

# Experimental determination of important factors for pesticide behaviour in soil and water

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## Abstract

Field monitoring samples of surface and groundwater show a large variety of contemporary and obsolete pesticides, with a frequency of detection depending on the frequency and amount of application. Modern pesticides have a tendency to be less chlorinated due to toxicological aspects. In a study of binding properties of 10 contemporary pesticides, 6 out of 10 were chlorinated. In a study of DDT in groundwater it was shown that the solubility of DDT increased with increasing concentration of humic acid when the pH of the samples was low (adjusted to about 5.5). The effect fluctuates in the humic acid concentration range from 200 to 300 mg/l, in accordance with humic acid hydrophobicity, operationally measured as liquid surface tension. The findings correspond to trends previously reported in the literature. The trend of increasing solubility was not found using fulvic acid or low molecular weight aliphatic acids. No trend was found adding humic acid without adjusting the pH. The mechanism of enhanced solubility due to humic compounds can explain relatively high levels of DDT in groundwater. The groundwater samples, however, had a moderately high concentration of maximum 6 µg/l compared to a maximum of about 300 µg/l in the water samples with humic acid in pure water. For highly nonpolar compounds such as DDT and aclonifen, the binding depends mostly on the organic material in the filter medium, and specifically of the high molecular C and low O type organics. For more polar compounds the binding properties seem also to be linked to the number of H atoms in the pesticide structure. Studies of binding properties are very useful for targeting filter media in runoff systems. Predicting soil leaching, however, is an entirely more difficult exercise that so far has been relatively unsuccessful.

## Background

Generally there are a number of compound specific factors that influence the environmental behaviour of pesticides in water and soil (Bailey and White, 1970). These factors include 1) chemical character (molecular shape and configuration), 2) acidity or alkalinity defined by pKa or pKb, 3) water solubility, 4) charge distribution on the organic cation, 5) polarity, 6) molecular size and 7) polarisability. The properties of solid materials are of course also important. It is mainly the soil organic carbon that influences soil mobility through four important mechanisms. The mechanisms for the retention of organic chemicals by humic substances in soil include: (1) ion exchange, (2) hydrogen bonding, (3) van der Waals forces, and (4) co-ordination through an attached metal ion through ligand exchange (Stevenson, 1985). Assuming that a liquid-liquid partition-like interaction with dissolved high-molecular-weight organic matter is responsible for increasing apparent water solubility, a plot of the apparent water solubility versus dissolved organic matter (DOM) concentration should yield a straight line (Chiou *et al.*, 1986). The effect of the molecular size of selected humic materials on solubility enhancement appears to be secondary, presumably because their molecular weights are sufficiently large (Chiou *et al.*, 1987).

DDT consists mainly of the isomers pp'-DDT and op'-DDT. DDT is persistent in many parts of the environment. For example, in a study by Krapac *et al.* (1995), residues of DDT were found in the soil at more than one third of agrochemical facilities in Illinois, USA. Residues were detected at a mean concentration of about 40 µg/kg, and a maximum concentration of about 1,200 µg/kg, at least five years after DDT has been used at the facilities. The solubility of DDT in water is reported to be 1 to 5.5 µg/l (WHO, 1989; Wershaw *et al.*, 1969; Chiou *et al.*, 1986; Weil *et al.*, 1974). Organic matter can change the aqueous solubility of DDT in water and also the adsorption and desorption of DDT in soil. In a study by Chiou *et al.* (1986), the apparent water solubility of pp'-DDT increased from approximately 5 to 40 µg/l when the concentration of dissolved organic matter (DOM) in water increased from 0 to 100 µg/l. Another study showed that environmental factors, such as pH, calcium concentration, ionic strength, and concentration of organic matter influence the binding of DDT to humic materials (Carter and Suffet, 1982). Organic carbon from landfill leachate has the ability to form complexes with heavy metals such as Cd, Ni and Zn, and the distribution coefficients have been reported reduced with a factor of 2 to 6 in the presence of dissolved organic carbon (Christensen *et al.*, 1996). Adding of DOM for enhancing soil cleanup procedures has been proposed, relating the concentration of DOM in water to a change in adsorption-desorption characteristics (Rebhun *et al.*, 1996).

The content of DOM in water varies in natural environments. For example, typical concentration of dissolved organic carbon (DOC) in groundwater is reported to range from 0.2 to 0.7 mg/l, of which humic substances constitutes 0.04 to 0.1 mg/l, and in groundwater associated with petroleum up to 100 mg/l (Thurman, 1985). Examples of environments with high contents of DOM are peat soils, sediments containing hydrocarbons, and leachate from waste.

Samples of pore water from peat soil in Norway typically have TOC values from 6 to 25 mg/l. Leachate from municipal solid waste has concentrations of TOC ranging from 10 to 10,000 mg/l, with an expected average of about 1,000 mg/l, and with extreme high values in the order of 200,000 mg/l, and with pH between 5 and 9 (Rowe, 1995; Robinson and Gronow, 1993; Haarstad & Mahlum, 1996). Typical values of TOC in leachate in Scandinavia are lower, from 150 to 400 µg/l, probably due to a high level of dilution from precipitation and infiltrating surface waters (Mæhllum and Haarstad, 1996). Leachate from columns filled with tree bark residues has TOC values of 100 to 1,000 mg/l. Organic waste degradation produces high values of fatty acids in the early degradation phase, while humic acids dominate later phases under anaerobic degradation. In an anaerobic environment microbes can use humic oxygen as an electronic acceptor lowering the content of oxygen in the humic substances, according to Thurman (1985). This can be beneficial since humic acids high in Carbon and low in Oxygen are more capable of organic nonpolar retention (Chiou *et al.* 1987).

We have studied results from monitoring programs in Norway, batch equilibrium experiments on 10 contemporary pesticides, and the concentration and solubility of DDT in local groundwater samples near two waste dumps with relatively large amounts (up to 3,000 mg/kg dry soil) of DDT in the soil. We also have measured the solubility of DDT in water samples with various concentrations of added DOM in the forms of humic and fulvic acids, as well as low molecular weight organic acids represented by a mixture of butyric and hexanoic acids, compounds representative for leachate from acidic phase waste degradation. We compared the solubility in pH-adjusted and non-adjusted mixtures of humic acid and DDT, to simulate a range of probable environments. The main objective of the laboratory experiments was to find important factors for K<sub>d</sub> variations and relatively simple and reproducible relations between pesticides and field environmental parameters, which can be helpful in evaluating actual field locations.

It is difficult to predict leaching of pesticides in soil. Simplified analyses such as those described by Beitz *et al.* (1994) predicting leachability risks if all the following mobility criteria are met: Water solubility >30 mg/l, K<sub>d</sub><5 (usually 1-2), (K<sub>oc</sub><300-500), Henry's K<10<sup>-3</sup> atm<sup>3</sup>/mol, negatively charged at ambient pH (low K<sub>a</sub>-values).

## Material and methods

Mobility and degradation, together with toxicity data, are standard parameters when the environmental behaviour of pesticides is evaluated. Data show, however, only a part of the picture, while field-monitoring shows another part. Surveillance data of pesticides in water samples have been collected from 1992 in Norway. Here pesticides that can be characterised as non-risky regularly are detected in both surface- and groundwater runoff. The effects of environmental concentrations are usually evaluated by some kind of concentration limit, see Table 1.

**Table 1. Examples of concentration limits in mg/l**

(MAC=maximum allowable concentration (can be based both on environmental effects (e.g. EC<sub>50</sub>/100), leaching model calculations or health effects), HA=health advisory limit, US EPA=Environmental Protection Agency, USA, WHO=World Health Organisation, FRG=Federal Republic of Germany, SSSR=Soviet Union)

The Norwegian Agriculture Inspection Service, 1996; USEPA, 1992; Beitz *et al.*, 1994.

USEPA =Maximum contaminant level or lifetime health advisory level (metribuzin), \*\* H=herbicide, F=fungicide, I=insecticide, nst=no standard

Pesticide	Type	Norwegian MAC	US EPA MAC (HA)	WHO MAC	FRG MAC	SSSR MAC
atrazine	H**	0.43	3	2	3	500
bentazone	H	53.5		30	10	
2,4 - D	H	14	70	30	10	100
dichloroprop	H	41			10	
glyphosate	H	12				100
mecoprop	H	52			10	2,000
metribuzin	H	0.22	(200)			
MCPA	H	50		2	1	2,000
diazinon	F	0.01				300
fenpropimorf	F	1.7				
iprodione	F	2.5				50
propiconazole	F	0.02				
thiabendazole	F	2.8				
lindane	I	1.6			3	3
DDT	I	0.004	nst			

Retention and degradation in soil or filter media could be one way to counteract leaching.

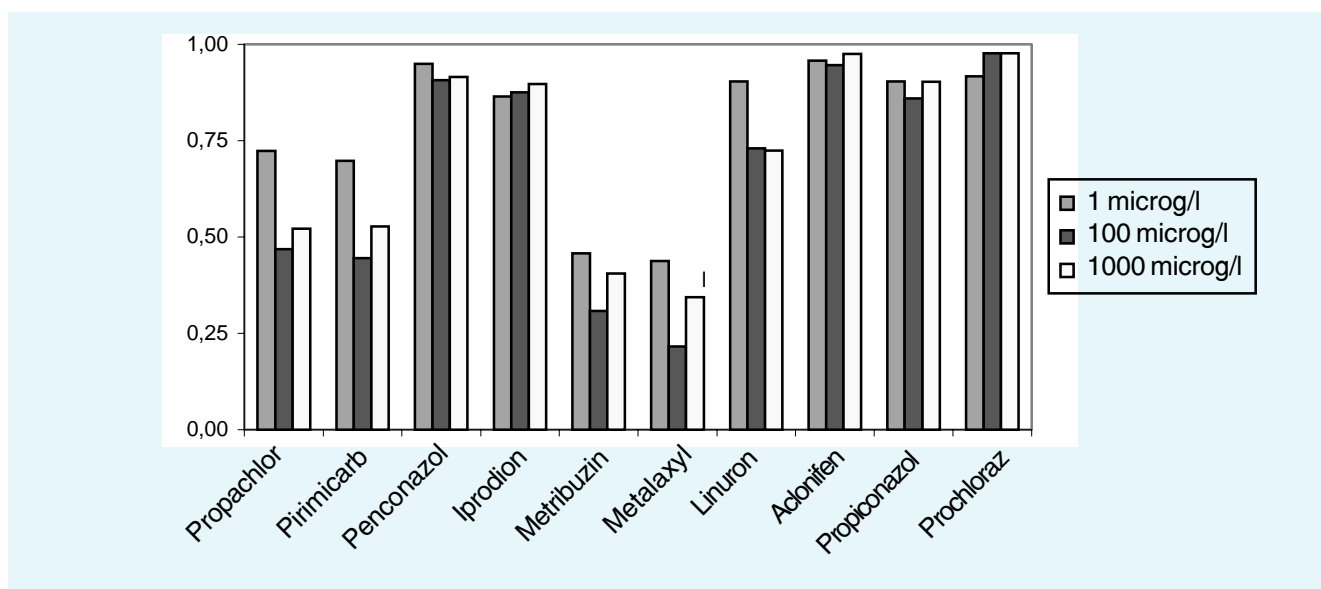
Laboratory batch studies on binding properties were carried out with 10 typical pesticides from contemporary Norwegian agriculture. These were combined in three concentrations, 1, 100 and 1000  $\mu\text{g/l}$ , and with five organic filter media, and five soil/mineral filter media. The batch experiments were carried out according to the OECD test guidelines 106, with minor modifications.

The laboratory experiments studied the solubility of DDT by looking at how much could be remobilised with water qualities from different treatments, such as distilled water and groundwater mixed with DOM, from the walls of centrifuge bottles. Control samples (DDT in distilled water) showed that the DDT contained 78% pp'-DDT, 22% op'-DDT. Both pp'-DDD and pp'-DDE was below the detection limit ( $< 0.02 \mu\text{g/l}$ ). Technical DDT normally contains about 25% op'-DDT. Different solutions were prepared with the approximate concentrations of: (1) 50 mg humic acid, (2) 500 mg humic acid, (3) 50 mg fulvic acid, produced according to Thurman & Malcolm (1981) and available through International Humic Substances Society (IHSS), and (4) a mixture of 100 mg hexanoic and 100 mg butyric acid. According to Kile and Chiou (1989) there is a substantial decrease of solute-solubility enhancement by DOM at pH of 8.5 relative to that reported at pH values of 4.0-6.5 due to a decrease in the intensity of the nonpolar environment at elevated pH. A batch of samples with humic acid was adjusted to a pH of about 5.5 from the original pH of about 8. This is comparable to the pH measured in the field samples. Fulvic and fatty acids were adjusted with less than 1 ml 1 M NaOH from the original pH of about 4. Particulate humus in the water samples could influence the analyses of water-soluble DDT. However, no change in colour was visible after filtration through  $0.45 \mu\text{m}$  of the non-acidified samples with added humus. The acidified humic water samples were centrifuged with the intent of separating particulate humus, but it was not possible to separate the humus from the water samples in this way. Therefore the humus in these samples was thus assumed to be completely in solution.

All samples were analysed by gas chromatography at the Pesticide Laboratory of the Norwegian Crop Research Institute, according to internal method M03 (Holen and Svensen, 1994). Liquid surface tension was analysed on a Kruss no. 12/0014 at the Institute of Biotechnology at the Norwegian University of Agriculture. Statistical differences were tested in pairs or groups with JMP (SAS Institute Inc.).

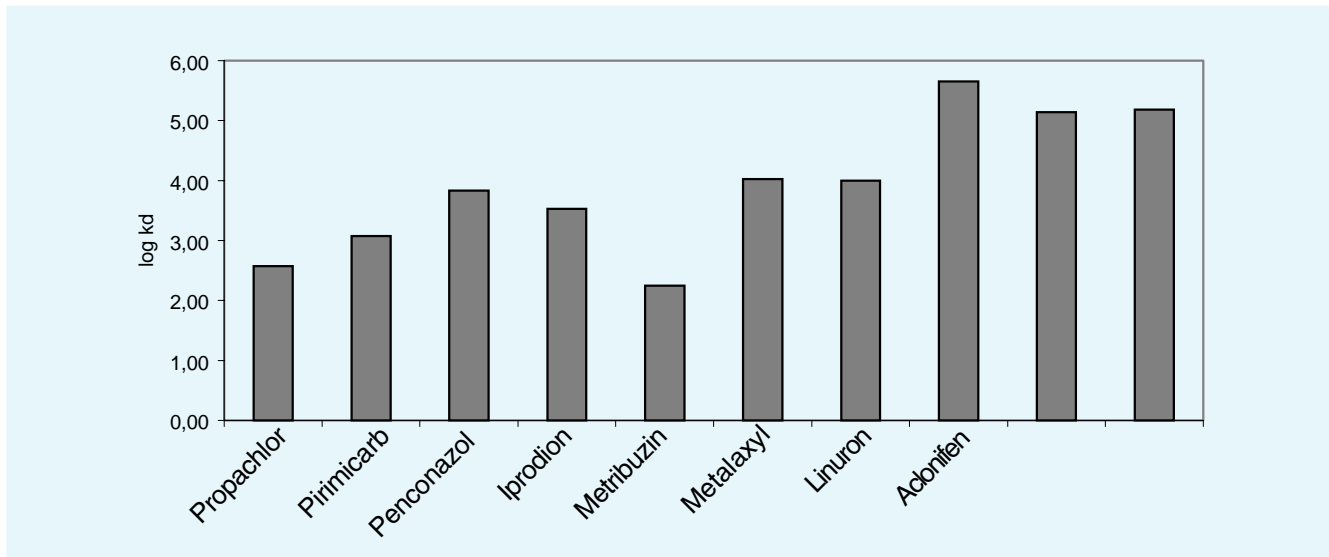
## Results and discussion

Figure 1 shows that the removal of pesticides from solution in batch experiments was effective for six of the ten compounds, in the concentration range 1 to 1,000  $\mu\text{g/l}$ .

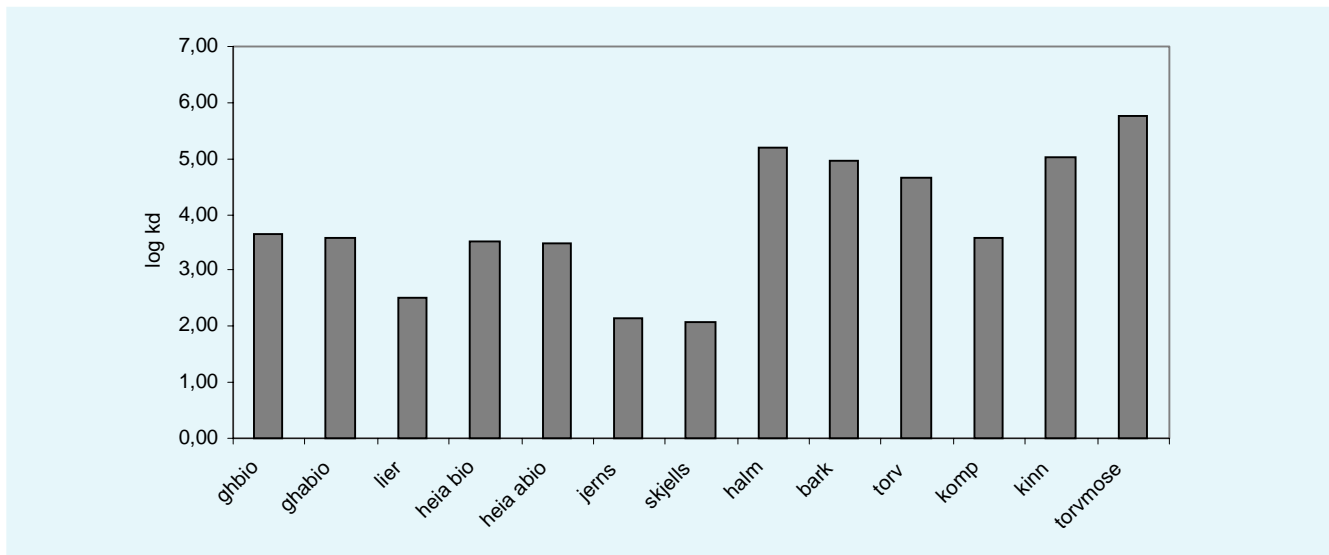


**Figure 1. Mean reduction of pesticide concentration in eight filter materials.**

The mean partition expressed as  $K_d$ -values for the different pesticides and filter media are shown in Figures 2 to 3. The three pesticides aclonifen, propiconazol and prochloraz showed a very high partitioning, while the more water-soluble herbicides (metribuzin and metalaxyl) showed lower partition, as expected.



**Figure 2. Mean partitioning (equals the log of the means of the partition coefficient) for compounds.**

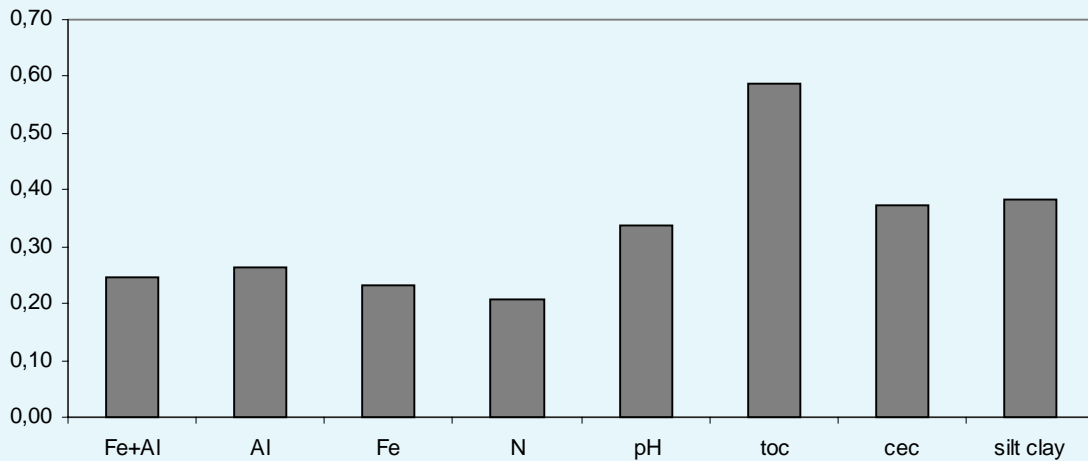


**Figure 3. Mean partitioning (equals the log of the means of the partition coefficient) for filter media.**

(ghbio=clay soil, biological active, ghabio=clay soil sterilised, lier=clay soil, heia =organic soil, jerns=iron rich sand, skjells=carboniferous shell sand, halm=straw, bark=tree bark residues, torv=peat material, komp=compost, kinn=organic soil, tormose=fresh peat plants)

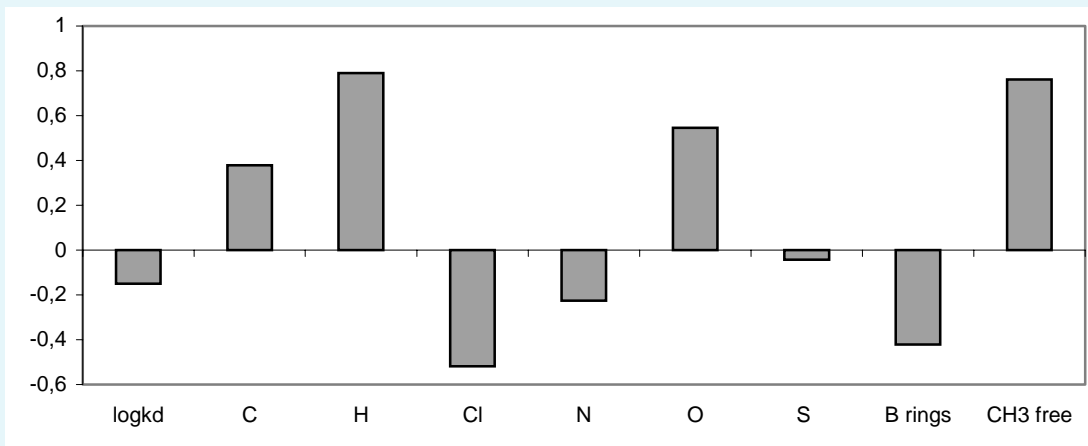
The most effective filter media for pesticide removal were organic rich material such as fresh peat, straw, bark and peat.

The variation in binding properties ( $K_d$ ) correlated highly with lipid partitioning ( $K_{ow}$ ,  $r=0.71$ ), but showed little correlation to water solubility ( $r=-0.15$ ). The correlation between  $K_{ow}$  and water solubility was  $r=-0.31$ .



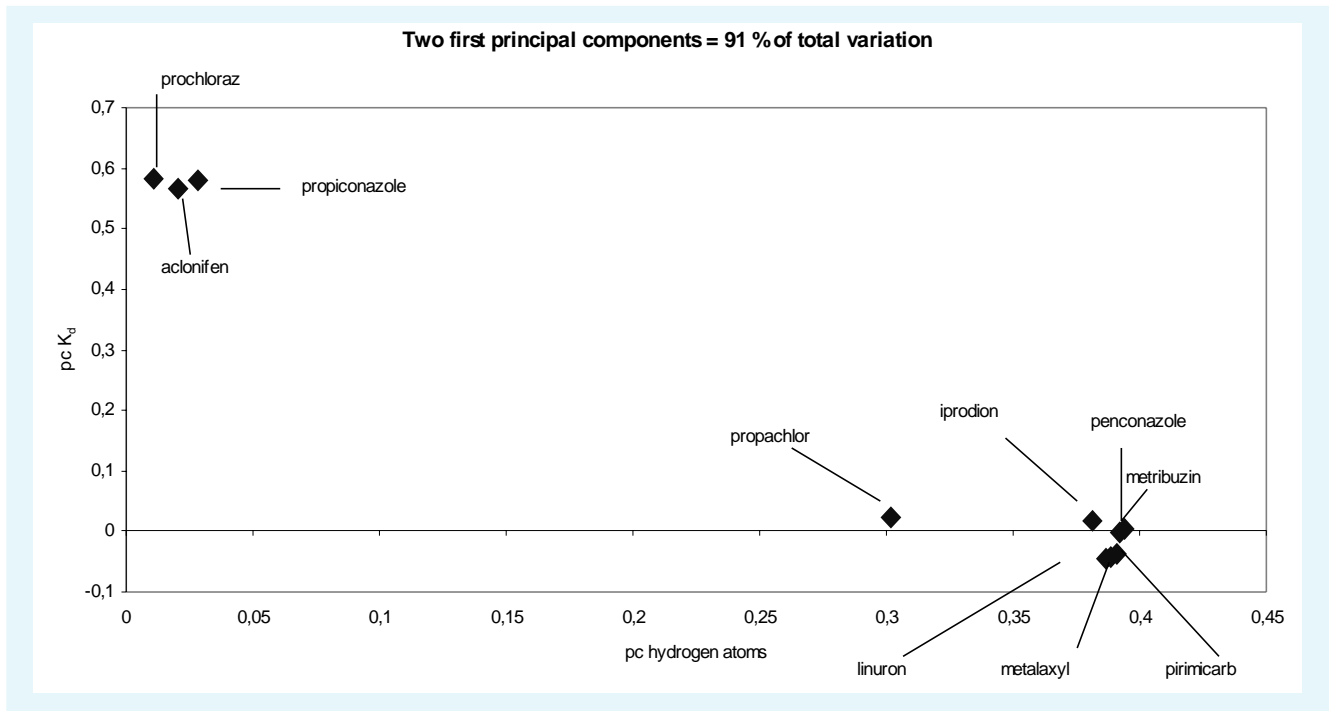
**Figure 4. Correlation between measured characteristics in filter media and Kd variation.**

Figure 4 shows that TOC explained most of the variation in Kd values, followed by silt and clay content, cation exchange capacity and pH. A correlation analysis between Kd-values and chemical properties of the compounds showed that H atoms and free methyl groups were most important, see Figure 5.



**Figure 5. Correlation between water solubility of pesticides and chemical characteristics of the compounds.**

Propiconaz  
Prochloraz

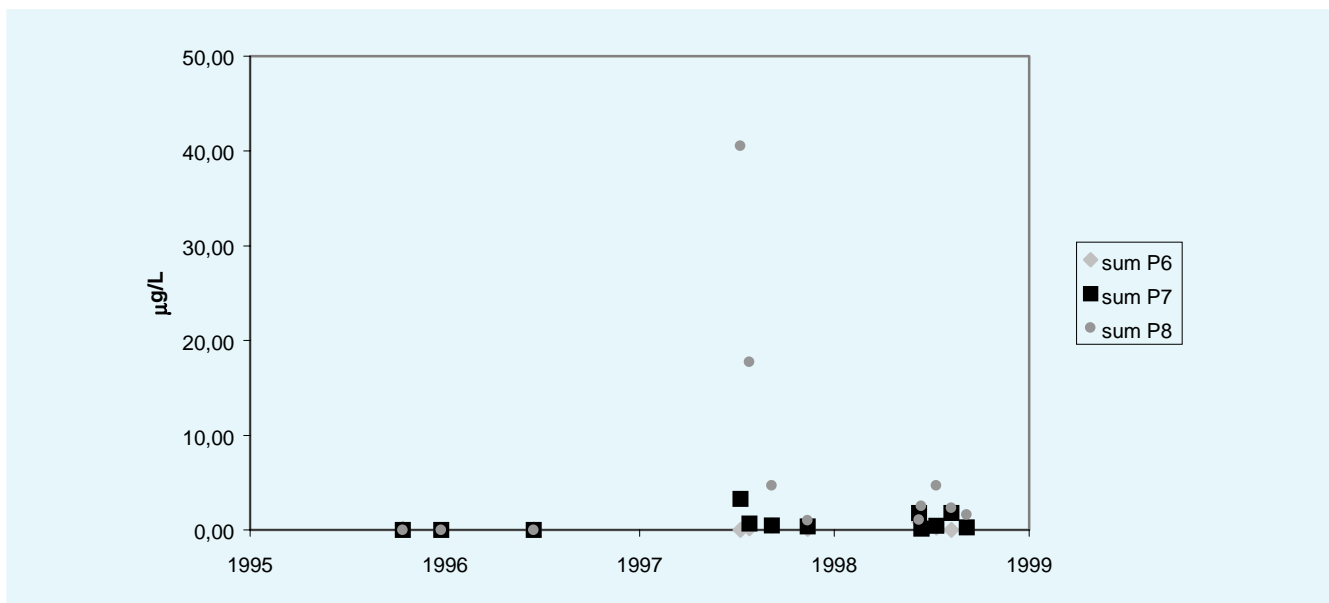


**Figure 6. Principal components in Kd variation**

Two principal components derived from a multivariable analysis explained more than 90% of the variation in binding properties, the Kd-values and the total number of H atoms in the pesticide chemical structure, as shown in Figure 6. It is not evaluated if these H atoms are in other chemical structures such as methyl groups etc.

### Field samples

Monitoring programs in Norway cover general agricultural areas, drinking water sources and more special locations such as tree nursery production sites. Figure 7 shows an example of a time series of pesticide concentration in shallow groundwater near agricultural fields, clearly showing an episode of leaching. The surveillance of pesticides in the Norwegian environment can be compared to the target concentrations in Table 1. It must be remembered, however, that the analytical programme has changed over time, and that many of the detected compounds have been removed from the list of compounds that can be sold legally.



**Figure 7. Total pesticide concentrations in shallow groundwater close to agricultural area.**

Groundwater from two field locations have been sampled and analysed for DDT over a period of more than 6 years. Figure 8 shows that DDT indeed can be mobilised to groundwater at concentrations that can be greater than DDT water solubility downstream a tree nursery production plant. We wanted to study factors that can influence this mobility. At location A, the DDT-polluted soil was buried in a depression in the local sandy soil and exposed directly to the groundwater at high water levels. Runoff water from the plant, including heated water with detergents, has also infiltrated the soil up to 1995 when the sewage outflow was connected to a pipeline. The polluted soil is also eroded by surface runoff. The landfill DDT has been estimated to be 200-1,000 kg (with 90% confidence). The groundwater from this location has typically low TOC and TDS values. The two groundwater sampling locations differ, in well 1 (A-W1) the water level is deeper (always more than 2 m below surface) and the maximum variation in water level is 0.7 m. At well 4 (A-W4) the minimum depth to the water level is only 0.2 m, and the maximum variation in water level is close to 2 m, due to excess infiltration of runoff water. Thus the probability for direct contact with soil polluted with DDT, and also for particle transport, is much greater in well 4, which has been described earlier (Haarstad, 1993).

At location B, the DDT-polluted soil, together with waste products from the tree nursery and some illegal dumping of municipal waste, was put on the top of a local sandy soil. The waste dump is underlain with boulders for drainage. The sand is partly covered with up to 1 m of natural humic topsoil. The groundwater level is 1.5-3 m below the bottom of the landfill. The groundwater from this location has TOC and TDS values significantly higher than location A. The mass of DDT in this landfill has been estimated to 600-1,200 kg (with 90% confidence). There was no top cover, and the DDT-polluted waste was infiltrated by precipitation with high oxygen content.

Particulate DDT was found in the groundwater at location A, well 4, but not at location B, well 3. The groundwater samples from location A had relatively high concentrations of DDT in the filtered particulate matter in contrast to location B, indicating that the transport at location B is due to soil water and groundwater mobility, while location A is more exposed to particle erosion and dislocation.

Sample A-W4 had almost 40% of DDE, indicating anoxic conditions at this sampling point (Haarstad, 1993). High groundwater levels have frequently occurred at this well, mainly because it is located in the low elevation of the site receiving sewage and storm water. DDT can degrade both chemically and biologically to DDE, by losing an HCl-molecule under aerobic conditions, and to DDD, by gaining H and losing Cl under anaerobic conditions (Abou-Donia and Menzel, 1968).

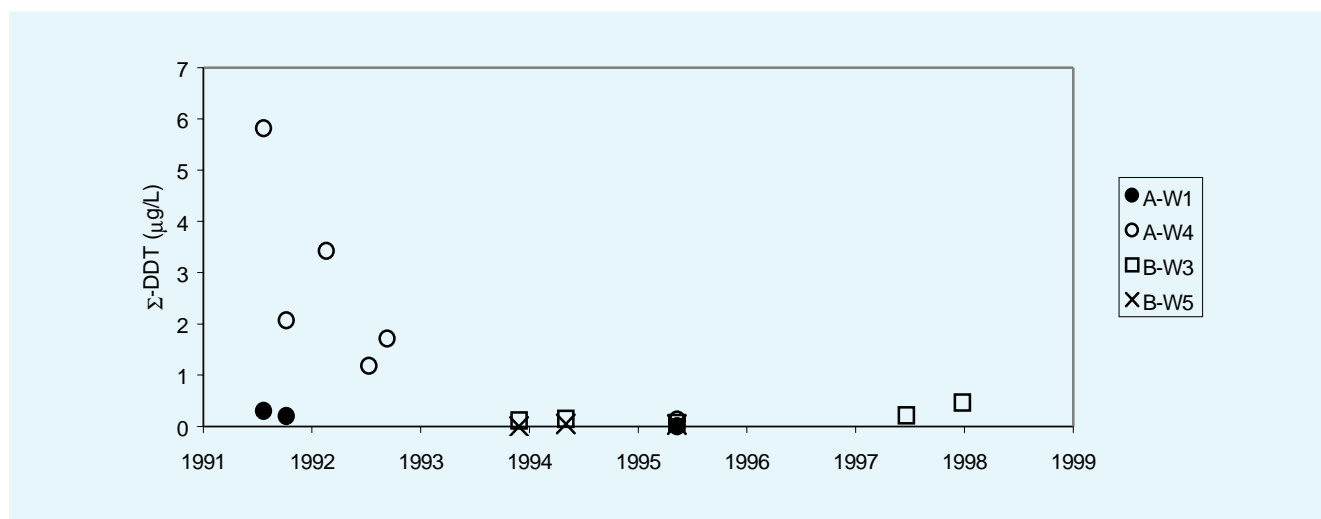
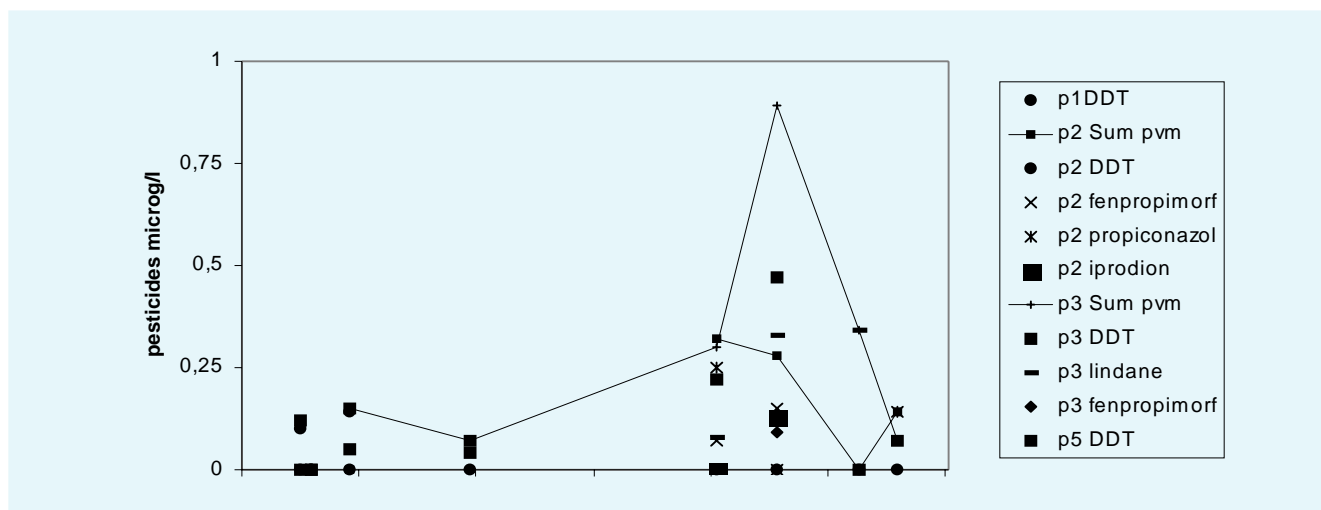


Figure 8. DDT in shallow groundwater at a nursery tree plant

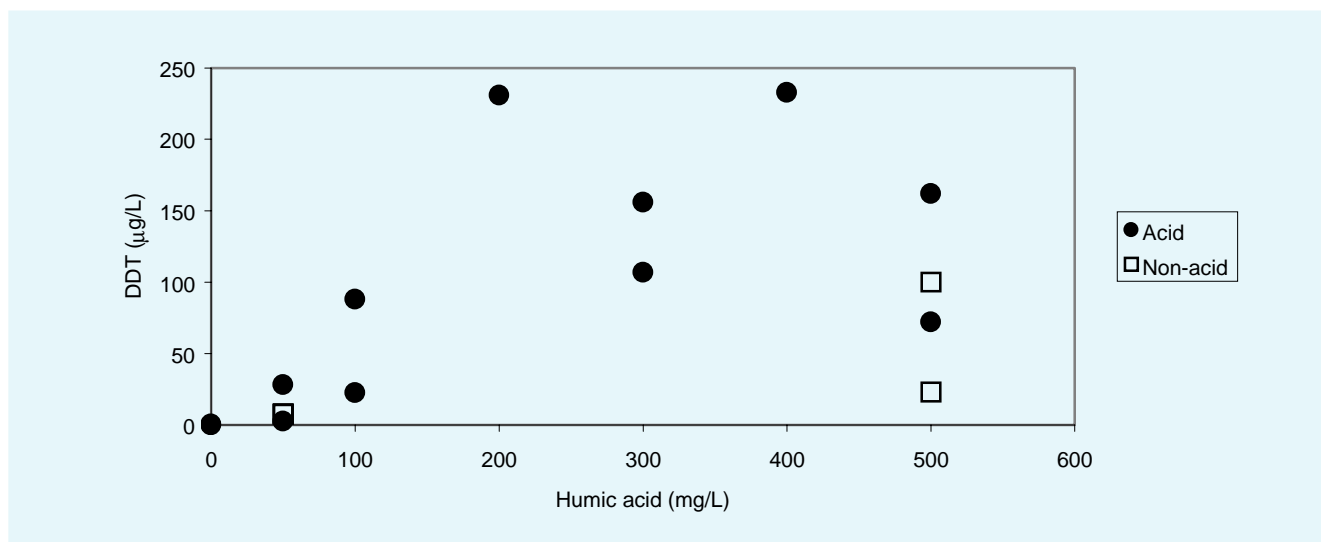
**Table 2. Pesticides (maximum concentrations) found in leachate or leachate-polluted groundwater at waste sites in the forest trees nurseries ( $\mu\text{g/l}$ )**

Pesticide	Max. C
fenvaterate	0.20
fenpropimorf	0.15
iprodion	0.13
lindane	3.31
propiconazole	0.25
tolyfluanid	1.80
DDT	5.00



**Figure 9. DDT and other pesticides in groundwater polluted with leachate from a tree nursery farm.**

Table 2 and Figure 9 show pesticides typical for tree nurseries.



**Figure 10. DDT and humic acid concentration in experiment.**



The results from the laboratory experiments show that there is a clear trend of increasing concentration of DDT with increasing concentration of humic acids, but this seems to level off between 200 and 400 mg/l humic acid concentration (Figure 10). There was no clear trend in DDT solubility in non-acidified samples with a pH of about 8. Excluding non-acidified samples, the two replicates with DDT and humic acids were not significantly different when tested as a difference between pairs (SAS Inst. 1995). There was no clear trend when adding fulvic acids or low molecular weight aliphatic acids such as butyric and hexanoic acids. Humic acids with high molecular weight and hydrophobicity are expected to have higher binding capacities to hydrophobic compounds than fulvic acids (Chiou *et al.*, 1986, Chiou *et al.*, 1987, Rebhun *et al.*, 1996). Colloidal DOM in the form of higher molecular weight humic acids generally has low charge densities, in contrast to the more soluble fulvic acids having higher anionic charge densities (Gregor *et al.*, 1997). We chose to use commercial DOM because it is easier to obtain for replicated studies than nature-derived acids. According to Malcolm and MacCarthy (1986) commercial humic acids are not appropriate for use as analogues of true soil and water humic substances. The degree of aromaticity of commercial humic acids, however, is only moderately dissimilar to most soil and water humic substances, and is relatively constant between batches. This will, however, influence the stability of the humic acid more than its solubility. According to Chiou *et al.*, 1987, the increased solubility enhancement of Aldrich and Fluka-Tridom humic acids compared to natural fresh water humic acids is strongly related to their high-carbon and low-oxygen contents, factors that greatly promote a partitionlike interaction with the non-ionic organic solutes.

We also observed the disappearance of *op'*-DDT from the acidified humic acid samples. It is well known that *pp'*-DDT can degrade to *pp'*-DDD or *pp'*-DDE in gas chromatographic analysis (Foreman and Gates, 1997). There is a reduced tendency to form hydrophobic microenvironments in humic acids at elevated pH, and the hydrophobic domains in the humic acid molecule are relatively unstructured (Engelbreton *et al.*, 1996). As the pH of a humic solution is lowered, and some of the charged sites are neutralised, a reduction in intramolecular repulsion is predicted (Engelbreton *et al.*, 1996). For illustrative purposes, the composition of functional groups in humic acids consists of about 43% total acidity, 11% carboxylic and 32% OH-phenolic in uncomposted organic material, and 41% total acidity, 17% carboxylic and 23% OH-phenolic in mature compost (Garcia *et al.*, 1991).

We measured liquid surface tension in our samples with and without adding HCl for pH-adjustment. There was a decreasing trend in hydrophobicity with increasing humic acid concentration in the acidified samples, as the surface tension is reduced by 13% from about 68 to 59. The decreasing trend ceased and may have approached a steady state at about 300 to 400 mg/l humic acid concentration, in accordance with the change in increasing DDT concentration.

The influence of dissolved H atoms in waters containing various amounts of dissolved humic acids, fulvic acids and other cosolutes over the range that may be encountered in an aquatic system was investigated (Wershaw *et al.*, 1969, Chiou *et al.*, 1986). But, as discussed in the introduction, certain environments can exhibit levels of TOC that are several orders of magnitude higher than 100 mg/l. These are environments such as municipal solid waste and other landfills, which are likely to contain hydrophobic organic compounds. In leachate from the methane fermentation stage with TOC of 675 mg/l, about 12% could be attributed to compounds with a molecular weight over 50,000 and 20% to compounds with a molecular weight between 1,000 and 50,000 (Harmsen, 1981). Solid waste degradation typically forms anaerobic environments that can produce humic substances high in carbon content and low in oxygen content that can be simulated by the elevated levels in commercial humic acids. Based on the present study and previous work, we believe that more work should be done to find the most important environmental factors and cosolutes that can influence the mobility of hydrophobic organic chemicals such as DDT with suspected high environmental or human toxicity. Long degradation times and unknown levels of mobility can lead to unexpected exposure and produce unacceptably high risks of contamination.

Prediction of pesticide leaching is difficult. The risk of leaching of the relevant pesticides in this report is listed in Table 3, based on simplified evaluations given by Börner (1994). Another set of simplified to more advanced calculations are shown in Table 4, showing relatively large discrepancy between methods.

**Table 3. Pesticide characteristics and leaching potentials \***

Pesticide	logK <sub>ow</sub>	pK <sub>a</sub>	Sol. (mg/l)	pol.	K <sub>d</sub> <5	Sol	K	H	pol
						leaching risk			
DDT	6.2		0.001	0		n	n	n	n
fenpropimorf	2.6	6.98	4.3	+		n		n	n
fenvalerat	5		<0.010		n	n	n	n	
iprodison	3		13		0	n	n	y	
lindane	3.7		7			n	n	n	
linuron	3		81		1	y	y	y	
aclonifen	4.4		1		0	n	n		
metalaxyl	1.8	<<0	8,400		3	y	y	y	y
metribuzin	1.6		1		2	n	n	y	
penconazole	3.7	1.51	73	-	0	y	n		y
pirimicarb	1.7	p <sub>kb</sub>	3,000	+	1	y	y	y	y
prochloraz	4.4	3.8	34	-	0	y	n	y	y
propakchor	2		613		1	y	y	n	
propiconazol	3.7	1.09	100	-	0	y	n		y

**Table 4. Disagreement + (in %) between risk assessments with different methods.**

Method	Method **				
	(i)	(ii)	(iii a)	(iii b)	(iv)
Risk class	(i)	0			
P. coeff.	(ii)	50	0		
Pest. low	(iii a)	50	33	0	
Pest. high	(iii b)	35	42	33	0
GUS	(iv)	41	52	57	39

+ Disagreement = (number of pairs of assessment with different outcome)/(total number of pairs of assessments)

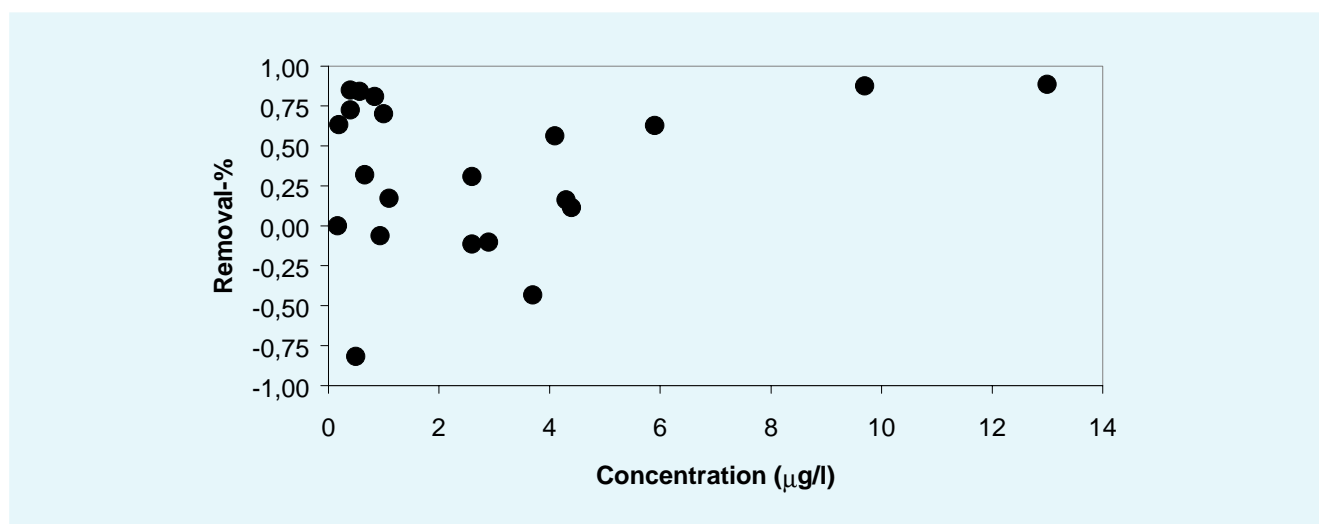
\*\* Method i=Risk class, ii=partition coefficient, iii a=pestan model with normal precipitation, iv=GUS index

Pesticides from point sources such as landfills are shown in Table 5, as results from grab samples over several years. The compounds include all groups of pesticides, and a range of mobility, and concentrations might be quite high. Studies have shown that pesticides decompose during waste degradation, except for organochloride insecticides (Büyüksönmez *et al.*, 1999).

**Table 5. Pesticides ( $\mu\text{g/l}$ ) found in MSW leachate samples in Norway**

Compound	B Oct. 97	B Oct. 98	B Sept. 99	E Oct. 97	E May 99	E Oct. 99	S Oct. 97	S Oct. 98	Type
fenpropimorph		0.04							F
tiabendazole				0.4					F
mecoprop	1.00	0.58	1.40	1.00	8.70	9.70	0.17	0.03	H
MCPA			1.50		0.35	0.84			H
dichloroprop	0.40	0.10	0.22	0.04	9.10	13.00	1.10	0.04	H
2,4-D		0.05	0.08	1.80	0.04	0.57			H
bentazone	0.50	0.41	0.87	0.56	5.60	5.90	1.00	0.18	H
chlopyralid					0.39				H
Sum pesticides	1.90	1.18	4.07	3.80	24.20	30.01	2.27	0.25	

\* B=Bolstad, E=Esval, S=Spillhaug Landfills



**Figure 11. Removal of pesticides from Bolstad (B) and Esval (E) landfill leachates.**

Figure 11 shows that for Norwegian conditions the removal of pesticides in aerobic leachate treatment systems is efficient when the pesticide concentration is above 5 mg/l. The removal starts to show large variations at lower concentrations.

## Conclusion

Environmental samples from Norway show pesticide concentrations from 0 to 70  $\mu\text{g/l}$  in river water, and 0 to 40  $\mu\text{g/l}$  in groundwater. The frequency of application is generally found also in the water samples.

Batch experiments show large variation in binding capacities but promising results for local remediation purposes for some compounds. The most important factor for pesticide partition is organic carbon measured as TOC. For highly nonpolar compounds such as DDT and aclonifen, the binding depends mostly on the organic material in the filter medium, and specifically of the high molecular C and low O type organics. This can be important e.g. in the application of composted or fermented soil conditioners that can have high contents of humic substances that can increase the risk for mobilisation of organochlorine compounds.

For more polar compounds the binding properties seem also to be linked to the number of H atoms in the pesticide structure.

The solubility of DDT in water increased with increasing concentration of added humic acid when the prepared samples were acidified from about pH 8.5 to 5.5. The trend corresponds to the previous results of other authors, but the levels of humic acid are higher in our experiment than in previous works. The solubility increased in groundwater samples with high natural TOC from waste dump conditions compared to those with commercial humic acid. Increasing solubility of DDT has not occurred with fulvic acids and fatty acids, such as in a mixture of butyric and hexanoic acid. No trends were found by adding humic acid without adjusting the pH. The mechanism of enhanced solubility has increased DDT concentration in water up to 300 µg/l. This can be a plausible explanation for the relatively high levels of DDT at 6 µg/l in groundwater found at one location with DDT polluted soil in Norway. The result shows that the mobility of DDT can be much higher than anticipated when the DDT residues are contacted by organic solutes found in a typical municipal landfill leachate. Such information can also be important when considering the recycling of treated organic waste product to agricultural soils, thus having different properties depending on the type of humus produced.

Strong partition for hydrophobic and nonpolar compounds is often improved for compounds high in organic carbon and low in molecular oxygen.

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