, etc.

DIAZINON IN THE ENVIRONMENT

• Mobility

Diazinon does not bind strongly to soil. It shows moderate mobility.

• Degradation

The values of DT_{50} in Table K are average values from several DT_{50} values reported in the field.

Diazinon does not persist in soil. Most of the diazinon applied is lost from soil through chemical and biological degradation within about two months of application. Hydrolysis has been reported to be slow at pH greater than 6, but may be significant in some soils.

Biodegradation is thought to be a major fate process in soils with reported half-lives of more than 1.2 to 5 weeks in non-sterile soils, as compared with half-lives of 6.5 to 12.5 weeks in sterile soils.

The rate of chemical degradation of diazinon strongly depends on environmental acidity. Diazinon is more stable in alkaline environments than at a neutral or an acidic pH value. Hydrolysis halflives are of 32 days (pH 5), 185 days (pH 7.4) and 136 days (pH 9) at 20°C.

• Degradation products

No data available.

• Volatilization/evaporation

Evaporation from the surface of soil is thought not to be an important transport process. Evaporation from a river may be significant, with a half-life of 46 days.

• Bioaccumulation

Diazinon is thought to sorb moderately to sediments but does not bioaccumulate in aquatic organisms.

- **Phytotoxicity**

About 50 percent of the diazinon was lost from treated rice plants within nine days through volatilization from the paddy water and transpiration from the leaves. Less than 10 percent of the radioactivity remains in plants and parent compounds.

PROPERTIES

Diazinon is a colourless liquid. It is more stable in alkaline environments than at a neutral or an acid pH. It has a shelf-life of at least three to five years when stored in a dry place and at minimum storage temperature.

TABLE K
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	-	
Vapour pressure		mPa	0.097	
Density		g/cm	1.11	
Degradation	DT_{50} soil	Weeks	1.2–5	Fairly degradable
Solubility	Solubility (water)	mg/l	40	Readily soluble
Mobility	Log K_{oc}		1.92	Moderately mobile
ADI		mg/kg/day	0.002	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	1 000	
	Consumption of vegetables	mg/kg dm soil	0.3	
	Consumption of drinking-water	µg/l	40	

Dieldrin

Common formulation

$C_{12}H_8Cl_6O$

CAS registry number

60-57-1

Use

This stereoisomer of endrin is used mainly to protect wood and wooden structures against attack by insects and termites, and by industry to protect against textile pests.

DIELDRIN IN THE ENVIRONMENT

- **Mobility**

If released into the soil, dieldrin binds strongly to it. It shows low mobility and remains immobile (Rf = 0.00), even at high temperatures and with prolonged leaching.

- **Degradation**

Dieldrin released into the soil persists for an extremely long time (more than seven years). However, it is lost from the soil very rapidly in tropical areas, with up to 90 percent disappearing within one month. Its low water solubility and strong adsorption to soil make leaching unlikely.

When released into the water system it does not undergo hydrolysis or biodegradation. It is subject to photolysis with a half-life of approximately four months, or somewhat faster in waters containing a photosensitizer.

- **Degradation products**

There is some evidence that microorganisms can form photodieldrin from dieldrin.

- **Volatilization/evaporation**

Small quantities of dieldrin may volatilize from the soil or be carried into the atmosphere on dust particles. Evaporation from water may be an important process (half-life of hours to months).

- **Bioaccumulation**

In water, dieldrin is thought to adsorb to sediments and to bioaccumulate in aquatic organisms.

- **Phytotoxicity**

The toxicity of dieldrin for higher plants is low.

PROPERTIES

Dieldrin forms tan flakes. It is stable in the presence of light, moisture, alkalis and mild acids but is sensitive to concentrated mineral acids, acid catalysts, acid oxidizing agents and active metals.

TABLE L
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	177	
Vapour pressure		mPa	0.4	
Density		g/cm	1.75	
Degradation	DT_{50}soil	Years	>7	Very slightly degradable
Solubility	Solubility (water)	mg/l	0.1	Slightly soluble
Mobility	Log K_{oc}		3.87	Slightly mobile
ADI		mg/kg/day	0.0001	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	50	
	Consumption of vegetables	mg/kg dm soil	0.1	
	Consumption of drinking-water	µg/l	2	

Dimethoate

Common formulation

$C_5H_{12}NO_3PS_2$

CAS registry number

60-51-5

Use

As an insecticide.

DIMETHOATE IN THE ENVIRONMENT

- **Mobility**

Highly soluble in water and adsorbing to soil, dimethoate may leach considerably.

- **Degradation**

Dimethoate does not persist. Soil half-lives of 4 to 16 days and as high as 122 days have been reported. Half-lives between 2.5 and 4 days were reported during drought and moderate rainfall conditions. Dimethoate breaks down faster in moist soils and is rapidly broken down by most soil microorganisms.

It is subject to significant hydrolysis, especially in alkaline waters. Hydrolysis half-lives of 3.7 and 118 days at pH 9 and pH 7 respectively have been estimated.

- **Degradation products**

No data available.

- **Volatilization/evaporation**

Evaporation from open waters is not believed to be significant.

- **Bioaccumulation**

It is thought not to bioaccumulate in aquatic organisms.

- **Phytotoxicity**

Dimethoate is not toxic to plants.

PROPERTIES

Dimethoate is a colourless solid. It undergoes rapid degradation in the environment and in sewage treatment plants.

TABLE M
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	49	
Vapour pressure		mPa	0.29	
Density		g/cm^3	1.28	
Degradation	DT_{50}soil	Days	4–122	Fairly degradable
Solubility	S_w	mg/1	25	Highly soluble
Mobility	Log K_{oc}		1	Highly mobile
ADI		mg/kg/day	0.01	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	5 000	
	Consumption of vegetables	mg/kg dm soil	0.5	
	Consumption of drinking-water	µg/l	200	

Dinoseb

Common formulation

$C_{10}H_{12}N_2O_5$

CAS registry number

88-85-7

Use

As a phenolic herbicide applied to soybeans, vegetables, fruits, nuts, citrus fruits and other field crops. It is also used as an insecticide for grapes and as a seed crop drying agent.

DINOSEB IN THE ENVIRONMENT

- **Mobility**

The phenolic form of dinoseb is slightly soluble in water and moderately sorbed by most soils. Studies have shown soil sorption capacity to be much greater at lower pH values. Thus, it should present only a moderate risk to groundwater. On the other hand, the ammonium and amine salt forms of dinoseb are much more watersoluble and much less strongly bound to soils. These may pose a significant risk to groundwater.

- **Degradation**

Dinoseb is of low persistence regardless of its form (phenolic or salt). Reported field half-life of both types of dinoseb range from 5 to 31 days. An overall representative value is estimated to be 20–30 days in most circumstances, although persistence may be much longer in the vadose zone. Photodegradation and microbial breakdown may play roles in the breakdown of dinoseb in the soil environment.

Photodegradation may occur in surface waters, but hydrolysis is essentially negligible.

- **Degradation products**

No data available.

- **Volatilization/evaporation**

Volatilization from water is thought not to be an important removal process. Vapour-phase dinoseb is degraded photochemically, with a half-life of 14 days.

- **Bioaccumulation**

Dinoseb is thought not to bioaccumulate in aquatic organisms.

- **Phytotoxicity**

Dinoseb persists on treated crop soils for two to four weeks under average conditions of use.

PROPERTIES

Dinoseb is a reddish-brown liquid or dark brown solid. The ester is slowly hydrolysed in the presence of water and is sensitive to acid or alkali. The shelf-life is a minimum of two years.

TABLE N
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	39–42	
Vapour pressure		mmHg	1	
Density		g/cm^3	1.26	
Degradation	DT$_{50}$soil	Days	5–31	Readily to fairly degradable
Solubility	S$_w$	mg/1	100	Readily soluble
Mobility	Log K$_{oc}$		2	Mobile
ADI		mg/kg/day	Not found	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil		
	Consumption of vegetables	mg/kg dm soil		
	Consumption of drinking-water	μg/l		

Endosulfan

Common formulation

$C_9H_6Cl_6O_3S$

CAS registry number

115-29-7

Use

As an insecticide for vegetable crops.

ENDOSULFAN IN THE ENVIRONMENT

- **Mobility**

Endosulfan is relatively immobile in soil. It adsorbs to soil strongly.

- **Degradation**

Endosulfan is biodegradable. The beta isomer is more stable. Reports mention soil half-lives of 60 days for alpha-endosulfan and 800 days for beta-endosulfan. Endosulfan may be subject to hydrolysis. Hydrolysis half-lives of 35.4 (alpha-endosulfan) and 37.5 days (betaendosulfan) have been determined at a pH of 7. At a pH of 5.5 the halflife may be as high as 187.3 for beta-endosulfan. The hydrolysis of endosulfan occurs faster in the presence of ferric hydroxide.

Its half-life in streams, rivers and lakes was estimated at 5.7, 7.2 and 304 days, respectively.

- **Degradation products**

The major degradation product is endosulfan sulphate.

- **Volatilization/evaporation**

Expectations are that endosulfan isomers exhibit only a minimum of volatilization and leaching into groundwater.

- **Bioaccumulation**

In water, endosulfan is thought to bioaccumulate in aquatic organisms.

- **Phytotoxicity**

In most fruits and vegetables, 50 percent of the residue is lost in three to seven days.

PROPERTIES

Endosulfan is a brown crystalline solid. It is composed of alphaendosulfan and beta-endosulfan. Endosulfan is stable in sunlight but unstable in alkaline media. It is subject to slow hydrolysis, and to oxidation in the presence of growing vegetation.

TABLE O
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	70–100	
Vapour pressure		mPa	1.2	
Density		g/cm^3	Not found	
Degradation	DT_{50}soil	Days	60–800	Slightly degradable
Solubility	S_w	mg/1	0.5	Slightly soluble
Mobility	Log K_{oc}		3.4	Slightly mobile
ADI		mg/kg/day	0.006	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	3 000	
	Consumption of vegetables	mg/kg dm soil	3	
	Consumption of drinking-water	µg/l	120	

Endrin

Common formulation

$C_{12}H_8Cl_6O$

CAS registry number

72-20-8

Use

It is used as insecticide on field crops such as cotton and grains.

ENDRIN IN THE ENVIRONMENT

- **Mobility**

Its low water solubility and strong adsorption to soil makes leaching into groundwater unlikely. Endrin is thought to maintain slight mobility in soil.

- **Degradation**

Endrin appears to be resistant to biodegradation in natural waters and most soils. Released to soils, it will persist for extremely long periods of time. Soil biodegradation half-lives of approximately 4–14 years or more have been reported. Biodegradation may be enhanced somewhat in flooded soils or under anaerobic conditions.

Endrin released to water systems will not hydrolyse. It will be subject to photodegradation to ketoendrin.

- **Volatilization/evaporation**

Small amounts of endrin may volatilize from soil or be carried by dust particles into the air. Evaporation from water will not be significant.

- **Bioaccumulation**

On the base of log K_{ow} endrin is thought to significantly accumulate in aquatic organisms.

- **Phytotoxicity**

It is not phytotoxic.

PROPERTIES

Endrin is a colourless to tan crystalline solid.

TABLE P
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	-	
Vapour pressure		mPa	2 × 10 E - 7	
Density		g/cm^3	1.7	
Degradation	DT_{50}soil	Days	4–14	Very slightly degradable
Solubility	S_w	mg/1	200µg/l	Slightly soluble
Mobility	Log K_{oc}		4.5	Hardly mobile
ADI		mg/kg/day	0.0002	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	100	
	Consumption of vegetables	mg/kg dm soil	8	
	Consumption of drinking-water	µg/l	4	

Fenitrothion

Common formulation

$C_9H_{12}NO_5PS$

CAS registry number

122-14-5

Use

As a contact insecticide; it is effective against a wide range of pests, e.g. penetrating, chewing and sucking insects.

FENITROTHION IN THE ENVIRONMENT

- **Mobility**

Fenitrothion shows medium to low mobility in soil.

- **Degradation**

Fenitrothion is biodegraded in soil by co-metabolism. Biodegradation occurs more rapidly under anaerobic conditions than under aerobic conditions. The biodegradation half-life of fenitrothion ranges from 4.4 to 53.7 days in non-flooded soils, and from 3.9 to 10.9 days in flooded soils.

At neutral pH values, the abiotic hydrolysis of fenitrothion in soil is not important. It increases, however, in alkaline environments. A halflife of 4.4 years was estimated for soil samples at pH 7.2. On the soil surface, fenitrothion is subject to photolysis, a process that may occur very rapidly. Photolysis half-life has been estimated at one day. For comparison, the volatilization half-life was found to be more than 12 days.

- **Degradation products**

The products of degradation are aminonitrophenol and demethyl aminofenitrothion.

- **Volatilization/evaporation**

According to estimates, the maximum volatilization half-life in an acid environment is 180 days. The volatilization half-life of fenitrothion in lake and brook water was estimated at 21 and 5 days, respectively.

- **Bioaccumulation**

Expectations are that in water, fenitrothion adsorbs moderately to strongly to suspended particles and sediments, and that it accumulates moderately in aquatic organisms.

- **Phytotoxicity**

Not applicable.

PROPERTIES

Fenitrothion is a yellow liquid. It is not stable in an alkaline environment.

TABLE Q

Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	n.a.	
Vapour pressure		mPa	0.15	
Density		g/cm³	1.32	
Degradation	DT_{50}soil	Days	4–54	Readily/fairly degradable
Solubility	S_w	mg/l	21	Readily soluble
Mobility	Log K_{oc}		2.4–3.19	Moderately/ slightly mobile
ADI		mg/kg/day	0.005	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	2 500	
	Consumption of vegetables	mg/kg dm soil	3	
	Consumption of drinking-water	µg/l	100	

Fenthion

Common formulation

$C_{10}H_{15}O_3PS_2$

CAS registry number

55-38-9

Use

As an insecticide against many biting pests, fruit flies, mosquitoes, etc.

FENTHION IN THE ENVIRONMENT

• Mobility

Fenthion adsorbs fairly strongly to soil particles and is thought to have very low mobility. It is thought not to move (or leach) throught soil.

• Degradation

When released into soil or water, fenthion degrades through photodegradation and biodegradation. It has moderate persistence in soil, with an average field half-life of 34 days under most conditions. In soil, residues of fenthion may persist for approximately four to six weeks. In one study of its persistence in water, 50 percent of applied fenthion remained in river water for two weeks, while 10 percent remained after four weeks. It is more rapidly degraded under alkaline conditions. The persistence half-life of fenthion in water under field conditions is reported to range from 3 to 21 days for various oceans, rivers and swamps. However, it may be more persistent in some environments, such as salt marsh sediments, where light and oxygen are limited.

- **Degradation products**

No data available.

- **Volatilization/evaporation**

Fenthion is thought not to volatilize.

- **Bioaccumulation**

Based on the value of K_{ow} (= 25) fenthion accumulates slightly in aquatic organisms.

- **Phytotoxicity**

Fenthion is phytotoxic (harmful to plants) to American linden, hawthorn and sugar maple trees, and to certain rose varieties. It is not considered phytotoxic when used at recommended rates, although injury has occurred in certain varieties of apples and cotton. Only about 10 percent of applied fenthion remained on rice plants after six hours. Almost half of the activity was found in the rice bran, 6.5 percent was in the husk, and 14.7 percent was in polished rice. Watersoluble metabolites were found 14 days after fenthion application to rice plants.

PROPERTIES

Pure fenthion is a colourless liquid. Fenthion is stable in the presence of light but may be subject to hydrolysis.

TABLE Q
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	7.5	
Vapour pressure		mPa	4	
Density		g/cm^3	1.25	
Degradation	DT_{50}soil	Days	34	Fairly degradable
Solubility	S_w	mg/1	2	Moderately soluble
Mobility	Log K_{oc}		3.1	Slightly mobile
ADI		mg/kg/day	0.001	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	500	
	Consumption of vegetables	mg/kg dm soil	0.2	
	Consumption of drinking-water	µg/l	20	

Fluoroacetamide

Common formulation

C_2H_4FNO

CAS registry number

640-19-7

Use

Formerly, as an insecticide on fruits to control insects, aphids and mites.

FLUOROACETAMIDE IN THE ENVIRONMENT

• Mobility

The low value of K_{oc} indicates a very high mobility for fluoroacetamide.

• Degradation

The primary decomposition process of fluoroacetamide in soil and water may be microbial degradation. Persistence (as determined by aphid toxicity) lasted for three weeks or less in soils at a concentration of 10 ppm during the test, and from 9 to 11 weeks at a concentration of 50 ppm. Aqueous hydrolysis is very slow (half-life of 2.4 years at pH 7).

• Degradation products

No data available.

• Volatilization/evaporation

Not applicable.

• Bioaccumulation

Bioaccumulation is thought not to be important in aquatic environments.

• Phytotoxicity

Not applicable.

PROPERTIES

Fluoroacetamide is a colourless crystalline powder. It sublimes on heating.

TABLE S

Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	108	
Vapour pressure		mPa	n.a.	
Density		g/cm^3		
Degradation	DT_{50}soil	Days	n.a.	-
Solubility	S_w	mg/l	>10	Readily soluble
Mobility	Log K_{oc}		0.8	Highly mobile
ADI		mg/kg/day	Not found	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil		
	Consumption of vegetables	mg/kg dm soil		
	Consumption of drinking-water	µg/l		

HCH (mixed isomers)

Active ingredient

γ-hexachlorocyclohexane (lindane)

Common formulation

$C_6H_6Cl_6$

CAS registry number

α- hexachlorocyclohexane 319-84-6

β- hexachlorocyclohexane 319-85-7

γ- hexachlorocyclohexane (lindane) 58-89-9

δ- hexachlorocyclohexane 319-86-8

Use

Hexachlorocyclohexane is mainly used as insecticide and as an agent against ecoparasites in veterinary and pharmaceutical products.

HCH (MIXED ISOMERS) IN THE ENVIRONMENT

- **Mobility**

Generally, the adsorption of HCH-isomers is rather strong. Less than 1 percent of the load reaches the groundwater. Based on the solubility of the different HCH isomers (0.2–9 mg/l) it can be expected that diffusion of HCH in the soil by leaching and subsequent percolation is possible.

• Degradation

HCH isomers were long considered to be persistent in aerobic environments, but they readily undergo biodegradation in predominantly anaerobic ecosystems such as flooded soils and lake sediments. Results of field studies showed that the relative rates of bioconversion of HCH isomers appeared to be γ-HCH > α-HCH > β-HCH » δ-HCH. In soils, average half-lives of 20–50 days for g-HCH and about 20 weeks for α-HCH were observed.

Breakdown of HCH in surface water takes place by both biological and chemical degradation.

• Degradation products

The most important metabolites of HCH isomers are γ-pentachlorocyclohexene, chlorobenzenes (tri-hexa) and chlorophenoles. It is not known to which level these metabolites can threaten the soil. It is known, however, that in aerobic conditions, chlorobenzenes are very persistent.

• Volatilization/evaporation

Because of the low vapour pressure and the high adsorption. HCH will evaporate slowly from the soil and the water.

• Bioaccumulation

Hexachlorocyclohexanes are thought to bioaccumulate in aquatic organisms.

• Phytotoxicity

Not applicable.

TABLE T
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C		
α-HCH			158	
β-HCH			309	
γ-HCH (lindane)			112.8	
δ-HCH			141	
Vapour pressure		mmHg		
α-HCH			0.02	
β-HCH			0.005	
γ-HCH (lindane)			3.26×10^{-6}	
δ-HCH			-	
Density		g/cm^3		
α-HCH			1.87	
β-HCH			1.89	
γ-HCH (lindane)			1.85	
δ-HCH			-	
Degradation	DT_{50}soil			

α-HCH		Weeks	20	Slightly degradable
β-HCH				
γ-HCH (lindane)		Days	20–25	
δ-HCH				
Solubility	S_w	mg/l		
α-HCH			2	Moderately soluble
β-HCH			1.5	
γ-HCH (lindane)			10	
δ-HCH		mg/1	2	
Mobility	Log K_{oc}			
α-HCH				
β-HCH				
γ-HCH(lindane)				
δ-HCH				
ADI		mg/kg/day	0.008	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	4 000	
	Consumption of vegetables	mg/kg dm soil	20	
	Consumption of drinking-water	µg/l	160	

Heptachlor

Common formulation

$C_{10}H_5Cl_7$

CAS registry number

76-44-8

Use

Primarily as an insecticide against termites, ants, soil insects in seed grains and on crops.

HEPTACHLOR IN THE ENVIRONMENT

• Mobility

Heptachlor and its epoxide bind moderately to soils and should not be highly mobile.

• Degradation

Heptachlor and heptachlor epoxide are highly persistent in soils, with a reported representative field half-life of 250 days. Data collected in Mississippi, New Jersey and Maryland showed a soil half-life for heptachlor of 0.4 to 0.8 years. The mean disappearance rates of heptachlor from soil ranged from 5.25 to 79.5 percent per year. depending on the soil type and mode of application. The highest rates of degradation were observed in sandy soils following an application of a granular formulation. Soil incorporation also led to rapid disappearance rates in all soil types. This compound has sometimes been detected in trace amounts in soil 14 to 16 years after application. Because of their long residence times, even low mobility may result in appreciable movement; thus heptachlor and its metabolite (heptachlor epoxide) may be considered to pose the risk of groundwater contamination over time. Very low levels of heptachlor have been found in well water. Heptachlor epoxide is not very susceptible to biodegradation, photolysis, oxidation or hydrolysis in the environment.

Heptachlor is almost insoluble in water, and enters surface waters primarily though drift and surface runoff. In water, heptachlor readily undergoes hydrolysis to a compound that is then readily processed (preferentially under anaerobic conditions) by micro-organisms into heptachlor epoxide. After hydrolysis, volatilization, adsorption to sediments, and photodegradation may be significant routes for the disappearance of heptachlor from aquatic environments.

- **Degradation products**

The degradation products of heptachlor are hydroxychlordane and 1-hydroxy-2,3-epoxychlordene.

- **Volatilization/evaporation**

Volatilization from soil surfaces, especially wet ones, is the major route of loss of heptachlor.

- **Bioaccumulation**

Heptachlor exhibits a high tendency for bioaccumulation in aquatic organisms.

- **Phytotoxicity**

In plants, the major breakdown product of heptachlor is the epoxide. Heptachlor is non-phytotoxic when used as directed.

PROPERTIES

Heptachlor is either a white wettable powder or a concentrate. It is stable in the presence of light, air, moisture and moderate heat (up to 160°C).

TABLE U
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	95–96 (pure)	
			46–74 (technical)	
Vapour pressure		mPa	53	
Density		g/cm^3	1.57 (at 9°C)	
Degradation	DT$_{50}$soil	Days	250	Very slightly degradable
Solubility	S$_w$	mg/l	0.18	Slightly soluble
Mobility	Log K$_{oc}$		4.3	Hardly mobile
ADI		mg/kg/day	0.0001	

Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	50	
	Consumption of vegetables	mg/kg dm soil	0.1	
	Consumption of drinking-water	µg/l	2	

Hexachlorobenzene

Common formulation

C_6Cl_6

CAS registry number

118-74-1

Use

In agriculture as a selective fungicide for seed treatment of wheat against bunt.

HEXACHLOROBENZENE IN THE ENVIRONMENT

• Mobility

Hexachlorobenzene adsorbs strongly to soil and is thought not to be mobile in soil. However, it is suggested that it may be transported in low organic carbon soils.

• Degradation

Hexachlorobenzene is a very persistent environmental chemical due to its chemical stability and resistance to biodegradation. Little biodegradation occurs.

• Degradation products

The degradation products of hexachlorobenzene are 1.3-dichlorobenzene and 1,3,5-trichlorobenzene.

• Volatilization/evaporation

The volatilization of the compound from water is rapid (half-life of eight hours), but its strong adsorption to sediment can result in long periods of persistence. If released into the atmosphere, HCB exists primarily in the vapour phase and degradation is extremely slow, with an estimated photodegradation half-life of two years.

• Bioaccumulation

Hexachlorobenzene is strongly accumulated in organisms.

- **Phytotoxicity**

Not applicable.

PROPERTIES

Hexachlorobenzene forms white needles. Hexachlorobenzene is extremely stable even in acid and alkaline environments.

TABLE V

Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	285	
Vapour pressure		mmHg	1.09×0^{-5}	
Density		g/cm^3	2.044	
Degradation	DT_{50}soil	Years	4	Very slightly degradable
Solubility	S_w	mg/1	0.02	Not soluble
Mobility	Log K_{oc}		4–5	Hardly mobile
ADI		mg/kg/day	0.0005	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	250	
	Consumption of vegetables	mg/kg dm soil	20	
	Consumption of drinking-water	µg/l	10	

Lindane (γ-hexachlorocyclohexane)

Common formulation

$C_6H_6Cl_6$

CAS registry number

58-89-9

Use

As an insecticide and fumigant; applied to a wide range of soil-dwelling and plant-eating insects. Commonly used on a wide variety of crops, in public health to control insect-borne disease, and as a seed treatment.

Warning

In the literature, is not always clear whether measured concentrations refer only to the γ isomer or to the sum of the isomers.

LINDANE IN THE ENVIRONMENT

• Mobility

Lindane exhibits a low affinity for soil binding and may be mobile in soils that have especially low organic matter content.

• Degradation

Lindane is highly persistent in most soils, with a field half-life of approximately 15 months. When sprayed on the surface, its half-life is typically much shorter than when it is incorporated into the soil. It may pose a risk of groundwater contamination.

Lindane is very stable in both fresh- and saltwater environments, and it is resistant to photodegradation. It disappears from the water by secondary mechanisms such as adsorption on sediment, biological breakdown by microflora and fauna, and adsorption by fish through gills, skin and food.

• Degradation products

The main degradation products of lindane are γ-pentachlorocyclohexene, chlorobenzenes (tri-hexa) and chlorophenoles. It is not known to which level these metabolites can threaten the soil. It is known however, that in aerobic conditions chlorobenzenes are very persistent.

• Volatilization/evaporation

Not applicable.

• Bioaccumulation

Lindane moderately accumulates in water organisms.

• Phytotoxicity

Plants may pick up residues not only from direct application, but through the water and vapour phases. Persistence is seen when plants are rich in lipid content, and crops such as cauliflower and spinach build up less residue than crops such as carrots. The metabolism in plants is not well understood, but carrots are estimated to metabolize lindane, with a half-life of just over ten weeks (based on plant uptake) whereas it may have a half-life in lettuce of only three to four days.

PROPERTIES

Lindane is a white to yellow crystalline powder. In its original packing, it is stable for several years, but decomposes in the presence of iron, aluminium and zinc powder and water. Metals corrode if they come into contact with lindane. In alkaline environments, the compound is not stable.

TABLE W

Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	113	
Vapour pressure		mPa	5.6	
Density		g/cm	1.85	
Degradation	DT_{50}soil	Months	15	Very slightly degradable
Solubility	Solubility (water)	mg/l	7.3	Readily soluble
Mobility	Log K_{oc}		3.04	Moderately mobile
ADI		mg/kg/day	0.008	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	4 000	
	Consumption of vegetables	mg/kg dm soil	1	
	Consumption of drinking-water	µg/l	160	

Malathion

Common formulation

$C_{10}H_{19}O_6PS_2$

CAS registry number

121-75-5

Use

As an insecticide against many insects, including aphids, spider mites and scale insects, as well as large number of other insects which attack fruits, vegetables and stored products.

MALATHION IN THE ENVIRONMENT

- **Mobility**

Malathion moderately sorbs to the soil and is moderately mobile.

- **Degradation**

If malathion is released into soil, it is subject to significant biodegradation and hydrolysis. Biodegradation may be an important fate process, especially in soils at pH 7 where the rate of hydrolysis may be slow. Reported biodegradation half-lives in soils range from four to six days.

Malathion in water is subject to hydrolysis with a half-life range of 0.2 weeks at pH 8 to 21 weeks at pH 6.

- **Degradation products**

The major degradation products are malaothion, malathionbetamonoacid, diethyl malthe and malaoxon.

- **Volatilization/evaporation**

Expectations are that volatilization is of little importance.

- **Bioaccumulation**

In water, malathion is thought not to bioaccumulate significantly in aquatic organisms.

- **Phytotoxicity**

Not applicable.

PROPERTIES

Malathion is a clear amber liquid. It hydrolyses above pH 7 and below pH 5. It is stable in solution buffered to pH 5.26.

TABLE X
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	2.9	
Vapour pressure		mPa	5.3	
Density		g/cm^3	1.23	
Degradation	DT_{50}soil	Days	4–6	Readily degradable
Solubility	S_w	mg/1	145	Highly soluble
Mobility	Log K_{oc}		3	Moderately mobile
ADI		mg/kg/day	0.02	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	10 000	
	Consumption of vegetables	mg/kg dm soil	100	
	Consumption of drinking-water	µg/l	400	

Mancozeb

Common formulation

$[\text{-SCS.NHCH}_2\text{CH}_2\text{NHCS.S.Mn-}]_x\ (\text{Zn})_y$

CAS registry number

8018-01-7

Use

To protect many fruit, vegetable, nut and field crops against a wide range of fungal diseases

MANCOZEB IN THE ENVIRONMENT

• Mobility

Based on the adsorption coefficient, mancozeb is thought to be slightly mobile in soil.

• Degradation

Mancozeb is of low soil persistence, with a reported field half-life of one to seven days. Mancozeb rapidly and spontaneously degrades to ETU in the presence of water and oxygen. ETU may persist for longer, somewhere in the order of five to ten weeks. Because mancozeb is practically insoluble in water, it is unlikely to infiltrate groundwater. Mancozeb degrades in water, with a half-life of one to two days in slightly acidic to slightly alkaline conditions.

• Degradation products

The major mancozeb metabolite of toxicological significance is ethylenethiourena (ETU), with carbon disulfide as a minor metabolite. A metabolite of mancozeb has the potential to be mobile in soils.

• Volatilization/evaporation

Not applicable.

• Bioaccumulation

Because mancozeb hydrolyses rapidly, it does not bioconcentrate in aquatic organisms.

• Phytotoxicity

When used as directed, mancozeb is not poisonous to plants.

PROPERTIES

Mancozeb is a greyish-yellow powder that on heating decomposes at 150°C without melting.

TABLE Y
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	-	
Vapour pressure		mPa	Negligible	
Density		g/cm^3	Not found	
Degradation	DT_{50}soil	Days	6–15	Readily degradable
Solubility	S_w	mg/l	6	Moderately soluble
Mobility	Log K_{oc}		>3.3	Slightly mobile
ADI		mg/kg/day	0.05	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	25 000	
	Consumption of vegetables	mg/kg dm soil	25	
	Consumption of drinking-water	µg/l	1 000	

Mercuric chloride

Common formulation

Cl_2Hg

CAS registry number

7487-94-7

Use

To preserve wood and anatomical specimens, as an intensifier in photography and as an insecticide and fungicide in medication (antiseptic, disinfectant).

MERCURIC CHLORIDE IN THE ENVIRONMENT

- **Mobility**

Not applicable.

- **Degradation**

Inorganic forms of mercury (Hg) can be converted into organic forms by microbial action in the biosphere.

- **Degradation products**

The major degradation products are mercuric chloride (I) and organic forms of mercury.

- **Volatilization/evaporation**

Certain bacteria are capable of transforming mercuric ions into the volatile element mercury. In the volatile phase, it can be transported hundreds of kilometres.

- **Bioaccumulation**

Many organisms are capable of accumulating mercury from water.

- **Phytotoxicity**

Not applicable.

PROPERTIES

Mercuric chloride is a colourless crystalline powder. It is slightly volatile at normal temperatures. In sunlight, mercuric chloride may decompose in the presence of organic matter to metallic mercury.

TABLE Z

Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	277	
Vapour pressure		mPa	18.6	
Density		g/cm^3	5.32	
Degradation	DT_{50}soil	Days	n.a.	-
Solubility	S_w	mg/l	6 900	Highly soluble
Mobility	Log K_{oc}		n.a.	-
ADI		mg/kg/day	Not found	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil		
	Consumption of vegetables	mg/kg dm soil		
	Consumption of drinking-water	µg/l		

Methamidophos

Common formulation

$C_2H_8NO_2PS$

CAS registry number

10265-92-6

Use

As an insecticide for control of potatoes, pome fruits, stone fruits, citrus fruits, cotton, maize and other crops.

METHAMIDOPHOS IN THE ENVIRONMENT

- **Mobility**

Methamidophos is thought to be highly mobile in soil.

- **Degradation**

Methamidophos readily degrades in soil. Metabolic degradation takes place in sandy soils on a extremely small scale. It is higher in loamy sands and reaches the highest rate in silt loam.

- **Degradation products**

No data available.

- **Volatilization/evaporation**

Based on measured vapour pressure, methamidophos slowly volatilizes from dry soil surface and is thought to slowly volatilize from water (with a half-life for a model river of 91 years and for a model lake of 998 years).

- **Bioaccumulation**

The accumulation of methamidophos in aquatic organisms is not important.

- **Phytotoxicity**

Not applicable.

PROPERTIES

Methamidophos forms colourless crystals. It is stable at ambient temperatures but 50 percent is decomposed in 140 hours at 40 C. It is stable at pH 3–8, but hydrolysed in acids and alkalis, more rapidly at higher temperatures.

TABLE AA
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	44.5	
Vapour pressure		mPa	2.3	
Density		g/cm^3	1.5	
Degradation	DT$_{50}$soil	Days	N/f	Readily degradable
Solubility	S$_w$	mg/l	>2 000 000	Readily soluble
Mobility	Log K$_{oc}$		0.58	Highly mobile
ADI		mg/kg/day	4	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	2 000	
	Consumption of vegetables	mg/kg dm soil	1 000	
	Consumption of drinking-water	µg/l	80	

Mirex

Common formulation

$C_{10}Cl_{12}$

CAS registry number

2385-85-5

Use

As insecticide formerly used to control ants. It was also formerly employed as a fire-retardant additive in thermoplastic, thermosetting, elastomeric resin systems, paper paint, etc.

MIREX IN THE ENVIRONMENT

• Mobility

The K_{oc} value of mirex indicates that it will be immobile in most soils.

• Degradation

Mirex is a highly stable insecticide. For the most part mirex is resistant to biological and chemical degradation.

• Degradation products

Persistent compounds such as kepone, and monohydro- and dihydroderivatives of mirex have been identified as products of the extremely slow transformation of mirex.

• Volatilization/evaporation

Mirex does not leach into the soil profile and is predicted to volatilize only slowly.

• Bioaccumulation

On the base of log K_{ow} mirex is thought to accumulate significantly in organisms.

• Phytotoxicity

Not applicable.

PROPERTIES

Mirex forms snow-white crystals from benzene. It is a highly stable insecticide. It has also been employed as flame retardant.

TABLE BB
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	485	
Vapour pressure		mPa	3 × 10-7	
Density		g/cm^3	-	
Degradation	DT_{50}soil	Days	>180	Very slightly degradable
Solubility	S_w	mg/l	<0.1	Not soluble
Mobility	Log K_{oc}		7.3	Immobile
ADI		mg/kg/day	-	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil		
	Consumption of vegetables	mg/kg dm soil		
	Consumption of drinking-water	µg/l		

Monocrotophos

Common formulation

$C_7H_{14}NO_5P$

CAS registry number

6923-22-4

Use

As an insecticide and acaricide on cotton, potatoes, peanuts, etc.

MONOCROTOPHOS IN THE ENVIRONMENT

• Mobility

Monocrotophos is thought to have very high mobility in soil.

• Degradation

Degradation of monocrotophos depends strongly on the acidity of the soil. A DT_{50} of 96 days (pH 5), 66 days (pH 7) and 17 days (pH 9) was calculated.

• Degradation products

No data available.

• Volatilization/evaporation

Monocrotophos is thought not to volatilize from dry soil surface or from water surface.

• Bioaccumulation

In water, monocrotophos is thought not to bioaccumulate in aquatic organisms.

• Phytotoxicity

Not applicable.

PROPERTIES

Pure monocrotophos forms colourless, hygroscopic crystals. It decomposes at a temperature of greater than 38°C.

TABLE CC
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	54–55	
Vapour pressure		mPa	0.29	
Density		g/cm^3	1.22	
Degradation	DT_{50}soil	Days	96	Slightly degradable
Solubility	S_w	mg/l	1 × 10^6	Highly soluble
Mobility	Log K_{oc}		1.3	Mobile
ADI		mg/kg/day	0.0006	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	25	
	Consumption of vegetables	mg/kg dm soil	0.1	
	Consumption of drinking-water	µg/l	1	

Paraquat

Common formulation

$C_{12}H_{14}N_2$

CAS registry number

4685-14-7

Use

As a contact herbicide for weed control in grass seed crops and orchards; as a crop desiccant and defoliant on potato vines and cotton.

PARAQUAT IN THE ENVIRONMENT

• Mobility

The K_{oc} value for paraquat in soil is in the range 15 473–1 000 000. These high K_{oc} values indicate that paraquat is strongly bound and almost immobile in soil. Paraquat may also be adsorbed in soil by forming complexes with the humic and fulvic materials present in soil. Therefore, adsorption of paraquat to soil generally increases with an increase in the soil's clay and organic content.

• Degradation

If released into soil, paraquat slowly degrades due to biodegradation. This slow biodegradation is caused by the strong adsorption of paraquat to clay or organic matter in the soil.

Unadsorbed paraquat present in a water solution may biodegrade easily.

Paraquat is completely removed from most surface waters within 8–12 days. Such removal is mainly due to sorbtion to suspended solids and sediment in water.

The hydrolysis of paraquat in the water of soil at neutral pH and acidic pH is not an important loss process.

- **Degradation products**

The major product of paraquat degradation is paraquat chloride.

- **Volatilization/evaporation**

Expectations are that volatilization is of little importance.

- **Bioaccumulation**

In water, paraquat is thought not to bioaccumulate in aquatic organisms.

- **Phytotoxicity**

Not applicable.

PROPERTIES

Paraquat dichloride forms colourless crystals decomposing at 300°C. Salts are stable in neutral and acid media but are oxidised under alkaline conditions.

TABLE DD
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	-	
Vapour pressure		mPa	Negligible	
Density		g/cm^3	1.24	
Degradation	DT_{50}soil	Days	1 000	Very slightly degradable
Solubility	S_w	mg/l	-	Readily soluble
Mobility	Log K_{oc}		1.1	Slightly mobile
ADI		mg/kg/day	0.004	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	2 000	
	Consumption of vegetables	mg/kg dm soil	1 000	
	Consumption of drinking-water	µg/l	80	

Parathion

Common formulation

$C_{10}H_{14}NO_5PS$

CAS registry number

58-38-2

Use

As an insecticide for wheat and nuts.

PARATHION IN THE ENVIRONMENT.

- **Mobility**

Parathion strongly adsorbs to soil and exhibits low mobility in soil.

- **Degradation**

Parathion degrades in soil within several weeks by biological and chemical processes. Degradation is faster in flooded soils. Parathion can be subject to photodegradation. The active metabolite paraxon (which is the product of photodegradation) is more toxic than parathion. The rate of degradation of parathion increases with increasing pH (in alkaline environments).

Adsorption to suspended particles and bottom sediments is the main removal process in open water. Parathion usually disappears within a week. The half-life for photodegradation of parathion in water is one to ten days.

- **Degradation products**

The degradation products of parathion are p-nitrophenol and diethylthiophosphoric acid.

- **Volatilization/evaporation**

No data available.

- **Bioaccumulation**

Not applicable.

- **Phytotoxicity**

Not applicable.

PROPERTIES

Pure parathion is a pale yellow liquid. It is stable at normal temperatures.

TABLE EE
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	6	
Vapour pressure		mPa	0.89	
Density		g/cm^3	1.26	
Degradation	DT_{50}soil	Weeks	1	Readily degradable
Solubility	S_w	mg/l	11	Readily soluble
Mobility	Log K_{oc}		3.5	Slightly mobile
ADI		mg/kg/day	0.005	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	2 500	
	Consumption of vegetables	mg/kg dm soil	3	
	Consumption of drinking-water	µg/l	100	

Parathion-methyl

Common formulation

$C_8H_{10}NO_5PS$

CAS registry number

298-00-0

Use

As an insecticide for rice, fruit and vegetables.

PARATHION-METHYL IN THE ENVIRONMENT

- **Mobility**

Parathion-methyl is thought to be moderately mobile in soil. Adsorption does not appear to be correlated with the organic content of soil, but the clay content of soil may be important.

- **Degradation**

Parathion-methyl degrades in soil and water as a result of biological and chemical processes. Loss from soil is primarily due to biodegradation (half-life is ten days to two months). Degradation increases with an increase in temperature and with exposure to sunlight. The major exception is for spills, where degradation occurs only after many years.

The primary process employed to remove the compound from water is biodegradation and photolysis. Within a period of two to four weeks, 100 percent degradation takes place. The hydrolysis occurs (5–11 percent in four days) in rivers and more slowly in marine systems. Parathion-methyl degrades by direct photolysis in natural water (half-life eight days summer, 38 days winter).

- **Degradation**

No data available.

- **Degradation products**

No data available.

- **Volatilization/evaporation**

Volatilization and evaporation are thought not be a significant transport process.

- **Bioaccumulation**

Based on the octanol-water partition coefficient, parathion-methyl is thought to accumulate moderately in aquatic organisms.

- **Phytotoxicity**

Not applicable.

PROPERTIES

Parathion-methyl is a white to tan solid. It is not very stable in storage. It undergoes rapid hydrolysis in alkali but hydrolyses slowly in weak acid.

TABLE FF
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	37–38	
Vapour pressure		mPa	1.3	
Density		g/cm^3	1.4	
Degradation	DT_{50}soil		10–60	Fairly degradable
Solubility	S_w	mg/l	n.a.	
Mobility	Log K_{oc}		1–2.6	Mobile to moderately mobile
ADI		mg/kg/day	0.02	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	10 000	
	Consumption of vegetables	mg/kg dm soil	3	
	Consumption of drinking-water	µg/l	400	

Pentachlorophenol

Common formulation

C_6HCl_5O

CAS registry number

87-86-5

Use

Was used as herbicide, algaecide, defoliant, wood preservative and fungicide.

PENTACHLOROPHENOL IN THE ENVIRONMENT

- **Mobility**

Pentachlorophenol has the tendency to adsorb to soil and is slightly mobile in soil. Adsorption to soil increases with an increase in the environment's acidity.

- **Degradation**

Pentachlorophenol biodegrades in both aerobic and anaerobic environments. Aerobic degradation was found to be more rapid than anaerobic degradation. Pentachlorophenol does not appear to oxidize or hydrolyse under environmental conditions; however, photolysis of the dissociated form in water may be an important process.

The loss of pentachlorophenol from a water surface depends on the temperature and pH. A half-life of 328 hours and of 32 120 hours has been reported at pH 5 and pH 6, respectively.

- **Degradation products**

Terachlorphenol is a major metabolite of pentachlorophenol.

- **Volatilization/evaporation**

Pentachlorophenol is thought not to volatilize from dry soil surfaces, based on a vapour pressure of 1.1×10^{-4} mmHg.

- **Bioaccumulation**

Pentachlorophenol is thought to accumulate in aquatic organisms.

- **Phytotoxicity**

Not applicable.

PROPERTIES

Pentachlorophenol is a colourless to white solid. It is stable at normal temperatures. At temperatures above 200°C it produces traces of octachlorodibenzo-para-dioxin.

TABLE GG
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	188–191	
Vapour pressure		mPa	Negligible	
Density		g/cm^3	1.98	
Degradation	DT_{50}soil	Weeks	Several weeks/months	Degradable
Solubility	S_w	mg/l	14	Readily soluble
Mobility	Log K_{OC}		3.1–4.4	Slightly to hardly mobile
ADI		mg/kg/day	0.03	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	15 000	
	Consumption of vegetables	mg/kg dm soil	20	
	Consumption of drinking-water	µg/l	600	

Phosphamidon

Common formulation

$C_{10}H_{19}Cl\ NO_5P$

CAS registry number

13171-21-6

Use

As an insecticide for citrus and cotton crops, fruit and nut crops, and rice.

PHOSPHAMIDON IN THE ENVIRONMENT

• Mobility

Phosphamidon is thought to have a great mobility in soil.

• Degradation

Phosphamidon biodegrades in soil, with a half-life of several days or several weeks depending on soil characterisation. Phosphamidon is stable in neutral and weakly acid solutions but is rapidly hydrolysed in alkaline solutions.

• Degradation products

The products of phosphamidon degradation are dimethyl phosphate and alpha-chloroacetoacetic acid diethylamide.

- **Volatilization/evaporation**

Phosphamidon is thought not to volatilize.

- **Bioaccumulation**

Based on the low octanol-water coefficient, phosphamidon does not accumulate in aquatic organisms. Its bioconcentration is also unlikely because it is rapidly metabolized in animals.

- **Phytotoxicity**

Not applicable.

PROPERTIES

Pure phosphamidon is a yellow liquid. The mix of phosphamidon isomers is stable in neutral and acid media and is subject to hydrolysis in an alkaline environment. It decomposes above 160°C.

TABLE HH
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	-45	
Vapour pressure		mPa	3.3	
Density		g/cm^3	1.21	
Degradation	DT_{50}soil	Days	21-32	Fairly degradable
Solubility	S_w	mg/l		Miscible with water
Mobility	Log K_{OC}		0.9	Highly mobile
ADI		mg/kg/day	0.0005	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	250	
	Consumption of vegetables	mg/kg dm soil	0.1	
	Consumption of drinking-water	µg/l	10	

Propoxur

Common formulation

$C_{11}H_{15}NO_3$

CAS registry number

114-26-1

Use

As an insecticide with rapid knock-down.

PROPOXUR IN THE ENVIRONMENT

• Mobility

Propoxur does not adsorb to the soil strongly.

• Degradation

Propoxur is biodegradable. Biodegradation half-lives of 44–59 days have been reported. The biodegradation rate increases in soils previously exposed to methylcarbonate. The half-life decreases to as little as 19 days under aerobic conditions, following the addition of glucose and peptone. It is subject to hydrolysis, especially in alkaline environments. The hydrolysis half-life at pH 8 has been estimated at 16 days. In sandy soils, 75 percent of the propoxur was degraded within 100 days, while no loss occurred in that same period in muck and silty loam soils. In these soils, the propoxur persisted for more than six months.

Propoxur is readily degradable in water. Particularly in the presence of humic material, it is subject to relatively rapid photolysis (half-life 13–88 hours).

• Degradation products

The main product of propoxur degradation is 2-isopropoxyphenol.

• Volatilization/evaporation

Expectations are that volatilization is of little importance.

• Bioaccumulation

In water, propoxur is thought not to bioaccumulate in aquatic organisms.

• Phytotoxicity

Not applicable.

PROPERTIES

Propoxur forms colourless crystals. It is unstable in highly alkaline media.

TABLE II
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	91	
Vapour pressure		mPa	1.3	
Density		g/cm^3	Not found	
Degradation	DT_{50}soil	Days	44–59	Fairly degradable
Solubility	S_w	mg/l	1.9	Moderately soluble
Mobility	Log K_{OC}		Not found	
ADI		mg/kg/day	0.02	

Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	10 000	
	Consumption of vegetables	mg/kg dm soil	1	
	Consumption of drinking-water	µg/l	400	

Toxaphene

Common formulation

$C_{10}H_{10}Cl_8$

CAS registry number

8001-35-2

Use

As insecticide for crops, fruits and nuts and agricultural premises.

TOXAPHENE IN THE ENVIRONMENT

• Mobility

A reported K_{OC} of 2.1 × 10+5 indicates that toxaphene will adsorb very strongly to soils and sediments. It is not expected to be mobile.

• Degradation

Toxaphene is extremely persistent. When released to soil, it will persist for long periods (1 to 14 years). Biodegradation may be enhanced by anaerobic conditions. Toxaphene released in water will not appreciably hydrolyse, photolyse, or significantly biodegrade.

• Degradation products

No data available.

• Volatilization/evaporation

Evaporation from soils and surfaces will be a significant process for toxaphene. The half-life of approximately six hours is estimated for the evaporation of toxaphene from rivers. Toxaphene may undergo extremely slow direct photolysis in the atmosphere. It can be transported long distances in the air (1 200 km), probably adsorbed to particular matter.

• Bioaccumulation

Toxaphene will accumulate very strongly in aquatic organisms.

- **Phytotoxicity**

Not applicable.

PROPERTIES

Toxaphene is a mixture of chlorinated camphenes that occur as a waxy amber solid. When heated to decomposition, it emits toxic fumes of hydrochloric acid and other chlorinated compounds. Toxaphene is available as wettable powder, emulsifiable concentrate, dust, granule, oil and emulsion.

TABLE JJ
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	65–90	
Vapour pressure		mmHg	0.4	
Density		g/cm^3	1.65	
Degradation	DT_{50}soil	Years	>14	Very slightly degradable
Solubility	S_w	mg/l	3	Moderately soluble
Mobility	Log K_{OC}		5.3	Immobile
ADI		mg/kg/day	Not found	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil		
	Consumption of vegetables	mg/kg dm soil		
	Consumption of drinking-water	µg/l		

2, 4, 5-T

Common formulation

$C_8H_5Cl_3O_3$

CAS registry number

93-76-5

Use

As a growth regulator to increase the size of citrus fruits and reduce the excessive drop of deciduous fruits.

2, 4, 5-T IN THE ENVIRONMENT

- **Mobility**

The adsorption coefficient values the indicate that 2, 4, 5-T mobility in soil varies from highly mobile in sandy soil, to moderately mobile in clay and silty loams, to slightly mobile in muck.

- **Degradation**

The persistence of 2, 4, 5-T in soil is reported to be 14–300 days, but usually does not exceed one full growing season regardless of the application rate. Degradation under anaerobic conditions in flooded soils is much slower than in moist soils. Chemical hydrolysis in moist soils is thought not to be important.

The dominant removal mechanisms of 2, 4, 5-T from water are photodegradation and biodegradation. The half-life of photolysis of the compound from the surface water has been calculated at 15 days.

- **Degradation products**

The degradation products are trichlorophenol and trichloranisole.

- **Volatilization/evaporation**

Based on the low vapour-pressure of 2, 4, 5-T, volatilization is thought to be not significant.

- **Bioaccumulation**

2, 4, 5-T moderately accumulates in aquatic organisms.

- **Phytotoxicity**

Not applicable.

PROPERTIES

2, 4, 5-T is a colourless to tan solid. It is stable up to its melting point. Temperatures above 158°C may cause sealed metal containers to burst.

TABLE KK
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	153	
Vapour pressure		mPa	Negligible	
Density		g/cm^3	1.8	
Degradation	DT_{50}soil	Days	14–300	Degradable
Solubility	S_w	mg/l	268	Highly soluble
Mobility	Log K_{OC}		1.9–2.4	Mobile to slightly mobile
ADI		mg/kg/day	0.03	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	15 000	
	Consumption of vegetables	mg/kg/dm soil	1	
	Consumption of drinking-water	µg/l	600	

Warfarin

Common formulation

$C_{19}H_{16}O_4$

CAS registry number

81-81-2

Use

To control rats in and around houses, animal and agricultural premises, etc.

WARFARIN IN THE ENVIRONMENT

- **Mobility**

No experimental data could be found for the adsorption of warfarin to soil. The estimated log K_{oc} indicates moderate adsorption to soil.

- **Degradation**

No data available.

- **Degradation products**

No data available

- **Volatilization/evaporation**

Volatilization is thought not to be a significant transport process.

- **Bioaccumulation**

Based on the estimated octanol-water partition coefficient, warfarin is thought to accumulate moderately in aquatic organisms.

- **Phytotoxicity** Not applicable.

PROPERTIES

Warfarin is a white powder. It is very stable, even in the presence of strong acids.

TABLE LL

Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	161	
Vapour pressure		mPa	n.a.	
Density		g/cm^3		
Degradation	DT_{50}soil	Days	1 000	Very slightly degradable
Solubility	S_w	Mg/l	1.7	Moderately soluble
Mobility	Log K_{oc}		2.7	Moderately mobile
ADI		mg/kg/day	Not found	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil		
	Consumption of vegetables	mg/kg dm soil		
	Consumption of drinking-water	µg/l		

APPENDIX 4
Fact sheets on chemical compounds

Crocidolite (asbestos)

Common formulation

$Na_{20}Fe_2O_3$. 3FeO. *SiO_2. H_2O

CAS registry number

12001-28-4

Use

Crocidolite — together with anthophyllite and actinolite — belongs to the group of asbestos. It is used as an inert filler medium, a reinforcing material in vinyl and asphalt flooring products (former use), fire- and rot-resistant material in felts, raw material for asbestos-based paper, a component of industrial talcs, etc.

CROCIDOLITE IN THE ENVIRONMENT

- **Mobility**

It appears that asbestos does not have an adsorptive affinity for solids.

- **Degradation**

Asbestos is considered to be non-biodegradable by aquatic organisms. As a mineral it is not affected by photolytic processes.

- **Degradation products**

No data available.

- **Volatilization/evaporation**

Not volatile.

- **Bioaccumulation**

No evidence has been found regarding the bioaccumulation of asbestos in aquatic organisms.

- **Phytotoxicity**

Not applicable.

PROPERTIES

Asbestos forms a blue fibre. It does not burn or rot and possesses extremely high tensile strength as well as resistance to acids, alkalis and heat.

TABLE A

Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	n.a.	
Vapour pressure		mPa	n.a.	
Density		g/cm^3	3.3–3.4	
Degradation	DT$_{50}$soil	Days	n.a.	
Solubility	S$_w$	Mg/l	<0.1	Not soluble
Mobility	Log K$_{oc}$		n.a.	
ADI		mg/kg/day	Not found	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil		
	Consumption of vegetables	mg/kg dm soil		
	Consumption of drinking-water	µg/l		

1,2-dibromoethane

Common formulation

$C_2H_4Br_2$

CAS registry number

106-93-4

Use

Formerly used as an insecticide, fumigant and nematicide.

1,2-DIBROMOETHANE IN THE ENVIRONMENT

• Mobility

1,2-dibromoethane exhibits moderate adsorption to soil.

• Degradation

1,2-dibromoethane biodegrades fairly readily in the environment. Its half-life can be as short as several days in surface soils and as long as many months in aquifer materials. Persistence can vary greatly from soil to soil. An experimental half-life ranging from 1.5 to 18 weeks has been determined. The long persistence was observed in one field where dibromoethane was detected 19 years after the last known application. This long persistence was a result of its entrapment in intraparticle micropores of the soil. In groundwaters 1,2-dibromoethane can be degraded by biodegradation and hydrolysis. Uncatalysed hydrolysis is slow (half-life six years) but hydrolysis catalysed by the presence of various natural substances may be competitive with biodegradation (half-life one to two months). 1,2-dibromoethane is removed from water primarily by evaporation.

- **Degradation products**

The major degradation product of 1,2-dibromoethane is 2-bromoethanol.

- **Volatilization/evaporation**

Based on its vapour pressure, 1,2-dibromoethane is thought to volatilize. The volatilization half-life in rivers and lakes is about 1 day and 5 days, respectively. In the atmosphere, 1,2-dibromoethane degrades photochemically (half-life 32 days).

- **Bioaccumulation**

Based on the low log K_{ow} (of 1.96) 1,2-dibromoethane is thought not to accumulate in aquatic organisms.

- **Phytotoxicity**

Not applicable.

PROPERTIES

1,2-dibromoethane is a colourless liquid or solid.

TABLE B
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	9.8	
Vapour pressure		mmHg	11	
Density		g/cm^3	2.7	
Degradation	DT_{50}soil	Years	10–350	Degradable
Solubility	S_w	mg/l	34	Readily soluble
Mobility	Log K_{oc}		2	Moderately mobile
ADI		mg/kg/day	1	
Permissible Concentrations	Human			
	Direct contact	mg/kg dm soil	50 000	
	Consumption of vegetables	mg/kg dm soil	500	
	Consumption of drinking-water	µg/l	20 000	

Polybrominated biphenyls (PBBs)

Common formulation

$C_{12}H_4Br_6$

CAS registry number

67774-32-7

Use

Polybrominated biphenyls are manufactured substances used as a pesticide to control a variety of harmful pests that attack many field crops and vegetables.

POLYBROMINATED BIPHENYLS IN THE ENVIRONMENT

- **Mobility**

PBBs bind moderately to soil and do not leach out easily.

- **Degradation**

Natural chemical reactions and bacteria may remove PBBs from soil and water. PBBs take about seven days to break down in water. In soil, they take about 3.5 to 290 days for half of them to break down, depending on soil type, moisture, and temperature.

- **Degradation products**

No data currently available.

- **Volatilization/evaporation**

No data currently available.

- **Bioaccumulation**

PBBs will accumulate in aquatic organisms.

- **Phytotoxicity**

No data currently available.

PROPERTIES

Polybrominated biphenyl is a colourless oil.

TABLE C
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	n.a.	
Vapour pressure		mPa	n.a.	
Density		g/cm³	n.a.	
Degradation	DT_{50}soil	Days	3.5–290	Very slightly degradable
Solubility	S_W	mg/l	n.a.	
Mobility	Log K_{oc}		n.a.	
ADI		mg/kg/day	9.00E-5	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	45	
	Consumption of vegetables	mg/kg dm soil	6	
	Consumption of drinking-water	µg/l	1.8	

Polychlorinated biphenyls (PCBs)

CAS registry number

1336-36-3

Use

Formerly as hydraulic fluids, plasticiser in synthetic resins, adhesives, heat transfer systems, wax extenders, pesticide extenders, inks, etc.

PCBS IN THE ENVIRONMENT

• Mobility

If released into soil, PCBs experience tight adsorption with adsorption generally increasing with the degree of chlorination of the PCB. They generally do not leach significantly in aqueous soil systems; the higher chlorinated congeners have a lower tendency to leach than the lower chlorinated congeners. In the presence of organic solvents, PCBs may leach quite rapidly through soil.

• Degradation

PCBs are mixtures of different congeners of chlorobiphenyl, and the relative importance of the environmental fate mechanisms generally depends on the degree of chlorination. In general, the persistence of PCBs increases with an increase in the degree of chlorination. Mono-, di- and trichlorinated biphenyls biodegrade relatively rapidly, tetrachlorinated biphenyls biodegrade slowly, and higher chlorinated biphenyls are resistant to biodegradation. Although the biodegradation of higher chlorinated congeners may occur very slowly on an environmental basis, no other degradation mechanisms have been shown to be important in natural water and soil systems; therefore, biodegradation may be the ultimate degradation process in water and soil. When released into water, adsorption to sediment and suspended matter is an important fate process; PCB concentrations in sediment and suspended matter have been shown to be greater than in the associated water column. Although adsorption can immobilize PCBs (especially the higher chlorinated congeners) for relatively long periods of time, eventual re-solution into the water column has been shown to occur. The PCB composition in the water is enriched by the lower chlorinated PCBs because of their greater water solubility, and the least water soluble PCBs (highest chlorine content) remain adsorbed. In the absence of adsorption, PCBs volatilize from water relatively rapidly. However, strong PCB adsorption to sediment significantly competes with volatilization, with the higher chlorinated PCBs having a longer half-life than the lower chlorinated PCBs. Although the resulting volatilization rate may be low, the total loss by volatilization over time may be significant because of the persistence and stability of the PCBs.

- **Degradation products**

Polychlorinated biphenyls degrade into less-chlorinated PCBs.

- **Volatilization/evaporation**

Vapour loss of PCBs from soil surfaces appears to be an important fate mechanism, with the rate of volatilization decreasing with increasing chlorination. Although the volatilization rate may be low, the total loss by volatilization over time may be significant because of the persistence and stability of PCBs. Enrichment of the low-chlorine PCBs occurs in the vapour phase relative to the original Aroclor; the residue is enriched in the PCBs containing high chlorine content. The dominant atmospheric transformation process is probably the vapourphase reaction with hydroxyl radicals, which have estimated half-lives ranging from 12.9 days for monochlorobiphenyl to 1.31 years for heptachlorobiphenyl.

- **Bioaccumulation**

PCBs have been shown to bioconcentrate significantly in aquatic organisms. Average log BCFs of 3.26 to 5.27, reported for various congeners in aquatic organisms, show increasing accumulation with the more highly chlorinated congeners.

- **Phytotoxicity**

Not applicable.

TABLE D
Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	-	
Vapour pressure		mPa		
Density		g/cm^3		
Degradation	DT_{50}soil	Years		Very slightly degradable
Solubility	S_w	mg/l	<0.1	Not soluble
Mobility	Log K_{OC}		>3.4	Slightly mobile
ADI		mg/kg/day	9.00E-5	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil	45	
	Consumption of vegetables	mg/kg dm soil	6	
	Consumption of drinking-water	µg/l	1.8	

Tris (2, 3-dibromo-1-propyl) phosphate

Common formulation

$C_9H_{15}Br_6O_4P$

CAS registry number

126-72-7

Use

Recommended for use in phenolic resins, paints, paper coatings and rubber (former uses). Rigid foams containing tris (2,3-dibromopropyl) phosphate are used in insulation, water flotation devices and furniture.

TRIS (2, 3-DIBROMO-1-PROPYL) PHOSPHATE IN THE ENVIRONMENT

- **Mobility**

A log K_{oc} value of 3.2 indicates that tris (2,3-dibromo-1-propyl) phosphate is immobilized in soil due to strong adsorption.

- **Degradation**

The biodegradation of tris occurs in activated sludge. A biodegradation half-life of 19.7 hours was obtained for tris in a laboratory-activated sludge system. No data are available regarding biodegradation in natural soils or waters. The hydrolysis and photolysis of tris is thought to be not important.

- **Degradation products**

No data available.

- **Volatilization/evaporation**

No data concerning the volatilization from water or soil are available.

- **Bioaccumulation**

Based on octanol-water partition coefficient, tris is thought to accumulate moderately in aquatic organisms.

- **Phytotoxicity**

Not applicable.

PROPERTIES

Tris (2,3-dibromopropyl) phosphate is a yellow liquid. It does not hydrolyse and is stable up to about 200°C.

TABLE E

Parameters

Property	Parameter	Unit	Value	Conclusion
Melting point		°C	5.5	
Vapour pressure		mPa	Negligible	
Density		g/cm^3	2.27	
Degradation	DT_{50}soil	Years	n.a.	
Solubility	S_w	mg/l	8	Moderately soluble
Mobility	Log K_{oc}		3.29	Slightly mobile
ADI		mg/kg/day	Not found	
Permissible Concentrations	Human:			
	Direct contact	mg/kg dm soil		
	Consumption of vegetables	mg/kg dm soil		
	Consumption of drinking-water	µg/l		

APPENDIX 5
Determining which pesticides are relevant

QUANTITY

Amounts less than 0.1 m^3 or 100 kg are considered too small to have caused serious contamination because it is assumed that such quantities can only contaminate limited amounts of soil or groundwater and that this contamination, because of dilution, will never reach concentrations that are high enough to cause health impacts. The amount has been chosen arbitrarily and more on an empirical than a scientific basis.

DEGRADATION RATE

The rate of degradation of pesticides is often expressed as *half-life* (DT_{50}), expressed in years, months or days. Every pesticide has its own half-life value. After this period only half of the original amount of pesticide is left, the other half having been degraded away. Degradation occurs because of biological organisms (bacteria, fungi) and by physicochemical interactions.

The rate of degradation of various pesticides is influenced by external factors such as temperature, light and soil acidity. As a rule, degradation of a compound is considered complete after a period of five times the half-life of that compound. Consequently, a pesticides spill will not lead to soil contamination if the age of the spill exceeds five times the half-life of the pesticides.

A DT_{50} value of one-half year for soil will be used as the criterion for assessing whether or not a pesticide is relevant in causing contamination. Only those pesticides with a DT_{50} value of one-half year or less will be considered relevant. This value is also used in Appendix 3.

For a pesticide with a half-life of a six months or less, the risk of soil becoming contaminated only exists for a period of 2.5 years after the release of the pesticide. After this period, the pesticide will have been degraded. In this way, a differentiation is made between pesticide spills that are more urgent because of the low degradation of the pesticide, and those that are less urgent because the pesticides concerned are subject to fast degradation.

APPENDIX 6
Determining distribution by wind

Table A presents the assumptions used for the calculations in the wind distribution model (see Figure, p.13).

TABLE A

Parameter	Assumptions
Emissions from the store	Diffuse, through natural ventilation only
Average wind velocity	4 m/year
Concentration of pesticides in store	1 000 mg/m^3
Emission rates	25; 12.5; 2.5 kg/h for open, moderately open and closed stores, respectively
Distribution model	Gaussic plume model (short term deposition)
Atmosphere stability	Neutral
Diameter pesticides particles	Moderately fine (80%d<4um; 17%4<d<10 um; 3% d>10 um)
Emission frequency	Every day throughout the year

The model does have its limitations. The fact that the calculations are carried out for the worst-case parameters means that the maximum emission and maximum distance are calculated to the effect that the long-distance calculations will be overestimates, and the short-distance calculations will be underestimates.

APPENDIX 7

Parameters for determining pesticide concentration in groundwater

INPUT PARAMETERS

A

surface area of building(s) with leaking tanks inside (m^2)

D

thickness of aquifer (m)

I

hydraulic gradient of the groundwater (dimensionless)

K

hydraulic conductivity of the aquifer (m/day)

log K_{OC}

partitioning coefficient between water and organic carbon

M

amount of pesticide leaked from tanks (kg)

R

annual rainfall (m/year)

Q

discharge of well, spring or river (m^3/year)

S

water solubility of the pesticide (kg/m^3)

T

time since tanks started leaking (years)

V

water volume of lake, reservoir or pond (m^3)

x

measured distance from storage facility to vulnerable object (m)

OUTPUT PARAMETERS

a

constant (dimensionless)

C_0

concentration in soil moisture at storage facility (kg/m^3)

C_l

concentration in groundwater at storage facility (kg/m^3)

C_g

concentration in well, spring or river (kg/m^3)

C_s

concentration in lake, reservoir or pond (kg/m^3)

d relative distance from store to vulnerable object (dimensionless)

f_g

dispersion factor for groundwater (dimensionless)

f_s

dispersion factor for surface water (dimensionless)

L

annual load of pesticide (kg/year)

mg

mixing factor for groundwater (dimensionless)

ms

mixing factor for surface water (dimensionless)

q

specific groundwater discharge (m/year)

r

retardation factor (dimensionless)

s

horizontal distance travelled by the centre of mass of the dispersion front (m)

Be sure to use the correct dimensions!

APPENDIX 8
Determining permissible concentrations

The calculations of permissible concentrations for direct contact are based on a daily intake of 2 mg of soil particles per kilograms body weight. Consequently, the maximum permissible levels, expressed in mg/kg soil (assuming no additional background exposure), are the TDI × 1 000/2 if the TDI is expressed in mg/kg body weight/day.

To calculate the maximum permissible levels of pesticides for a vegetable garden, the amount of contaminated vegetables ingested and the concentration of the pesticide in the edible parts of the plant must be considered. The quantity ingested depends on the daily ingestion of vegetables and the amount of vegetables growing at the contaminated site. It is assumed that all vegetables consumed come from a contaminated site. The quantity ingested on a daily basis is estimated to be 180 g leafy vegetables and tubers for adults of 60 kg.

The concentration of the contaminant in plants can be estimated using the rate of transfer between the soil and the plant — the Bio Concentration Factor (BCF). The BCF can be calculated on the basis of the log K_{OW} of the relevant chemical, and soil parameters such as the percentage of humus and the porosity of the soil defining the concentration in pure water. For these calculations various mathematical models can be used. The model selected for this manual was the Mackay model for the calculation of ground water concentrations, and the estimation of the BCF by the model was based on the data of Ryan et al., as presented by the HESP and Csoil model.

The critical concentrations can then be calculated by defining the concentration of the pesticides in soil, giving a concentration in vegetables and tubers that will lead to a daily intake of the contaminant equal to the ADI. The maximum permissible concentration (C) in tubers or vegetables is ADI/ consumption, the latter being 3 g/kg/day. The ADI needs to be expressed in mg/kg/day. The maximum permissible concentration in groundwater (Cgr max) is then C/BCF. Since C is expressed in mg/kg the Cgr max is also presented in mg/L. The Csoil max can then be calculated from Cgr max under equilibrium conditions.

An example has been worked out in Table A.

TABLE A

	ADI[µg/kg.d]	BCF for tubers	BCF of leafy vegetables	Premissible exposure level for contaminated soils in which vegetables and tubers are grown [mg/kg soil]
DDE	20	780	3.3	8
DDT	20	1 700	1.9	-*
a-HCH	1	31	5.7	0.1
b-HCH	0.02	31	5.7	0.2**
Endrin	0.1	200	5.8	0.2

* No critical concentration thanks to the maximum solubility of DDT in water.

** Data indicate maximum permissible concentrations in mg/L for groundwater; for soil, the concentrations are at detection limits.

APPENDIX 9
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