Risk assessment of Cd in mineral fertilisers in Norway using model calculations

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Summary:

The main purpose of the risk assessment is to assess the future risk from cadmium in mineral P-fertilisers to human health, soils and waters using model calculations. The risk assessment of Cd in mineral fertilisers has been performed according to procedures suggested by ERM (2000). The procedure consists of three modules: 1) The accumulation module; 2) The exposure module; 3) The risk characterisation module. Two scenarios for Cd in mineral P-fertilisers were used: 2.3 mg Cd kg^{-1} P_2O_5-(present level of Cd) and 60 mg Cd kg^{-1} P_2O_5 average EU-level).

In the accumulation module the future (in 100 years) concentration of Cd in soils was calculated using a mass balance model. Application of P-fertiliser containing 60 mg Cd kg^{-1} P_2O_5 increases the soil concentration of Cd by 16 to nearly 100 percent depending on type of crop and region.

In the exposure module, the uptake of Cd from the soil to wheat, potato and carrot is calculated as well as the relative contribution from fertilisers to the human uptake of Cd. The application of P-fertilisers containing 60 mg Cd kg^{-1} P_2O_5 in 100 years increase the daily intake of Cd by 76 percent i.e from 9.6 to 16.9 µg $person^{-1}$ day^{-1}. Applying mineral P-fertilisers for 100 years with the present average level of Cd (2.3 mg Cd kg^{-1} P_2O_5) increase the daily human intake by 4.3 percent.

Future application (100 years) of mineral P-fertilisers containing the present level of Cd (2.3 mg Cd kg^{-1} P_2O_5) results in minor changes in soil Cd concentrations. For human health the margin of safety (MOS) using fertiliser with this level of Cd is in the range 4-7 depending on the No (Lowest) Observable Adverse Effect Level (N(L)OAEL). Taking into consideration the uncertainties in the N(L)OAEL it seems advisable to keep the future application of Cd to soils from mineral P-fertilisers at as low level as possible. Using mineral P-fertilisers containing 60 mg Cd kg^{-1} P_2O_5 (EU level), MOS decreases by approximately 40%.

The level of no effect concentrations for organisms in Norwegian soils and waters are uncertain and the representativeness of the suggested PNEC values for Norwegian conditions questionable. The calculations performed indicate however that organisms in surface waters seem to be at higher risk from Cd in mineral P-fertilisers than soil living organisms

Head of Department	Project leader
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Hans Blom	Carl Einar Amundsen

Preface

It has been agreed within EU Member States that the risk assessment of Cd in phosphate fertilisers should be performed by determining their contribution to Cd build-up in arable soil and soil solution. Environmental Resource Management has proposed a programme for this risk assessment, which consist of three parts (ERM 2000):

Study 1 – establishment of detailed requirements for data and a data collection programme

Study 2 – establishment of procedures for carrying out a risk assessment

Study 3 – summary of the various risk assessments from different EU member states

In Norway the data necessary to perform this risk assessment (study 1) has been performed in 1998-99 and has been reported in two formerly published reports:

Singh, B.R. (project coordinator), Almås, Å., Amundsen, C.E., Meltzer, H.M. and Alexander, J. 1999. Cadmium in fertilisers; soil-plant system, environment and human health. Norwegian Agricultural Inspection Service, N-1430 Ås, Norway.

Amundsen, C.E. (project coordinator), Almås, Å. and Singh, B.R. 2000. Cadmium in soil, soil solution, and plants. Data as basis for risk assessment of Cd in mineral fertilisers. Centre for Soil and Environmental Research, N-1430 Ås, Norway.

The data gathered in these reports, together with the risk assessment procedure proposed by ERM (2000), make the basis for the assessment of the current and future risks from cadmium in inorganic phosphate fertilisers in Norway (present study; study 2).

The risk assessment was executed by

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Content

Summary

The main purpose of the risk assessment is to assess the future risk from cadmium in mineral P-fertilisers to human health, soils and waters.

The risk assessment of Cd in mineral fertilisers has been performed according to the procedures suggested by ERM (2000). The procedure consists of three modules:

1. The accumulation module
2. The exposure module
3. The risk characterisation module

In the accumulation module, the future (in 100 years) concentration of Cd in soils was calculated using a mass balance model. This model requires data for input of Cd to soils, removal through plant uptake and leaching. Two scenarios for Cd in mineral P-fertilisers were used: 2.3 mg Cd kg^{-1} P_2O_5 (present mean level of Cd in P-fertilisers) and 60 mg Cd kg^{-1} P_2O_5. Due to a lack of sufficient Norwegian data for the distribution of Cd between soil and soils solution, representative national and regional values for Cd in soils, algorithms for plant uptake, as well as representative data for the water balance in soils, the calculated future values for Cd in soils are uncertain. Application of mineral P-fertiliser containing 60 mg Cd kg^{-1} P_2O_5 increases soil concentration of Cd from 16 to nearly 100 percent depending on type of crop and agricultural region.

In the exposure module the uptake of Cd from the soil to wheat, potato and carrot is calculated as well as the relative contribution from fertilisers to the human uptake of Cd. The calculated uptake of Cd from soils is sensitive to plant-uptake algorithms used. The application of mineral P-fertilisers containing 60 mg Cd kg^{-1} P_2O_5 in 100 years increase the daily intake of Cd by 76 percent i.e from 9.6 to 16.9 µg $person^{-1}$ day^{-1}. This increase is much higher than when using mineral P-fertilisers with the present level of Cd (4.3 percent increase).

Future application (100 years) of mineral P-fertilisers containing the present level of Cd (2.3 mg Cd kg^{-1} P_2O_5) results in minor changes in soil Cd concentrations. For human health the margin of safety (MOS) using fertiliser with this level of Cd is in the range 4-7 depending on the No (Lowest) Observable Adverse Effect Level (N(L)OAEL). Taking into consideration the uncertainties in the N(L)OAEL it seems advisable to keep the future application of Cd to soils from mineral P-fertilisers at as low level as possible. Using mineral P-fertilisers containing 60 mg Cd kg^{-1} P_2O_5 (EU level), MOS decreases by approximately 40%.

The level of no effect concentrations for organisms in Norwegian soils and waters are uncertain and the representativeness of the suggested PNEC values for Norwegian conditions questionable. The calculations performed indicate however that organisms in surface waters seem to be at higher risk from Cd in mineral P-fertilisers than soil living organisms.

1. Introduction

1.1. General

This risk assessment of Cd in inorganic fertilisers is based on the procedure proposed by ERM (2000). The algorithms used and the principles for risk characterisation are taken from the proposed procedure of ERM. The procedure and algorithms are, however, adjusted to fit to typical Norwegian climatic conditions, agricultural practices, and available statistics on the production of agricultural crops.

The present and future risks from cadmium in inorganic phosphate fertilisers has been assessed for

- human health
- soils
- waters

The Cd balance in Norwegian soils is controlled by the differences in natural (from mineral weathering) and anthropogenic sources of Cd and by the variation of important soil properties like pH, content of clay and soil organic matter. Annual rainfall and air temperatures are important for the water balance in agricultural soils, and are some of the main factors controlling precipitation excess. Our knowledge about how input sources of Cd, soil and climatic conditions influence Cd adsorption, plant uptake of Cd and Cd leaching from soils make it necessary to take regional differences into account when performing the risk assessment.

Regional differences in input sources of Cd, soil properties and climatic conditions have been reported earlier (Amundsen *et al*. 2000).

1.2. Defined agricultural regions

Because of the differences between regions in soil and climatic conditions, agricultural practices vary considerably throughout the country.

The most important agricultural area in Norway is region 1 and 2 (Figure 1). This area accounts for 83% of the wheat, 60% of barley and 80% of the oat, and about 50% of the potato and carrot production in Norway (Table 1). Very little wheat is produced in region Region 3 and 4, were animal farms are much more dominating. The production of potato and carrot in region 3 and 4 accounted for 22 and 31 % of the total Norwegian production in 1996.

When it comes to green fodder and hay, regions 3 and 4 are more important. In general, animal farms are much more frequent in the western and northern parts of Norway.

Table 1: Percent distribution of agricultural crops produced in different regions in 1996 (SSB 1998)

Crop	Region 1	Region 2	Region 3	Region 4	Sum
Wheat	72.3	10.4	0.0	0.0	82.7
Barley	37.4	21.1	1.7	18.0	78.2
Oat	62.4	19.1	0.5	2.8	84.8
Potatoes	21.7	32.4	7.8	14.3	76.1
Carrot	29.8	18.4	17.4	13.8	79.4
Hay	4.6	6.3	15.2	21.9	47.9
Green fodder and silage	7.5	6.7	37.3	18.7	70.2

Since most soil properties and agricultural statistics are defined in databases that are defined by county the agricultural regions have been defined by applying county borders (Figure 1).

The production of wheat, potato and carrot, which are the agricultural crops most important for the risk assessment of Cd in mineral fertilisers for human health, the defined regions accounts for about 80% of the total Norwegian production. The rest (20%) is mainly produced in counties (Buskerud and Oppland) adjacent to region 1 and 2, areas which have similar soil properties, climatic conditions and rate of Cd input as these regions. Performing the risk assessment using data from the defined regions is assumed to give representative national numbers for the future human intake of Cd.

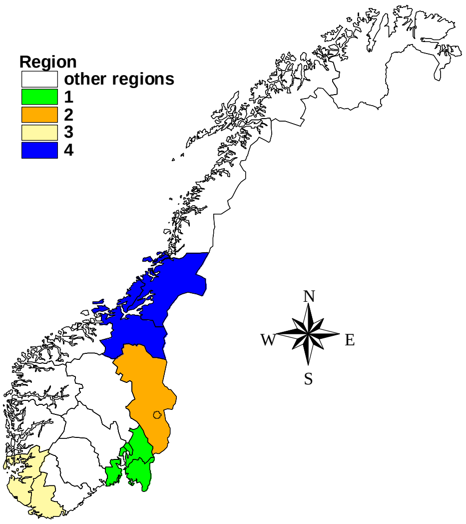

Figure 1: Agricultural regions used in the risk assessment of Cd in mineral phosphate fertilisers

Contrast between region 3 and other regions is not very distinct. It should be made to differentiate them.

1.3. Report structure

This report on the risk assessment of Cd in mineral phosphate fertilisers is divided in three sections:

1. **Accumulation module**: calculates the soil concentration of Cd (PEC) in the different regions in 100 years using two scenarios of Cd concentrations in mineral fertilisers.
2. **Exposure module**: the significance of soil Cd accumulation for plant uptake and subsequent intake by humans is evaluated.
3. **Risk characterisation**: Calculates risk factors (PEC/PNEC) for soil and water and margin of safety (MOS) for human health by comparing No (Lowest) Observed Adverse Effect Level ((N(L)OAEL) with predicted exposure.

2. The accumulation module

The aim of the accumulation module is to calculate the soil concentration of Cd in the different regions in 100 years using two scenarios of Cd concentrations in mineral P-fertilisers.

2.1. Input of Cd to agricultural soils, k_i

2.1.1. Atmospheric deposition

There are large regional differences in the atmospheric deposition of Cd in Norway (Berg et al. 1994; SFT 1999). The deposition in the southern parts of the country (region 1-3, Figure 1) are about five times the deposition levels in Region 4 and five to ten times the amounts deposited in northern Norway (SFT 2000).

Table 2: Atmospheric deposition of Cd (unit: g ha^{-1} year^{-1}) measured at air and precipitation monitoring stations in different regions in Norway (SFT 2000). Bulk precipitation collectors are used.

Region	Station	1991	1992	1993	1994	1995	1996	1997	1998	1999	Median 91-99
1	Nordmoen	0.42	0.31	0.37	0.41	0.32	0.33	0.41			0.37
2	Osen	0.17	0.35	0.46	0.32	0.43	0.18	0.15	0.22	0.32	0.32
3	Birkenes	0.71	0.5	0.75	0.7	0.67	0.66	0.38	0.66	0.76	0.67
3	Ualand		0.6		0.85	0.59	0.52	0.36	0.5	0.59	0.59
4	Kårvatn	0.19	0.09	0.14	0.3	0.21	0.15	0.14		0.24	0.17
Northern Norway	Øverbygd/Jergul	0.09	0.21	0.17	0.08	0.09	0.17	0.05	0.08	0.09	0.09
Average Norway											0.37

The atmospheric deposition of Cd has also been calculated using moss data (*Hylocomium splendens*) (Røyset 1996) (Table 3). The moss data are calculated using deposition estimators, which connects the concentration of Cd in moss (Steinnes *et al*. 1997) to the atmospheric deposition measured by bulk precipitation collectors. By using these deposition estimators the deposition of Cd to agricultural soil were calculated using data from the national moss surveys in 1995 which counts about 450 moss samples (Steinnes *et al*. 1997). The moss sampled in 1995 represents a mean value for Cd deposition for the period 1993-95.

Table 3: Calculated atmospheric deposition of Cd (unit: g ha^{-1} year^{-1}) based upon moss analyses (Røyset 1996).

Region	Mean	Median	Minimum	Maximum
1	1.24	1.21	0.82	1.70
2	0.67	0.74	0.27	0.91
3	0.79	0.73	0.48	1.27
4	0.22	0.21	0.16	0.35
Northern Norway	0.28	0.27	0.14	0.55
Average Norway	0.62	0.51	0.14	2.40

Input data for atmospheric deposition

The calculated deposition of Cd using moss data (Table 3) is higher than the median values for measured Cd deposition (Table 2). The measured deposition of Cd using bulk precipitation samplers gives the most accurate data for Cd deposition. But since the quality of deposition estimators for Cd has been shown to be good and the moss data give a far better area resolution than the deposition data, it was decided to use the mean values of precipitation measurements (Table 2) and moss predictions (Table 3) as input in the accumulation module (Table 4).

Table 4: Input of Cd from atmospheric deposition (unit: g ha^{-1} year^{-1}) used in the accumulation calculations

Region	g ha^{-1} year^{-1}
1	0.80
2	0.50
3	0.70
4	0.20
Northern Norway	0.20
Norway	0.50

2.1.2. Sewage sludge

The major wastewater treatment plants in Norway are located in the areas around the Oslofjorden (Region 1). Since 1974 when disposal of sewage sludge to sea was abandoned, the application of sewage sludge to agricultural soils has increased. In 1997 and 1998 the total annual production of sewage sludge in Norway was about 90 000 tons, of which about 53 000 tons were applied to agricultural soils (59 percent). The mean content of Cd in sewage sludge for 1997 was 0.9 mg Cd kg^{-1}, which gives 47 kg of Cd. Seventy percent of the sewage sludge that was applied to agricultural soils was produced and applied in region 1. Assuming that only those areas being used for grain production are amended with sewage sludge, the Cd addition through sewage sludge equals to 0.20 g Cd ha^{-1}.

2.1.3. Animal feed

The input of Cd through manure to agricultural soils is a sum of the Cd content in feed produced at the farm and the concentrated feed that is used as a supplement. A major fraction of Cd in the crop feeds produced at the farm will be a part of an internal Cd cycle and will not contribute to the increment of the Cd content in the soil. Because of this, the input of Cd only trough feed concentrates is used as input instead of manure (Table 5).

Table 5: Amount of Cd applied to agricultural soils through concentrated feed in 1996 (data from Amundsen et al. 2000).

	Region 1	Region 2	Region 3	Region 4	Average Norway
g Cd ha^{-1} year^{-1}	0.09	0.04	0.11	0.06	0.04

It is assumed that the amount of Cd from concentrated feed is distributed only on soils used for hay, green fodder and silage production.

2.1.4. Lime

Data from the Norwegian Agricultural Inspection Service (1998) show that the annual amount of Cd applied to agricultural soils equals 12.5 kg. This corresponds to about 0.02 g Cd ha^{-1}. This amount is assumed to be equal for all regions.

2.1.5. Mineral fertiliser

The calculations of Cd input through mineral fertilisers requires information about the amount of Cd pr. kg P_2O_5 in P-fertilisers (Table 6) and the amount of fertiliser used in the different crop rotation systems (Table 7).

Amount of Cd in mineral fertilisers

The amount of Cd in most mineral fertilisers used in Norway is generally low and the amount applied to agricultural soils is on average 0.10 g Cd ha^{-1} during the 1990ies (Table 6).

Table 6: Amount of Cd added to Norwegian agricultural soils in the period 1992-1998 (data from the Norwegian Agricultural Inspection Service 1998).

	1992	1993	1994	1995	1996	1997	1998
kg Cd year-1	191	128	95.2	102	79.9	55.6	72
g Cd ha-1 year-1	0.19	0.13	0.095	0.1	0.08	0.06	0.07

The numbers given in Table 6 is based upon information on the amount of Cd in different fertilisers and the application of these fertilisers in Norwegian agriculture.

In 1998/99, the application of P_2O_5 to agricultural soils in Norway was in the range of 30.000 tons. Using the data from Table 6, the present average content of Cd in mineral fertilisers is 2.3 mg Cd kg^{-1} P_2O_5.

In the risk assessment of Cd in mineral P-fertilisers, the present level of Cd in Norwegian fertilisers (2.3 mg Cd kg^{-1} P_2O_5) and 60 mg Cd kg^{-1} P_2O_5 will be used. This level is higher than the maximum permissible level in Norway (44 mg kg^{-1} P_2O_5), but is assumed to be at an average EU-level (using data from Table 4.4b, p.32 in ERM, 2000).

Amount of Cd applied in different crop rotations

The calculations of future soil Cd concentrations will be done for soils used for the production of grains, potato, carrots and grass. Representative crop rotations have been defined for these crops (Table 7).

Table 7: Annual amount of Cd applied to soils under different crop rotations.

	Crop rotation	kg P_2O_5 ha^{-1} year^{-1}	g Cd ha^{-1} year^{-1} 2.3 mg Cd Present level	 60 mg Cd EU level
I	Autumn wheat-autumn wheat-oat-barley-oil seeds	50	0.12	3.02
II	Potato-autumn wheat-oat	69	0.16	4.12
III	Carrot-potato-wheat	92	0.21	5.49
IV	Grass-grass-wheat	80	0.18	4.81

Since there are no large differences in P application for the crop rotations I-IV among regions, the same P application rates have been used for the crop rotations in the defined regions.

The grass rotation is in this risk assessment not important for the human exposure of Cd. The soil balance of Cd in typical grass rotations is however included in the water risk assessments.

2.1.6. Summary, ki

The present level of Cd in mineral P-fertilisers contributes on average 24.7 percent to the total Cd added to agricultural soils (Table 8). The lowest percentage contribution is in areas used for grain production in south-east Norway (region 1), where Cd sources like atmospheric deposition and sewage sludge are the most significant (Table 9). The highest percentage contribution from mineral P-fertilisers is in areas with carrot and potato production and which is low in atmospheric deposition (like in central Norway-region 4).

Applying mineral fertilisers with Cd content equal to the EU level makes mineral P-fertilisers by far the most important source for Cd in agricultural soils (Table 8). In areas in central Norway used for grain production, as much as 96% of the Cd applied come from mineral fertiliser when applying P-fertilisers containing this level of Cd.

Table 8: Percent contribution of Cd from mineral fertilisers to agricultural soils using present level and EU level of Cd in mineral P-fertilisers.

	Present level Cd	EU level Cd
Mean	24.7	88.0
Median	23.1	88.7
Min	10.2	74.8
Max	49.4	96.2

The input data used in the calculations in the accumulation module is summarised in Table 9.

Table 9: Input of Cd (unit: g ha^{-1} $year^{-1}$) to agricultural soils in different regions (defined in Figure 1) and for different crop rotations (Table 7). Two scenarios of Cd in mineral P-fertilisers are used (2.3 and 60 mg Cd kg^{-1} P_2O_5).

						Mineral P-fertiliser		Sum Cd application	
	Crop rotation	Atm dep.	Sewage sludge	Lime	Feeds	Present level Cd	EU level Cd	Present level Cd	EU level Cd
Region 1	Grains	0.8	0.20	0.02		0.12	3.02	1.13	4.04
	Potato	0.8		0.02		0.16	4.12	0.97	4.93
	Carrot	0.8		0.02		0.21	5.49	1.03	6.31
	Gras	0.8		0.02	0.09	0.18	4.81	1.09	5.71
Region 2	Grains	0.5		0.02		0.12	3.02	0.63	3.54
	Potato	0.5		0.02		0.16	4.12	0.67	4.63
	Carrot	0.5		0.02		0.21	5.49	0.73	6.01
	Gras	0.5		0.02	0.04	0.18	4.81	0.74	5.36
Region 3	Grains	0.7		0.02		0.12	3.02	0.83	3.74
	Potato	0.7		0.02		0.16	4.12	0.87	4.83
	Carrot	0.7		0.02		0.21	5.49	0.93	6.21
	Gras	0.7		0.02	0.11	0.18	4.81	1.01	5.63
Region 4	Grains	0.2		0.02		0.12	3.02	0.33	3.24
	Potato	0.2		0.02		0.16	4.12	0.37	4.33
	Carrot	0.2		0.02		0.21	5.49	0.43	5.71
	Gras	0.2		0.02	0.06	0.18	4.81	0.46	5.08
Average Norway	Grains	0.5		0.02		0.12	3.02	0.63	3.54
	Potato	0.5		0.02		0.16	4.12	0.67	4.63
	Carrot	0.5		0.02		0.21	5.49	0.73	6.01
	Gras	0.5		0.02	0.04	0.18	4.81	0.74	5.36

The application rate, k_i (mg kg^{-1} year^{-1}) is calculated using equation 1:

$$k_i = \frac{g\,Cd\;ha^{-1}\;year^{-1}}{10^4 \cdot r \cdot d_p}, (mg\;kg^{-1}\;year^{-1}) \qquad (1)$$

where

g Cd ha^{-1} year^{-1} = input of Cd (from Table 9)

ρ = soil bulk density (kg m^{-3})

d_p = depth of plough layer (0.25m)

The calculated values for k_i are shown in Appendix 1.

2.2. Cadmium removal rate (k_p)

In the calculation of crop removal of Cd for different crop rotations in the different regions, the content of Cd in the different crops (Table 10) and the normal production level of the different crops in the defined regions (Table 11) have been used.

Table 10: Content of Cd in crops that are included in the crop rotations (data from Singh et al. 1999; Amundsen et al. 2000; Alne and Gjerstad 1998; Waaler 1996)

Crop	(µg kg^{-1} dw)
Wheat	60
Barley	17
Oat	24
Oil seeds	82
Potato	54
Carrot	270
Grass	50

The numbers for normal crop production are based upon production values for 1996 and assumed average production values for the different regions (Table 11).

Table 11: Normal crop production in defined regions (Unit: ton dw ha^{-1} year^{-1})

	Region 1	Region 2	Region 3	Region 4	Average Norway
Wheat	3.8	3.8	3.4	3	3.5
Barley	3.4	3.4	3	2.7	3.1
Oat	3.4	3.4	3	2.7	3.1
Oil seeds	1.5	1.5	1.5	1.5	1.5
Potato	5.5	5.5	5.5	5.5	5.5
Carrot	4.1	4.1	4.1	4.1	4.1
Grass	7	7	8.5	7	7.4

The plant removal rate, k_p (year^{-1}) was calculated according to equation 2.

$$k_p = \frac{g\ Cd\ ha^{-1}\ year^{-1}}{10^4 \cdot d_p \cdot r \cdot Cd_{Soil}},\ \left[year^{-1}\right] \qquad (2)$$

where

d_p = depth of plough layer (0.25 m)

ρ = soil bulk density (kg m^{-3})

Cd_{Soil} = cadmium concentration in soil (mg kg^{-1} dw)

The values of soil bulk density and cadmium concentrations in soils are reported in Amundsen *et al.* (2000) (Appendix 2).

Table 12: Removal of Cd through crops. Calculated data for different crop rotations.

	g Cd ha^{-1} $year^{-1}$					$year^{-1}$				
Crop rotation	Reg 1	Reg 2	Reg 3	Reg 4	Average Norway	Reg 1	Reg 2	Reg 3	Reg 4	Average Norway
Grains	0.144	0.144	0.131	0.119	0.134	0.00029	0.00029	0.00027	0.00039	0.00019
Potato	0.202	0.202	0.191	0.181	0.194	0.00040	0.00040	0.00040	0.00060	0.00028
Carrot	0.544	0.544	0.536	0.528	0.538	0.00108	0.00108	0.00112	0.00175	0.00078
Grass	0.309	0.309	0.351	0.293	0.316	0.00062	0.00062	0.00073	0.00097	0.00046

In the calculations of k_p, the same soil bulk densities were used for the different crops within the regions.

2.3. Leaching

2.3.1. Distribution coefficient, K_d

The accumulation module involves estimations of the leaching rate of Cd pr. year. An essential parameter in this context is the distribution coefficient (K_d) indicating the partitioning of Cd between soil and soil solution. Processes of adsorption, complex formation and (co) precipitation to soil components, control the presence of Cd in the solid phase, and these processes are highly pH dependent. Adsorption is normally more important for the Cd solubility than (co) precipitation. In default of empirical K_d values obtained from studies of national soil types, K_d values have to be predicted by using pH of soil solution and the organic matter content of soils, %OM (or organic carbon). pH and organic matter content are available for most agricultural soils registered at the "Centre for Soil and Environmental

Several algorithms have been reported to predict K_d for Cd. According to the ERM (2000) procedure, the algorithms presented by Römkens and Salomons and later updates give the best fit with a range of data sets (Equation 4 below). Two other possibilities are the algorithms developed by Christensen (1989) and McBride *et al.* (1997) (Equation 3 and 5 below), both suggested by ERM (2000).

Christensen used 61 agricultural soils with pH of 4.1-7.7, which are also representative for Norwegian conditions, but these soils have a low range of organic matter (0.3-4.1%). This algorithm overestimates K_d, when OM% gets higher than 10-15%.

The algorithm developed by McBride et al. (1997) involves 31 agricultural soils from France, Netherlands and UK. These soils cover a much wider range of organic matter (1.1-34%), which is more representative for Norwegian conditions.

$\log K_d = -1{,}35+0{,}587\text{pH (of soil solution)}+0{,}157(\%\text{OM})$ (Christensen, 1989) (3)

$\log K_d = -1{,}00+0{,}44\text{pH(of soil)}+1{,}03\log(\%\text{OM})$ (Römkens and Salomons, 1998)) (4)

$\log Cd_l = 3.62-0.5\text{pH}+0.96\log Cd_T-0.45\log(\text{OM})$ (McBride *et al.*,1997). (5)

where

K_d = distribution coefficient (l kg^{-1})

OM% = organic matter (%) or OM = g kg^{-1}

Cd_T = total concentration of Cd in the soil (mg kg^{-1})

Cd_l = Cd in soil solution ($\mu\text{g l}^{-1}$)

We calculated K_d-values using all three algorithms. It seemed quite obvious that the algorithm developed by Christensen et al. (19 89) overestimate K_d-values when the organic matter content gets higher than 10%. The algorithm developed by Römkens and Salomons (1998) underestimate the K_d-values considerably and are on average about five times lower than values we suppose are representative for Norwegian arable soils (based upon a few unpublished data).

We decided to use the algorithm developed by McBride et al. (1997) because of a larger range in soil organic matter content (1.1-34%) and because this algorithm estimates K_d-values, that are more similar to the assumed Norwegian range.

2.3.2. Precipitation excess, F

There are large variations in annual precipitation among the different regions in Norway. In the southeastern parts of the country (region 1 and 2), the precipitation varies in the range 300-800 mm, but the region also has areas with extreme low precipitation (below 300 mm annually). The southeastern parts of Norway are also characterised by relatively high mean temperature, little wind and low air humidity. In the western parts of the country (region 3), the precipitation is higher, ranging from 1500 to 3000mm. The main agricultural areas in this region have, however, lower annual precipitation and are in the range of 1200-1500mm annually. This region in general is windier and has a higher relative air humidity. In the central and northern parts of the country the annual precipitation is relatively high and high wind velocity and low temperatures dominate the area.

Field investigations of runoff from agricultural soils in Norway show that the differences in precipitation between regions are reflected in measured precipitation excess (drainage water and surface runoff). For region 1 and 2 precipitation excess normally is in the range 0.1-0.3 m year^{-1}. In some of the investigated fields surface runoff is typically in the range 0.05-0.15 m year^{-1}, but may be as high as 0.25 m year^{-1} and thus equal to the drainage. Surface runoff is not taken into account in this investigation and contributes significantly to the uncertainty in the balance calculations for soil Cd.

In region 3 the measured precipitation excess is higher and typically in the range 0.6-0.8 m year^{-1}, while in region 4 it is in the range 0.4-0.6 m year^{-1} (Kværnø and Delstraa 2000). In areas with clay and clay like soils (region 1, 2 and partly 4), a substantial amount of the precipitation can be transported through macropore flow. Water flowing in macropores may transport both soluble and particle bound Cd, but this flow does not influence the soluble Cd in soil solution. The quantification of this transport is not done in any large-scale experiments and lack of knowledge about the importance of these transport processes for the soil Cd balance make the accumulation module more uncertain.

It is very likely that the measured leaching rates given in Table 13 is the upper leaching limit, especially in regions 1, 2 and 4. Macropore flow might reduce the transport of soluble Cd but on the other hand enhance particle bound transport through internal erosion processes.

In the calculations of leaching rate (k_l) (equation 6) and L (equation 7), we have, in addition to using the measured field values, reduced the leaching rate by 30% and 50% in the calculations. This is done to show the significance of precipitation excess (F) on soil Cd accumulation and human exposure. The values for precipitation excess used in the calculations of k_l for the different regions, are given in Table 13.

Table 13: Values for precipitation excess, F (m year^{-1}) used in the accumulation module.

Region	Measured values	30% reduction	50% reduction
1	0.2	0.15	0.1
2	0.2	0.15	0.1
3	0.7	0.5	0.35
4	0.5	0.35	0.25
Average Norway	0.4	0.3	0.2

The leaching rate, k_l, was given by

$$k_l = \frac{1000 \cdot F}{K_D \cdot d_p \cdot r}, \left[year^{-1}\right] \qquad (6)$$

where

F = annual precipitation excess (m year^{-1})

K_D = distribution coefficient (l kg^{-1})

d_p = depth of plough layer (0.25 m)

ρ = soil bulk density (kg m^{-3})

The annual Cd loss from the soil was calculated according to

$$L = Cd_l \cdot 10 \cdot F , \quad (g\ ha^{-1}\ year^{-1}) \qquad (7)$$

where

Cd_l = Cd-concentration in soil solution (µg l^{-1})

F = annual precipitation excess (m year^{-1})

The mass balance model, proposed by ERM (2000), was used to calculate the accumulation of Cd in the plough layer of Norwegian agricultural soils (equation 8).

$$\frac{d(Cd_s)}{dt} = k_i - (k_p + k_l) \cdot Cd_{s,} \ (mg\,kg^{-1}\,year^{-1}) \tag{8}$$

where

Cd_s = cadmium concentration in soil at time t (mg kg^{-1} dry weight)

k_i = input rate of Cd (mg kg^{-1} $year^{-1}$)

k_p = cadmium removal by plants ($year^{-1}$)

k_l = cadmium leaching from the plough layer ($year^{-1}$)

The analytical solution of equation 8 is given by

$$Cd_s(t) = Cd_s(0) \cdot e^{-(k_p+k_l)t} + \left(\frac{k_i}{k_p + k_l}\right) \cdot \left(1 - e^{-(k_p+k_l)t}\right) \tag{9}$$

where

Cd_s = cadmium concentration in soil at time t (mg kg^{-1} dry weight)

$Cd_s(0)$ = initial concentration of cadmium in soil (present day concentration)

k_i = input rate of Cd ($year^{-1}$)

k_p = cadmium removal by plants ($year^{-1}$)

k_l = cadmium leaching from the plough layer ($year^{-1}$)

The steady state concentration in soils has been calculated according to equation 10

$$Cd_s(SS) = \frac{k_i}{k_p + k_l}, (mg\,kg^{-1}) \tag{10}$$

where

$Cd_s(SS)$ = steady state concentration of Cd in the plough layer

k_i = input rate of Cd (mg kg^{-1} $year^{-1}$)

k_p = cadmium removal by plants ($year^{-1}$)

k_l = cadmium leaching from the plough layer ($year^{-1}$)

2.4. Soil accumulation of cadmium

The accumulation of Cd in soils after 100 years of P-fertiliser application, have been calculated for two levels of Cd (given in Table 7) in mineral P-fertilisers The steady state concentrations for the two scenarios are also shown (Table 14).

Application of mineral P-fertilisers containing the present level of Cd, results in an accumulation of Cd only in soils used for grain production (Table 14) and only in region 1 where most of the Norwegian sewage sludge is applied. When applying mineral P-fertilisers containing 60 mg kg^{-1} P_2O_5, soil accumulation occur for all crops and in all regions. In soils used for carrot production, the soil concentration increases by nearly 100% during 100 years.

For all scenarios, soil Cd concentration is not at steady state within 100 years.

Table 14: Calculated soil concentrations of Cd (equation 9). Pres Cd-present Cd concentration in soil, SS-steady state concentration (equation 10). F = measured values in Table 13 (highest precipitation excess). Unit: mg kg^{-1}.

		Grains				Potato				Carrot			
		Present level Cd		EU level Cd		Present level Cd		EU level Cd		Present level Cd		EU level Cd	
Region	Pres Cd	100y	SS	100y	SS	100y	SS	100y	SS	100y	SS	100y	SS
1	0.17	0.19	0.31	0.28	1.10	0.17	0.18	0.29	0.90	0.17	0.15	0.33	0.91
2	0.17	0.17	0.19	0.27	1.06	0.16	0.11	0.28	0.76	0.16	0.10	0.32	0.86
3	0.19	0.14	0.06	0.22	0.29	0.12	0.04	0.22	0.25	0.14	0.06	0.28	0.43
4	0.11	0.09	0.04	0.18	0.37	0.08	0.03	0.18	0.30	0.10	0.06	0.25	0.74
Average Norway	0.24	0.21	0.09	0.30	0.53	0.19	0.07	0.30	0.45	0.20	0.08	0.35	0.65

The two scenarios for Cd in mineral P-fertilisers result in quite different accumulation rates for Cd in soils. The highest accumulation will occur in south-east Norway (Region 1) where the total input of Cd is highest and least in western Norway (Region 3), where the leaching is highest (Table 14).

The soil accumulation rate sfor low-level and high-level Cd in mineral P-fertilisers are very different, showing that the level of Cd in P-fertilisers is very important for future levels of Cd in soils. Figure 2 shows the difference for soils used for grain production in region 1.

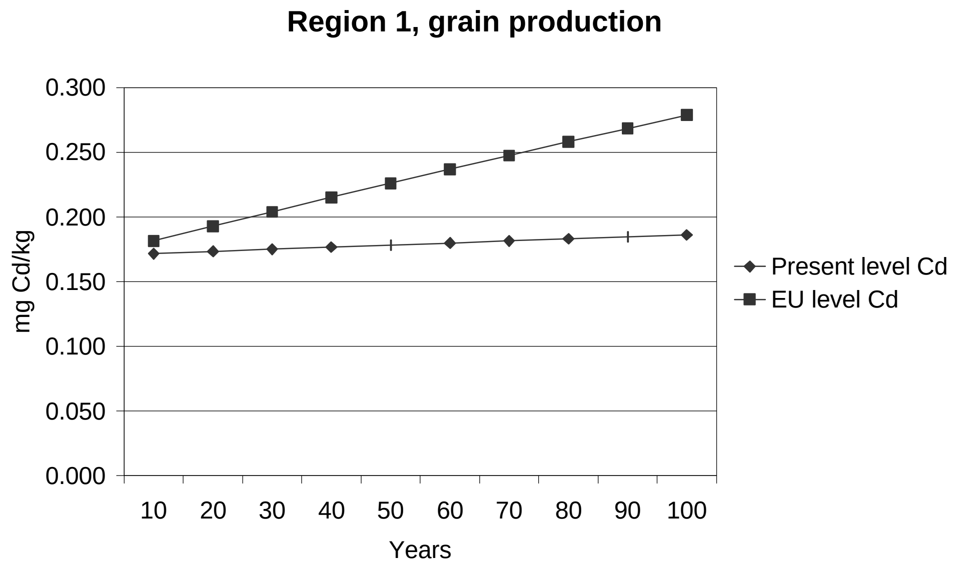

Figure 2: Soil accumulation rate of Cd in grains growing in Region 1 at present level and EU level of Cd in mineral P-fertilisers. F=0.2 m year^{-1}.

There are also large differences in accumulation rate among regions (Figure 3).

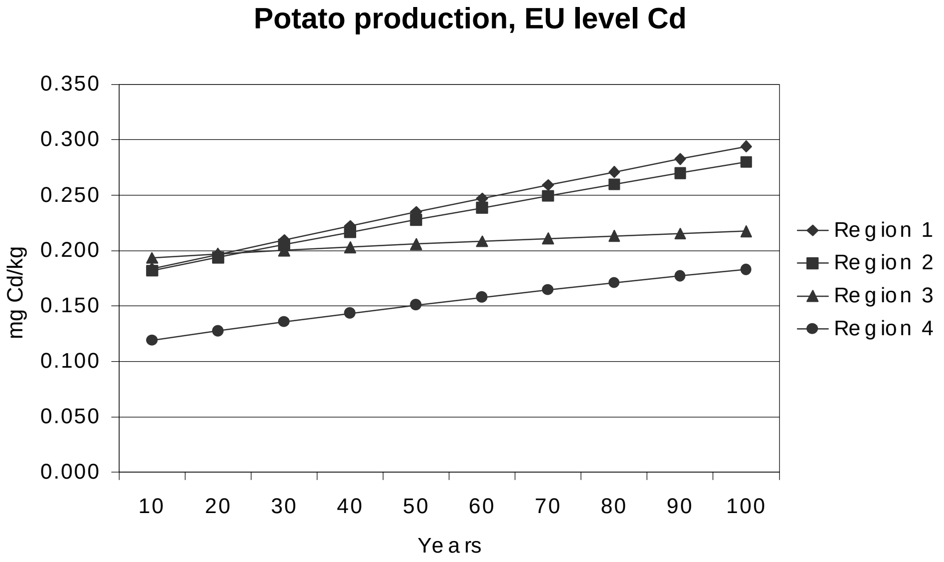

Figure 3: Accumulation rates of Cd in soils used for potato production in the defined regions. EU level of Cd in P-fertilisers is used and F=measured values (highest precipitation excess).

The rate of soil accumulation is sensitive to the precipitation excess (F). Two examples are given for soils used in grain production in region 1 and 4 (Figure 4). In region 1 Cd is accumulating in the soils, while in region 4 where the leaching is higher, there is a decreasing trend. Even with an excess precipitation of F=0.2 the calculations results in a negative balance in region 4 (lower atmospheric deposition and no sewage sludge amendments).

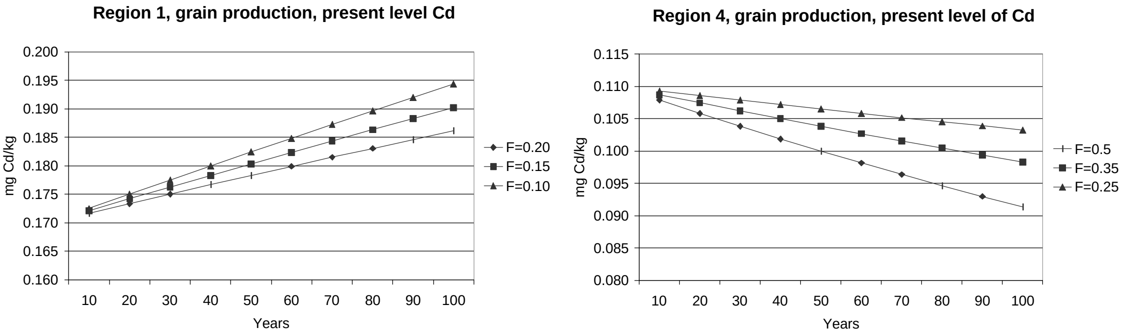

Figure 4: Accumulation rates for grain production in region 1 and 4 applying mineral fertilisers containing the present level of Cd in P-fertilisers for 100 years.

In all calculations of soil leaching rates, the median values for K_d are used. This implies that the accumulation rates presented here also are median values. When using these data in the exposure module, the calculations will result in median increase in plant uptake, which will be appropriate when calculating the increased exposure for the mean population. Because of a relatively skewed distribution of the K_d-values, median values instead of mean values were used.

3. Exposure module

3.1. Plant uptake algorithms

In Norway information about how soil properties like pH and organic matter under field conditions influence the uptake of cadmium in agricultural soils are limited. The calculation of future plant concentrations of Cd have therefore been done using the recommended algorithms given by ERM (2000) (Table 15) and Eriksson *et al*. (1996) (Table 16). He and Singh (1993) have calculated the relationship between different soil properties and Cd uptake by oat and grasses, but not for the plant species of interest in this risk assessment.

Table 15: Algorithms proposed by ERM (2000) for calculating the future plant concentrations of Cd, Cd_p.

Crop	Algorithm	Reference
Winter wheat / Cereals (grain)	$Cd_p = 81 – 10.3\ pH + 100\ Cd_s$	Based on Eriksson et al. (1996) with mean Zn_s = 42.1 mg kg^{-1}
Potatoes	$Cd_p = 177 – 24.1\ pH + 39\ Cd_s$	Based on Eriksson et al. (1996) with mean %OM = 17.3
Carrot / other root vegetables	$Cd_p = 1289 - 165\ pH$	Based on Eriksson et al. (1996)

Table 16: Algorithms from Eriksson et al. (1996) used for calculation of future plant Cd concentrations, Cd_p.

Crop	Algorithm
Winter wheat (grain)	$Cd_p = 78.8 – 7.26\ pH - 1.58\ (\%OM) + 0.8(\%Clay) + 184.8 Cd_s – 0.73 Zn_s$
Potatoes	$Cd_p = 193 - 24.1 pH – 0.94(\%OM) + 39\ Cd_s$
Carrot	$\log Cd_p = 4.16 – 0.29 pH + 1.00\ Cd_s$

The algorithms proposed by ERM (2000) are modifications of the algorithms made by Eriksson *et al*. (1996) using constant values for soil Zn and organic matter content. The algorithms given by Eriksson *et al*. (1996) for winter wheat involves both clay and Zn content, both factors that may be important for Cd uptake. For comparison, we have used both sets of algorithms in the calculations of the present level of Cd in grains, potato and carrot (Table 17).

In these calculations we have used the median values for soil pH and organic matter content given in chapter 4.3.2 for wheat, potato and carrot soils in the different regions. The clay content necessary in the winter wheat algorithm (Table 16), are shown in Table 17. The values used for present level of Cd and Zn in soils are shown in Appendix 2. No distinction on Cd and Zn level in soils used for wheat, potato and carrot production is made.

Table 17: Clay contents used in the algorithm for calculating wheat Cd content.

Region	**Clay content (%)**
1	30
2	15
3	5
4	15
Average Norway	20

The uptake of Cd in winter wheat, potatoes and carrots calculated using the algorithms in Table 15 and 16 should be in accordance with the measured values given in Table 10.

Table 18: Calculations of crop Cd contents using algorithms from Table 15 and 16. The present level of Cd in soils is used (Appendix 2). Values for soil pH and organic matter content is shown in chapt. 4.3.2. The values for soil clay content are shown in Table 17.

	Algorithms from Table 15 (ERM 2000)					
	Region 1	Region 2	Region 3	Region 4	Average Norway	Measured values (Table 10)
Winter wheat	40.8	41.8	42.8	34.8	47.8	60
Potato	56.4	60.7	62.7	58.4	61.3	54
Carrot	388	418	373	268	388	270
	Algorithms from Table 16 (Eriksson *et al*. 1996)					
Winter wheat	33.3	19.8	52.4	17.8	43.8	60
Potato	69.4	73.6	72.9	70.2	73.9	54
Carrot	558	584	486	558	656	270

The algorithms that are proposed by ERM (2000) seem to give the best fit with the measured values shown in Table 10. Both algorithms underestimate the level of Cd in wheat, but overestimates the Cd content in potato and especially carrot (see Table 18).

There is a great need for Norwegian field investigations where the relationships between plant content and soil properties are investigated. The investigations performed by He and Singh (1993) clearly indicate that other soil properties than pH and organic matter content are of importance for plant uptake of Cd.

3.2. Incremental dietary intake of cadmium due to fertiliser use

Dietary intake of cadmium as a result of consumption of foods grown on fertiliser-applied soils can according to ERM (2000) be calculated from the following algorithm:

$$I_{Diet} = \sum (C_i \cdot P_i \cdot FI_i) + I_{Background} \qquad (11)$$

where

I_{Diet} = total dietary intake of cadmium from all relevant food sources

C_i = concentration of cadmium in food item i

P_i = daily, weekly or annual consumption of food item i

FI_i = fraction of food item i that is grown on fertiliser-amended soils

$I_{Background}$ = cadmium intake from foods not impacted by fertiliser application

The total dietary intake of cadmium has been presented earlier (Singh *et al*. 1999). The values are given in Table 19. Potatoes, cereals and other vegetables (of which carrots probably are the dominating vegetable), accounts for 81 percent of the daily Cd intake of Norwegian habitants (Table 19).

Table 19: Calculations of the Cd intake (mg day^{-1}) from the major food groups in Norway based on analyses of individual food items (calculated by using F=measured values). The calculations are made for two scenarios of Cd in mineral P-fertilisers: present level of Cd (2.3 mg Cd kg^{-1} P_2O_5) and EU level (60 mg Cd kg^{-1} P_2O_5).

		ERM (2000)		Eriksson *et al*. (1996)	
Food group	Present Cd intake	Present level Cd	EU level Cd	Present level Cd	EU level Cd
Milk	0.12	0.12	0.12	0.12	0.12
Diary products					
Fats, oils					
Fruits					
Leafy vegetables	0.05	0.05	0.05	0.05	0.05
Other vegetables (carrots)	**0.8**	**0.8**	**0.8**	**0.77**	**1.11**
Potatoes	**1.38**	**1.36**	**1.47**	**1.37**	**4.43**
Cereals	**5.6**	**5.80**	**7.06**	**6.05**	**9.50**
Meat	0.38	0.38	0.38	0.38	0.38
Organs, offal	0.11	0.11	0.11	0.11	0.11
Fish	0.36	0.36	0.36	0.36	0.36
Moll.crustacea	0.81	0.81	0.81	0.81	0.81
Eggs/egg products					
Alcoholic beverages					
Non-alcohol. beverages					
Total	**9.6**	**9.8**	**11.2**	**10.0**	**16.9**

The present daily intake of Cd given in Table 19 are not complete because 6 food items are not included (Singh *et al*. 1999).In a study of 32 healthy, free-living women collecting duplicate portions of all foods and beverages (including tap water) consumed during 4 days in1988, the average Cd intake determined by chemical analysis was found to be 12 µg day^{-1} (range: 7-21) (Meltzer, unpublished). Adding the information from the duplicate diet study, it seem reasonable to assume that the average total Norwegian intake is in the order of 12-15µg day^{-1}. This implies that the intake of Cd from those food items not given numbers in Table 18 is in the range 2-5 µg day^{-1}. At present more detailed investigations about the food habits of Norwegian habitants are performed, which will contribute to more accurate data for Cd intake. In the present risk assessment the values given in Table 19 will be used.

On an energy basis, the Norwegian produced food accounts for 50 percent (in 1998) of the grain products, 90 percent of the potato products and 61 percent of the vegetables (carrots much higher) of total consumption in Norway. For other important products such as meat, egg and milk products, almost 100 percent are produced in Norway.

Almost all (99.5%) of agricultural crops produced in Norway are grown on fertiliser-amended soils (FI_i=1).

As shown in chapter 1.2, there are differences in the importance of various regions in the production of wheat, potatoes and carrot (Table 1). In the calculation of plant Cd increase due to fertiliser use, this is taken into account. The increase in daily intake of Cd on a national scale for eg. wheat is calculated by weighing the increase in each region with respect to the fraction of wheat production in each region (Table 1).

As can be seen from Table 19, the application of P-fertilisers containing EU level of Cd in 100 years increase the daily intake of Cd by 76 percent i.e from 9.6 to 16.9 µg person^{-1} day^{-1}. This increase is much higher than when using mineral fertilisers with low-level of Cd (4.3 percent increase). The algorithm used is very important for the calculated future intake of Cd (Table 19). Using the algorithm proposed by ERM (2000), lower daily intake is calculated. One reason for this is that the uptake of Cd in carrot is not dependent on Cd_s in this algorithm (Table 15).

The significance of precipitation excess on the future daily human intake of Cd is calculated using the three values for F given in Table 13. The differences in daily Cd uptake between the different F-values (Table 20) are much smaller than the differences between plant uptake algorithms (Table 19).

Table 20: Daily intake of Cd calculated for different values of precipitation excess, F. The algorithms defined by Eriksson et al. (1996) is used in the calculations. Pres Cd-present level of Cd in mineral P-fertilisers; EU Cd- EU level of Cd in mineral P-fertilisers

		F=max		F=30%		F=50%	
Food group	Present daily intake	Pres Cd	EU Cd	Pres Cd	EU Cd	Pres Cd	EU Cd
Milk	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Diary products							
Fats, oils							
Fruits							
Leafy vegetables	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Other vegetables (carrots)	**0.8**	**0.77**	**1.11**	**0.79**	**1.13**	**0.80**	**1.16**
Potatoes	**1.38**	**1.37**	**4.43**	**1.37**	**4.46**	**1.38**	**4.48**
Cereals	**5.6**	**6.05**	**9.50**	**6.18**	**9.76**	**6.32**	**10.04**
Meat	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Organs, offal	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Fish	0.36	0.36	0.36	0.36	0.36	0.36	0.36
Moll.crustacea	0.81	0.81	0.81	0.81	0.81	0.81	0.81
Eggs/egg products							
Alcoholic bererages							
Non-alcohol. Bev.							
Total	**9.6**	**10.0**	**16.9**	**10.2**	**17.2**	**10.3**	**17.5**

The difference in future daily intake of Cd using different F-values in the calculations of is only 3.4%, indicating that excess precipitation is of minor importance for the daily intake of Cd.

3.3. Discussion

In the calculations median values for K_d, pH, organic matter content and soil concentration of Cd and Zn are used. This implies that a mean value for plant uptake and daily intake of Cd is calculated being representative for the average population eating “normal” quantities of specified food items and which have a “normal” health. We do know however that higher soil accumulation may occur locally (high pH, high organic matter) and that locally produced food may lead to increased intake. To be able to perform risk assessments taking local soil and dietary habits into consideration, more knowledge on these items in Norway is necessary. Furthermore, with limited reserves of low Cd phosphate rocks, presuming that the present low level of Cd in mineral P-fertiliser will persist for a long period will be erroneous and hence for a long-term scenario, high level Cd may be realistic value. This means that intake of Cd through fertiliser will increase in the longer run.

4. Risk characterisation

4.1. Human health

ERM (2000) suggests using the current Provisional Tolerable Daily Intake (PTDI) set by JECFA (FAO/WHO Joint Expert Committee on Food Additives and Contaminants) at 1µg kg^{-1} body weight day^{-1}, as the No (Lowest) Observed Adverse Effect Level ((N(L)OAEL). This is equivalent to 70µg $person^{-1}$ day^{-1}.

From Table 19 it can be seen that the increased human intake of Cd due to increased content of Cd in mineral fertilisers, do not approach the PTDI suggested by WHO. Using the high Cd P-fertiliser (average EU level), increase the daily intake from about 10µg $person^{-1}$ day^{-1} to 16.9. This intake levels approach 30µg $person^{-1}$ day^{-1} which was suggested by Jarüp et al (1997) as a new upper limit for daily intake of Cd.

Table 21: Margin of safety (MOS) for different levels of daily intake of Cd.

		Daily intake µg day^{-1}	N(L)OAEL µg day^{-1}	MOS
Present intake of Cd		9.6	70	7.3
			30	3.1
Calculated intake after 100 years of P-mineral fertilisation	Present level Cd	10.3	70	6.8
			30	2.9
	EU level Cd	17.5	70	4.0
			30	1.7

The margin of safety (MOS), equal to the ratio No (Lowest) Observable Adverse Effect Level (N(L)OAEL) to exposure levels (Table 21), is for all scenarios higher than 1. Using 70 µg $person^{-1}$ day^{-1} as the N(L)OAEL, MOS varies from 7 to 4. Using 30 µg $person^{-1}$ day^{-1}, MOS varies in the range 3.1-1.7. Application of high-level Cd mineral P-fertilisers decrease the margin of safety by 40%.

Taking into account that the present daily intake of Cd is 2-5 µg day^{-1} higher than shown in Table 19, MOS is even lower than shown in Table 21.

The present and calculated future daily intake of Cd are representative for the average consumer. In specific risk groups the intake may be substantially higher.

4.1.1. Risk groups

As reported by Singh *et al*. (1999), there are only a few groups that risk ingesting high-level Cd foods in Norway: 1) high-consumers of shellfish; 2) high consumers of wheat grown in Cd-rich soils; and 3) vegetarians on a high fibre, high-vegetable diet. In risk groups 1 and 2 it is very likely that the PTWI of 70 µg $person^{-1}$ day^{-1} will be exceeded for the most extreme persons in these groups.

Women with low iron stores (and possibly low Zn stores) also are at risk because of high bioavailability of consumed Cd.

4.1.2. Discussion

Margins of safety calculated in this report are representative only for the average population and not for any of the mentioned risk groups. ERM (2000) recommends doubling the predicted intake for persons with low iron stores. In this risk group extreme consumers i.e. 95th percentile or more probably will have an intake of Cd that exceeds 70 µg day^{-1}. The MOS for these groups probably are below 1 in the most extreme cases.

Considering the uncertainty in that the present PTWI of 70 µg day^{-1} for an adult actually is a safe limit (NOAEL) and the lack of Norwegian data for potentially sensitive groups, it seems advisable not to increase the dietary intake of Cd.

More detailed risk assessments of specific risk groups may be performed when information from ongoing research on food habits in different parts of Norway will be available (Meltzer *et al*. 2000).

4.2. Soil

4.2.1. PNEC values for soils

ERM (2000) has suggested several values for PNEC in soils.

Table 22: PNEC values for soil suggested by ERM (2000)

Value (mg kg^{-1})	**Derivation**	**Organisms**	**Reference**
0.06	Lowest NOEC Assessment factor = 10	Grasshopper (*Aiolopus thalassinus*)	FEI (1997)
0.18	Lowest NOEC Assessment factor = 10	Higher plants	BFDE (1999)
2.6	5-percentile of NOEC values; no assessment factor	3 trophic levels	BFDE (1999)

The PNEC-value of 0.06 mg kg^{-1} which is obtained using reduction in egg hatching of the grasshopper *Aiolopus thalassinusis* as endpoint, is far below the concentration of most Norwegian soils. This species of grasshopper do not exist in Norway and the PNEC value obtained will therefore not be used.

The PNEC-value of 0.18 mg kg^{-1} is within the range of Cd background concentrations of Norwegian soils. Most agricultural soils in Norway have at present a higher value for Cd than 0.18 mg kg^{-1}.

The PNEC-value suggested used by ERM is 2.6 mg kg^{-1}. This PNEC-value was calculated as the 5th percentile of a log-logistic distribution of 72 selected NOEC values. Of these, 22 were tests on microflora, 44 tests on higher plants and 16 tests on soil fauna.

4.2.2. Soil properties

When the risk for soil organisms due to application of mineral fertilisers are to be assessed, the most sensitive soils have to be considered. Since bioavailability is not considered in this work, it must be assumed that the most sensitive soils are those with the highest potential for Cd accumulation. In general, these are the soils with highest pH and organic matter content.

To characterise the future risk of Cd in mineral P-fertilisers for soil health, accumulation scenarios for 10 soils (S1-S10) will be made. The pH and organic matter content of these soils are based upon the values for these parameters in soils used for wheat, potato and carrot production.

Wheat

83 percent of the Norwegian wheat production occur in region 1 and region 6. The mean pH in these areas is about 5.6 (range 4.1-7.4). The organic matter content in wheat soils in Norway varies considerably (0.1-48%), with a median value of 4. The content of organic matter in soils used for wheat production is on average lower in region 1 than in region 2.

Table 23: pH and organic matter content (%) in soils used for ***wheat*** *production*

	pH $CaCl_2$						
Region	Mean	Min	25 %	Median	75 %	Max	N
1	5.56	4.18	5.28	5.55	5.82	7.37	1241
2	5.62	4.55	5.28	5.46	6.01	6.83	63
Norway	5.56	4.09	5.28	5.55	5.82	7.37	1504

	Organic matter (%)						
Region	Mean	Min	25 %	Median	75 %	Max	N
1	4.73	0.1	2.9	3.92	5.71	26.8	1241
2	5.96	0.1	3.02	5.28	7.6	18	63
Norway	4.9	0.1	2.8	4	5.94	48	1494

Potato

Soils used in the production of potato have pH in the range 3.6-7.0 (median 5.2) and organic matter content in the range 0.2-36 (median 3.6). About 80 percent of the soils have a clay content less than 10 percent. There are no large differences in pH($CaCl_2$) between the different regions (Table 24), but there is a tendency towards lower pH values in soils from region 3. The content of organic matter is lowest in southeastern Norway (Region 1 and 6) and highest in southwester Norway (Table 24).

Table 24: Soil properties in areas with ***potato*** *production.*

	pH $CaCl_2$						
Region	Mean	Min	25 %	Median	75 %	Max	N
1	5.27	3.73	5	5.28	5.55	7.01	1249
2	5.13	3.82	4.82	5.1	5.37	6.73	1201
3	5.14	3.64	4.73	5.05	5.48	6.73	78
4	5.1	4.09	4.82	5.1	5.33	6.83	105
Norway	5.24	3.64	4.91	5.19	5.55	7.01	3795

	Organic matter (%)						
Region	Mean	Min	25 %	Median	75 %	Max	N
1	4.12	0.22	2.18	3.15	4.77	34.1	1242
2	4.1	0.76	2.29	3.32	4.9	31.9	1191
3	6.52	1.32	3.41	6.18	9.19	20.3	71
4	5.51	0.99	2.99	4.5	7.4	21.1	104
Norway	4.47	0.22	2.42	3.55	5.44	36.4	3755

In general, the soil used for potato production has a lower pH than soils used for wheat and carrot production.

Carrot

Data for 244 Norwegian soils (Table 25) show that the pH values varies in the range 3.8-7.0 (median 5.5) and organic matter content in the range 0.8-32 (median 3.7%) in soils used for carrot production. Almost all the soils have clay content in the range 5-10 percent.

Table 25: Soil properties in areas with ***carrot*** *production*

	pH $CaCl_2$						
Region	Mean	Min	25 %	Median	75 %	Max	N
Norway	5.5	3.82	5.1	5.46	5.91	7.01	244

	Organic matter (%)						
Region	Mean	Min	25 %	Median	75 %	Max	N
Norway	5.02	0.76	2.3	3.67	6.18	31.9	229

On the basis of data from Table 23-25, risk characterisation will be performed using soils with pH and organic matter content given in Table 26.

Table 26: Soil properties for which risk characterisation will be performed. Cd_l-concentration of Cd in soil solution (µg l^{-1}), K_d-distribution coefficient

Soil	**pH**	**OM%**	**Cd_l**	**K_d**
S1	4	2	2.087	86
S2	5.5	2	0.371	485
S3	7	2	0.066	2727
S4	4	10	1.012	178
S5	5.5	10	0.180	1000
S6	7	10	0.032	5626
S7	3.5	25	1.191	151
S8	4	25	0.670	269
S9	5.5	25	0.119	1511
S10	7	25	0.021	8497

In the calculations, the algorithm defined by McBride *et al*. (1997) is used.

The soils S2 and S5 are the most representative for wheat production, S4, S8 and S9 for potato production and S5 and S9 for carrot production.

4.2.3. Risk characterisation

The risk characterisation will be performed by using the algorithms described by McBride *et al*. (1997) and for two scenarios of Cd in mineral fertilisers (present Norwegian level and EU level). In the calculation of soil accumulation, Norwegian mean values for plant uptake (wheat, potato and carrot), mean Norwegian soil Cd-concentration and mean soil density have been used. Since excess precipitation is a key factor with respect to leaching and thereby soil accumulation, three scenarios of excess precipitation have been used: F=0.4, 0.3 and 0.2.

Table 27: Calculated soil concentration levels (mg kg^{-1}) using 2 scenarios of Cd in mineral fertiliser (present level) and three levels of excess precipitation. The calculations are performed for S1-S10 (from Table 26) The steady state concentrations are also calculated (Equation 10).

	F=0.4				F=0.3				F=0.2			
	Present level Cd		EU level Cd		Present level Cd		EU level Cd		Present level Cd		EU level Cd	
	100y	S state	100y	S state	100y	S state	100y	S state	100y	S state	100y	S state
S1	0.06	0.02	0.11	0.08	0.09	0.03	0.14	0.11	0.13	0.05	0.19	0.16
S2	0.21	0.12	0.29	0.43	0.22	0.16	0.31	0.56	0.24	0.23	0.33	0.81
S3	0.26	0.54	0.36	1.87	0.26	0.66	0.36	2.28	0.27	0.84	0.36	2.92
S4	0.13	0.05	0.20	0.17	0.16	0.06	0.23	0.22	0.19	0.09	0.27	0.32
S5	0.24	0.24	0.33	0.83	0.25	0.31	0.34	1.07	0.26	0.43	0.35	1.48
S6	0.27	0.86	0.36	2.97	0.27	1.00	0.37	3.44	0.27	1.19	0.37	4.10
S7	0.12	0.04	0.18	0.14	0.14	0.05	0.21	0.19	0.18	0.08	0.25	0.28
S8	0.17	0.07	0.24	0.25	0.19	0.09	0.27	0.32	0.21	0.14	0.30	0.48
S9	0.25	0.34	0.34	1.18	0.26	0.43	0.35	1.49	0.26	0.58	0.36	2.01
S10	0.27	1.06	0.37	3.65	0.27	1.19	0.37	4.12	0.27	1.36	0.37	4.71

The Cd accumulation in soils occurs first of all in soils with high pH (>5.5) and high levels of organic mater (>10%) i.e in soils S3, S6 and S10. It is these soils which are most at risk when considering increased Cd levels in soils. The calculations show that these soils will accumulate Cd also by using low-level Cd mineral P-fertilisers (Norwegian average).

In soils with low pH (S1 and S7) there will be no accumulation of Cd even if high-level Cd mineral P-fertilisers are used, except for the scenario with the lowest precipitation excess (F=0.2). The precipitation excess has the most pronounced influence on Cd accumulation in the low pH soils.

On average, mineral P-fertilisers with a EU level of Cd increase soil concentration by 38% relative to the present level of Cd in mineral P-fertilisers.

Risk factors (PEC/PNEC) are relatively low also when using mineral fertilisers with average EU level of Cd (Table 28). The differences between crops are small.

Table 28: Summary of calculated risk factors(PEC/PNEC) for soils S1-S10 and for the production of wheat, potato and carrot. The values are calculated only for the scenario with least precipitation excess, F=0.2. PNEC=2.6mg kg^{-1}.

	Present level Cd				EU level Cd			
	Mean	Min	Median	Max	Mean	Min	Median	Max
Wheat	0.088	0.049	0.095	0.105	0.121	0.075	0.131	0.142
Potato	0.085	0.047	0.093	0.102	0.131	0.082	0.141	0.153
Carrot	0.08	0.05	0.09	0.10	0.14	0.09	0.15	0.16

The application of mineral fertilisers with average EU-level of Cd increase the risk factors by on average 55% relative to the application of mineral fertilisers with a content of Cd equal to the present concentration of Cd.

4.2.4. Discussion

The bioavailability of Cd in soils is a crucial factor when evaluating the PNEC values. The availability of Cd is influenced by soil properties such as pH, organic matter and clay content. Norwegian agricultural soils influenced by alum shales may have total concentrations of Cd being 20 times higher (more than 4 mg kg^{-1} has been measured) than the average level in Norwegian soils. Still these soils are among the most productive soils in Norway with respect to crop yield and they have a high nitrification potential and respiration activity. Cadmium is strongly bound in these soils. In contrast to the alum shale soil, Norwegian sandy soils with low pH and low content of organic matter have a very low binding capacity resulting in higher bioavailability for Cd.

Assuming a PNEC value of 2.6 mg kg^{-1} is representative for Norwegian conditions, application of mineral fertilisers to agricultural soils do not pose any risk to soil organisms. The representativenes may however be questioned because the methodology used in the derivation of these PNEC-values protects only 95% of the species. Out of the entire data set used in the calculation of the PNEC value, only three are reported to be below 2.6 mg kg^{-1} and that soils with clay content less than 10% have lower PNEC values (1.5 mg kg^{-1}). The PNEC value for Norwegian soil organisms probably are between 0.18 and 2.6 mg kg^{-1}, depending on the bioavailability in the soils. The mean and median Cd concentration in sub-surface agricultural soils (>40cm) is 0.14 and 0.07 mg kg^{-1}, while the values in the topsoil are 0.22 and 0.14 mg kg^{-1}, respectively (Amundsen *et al*. 1995, Esser 1996). This may indicate that there has been an increase in Cd concentration in the topsoil in the range 60-100%, assuming that the soil concentration at depth >40cm is representative for background soil concentrations. The hypothesis that soil organisms already are influenced at the present soil concentrations can not be rejected without further investigations.

In the upper 0-5cm most soil concentrations are higher than the PNEC values of 0.06 and 0.18 mg kg^{-1}. Using these PNEC values in the risk characterisation of soils, risk factors for the major part of Norwegian soils are higher than one and at considerably higher risk than the risk factors shown in Table 28 indicate.

The uncertainty of how representative the different PNEC-values are for Norwegian soils (bioavailability) and the lack of Norwegian data on the effects of Cd on soil organisms and plants, make it necessary to keep the Cd soil accumulation as low as possible.

4.3. Water

4.3.1. PNEC water

Also for water, different PNEC values have been suggested by ERM (2000) (Table 29)

Table 29: Suggested PNEC-values for water (from ERM (2000)).

PNEC (µg l^{-1})	Derivation	Organisms	Reference
0.0085	Lowest NOEC Assessment factor 10	*Daphnia Magma*	FEI (1997)
0.047	Lowest NOEC Assessment factor 10	Different species	BFDE (1999)
0.39	5-percentile of NOEC values; no assessment factor	40 chronic tests 3 trophic levels	BFDE (1999)

The suggested PNEC-values of 0.0085 µg l^{-1} is very low compared to measured values in groundwater (Table 30) and in runoff from agricultural soils (Table 31) in Norway.

Table 30: Cadmium (µg/l) in groundwater in Norway (Frengstad *et al*. 2000)

Region	No of samples	Mean	Median	Minimum	Maximum
1	80	0.054	0.027	0.003	0.570
2+3	181	0.029	0.014	0.001	0.510
4	19	0.340	0.410	0.003	0.780
5	4	0.011	0.007	0.003	0.024
6	15	0.559	0.009	0.001	8.090
Whole country	480	0.063	0.017	0.001	8.090

The measured concentrations of Cd in drainage water from different basins in Norway are mostly less than 0.05µg/l (detection limit). In the period 1996-98 only 16 samples out of 66 from 7 basins were above this limit (Table 31). The actual mean value in drainage water is therefore lower than 0.07µg/l. By including all 66 samples and using half the detection limit for those samples that were less than the detection limit, the mean value worked out to be 0.04µg/l.

Table 31: Concentration of Cd in drainage water and calculated annual mean runoff from 7 basins in the period 1996-98.

	Unit	No of samples	Mean	Median	Minimum	Maximum
Drainage water	µg/l	16	0.07	0.07	0.05	0.16
Runoff	g Cd/ha/y	7	0.17	0.12	0.04	0.52

4.3.2. Risk characterisation

ERM (2000) suggest a set of $\text{PNEC}_{\text{water}}$-values, but does not suggest any procedure for how to calculate PEC values in waters which are influenced by mineral fertilisers. There certainly are a number of possible scenarios, both regarding the water quality of the water bodies that are influenced, dilution of water leached from soils amended with mineral fertilisers, type of water (rivers, lakes etc) and organisms, which are exposed to Cd.

The mean value both in groundwater and drainage water appear to be higher than the lowest PNEC and at the same level as PNEC=0.047. These facts may indicate that Norwegian waters already are at risk when it comes to cadmium.

To assess the risk of Cd in mineral fertilisers to surface waters, risk characterisation will be performed for two scenarios.

(1) Episodic scenario

A worst case scenario may occur in episodes in the springtime after soil fertilisation. At this time of the year, the soil may be water saturated and surface runoff may under these circumstances “wash out” the applied fertiliser.

In Norway precipitation events may occur with intensity off 50 mm over a short period of time. On one ha surface area there will be 500000 litres of water. Water concentrations of Cd are calculated by diluting the amount of mineral fertiliser used in different crop rotations in this amount of water (Table 32).

The calculated concentrations in waters influenced by surface runoff from mineral fertilised soils, is given in Appendix 3.

Table 32: Risk factors (PEC/PNEC) for surface runoff scenario. Mean values of atmospheric deposition are used (from Table 4).

	PNEC=0.0085µg l^{-1}		PNEC=0.39µg l^{-1}	
	Present level Cd	EU level Cd	Present level Cd	EU level Cd
Grains	14	355	0.30	7.7
Potato	19	485	0.40	10.6
Carrot	25	646	0.54	14.1
Gras	22	565	0.47	12.3

A summary of the risk factors for these waters (Table 32) show that waters are at higher risk than soils. It may be argued that the dilution of surface runoff must be higher, and that at least some of the precipitation infiltrates the soil reducing the Cd concentration through soil adsorption processes. We do know however that precipitation events like the one described actually occur, especially in south-east Norway.

(2) Long term scenario

In the soil risk characterisation 10 soils with varying properties of pH and organic matter were used. The soils that represent both typical and “extreme” Norwegian agricultural soils will be used to characterise the future risk of Cd in mineral P-fertilisers for surface waters.

After 100 years of cultivation, the concentration of Cd in the soils S1-S10 is calculated (Appendix 4). Using the 100 year soil concentrations and the calculated distribution coefficients for these soils (Table 25), the Cd_l-concentrations after 100 years of cultivation have been calculated (Table 33). Assuming that these Cd_l-values are equal to leachate concentrations, risk factors may be calculated for the different soils and for the two scenarios of Cd in mineral P-fertilisers (Table 33).

Table 33: Concentrations of Cd in soil solution (µg l^{-1}) after 100 years of cultivation. Risk factors (PEC/PNEC) using PNEC=0.0085 µg l^{-1} are shown.

	Grains				Potato				Carrot			
	Pres level Cd		EU level Cd		Pres level Cd		EU level Cd		Pres level Cd		EU level Cd	
	100y	Risk fact	100y	Risk fact	100y	Risk fact	100y	Risk fact	100y	Risk fact	100y	Risk fact
S1	1.48	175	2.25	265	1.43	168	2.47	291	1.38	163	2.74	322
S2	0.49	58	0.68	80	0.48	56	0.73	86	0.46	54	0.79	93
S3	0.10	12	0.13	16	0.10	11	0.14	17	0.09	11	0.15	18
S4	1.06	125	1.51	178	1.03	121	1.64	193	0.99	117	1.79	210
S5	0.26	30	0.35	41	0.25	29	0.38	44	0.24	28	0.41	48
S6	0.05	6	0.07	8	0.05	6	0.07	8	0.05	5	0.08	9
S7	1.17	138	1.68	198	1.13	133	1.83	215	1.09	128	2.00	235
S8	0.80	94	1.11	131	0.77	91	1.21	142	0.74	88	1.31	154
S9	0.17	20	0.24	28	0.17	20	0.25	30	0.16	19	0.27	32
S10	0.03	4	0.04	5	0.03	4	0.05	5	0.03	4	0.05	6

The waters at highest risk are those which receives drainage from acidic, low organic matter soils (S1, S4, S7). Waters receiving drainage from carrot soils are more at risk than waters adjacent potato and grain production areas (Table 26) because of the higher P-application. The risk factors are higher than 1 also when applying mineral fertilisers containing the present level of Cd (low-level Cd).

The difference in risk factors between the two Cd P-fertiliser scenarios is lower in the long-term scenario (2) than in the episodic scenario (1).

5. Discussion

Using the procedure described by ERM (2000) and the best available Norwegian data the risk assessment of Cd in mineral P-fertilisers is performed. The risk characterisation of human health, soil and water presented in this report is encumbered with uncertainties. This is first of all due to the lack of representative Norwegian data for the distribution coefficient for Cd in soils, the content of Cd in soils, algorithms for the uptake of Cd in different crop species and data for the water balance in soils in different regions. When the risk assessment for Cd in mineral P-fertilisers is based upon algorithms and calculations without almost any empirical data, the possibility for misjudgements are impending and highly probable.

More systematic investigations on a local, regional and national scale have to be initiated to make the different parts of the risk assessment more reliable both for short-term and long-term scenarios.

Investigations must include

- studies on uptake of Cd in crops used for human consumption and how soil properties like pH, soil organic matter, soil texture and soil solution chemistry (and others) influence the uptake of Cd. Such studies must be performed both at field and laboratory scales and in the most important agricultural regions in Norway
- studies on how the water balance in Norwegian soils influence transport, retention and plant uptake of Cd. Data on the significance of macropore transport and erosion processes for particle bound and soluble Cd is of great importance for the residence time of Cd in soils

The MOS and risk factors calculated depend to a large degree on the N(L)OAEL and PNEC values used. These values are proposed by ERM (2000). The relevance of their applicability for Norwegian conditions has not been evaluated in full. Values used are assumed to be the most relevant for Norwegian conditions but more experimental data based upon Norwegian environmental conditions should make the basis for more relevant national PNEC-values.

6. Conclusions

Future application (100 years) of mineral P-fertilisers containing the present level of Cd (2.3 mg Cd kg^{-1} P_2O_5) results in minor changes in soil Cd concentrations. For human health the margin of safety (MOS) using fertiliser with this level of Cd is in the range 4-7 depending on the No (Lowest) Observable Adverse Effect Level (N(L)OAEL). Taking into consideration the uncertainties in the N(L)OAEL the results from the model calculations indicate that the future application of Cd to soils from mineral P-fertilisers should be kept at as low level as possible. Using mineral P-fertilisers containing 60 mg Cd kg^{-1} P_2O_5 (EU level), MOS decreases by approximately 40%.

The level of no effect concentrations for organisms in Norwegian soils and waters are uncertain and the representativeness of the suggested PNEC values for Norwegian conditions questionable. The calculations performed indicate however that organisms in surface waters seem to be at higher risk from Cd in mineral P-fertilisers than soil living organisms

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8. Appendix

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Appendix 1

Calculated values for k_i:

$$k_i = \frac{g\,Cd\,ha^{-1}\;year^{-1}}{10^4 \cdot r \cdot d_p}, (mg\,kg^{-1}\;year^{-1})$$

g Cd ha^{-1} $year^{-1}$ = input of Cd (from Table 9)

ρ = soil bulk density (kg m^{-3})

d_p = depth of plough layer (0.25m)

		Sum Cd application			
		g Cd ha^{-1} $year^{-1}$		k_i (mg kg^{-1} $year^{-1}$)	
	Crop rotation	Present level Cd	EU level Cd	Present level Cd	EU level Cd
Region 1	Grains	1.13	4.04	0.00038	0.00137
	Potato	0.97	4.93	0.00033	0.00167
	Carrot	1.03	6.31	0.00035	0.00214
	Gras	1.09	5.71	0.00037	0.00194
Region 2	Grains	0.63	3.54	0.00021	0.00120
	Potato	0.67	4.63	0.00023	0.00157
	Carrot	0.73	6.01	0.00025	0.00204
	Gras	0.74	5.36	0.00025	0.00182
Region 3	Grains	0.83	3.74	0.00028	0.00127
	Potato	0.87	4.83	0.00030	0.00164
	Carrot	0.93	6.21	0.00031	0.00210
	Gras	1.01	5.63	0.00034	0.00191
Region 4	Grains	0.33	3.24	0.00011	0.00110
	Potato	0.37	4.33	0.00013	0.00147
	Carrot	0.43	5.71	0.00014	0.00193
	Gras	0.46	5.08	0.00016	0.00172
Average Norway	Grains	0.63	3.54	0.00021	0.00120
	Potato	0.67	4.63	0.00023	0.00157
	Carrot	0.73	6.01	0.00025	0.00204
	Gras	0.74	5.36	0.00025	0.00182

Appendix 2

Values for soil bulk density (kg m^{-3}), cadmium and zinc content in agricultural soils in different regions. Data reported in Amundsen *et al*. (2000).

Soil density (kg m^{-3})

Region	No of samples	Mean	Median	Minimum	Maximum
1	102498	1.2	1.18	0.04	1.99
2	36208	1.17	1.19	0.1	1.99
3	15722	0.95	1.01	0.13	1.72
4	16896	1.09	1.1	0.04	1.88
Average Norway	186104	1.1	1.15	0.04	1.99

Cd HNO_3 extractable (mg kg^{-1})

Region	No of samples	Mean	Median	Minimum	Maximum
1	47	0.18	0.17	0.09	0.33
2	64	1.39	1.13	0.04	4.3
3	31	0.21	0.19	0.03	0.4
4	51	0.11	0.11	0.02	0.26
Average Norway	241	0.6	0.24	0.02	4.3

Zn HNO_3 extractable (mg kg^{-1})

Region	No of samples	Mean	Median	Minimum	Maximum
1	118	78	74.5	17.4	199
2	53	112	108	25	282
3	31	25.9	25.9	7.3	157
4	51	65.2	64	27	108
Average Norway	301	71.3	66.7	7.3	282

Appendix 3

Calculated risk factors for water: PNEC=0.39 and 0.0085 µg l^{-1}

		Input of Cd g ha^{-1} $year^{-1}$		Risk factors (PEC/PNEC) 0.0085		0.39	
	Crop rotation	Pres Cd	EU Cd	Pres Cd	EU Cd	Pres Cd	EU Cd
Region 1	Grains	0.12	3.02	13.6	355	0.3	7.7
	Potato	0.16	4.12	18.6	485	0.4	10.6
	Carrot	0.21	5.49	24.8	646	0.5	14.1
	Gras	0.18	4.81	21.7	565	0.5	12.3
Region 2	Grains	0.12	3.02	13.6	355	0.3	7.7
	Potato	0.16	4.12	18.6	485	0.4	10.6
	Carrot	0.21	5.49	24.8	646	0.5	14.1
	Gras	0.18	4.81	21.7	565	0.5	12.3
Region 3	Grains	0.12	3.02	13.6	355	0.3	7.7
	Potato	0.16	4.12	18.6	485	0.4	10.6
	Carrot	0.21	5.49	24.8	646	0.5	14.1
	Gras	0.18	4.81	21.7	565	0.5	12.3
Region 4	Grains	0.12	3.02	13.6	355	0.3	7.7
	Potato	0.16	4.12	18.6	485	0.4	10.6
	Carrot	0.21	5.49	24.8	646	0.5	14.1
	Gras	0.18	4.81	21.7	565	0.5	12.3
Average Norway	Grains	0.12	3.02	13.6	355	0.3	7.7
	Potato	0.16	4.12	18.6	485	0.4	10.6
	Carrot	0.21	5.49	24.8	646	0.5	14.1
	Gras	0.18	4.81	21.7	565	0.5	12.3
	Mean	0.17	4.36	19.7	513	0.4	11.2
	Median	0.17	4.46	20.1	525	0.4	11.4
	Min	0.12	3.02	13.6	355	0.3	7.7
	Max	0.21	5.49	24.8	646	0.5	14.1

Appendix 4

Calculated soil concentrations (mg kg^{-1}) in soil S1-S10 for wheat, potato and carrot production. St state=steady state concentration.

		Grains				Potatoe				Carrot			
		Pres level Cd		EU level Cd		Pres level Cd		EU level Cd		Pres level Cd		EU level Cd	
		100y	St state	100y	St state	100y	St state	100y	St state	100y	St state	100y	St state
S1	0.24	0.13	0.05	0.19	0.16	0.12	0.04	0.21	0.19	0.12	0.04	0.24	0.23
S2	0.24	0.24	0.23	0.33	0.81	0.23	0.19	0.36	0.94	0.22	0.16	0.38	0.94
S3	0.24	0.27	0.84	0.36	2.92	0.26	0.62	0.39	3.02	0.25	0.35	0.42	2.04
S4	0.24	0.19	0.09	0.27	0.32	0.18	0.08	0.29	0.39	0.18	0.07	0.32	0.44
S5	0.24	0.26	0.43	0.35	1.48	0.25	0.34	0.38	1.66	0.24	0.24	0.41	1.42
S6	0.24	0.27	1.19	0.37	4.10	0.26	0.82	0.40	4.00	0.25	0.40	0.42	2.35
S7	0.24	0.18	0.08	0.25	0.28	0.17	0.07	0.28	0.33	0.17	0.07	0.30	0.38
S8	0.24	0.21	0.14	0.30	0.48	0.21	0.12	0.32	0.56	0.20	0.10	0.35	0.62
S9	0.24	0.26	0.58	0.36	2.01	0.26	0.45	0.38	2.18	0.25	0.29	0.41	1.70
S10	0.24	0.27	1.36	0.37	4.71	0.27	0.92	0.40	4.46	0.25	0.42	0.43	2.47