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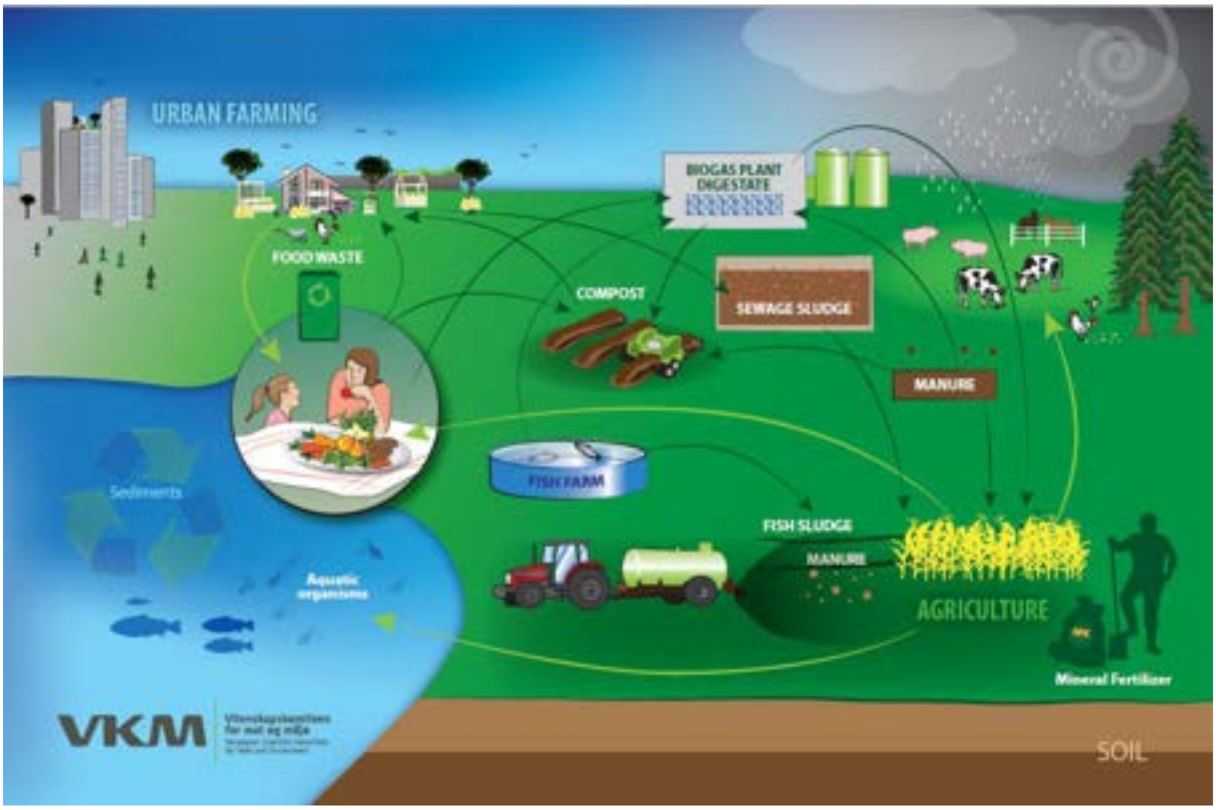

VKM Report 2022: 09

Risk assessment of potentially toxic elements (heavy metals and arsenic) in soil and fertiliser products – fate and effects in the food chain and the environment in Norway

Scientific opinion of the Panel on Animal Feed of the Norwegian Scientific Committee for Food and Environment

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Norwegian Scientific Committee for Food and Environment (VKM)
Po 222 Skøyen
N – 0213 Oslo
Norway

Phone: +47 21 62 28 00
Email: vkm@vkm.no

vkm.no
vkm.no/english

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Risk assessment of potentially toxic elements (heavy metals and arsenic) in soil and fertiliser products – fate and effects in the food chain and the environment in Norway

Preparation of the opinion

The Norwegian Scientific Committee for Food and Environment (Vitenskapskomiteen for mat og miljø, VKM) appointed a project group to answer the request from The Norwegian Food Safety Authority. The project group consisted of 11 persons, and a project leader from the VKM secretariat. Two external referees reviewed and commented the manuscript. The VKM Panel on Animal Feed evaluated and approved the final opinion drafted by the project group.

Authors of the opinion

Members of the project group that contributed to the drafting of the opinion (in alphabetical order behind the chair of the project group):

Trine Eggen – Chair of the project group and member of the Panel on Animal Feed in VKM. Affiliation: 1) VKM; 2) Norwegian Institute of Bioeconomy Research (NIBIO)

Heidi Amlund – Member of the project group and member of the Panel on Contaminants in VKM. Affiliation: 1) VKM; 2) National Food Institute, Technical University of Denmark

Robert Barneveld - Member of the project group. Affiliation: Norwegian Institute of Bioeconomy Research (NIBIO)

Aksel Bernhoft - Member of the project group. Affiliation: Norwegian Veterinary Institute

Gunnar Sundstøl Eriksen - Member of the project group and member of the Panel on Contaminants in VKM. Affiliation: 1) VKM; 2) Norwegian Veterinary Institute

Belinda Flem - Member of the project group. Affiliation: The Geological Survey of Norway (NGU)

Torsten Källqvist - Member of the project group. Affiliation: Former researcher in Norwegian Institute for Water Research (NIVA)

Line Emilie Sverdrup – Member of the project group. Affiliation: Det Norske Veritas (DNV)

Stefan Trapp - Member of the project group. Affiliation: Department of Environmental Engineering, Technical University of Denmark

Anne Falk Øgaard - Member of the project group. Affiliation: Norwegian Institute of Bioeconomy Research (NIBIO)

Tron Gifstad – Project leader in the VKM secretariat. Affiliation: VKM

Members of the VKM Panel on Animal Feed that assessed and approved the manuscript:

In addition to Trine Eggen these were (in alphabetical order before chair of the Panel):

Christiane Kruse Fæste. Affiliation: 1) VKM 2) Norwegian Veterinary Institute

Erik-Jan Lock. Affiliation: 1) VKM 2) Institute of Marine Research Live Nesse. Affiliation: 1) VKM 2) Norwegian Veterinary Institute

Einar Ringø. Affiliation: 1) VKM 2) The Artic University of Norway (UiT)

Håvard Steinshamn. Affiliation: 1) VKM 2) Norwegian Institute of Bioeconomy Research (NIBIO)

Robin Ørnsrud. Affiliation: 1) VKM 2) Institute of Marine Research

Åshild Krogdahl - Chair of the Panel on Animal Feed in VKM. Affiliation: 1) VKM; 2) Norwegian University of Life Sciences

Acknowledgment

VKM would like to thank Augustine Arukwe (Norwegian University of Science and Technology) and Carl Einar Amundsen (The Norwegian Defence Estates Agency) for their valuable comments through critical review of the draft opinion. VKM emphasises that the two referees are not responsible for the content of the final opinion. In accordance with VKM's routines for approval of a risk assessment (VKM 2018), VKM received their comments before evaluation and approval by the Panel and before the opinion was finalised for publication.

VKM would also like to thank Ester Bloem, Stein Turtumøygård og Trond Knapp Haraldsen (Norwegian Institute of Bioeconomy Research) and Andreas Brilke (Stjørdal Municipality) for their valuable help through review of the draft opinion.

Competence of VKM experts

Persons working for VKM, either as appointed members of the Committee or as external experts, do this by virtue of their scientific expertise, not as representatives for their employers or third-party interests. The Civil Services Act instructions on legal competence apply for all work prepared by VKM.

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Summary

Key words: VKM, risk assessment, Norwegian Scientific Committee for Food and Environment, Norwegian Environment Agency, potential toxic elements (PTEs), fertiliser, soil improver, fertiliser products, growing media, circular economy, circulation of organic fertilisers, arsenic (As), cadmium (Cd), chromium Cr(tot) (Cr(III) and Cr(VI)), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), zinc (Zn).

Background and purpose of the report

The potentially toxic elements (PTE) arsenic (As), cadmium (Cd), chromium Cr(tot) (Cr(III) and Cr(VI)), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni) and zinc (Zn) occur as ingredients or contaminants in many fertilisers, soil improvers, engineered soil and growing media. Application of these fertiliser products might represent a risk towards the environment, farm animals and humans, particularly when applied annually over several years. The present risk assessment evaluates the application of selected fertilisers according to certain scenarios for representative Norwegian agricultural areas, from Troms in the North to Ås in Southeastern and Time in Southwestern Norway, with different soil properties, precipitation and PTE concentration in present agricultural soil.

There is an increasing trend to produce locally (e.g. in urban farming) and home-grown vegetables that are cultivated in engineered soil and growth media. The maximum levels (MLs) set for PTEs in different organic fertilisers, engineered soil and growing media for use in urban farming, home growing and the cultivation of vegetables and garden fruits, and a set of MLs also for application in agricultural cultivation of crops, have been evaluated. Environmental fate processes and the transfer of PTEs have been modelled and the environmental risks for terrestrial and aquatic organisms, including from secondary poisoning have been estimated. Potential risks to humans and farmed animals by increased exposure to PTEs from, respectively, agriculturally produced crops, vegetables cultivated at home and urban farming or forage and grazing have been evaluated.

The recycling of nutrients is urgently needed to achieve circular economy, but the derived sustainable products have to be safe, which requires the introduction of and adherence to science-based maximum levels of unwanted substances (e.g. pollutants). This assessment evaluates consequences of the application of different fertiliser products: mineral P fertilisers, manure from cattle, pig, poultry and horse, fish sludge, digestates and sewage sludge - in order to identify PTE sources with potential environmental, animal and human health risks, and to evaluate the appropriateness of the current MLs regarding different applications of organic-based fertilisers, engineered soil and growing media at present, and in a 100-year perspective.

Approach and methods applied

The approach for environmental and health risk assessments builds on previous work performed for hazardous substances in soil (e.g. VKM 2019, VKM 2014, VKM, 2009, Six and Smolders, 2014). Concentrations of PTEs in soil over time were calculated using a mass balance model, which considers the input by atmospheric deposition, use of fertilisers and soil improvers, as well as loss by leaching, run-off and plant uptake. The resulting first-order differential equation was solved analytically and implemented into Excel®. Run-off and loss by leaching were estimated from data on precipitation, infiltrating fraction and run-off fraction of the water under consideration of the distribution coefficient Kd for the concentration ratio of bulk soil-to-water. This Kd value takes aging sufficiently into account and is thus more realistic than those derived from batch tests. The Kd was estimated separately for each region using established regression equations, with soil pH, organic matter content and clay content as predictors. Relevant criteria for the selection of Kd-regression equations were comprehensiveness (sources with regressions for more than one PTE were preferred), applicability (predictor variables for Norwegian soils known), realism (conditions comparable to those in Norwegian agriculture, i.e. field studies) and quality of documentation (of methods, units). Consequently, most Kd-values were chosen from Sheppard (2011). Predictive simulations were made for a period of 100 years. The primary model output was the predicted environmental concentration (PEC) in soil (PEC_{soil}) and plants (PEC_{plants}), as well as loss (g ha^{-1} $year^{-1}$ or %), from which secondary output values such as concentrations in surface water (PEC_{sw}) and sediments (PEC_{sed}), and the exposure of farm animals and humans were derived. Uptake into plants was calculated using measured transfer factors (TF), specific for each crop and PTE, and the concentrations in the harvest plants (PEC_{plant}) were derived from multiplication of the specific TF with the concentration in soil for the given scenario. TFs were selected based on literature review, using the same criteria as for the Kd values. Most TF-values were taken from a comprehensive recent study in Central Europe (Novotna et al. 2015) and from the US EPA Soil Screening Guidance (US EPA 1996).

For predicting the PTE uptake in vegetables and garden fruits cultivated in home growing and urban farming, the regulated maximum limits (MLs) in organic-based growing media and engineered soil were used as soil concentrations in the modelling. PTE loss by leaching over time was not included in the estimation.

In the model used to calculate the transport of PTEs to surface water, the water leaving the soil by leaching and runoff was assumed to end up in an adjacent surface water recipient. The distribution of PTEs between the dissolved and adsorbed fractions were described by specific Kd factors for each PTE/soil combination. The model was designed to simulate a watercourse, which receives leaching and runoff from agricultural soils with a constant dilution factor of 10. The output parameter was the concentration of PTE dissolved in surface water, PEC_{sw}, which is the predicted exposure concentration for aquatic organisms. The calculated PEC_{sw} took the background concentration of PTEs in the receiving water, the adsorption to suspended solids in the receiving water and the runoff water into account. The exposure concentration of sediment dwelling organisms (PEC_{sed}) was calculated from the

PEC_{sw} using PTE-specific sediment/water partitioning coefficients. Most coefficients used for the calculation of partitioning between suspended matter and water, or sediment and water, were taken from a comprehensive review by Allison & Allison (2005).

Selected case areas, PTE sources, and evaluation of relevant regulations

Soil properties, climatic conditions, agricultural practices, crop rotations and crop yield vary considerably throughout Norway. Considering the regional differences, five major agricultural regions were included in the risk assessment –northern Norway (case area Målselv municipality); Mid-Norway (case area Melhus municipality); Hedmark region (case area Stange municipality; and case area alum shale region); Southeastern Norway (case area Ås municipality); southwestern Norway (case area Time municipality). Alum shale has naturally high contents of elements such as As, Cd and Ni, and soil samples classified as alum shale from areas in Hedmark have been treated as a separate case. The only difference in the evaluation of case areas alum shale and Stange was the actual concentration of PTEs in the agricultural soil, all other parameters as well as input sources were the same.

Specific application rates for different fertilisers and soil improvers were used in the calculations. Moreover, the measured mean PTE concentrations were used except for cattle and pig manure, where also measured maximum PTE values were included. The estimated contribution of atmospheric PTE was included in the application rate of the fertiliser scheme, but also evaluated as a separate input source for PTEs. In addition, five sets of MLs for organic fertiliser, soil improvers, engineered soil and growing media were evaluated.

It was decided to use the same atmospheric PTE contribution for all over Norway even if regional sources are known to contribute to some extent. The predicted contribution was based on a worst-case approach using total excess of PTE influx over 200 years. The estimated PTE contribution from wet deposition based on data from The Norwegian Institute for Air Research, NILU, including only rain and not dry deposition, was thus reflecting a lower limit estimate.

Assessment methods

Terrestrial and aquatic organisms (PNEC)

The risk assessments of PTEs for terrestrial organisms including agricultural plants, and to aquatic organisms in surface waters and sediments, were based on predicted no-effect concentrations (PNEC) and environmental quality standards (EQS) as formulated in the European Council Regulation (EEC) 793/931 on the evaluation and control of the risks of "existing" substances, and Council Directive 2008/105 EC on environmental quality standards in the field of water policy.

To assess the risk caused by PTEs, the risk characterisation ratio (RCR) was calculated as PEC/PNEC for each PTE and environmental compartment (soil, surface water and sediment). A risk was identified, when PEC was higher than PNEC, i.e. when RCR>1

Farm animals (MTL)

The predicted PTE intake in farm animals by grazing or feeding on compound feeds today and in a 100-year perspective under consideration of the various organic fertilising schemes was calculated based on the average dietary intake relative to the body weight of different livestock species at different physiological stages, combined with common diet composition. The data were adapted to Norwegian practices.

For the risk assessment of PTEs in farm animals, maximum tolerable levels (MTL) in feed were used, as proposed in international research reviews, in particular the Mineral Tolerance of Animals by NRC (2005).

Humans

For humans, changes in the dietary exposure considering the different fertilising schemes were not determined.

The assessment of human risk from dietary exposure to PTEs was based on available international risk assessments using established health-based guidance values (HBGVs) such as Tolerable Daily Intake (TDI), Tolerable Weekly Intake (TWI), and Benchmark dose modelling (BMDL). The significance of using fertilisers for the extent of the human exposure to PTEs was determined by considering potential changes in PTE concentrations in plants and comparing the contribution of these plants to the previously estimated total dietary intake.

RESULTS

Regional differences due to environmental factors and fate processes

Norway has a high geological variation, and regional differences highly influence the outcome of the risk assessment from PTE exposure. The present concentrations in soil are decisive factors for the modelling of PTE concentrations in soils, determining accumulation or decrease, so that regional differences in the PTE concentrations greatly influence their fate in the environment and the connected risks. The predicted increase (or decrease) depends on the ratio of input to loss. If the annual input exceeds the annual loss, the concentrations of PTE in soil increases. The loss is proportional to the amount of PTE present in soil, meaning that the loss increases with increasing concentrations. Thus, the same PTE input can lead to a concentration increase at one site/in one region increases, while it leads to a decrease in another region. This can e.g. be observed in the Stange area as compared to the alum shale area, which both are situated in Hedmark. The highest percent (%) increase is thus predicted for regions with the lowest present concentration, although the actual concentrations are the highest in regions with already high backgrounds.

Soil properties (particularly pH and organic matter, but also clay content) and precipitation are factors influencing regional differences, which in addition to the inherent molecular properties of the PTEs can influence their environmental fate and derived risks. For instance, Time, in southwestern Norway, is the case area with the highest annual precipitation and shows the highest % loss of PTEs related to the present concentration in soil, particularly with regard to Cd and Ni, which are elements with low Kd and low binding affinity to soil. In contrast, Målselv and Stange are the case areas with the lowest annual precipitation, low present concentrations for most PTEs. Nevertheless, is Stange the region with the highest increase for many PTEs in the different calculated scenarios.

The loss of PTEs via leaching and run-off was typically one order of magnitude higher than their removal via plant harvesting except for Hg, where plant removal was more relevant. Ongoing climate change can be expected to result in increased fluxes from soil to water, especially for the most mobile PTEs. Different pathways for PTE transport (runoff, drainage, deep percolation) are likely also affected by changes in weather patterns. Higher flood frequencies will probably cause high PTE fluxes to surface waters, as well as (temporary) waterlogging. In the summer period, dry spells are expected to get prolonged. Transport through the macropores and cracks in dry soils, especially clay rich profiles, will also result in a quick flushing of soil profiles, when precipitation occurs. Longer periods with waterlogging might influence the extent of element speciation, e.g. the methylation of Hg.

The same contribution from atmospheric PTE deposits was considered for all scenarios performed for Norwegian regions, even if regional sources are known to contribute additionally to some extent. The predicted contribution was based on a worst-case approach using the total excess of PTE influx over 200 years. The estimated PTE contribution from wet deposition based on data from NILU include only rain and not dry deposition, and thus reflected a lower limit estimate.

Environmental risk - current

The present concentrations of PTEs in soil (PEC_{soil}) are below the predicted no-effect concentrations ($PNEC_{soil}$), indicating that there is no environment risk connected with all considered PTE elements except for Ni. In the alum shale area, the $PNEC_{soil}$ for Ni was exceeded, indicating a toxic risk to terrestrial organisms by direct exposure and by secondary poisoning. However, it is likely that the bioavailability of Ni originating from alum shale minerals is lower than from anthropogenic sources, an issue that has not been considered in the model.

The calculated present PTE concentrations in surface water and sediments are derived from the concentrations measured in soil. Only the Cd concentration exceeded the predicted no-effect concentrations in surface water ($PNEC_{sw}$), especially in the Alum shale area but also in Time. A low risk for adverse effects caused by Ni in surface water was indicated for Målselv, Melhus and the alum shale region. For Zn, a notable risk was indicated for effects on sediment-dwelling organisms in all regions. The regions, where environment risks are indicated with regard to the present concentrations of some PTEs exceeding the respective PNECs for terrestrial and aquatic organisms, are presented in Table Summary A.

Table Summary A. Identified risks for environmental effects of PTEs on terrestrial and aquatic organisms by the present concentrations in soil, surface water and sediments. Risk Characterisation ratios (RCR = PEC/PNEC).

PTE	Risk, Terrestrial (RCR)	Risk. Surface water (RCR)	Risk, Sediment (RCR)
As			
Cd		Alum shale (2.6), Time (1.3)	
Cr		Melhus (1.0)	
Cu			
Hg			
Ni	Alum shale (1.1), Secondary poisoning: Alum shale (2.3), Melhus (1.0)	Målselv, Melhus, Alum shale (1-1.7)	Alum shale (1.9)
Pb			
Zn			All regions (1.3-2.2)

Accumulation

For some PTEs the atmospheric contribution alone is sufficient to cause accumulation and increasing concentrations in soil. The model estimates predict accumulation of Hg in all regions, while Pb accumulates in all regions except for Time, where the high precipitation is predicted to cause a higher loss by leaching.

With the additional input of PTEs from fertilisers, increased accumulation is expected. The scenarios and regions that contributed considerably to PTE accumulation are:

Organic fertilisers quality class II (scenario #2, see footnote Table B) (regulation – MLs)

- As: Målselv, Melhus, Stange, Ås and Time
- Cd: Målselv, Melhus and Stange
- Cr: Målselv, Stange, Alum shale, Ås and Time
- Cu, Pb, Hg and Zn: All regions

Sewage sludge (#3, see footnote Table B)

- Cd: Melhus, Stange
- Cr: Stange
- Cu. Hg and Pb: All regions

Cattle and pig manure, max. conc. (#4, see footnote Table B)

- Cd and Cr: Stange
- Cu, Hg and Pb: All regions
- Zn: Målselv, Melhus, Stange, Alum shale and Ås

All scenarios leading to more than 10% accumulation after 100 years are indicated in Table Summary B.

Environmental risk – 100 years

In some cases, PTEs are predicted to accumulate to concentrations causing an environmental risk in soil, surface water or sediments in regions, where the present concentrations are below the level of concern:

Organic fertilisers quality class 2 (#2)

- Cd: Stange (surface water)
- Cr: Målselv, Stange, Alum shale, Ås and Time (soil)
- Hg: All regions (Secondary poisoning), Time (soil)

Cattle and pig manure, max. conc. (#4)

- Zn: Stange and Alum shale (soil)

Scenarios, where environmental risks were predicted in a 100-year perspective are shown in Table Summary B.

Table Summary B. Scenarios predicting increasing PTE concentrations (accumulation) and risk to terrestrial and aquatic organisms after 100 years.

PTE	Accumulation >10% (soil)	Risk, Terrestrial	Risk, Surface water	Risk, Sediment
As	#2, most regions			
Cd	#2 (Målselv, Melhus, Stange), #3 (Melhus, Stange), #0b, #4 (Stange),		#0a-10 (Alum shale), #2 (Stange, Alum shale)	
Cr	#2 (most regions)	#2 (most regions)	#2 (Melhus)	
Cu	#2, #3, #4, #7, #8, #9, #10, (most regions)			#2 (Alum shale and Time)
Hg	#0a, #1, #2, #6, #7, #8, #9 (all regions)	#2 (Time), Secondary poisoning (all regions)		
Ni		#0a-10 (Alum shale), Secondary poisoning	#0a-10 (Alum shale)	#0a-10 (Alum shale)
Pb	#0a, #1, #2, #3, #4, #5, #6, #7, #8, #9 (most regions)			
Zn	#2, #3, #4, #5, #6, #7, #8, #10 (several regions)	#4 (Stange, Alum shale)		#0a-10 (most regions)

#0a: Atmospheric contribution, **#1**: Mineral P fertilisers, **#2**: Regulation organic fertilisers, **#3**: Sewage sludge. **#4**: Cattle & pig manure (max), **#5**; Cattle & pig manure (mean), **#6**: Fish sludge, **#7**: Digestate (food waste & manure), **#8**: Digestate (food waste), **#9**: Horse manure, **#10**: Poultry manure

Evaluation of predicted concentrations in crops including vegetables, garden fruits, and mushrooms

Predicted transfer and concentrations of PTEs in crops and vegetables follow the same trends over time as presented for soil with respect to the annual application of selected fertilisers in accordance to the MLs stated in the regulation for organic fertilisers of quality class II. Since human exposure to As, Cd, Hg and Pb is already high and no further increase is desired, these elements are in focus.

The concentrations of these PTEs will increase over time for one or more applications scenarios. Due to the high natural concentrations of many these elements in alum soil, the highest concentrations of several PTEs in crops were estimated to occur in the alum shale area. For Cr, the highest concentration in crops was predicted for the case area Melhus and for Hg and Pb for the case area Time.

The comparison of five sets of MLs for organic fertiliser regulation, showed that the highest MLs are set for the quality class 2 in the Norwegian regulation (scenario growing media) with regard to Cd and Hg, and for CE-labelled growing media with regard to As and Pb in the respective EU regulation. The MLs used for engineered soil (scenario exemplifying home growing in engineered soil) were similar or lower than these MLs. The MLs used in the scenario for growing media organic fertiliser regulation quality class 0 were lower for all PTEs except for Zn (similar) as the MLs considered for engineered soil.

Comparing the predicted concentrations of As, Cd, Hg and Pb in carrot and potato cultivated in alum shale using the present soil concentrations with the levels predicted for the application of organic fertiliser products according to quality class 2 (#2), and carrot and potato cultivated in engineered soil (two sets of MLs) and growing media (three set of MLs), vegetables in agricultural soil have lower concentrations of Hg and Pb than cultivated for private and urban growing for.

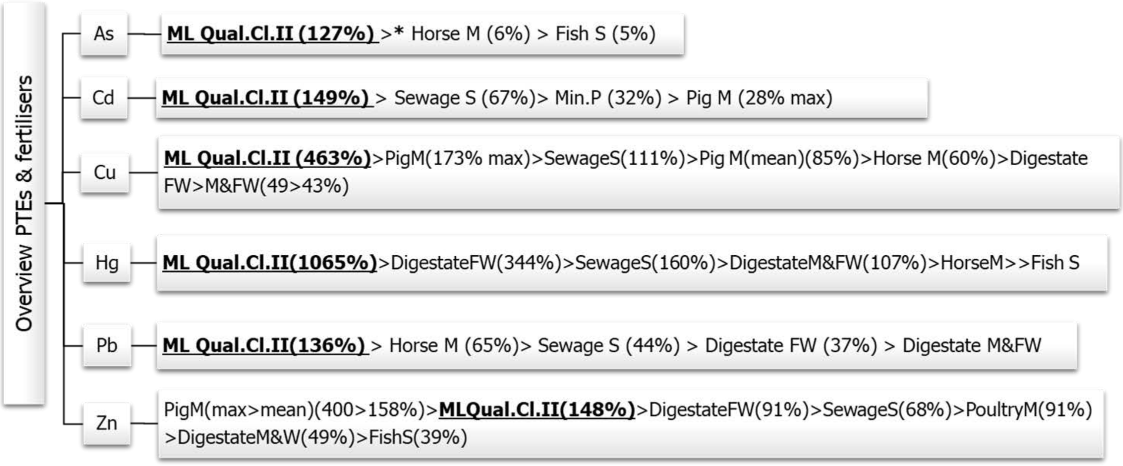
These calculations showed that the As concentration in carrot and potato cultivated in CE-labelled growing media represented the only case, where the predicted concentration was higher than in carrots and potatoes that are cultivated in agricultural soil (at present and after 100 years).

A similar pattern was found for Cd, with the exception that the highest concentrations were estimated for vegetables cultivated in growing medium with MLs according to the Norwegian organic fertiliser regulation, quality class 2. The chosen transfer factor (TF) for Cd in carrot was found to underestimate the modelled concentration as compared to the measured values.

For persons consuming considerable amounts of mushrooms (mushroom enthusiast), cultivated mushrooms could be an important additional dietary source of PTEs. The estimated concentrations in edible mushrooms cultivated on agro-industrial wastes, using the same three set of MLs, which were evaluated for growth media, and selected TFs for Cd, Cu, Hg and Zn resulted in high levels compared to presented in literature. However, due to high bioaccumulation factors reported for Cd, Cu, Hg and Zn in the literature give reason to call for more knowledge of transfer of these elements to cultivated mushroom, and if people with high intake of cultivated mushroom have an additional exposure source for these PTEs.

Comparison of estimated and measured data

Overall, agreement between estimated and measured concentrations of PTEs in crops was satisfactory, despite a few deviations. The correct prediction of PTE concentrations in crops would require that the measured levels in soil were representative for the investigated area, and that the soil-to-crop transfer factors (TF) chosen are representative for the areas. The TF applied for Cd in carrot was found to result in an underestimation as compared to the measured values, and the scenario calculation was repeated with a higher TF. Given the mentioned large variations both, in the actual soil and crop concentrations and the many influencing parameters, processes and factors, a successful prediction of PTE concentrations is dependent on the selection of adequate input parameters.



M:manure, S:sludge, FW: food waste, *use of Upper-Bound-values for cattle and pig manure gave 6% increase but not included in the figure.

Figure Summary A Overview of PTEs with increasing PEC_{soil} in 100-year perspective after application of the selected input sources in the scenario calculations. Only the region with the highest increase is shown.

Farm animals

Regarding the elements of potentially most toxic concern, Cd, Hg and Pb, the current levels in animal diets are generally far below the levels that are evaluated to be of risk to animal health. Considering the common practices for organic fertiliser applications and the connected PTE levels in compound animal diets, it is expected that the levels of these heavy metals will further decline (following the same trend as described above). However, there are some scenarios, which predict an increase of the Cd, Hg and Pb levels in animal diets. Using the maximum levels for PTEs and the maximum application rate permitted in the regulation for organic fertiliser quality class II (#2) for the prediction of concentrations resulted in increasing levels over a 100-year period, but they were nevertheless below the levels of concern for animal health. The Hg content in animal diets is also expected to rise by using digestate (food waste) as fertiliser, and Pb is expected to somewhat increase by using horse manure. Because Cd, Hg and Pb are potential toxic elements without physiological functions, it is an important goal to keep their levels as low as possible.

The current level of As in animal diets is also far below the level evaluated as maximum tolerable in animals. Considering the most common fertiliser application scenarios, the temporal trend of As in animal diets added by grazing and feeding stuffs is expected to decrease. However, if the maximum PTE levels stated in the regulation for organic fertiliser quality class II were used in the scenario calculation (#2), an increase of As was predicted, particularly in regions with currently low soil As concentrations such as in Stange. However, the levels expected after 100 years of fertiliser application would still be far below the level of concern for health risks in farm animals.

In all regions, the current levels of Cr and Ni in animal diets added by pasture and feeding stuffs are far below the maximum tolerable levels. For Ni, a decline was predicted in all scenarios. Comparably, it was predicted that the Cr levels in animal diets will further decline, with the exception of scenario #2 using the maximum allowed levels for organic fertiliser quality class II, which implied an increase in most regions. The increase of Cr would, however, not present a health risk for farm animals as it mostly occurs in its low-toxic trivalent state.

The same development was predicted for Cu, when the maximum levels stated in the quality class II organic fertiliser regulation (#2) were used in the scenario calculation, resulting in increased levels in animal diets. In Stange, and particularly in the alum shale area, the soils contain elevated Cu levels that are considered to be harmful for grazing sheep (maximum tolerable dietary levels 15 mg kg^{-1}). For other farm animals, these levels are considered to pose no risk. Moreover, the application of pig manure (#4) in the alum shale area with already elevated background Cu levels could increase the Cu even more to levels posing a risk to grazing sheep.

The background levels of Zn in the different Norwegian regions considered are below the level of concern for animal health. The application of quality class II organic fertilisers at the maximum levels stated in the regulation (scenario #2) could lead to a slight increase of Zn in all regions. However, the highest increase of Zn in animal diets would be caused by the use of pig manure (scenario #4) in Stange (430 % increase) and in the alum shale area (160 %). But even after 100 years of applying fertilisers according to scenario #4, grazing animals in Stange and the alum shale area would not be dietary exposed to Zn levels of concern. The use of pig manure will also lead to an increase of the Zn levels in soil and animal diets in other regions, but to a lower extent than in Stange and the alum shale area.

The increase of Zn and Cu levels through the use of pig manure results from the high Zn and Cu contents in pig diets. The dietary exposure of animals at levels above the physiological requirements may potentially induce problems with regard to the development of bacterial resistance, but this situation is not very likely to occur under the conditions assessed in the performed scenarios. Thus, the risk that the Zn or Cu levels predicted in the scenarios for fertilising with pig manure could lead to microbial resistance problems against these elements in animal guts and the environment and possibly co-resistance to antimicrobial drugs is considered as low.

Humans

The application of quality class 2 organic fertilisers at the maximum levels (MLs) regulated in Norway (scenario #2) is predicted to lead to an increase in the concentrations of As, Cd, Pb and Hg in agricultural crops (wheat, carrots and potatoes) in some regions (Målselv, Melhus, Stange and Ås). The consumption of these crops will lead to increased dietary exposure. Since the dietary exposure levels to As, Cd and Pb are already high in the Norwegian population, further increase is not desirable. For Hg, the contribution from the consumption of crops will be small compared to the contribution from fish and other seafood.

According to the modelled scenarios, the use of engineered soil and growing media is expected to lead to an increase of PTE concentrations in vegetables and fruits, especially concerning As, Cd, Hg and Pb. Since dietary exposures to As, Cd and Pb are already in the range of or exceeding the health-based guidance values, any increase in exposure levels from the consumption of crops is not desirable.

In a study investigating consequences of urban farming in Copenhagen, Denmark, potential human health risks from exposure to heavy metals in the produced products were evaluated (Warming and Hansen 2013, Warming et al. 2015).

Analyses showed that the highest contaminated soil situated on a former landfill contained 21.8, 2.6, 591, and 1298 mg kg^{-1} dry weight (DW) of As, Cd, Pb and Zn, respectively. In comparison, mean and maximum concentrations of As, Cd and Zn in alum shale (Appendix I) were 21 and 66 mg kg^{-1} DW, 1.2 and 4.4 mg kg^{-1} DW, and 38-110 and 110-360 mg kg^{-1} DW, respectively. The mean and maximum concentrations of Pb in Southwestern Norway were 27 and 96 mg kg^{-1} DW, respectively. The main risk for humans identified in this study was exposure to Pb from direct soil ingestion, which was of particularly concern for children.

Uncertainties and knowledge gaps

The sensitivity of the input parameters for the mathematical model used in the scenario calculations was assessed. For all PTEs, the present (initial) concentrations in soil and the Kd had the greatest influence on the results. The Kd was estimated based on the pH in soil (except for Cr and Hg where fixed Kd was used), so that the pH had a high impact on the predicted concentrations. In the prediction of PTE levels for a 100 year-perspective, the input of PTEs from air or with fertilisers contributed significantly to the results, while it had less impact for shorter periods (≤ 10 years). For the estimation of PTE concentrations in crops, TF was very important, and for the calculation of PEC_{sw}, the dilution factor played an important role.

The identified relevant data gaps and known assessment weaknesses include:

- Few analyses are available that report the present concentrations of PTEs in soil, surface water and crops, and there is no harmonised sampling and analysis procedure for such samples. The present PTE soil concentration is one of the most important factors (high sensitivity) for the outcome of the risk evaluation, and the lack of adequate data is thus one of the most important knowledge gaps.

- The evaporation of Hg from soil is not included in the models used in this assessment because of knowledge gaps and the lack of relevant data. This uncertainty might have influenced the predicted high increase of Hg in soil, also with regard to the atmospheric contribution alone.
- Only a few analyses are available that report the present concentrations of PTEs in fertilisers
- No available data of Hg, Cr and As speciation in fertiliser products, and very little knowledge of their fate and toxicity in the environment.

Other factors adding uncertainty to the conclusions include:

- Use of median and mean values of PTEs instead of performance of a full probabilistic assessment
- There is a large variation in agricultural practices and yields, and for this assessment, a set of data for crop rotation and fertilisation frequency for each case area had to be selected. Alternative crop rotations were calculated, but the results showed that the variation between crop rotations and PTE concentrations was low, typically 5%, so that they were considered as insignificant for the modelling.
- Some of the determined environmental tolerance thresholds (PNECs) are based on limited data sets. For As, Hg and Cr, particularly for sediment dwelling organisms, the calculated PNECs are therefore associated with a larger uncertainty.

Sammendrag på norsk

Stikkord: VKM, risikovurdering, Vitenskapskomiteen for mat og miljø, Miljødirektoratet, potensielle giftige elementer (PTE), gjødsel, jordforbedringsmiddel, vekstmedie, sirkulær økonomi, sirkulasjon av organisk gjødsel, arsen (As), kadmium (Cd), krom Cr(tot), (Cr(III) og Cr(VI)), kobber (Cu), bly (Pb), kvikksølv (Hg), nikkel (Ni), sink (Zn).

BAKGRUNN OG MÅL MED RAPPORTEN

De potensielt giftige grunnstoffene (potentially toxic elements – PTE) arsen (As), kadmium (Cd), krom Cr(tot), (Cr(III) og Cr(VI)), kobber (Cu), bly (Pb), kvikksølv (Hg), nikkel (Ni) og sink (Zn) forekommer i mange typer gjødsel, jordforbedringsmidler, jordblandinger og vekstmedier. Bruk av slike produkter som gjødsel kan utgjøre en risiko for miljøet, husdyr og mennesker, spesielt når bruken gjentas over flere år. Samtidig er resirkulering av næringsstoffer er avgjørende for å oppnå sirkulær økonomi, men resirkuleringen må være trygg både for miljøet og for helsa til dyr og mennesker. Det krever blant annet en vurdering av potensielle skadelige effekter av uønskede forbindelser (f.eks. forurensninger) i produktene som resirkuleres. Vurderingene må inneholde en helhetlig vurdering av miljø og helse og være basert på en vitenskapelig tilnærming. I denne risikovurderingen har vi vurdert mulige konsekvenser av bruk av ulike gjødselprodukter for å identifisere gjødselvarer som PTE-kilder med potensiell risiko for miljø og helse for dyr og mennesker. Vi har også vurdert hvor hensiktsmessige gjeldende maksimumsnivåer er. Vurderingen omfatter bruk av mineralsk P-gjødsel, gjødsel fra storfe, gris, fjørfe og hest, fiskeslam, og avløpsslam i dag, og i et 100-års perspektiv. Bruken er vurdert ut fra representative scenarioer for dyrkingspraksis i utvalgte norske jordbruksområder med ulike jordegenskaper, klima (temperatur og nedbør) og PTE-konsentrasjoner i dagens jordbruksjord.

Det er en økende trend å produsere mat lokalt, f.eks. i urbant jordbruk og hjemmedyrking av grønnsaker i jordblandinger og vekstmedier. Prosjektgruppen har vurdert maksimumsnivåene (ML) som er satt for PTE-er i forskjellige typer jordblandinger og vekstmedier for bruk i urbant jordbruk og hjemmedyrking, samt evaluert organisk gjødsel og jordforbedringsmidler som brukes i jordbruket, både med gjennomsnittlige PTE-nivåer og ML-verdier. Prosjektgruppen har modellert transport av grunnstoffene i miljøet og overføring av PTE-er fra jord til planter, næringskjeden og vann, og estimert miljørisikoen for terrestriske og akvatiske organismer, inkludert sekundær forgiftning. Potensiell risiko for mennesker ved økt PTE-eksponering fra jordbruksprodukter, grønnsaker dyrket hjemme eller i urbant jordbruk, og for husdyr ved PTE-eksponering fra grovfôr og beite, er også evaluert.

TILNÆRMING OG ANVENDTE METODER

Tilnærmingen for miljø- og helserisikovurderingen bygger på tidligere arbeid utført for farlige stoffer i jord (f.eks. VKM 2019, VKM 2014, VKM, 2009, Six og Smolders, 2014).

Konsentrasjoner av PTE i jord over tid ble beregnet ved hjelp av en massebalansemodell, som tar hensyn til tilførselen av PTE ved bruk av gjødsel og jordforbedringsmidler. Modellen inkluderer også atmosfærisk avsetning, og tap av PTE ved utlekking, avrenning og planteopptak. Tap av PTE ved utlekking og erosjon ble estimert ut ifra data om nedbør, avrenning, infiltrasjons-egenskapene i jorda, og fordelingskoeffisienten Kd for konsentrasjonsforholdet mellom PTE i jordpartikler og jordvæske. Denne Kd-verdien tar større hensyn til binding i jord over tid og er dermed mer realistisk enn verdiene som er utledet fra batch-tester. Kd ble estimert separat for hver region ved bruk av etablerte regresjonsligninger, og regionale verdier for pH, organisk materiale og leirinnhold. Unntaket var for Hg og total Cr, hvor det ble brukt fast Kd. Kriterier for valg av Kd-regresjonsligninger var flere; kilder med regresjonsligninger for mer enn én PTE ble foretrukket, anvendbarhet, dvs. parametere som er kjent fra norske feltstudier på jordbruksjord, var foretrukket, og kvaliteten dvs. dokumentasjonen av metode, enheter osv. Med disse kriteriene ble de fleste Kd-verdier valgt fra Sheppard (2011). Modellen simulerte: predikert miljøkonsentrasjon (PEC) i jord (PEC_{jord}) og i planter ($PEC_{planter}$), tap av PTE-er fra jord oppgitt som g per hektar per år (g ha^{-1} $år^{-1}$) eller %. Basert på disse verdiene ble PTE-konsentrasjoner i overflatevann ($PEC_{overflatevann}$) og sediment ($PEC_{sediment}$) beregnet. Verdiene ble videre brukt til å beregne PTE-eksponering for organismer som lever i jord, vann og sediment, og husdyr og mennesker som spiser fôr og mat dyrket i de valgte regionene.

Opptak i planter ble beregnet ved å bruke opptaksfaktorer (jord til planter (TF)) for korn, gras, potet og gulrot. Konsentrasjonene i planter ble beregnet for hver region og scenario basert på konsentrasjon i jord og de valgte TF for hver enkelt PTE og plantesort. TF-er ble valgt basert på litteraturgjennomgang, ved å bruke de samme kriteriene som for Kd-verdiene. De fleste TF-verdiene er hentet fra en omfattende studie i Sentral-Europa (Novotna et al. 2015) og fra US EPA Soil Screening Guidance (US EPA 1996).

For å forutsi PTE-opptaket i grønnsaker, bær og frukt ved hjemmedyrking og urbant jordbruk, ble maksimumsnivåene (ML) i forskriften om organisk-baserte vekstmedier og jordblandinger brukt som jordkonsentrasjoner i modelleringen. PTE-tap ved utlekking over tid ble ikke inkludert i estimeringen.

I modellen som ble brukt for å beregne transport av PTE-er til overflatevann, ble vannet som forlater jorda ved utvasking og avrenning antatt å havne i en tilstøtende overvannsresipient. Fordelingen av PTE mellom de oppløste og adsorberte fraksjonene ble beskrevet av spesifikke Kd-faktorer for hver PTE/jord-kombinasjon. Modellen ble designet for å simulere et vassdrag, som mottar utvasking og avrenning fra jordbruksjord med en konstant fortynningsfaktor på 10. Utgangsparameteren var konsentrasjonen av PTE oppløst i overflatevann ($PEC_{overflatevann}$), som er den predikerte eksponeringskonsentrasjonen for vannlevende organismer. Den beregnede $PEC_{overflatevann}$ tok bakgrunnskonsentrasjonen av PTE i mottaksvannet, adsorpsjonen til suspenderte faste stoffer i mottaksvannet og avrenningsvannet i betraktning. Eksponeringskonsentrasjonen av sedimentlevende organismer (PEC_{sed}) ble beregnet fra $PEC_{overflatevann}$ ved bruk av PTE-spesifikke sediment/vann-fordelingskoeffisienter. De fleste koeffisientene som ble brukt for å beregne fordeling mellom suspendert materiale og vann, eller sediment og vann, ble hentet fra en omfattende gjennomgang av Allison & Allison (2005).

Valgte jordbruksregioner, gjødselvarer, og evaluering av relevant regelverk

Jordegenskaper, klimatiske forhold, jordbrukspraksis, vekstskifte og avling varierer betydelig i Norge. For å dekke regionale forskjeller, ble fem store jordbruksregioner inkludert i risikovurderingen: Nord-Norge (caseområdet Målselv); Midt-Norge (caseområdet Melhus); Hedmarksregionen (caseområdet Stange, og med alunskiferområder i Hedmark som en separat region); Sørøst-Norge (caseområdet Ås kommune); sørvest-Norge (caseområdet Time). Alunskifer har naturlig høyt innhold av grunnstoffene As, Cd og Ni, og jordprøver klassifisert som alunskifer fra områder i Hedmark er behandlet som et eget tilfelle. Den eneste forskjellen mellom områdene alunskifer og Stange var konsentrasjonen av PTE i jordbruksjorden. Alle andre parametere, samt tilførselskilder, var de samme.

Informasjon om tilførselsmengder av ulike gjødselmidler ble innhentet fra Norsk Landbruksrådgiving og brukt i beregningene. For jordforbedringsmidler ble tillatt tilførselsmengde i kvalitetsklasse II brukt. Gjennomsnitt av målte PTE-konsentrasjoner ble brukt i beregningene, med unntak for storfe- og grisegjødsel, hvor også målte maksimalverdier ble inkludert. Estimert tilførsel av atmosfærisk PTE ble inkludert som et tillegg til de ulike gjødselvarene, men også vurdert som en separat kilde for PTE-er. Grenseverdier (maksimumsnivå, ML) for organiske gjødselvarer, jordforbedringsmidler, jordblandinger og vekstmedier ble også evaluert.

Det ble besluttet å bruke samme atmosfæriske PTE-bidrag for hele Norge, selv om værforhold, for eksempel nedbørsmengde og vindretning, vil gi regionale variasjoner. I tillegg kan også lokale kilder bidra i noen grad. Estimert atmosfærisk bidrag var basert på en worst-case-tilnærming beregnet ved å sammenligne konsentrasjoner i pløyelaget med konsentrasjonen i de dypere jordlagene som ikke er signifikant påvirket av jordbruksaktiviteten. Den forhøyede konsentrasjonen funnet i pløyelaget, ble så antatt tilført over 200 år. Data av PTE i våtdeponering fra Norsk institutt for luftforskning, NILU, inkluderte kun regn, og reflekterte dermed et nedre grenseestimat.

VURDERINGSMETODER

Terrestriske og akvatiske organismer (PNEC)

Risikovurderingene av PTE for landlevende organismer, inkludert jordbruksvekster, og for vannlevende organismer i overflatevann og sedimenter, var basert på estimerte ingen-effektkonsentrasjoner (PNEC) og miljøkvalitetsstandarder (EQS) som formulert i Det europeiske rådsforordningen (EEC 793/931 om evaluering og kontroll av risikoen ved "eksisterende" stoffer), og rådsdirektiv 2008/105 EF om miljøkvalitetsstandarder innen vannpolitikk.

For å vurdere risiko forårsaket av PTE, ble risikokarakteriseringsforholdet (RCR) beregnet som PEC/PNEC for hver PTE og miljøseksjon (jord, overflatevann og sediment). Risiko ble identifisert når PEC var høyere enn PNEC, dvs. når RCR>1.

Husdyr

Det estimerte PTE-inntaket hos husdyr gjennom beiting eller fôring i dag og i et 100-årsperspektiv ved bruk av de ulike organiske gjødseltypene, ble beregnet fra gjennomsnittlig fôrinntak i forhold til kroppsvekt hos ulike husdyrarter ved ulike fysiologiske stadier og produksjoner, kombinert med kunnskap om normal fôrsammensetning. Dataene er tilpasset norsk praksis.

For risikovurderingen av PTE hos husdyr ble det vist til maksimalt tolerabelt nivå (MTL) av grunnstoffene i fôr, som er angitt i internasjonale sammenstillinger av slike data, spesielt Mineral Tolerance of Animals av NRC (2005).

Mennesker

Vurderingen av human fare som følge av inntak av PTE fra mat, ble basert på tilgjengelige internasjonale risikovurderinger ved bruk av etablerte helsebaserte veiledningsverdier (HBGVs), som tolerabelt daglig inntak (TDI), tolerabelt ukentlig inntak (TWI) og benchmark dose modellering (BMDL) for de ulike PTE. Eksponeringen som en følge av bruken av de vurderte gjødslingsformene, ble gjort ved å se på modellerte potensielle endringer i PTE-konsentrasjoner i matplanter, sammenligne bidraget fra disse plantene med det tidligere estimerte totale kostinntaket og det tidligere beregnede inntaket mot gjeldende HBGV.

RESULTATER

Regionale forskjeller på grunn av miljøfaktorer og prosesser i miljøet

Norge har store geologiske variasjoner som i stor grad påvirker resultatet av risikovurderingen. De nåværende konsentrasjonene av PTE i jord er avgjørende faktorer for om modelleringen resulterer i akkumulering eller reduksjon over tid. Regionale forskjeller i PTE-konsentrasjonene vil i stor grad påvirke deres skjebne i miljøet og de tilknyttede risikoene. Den estimerte endringen i PTE-konsentrasjon i jord over tid avhenger av forholdet mellom tilførsel og tap. Dersom den årlige tilførselen av PTE overstiger det årlige tapet, øker konsentrasjonene av PTE i jord. Tapet er proporsjonalt med mengden PTE som finnes i jord, noe som betyr at tapet øker med økende jordkonsentrasjoner. Dermed kan den samme PTE-tilførselen føre til at konsentrasjonen på ett sted/i en region øker, mens det fører til en nedgang i en annen region. Dette kan f.eks. observeres i Stange-området sammenlignet med alunskiferområdet, som begge ligger i Hedmark. Den høyeste prosentvise økningen er dermed forventet for regioner med lav naturlig konsentrasjon, selv om de faktiske konsentrasjonene er høyest i regioner med naturlig høy bakgrunn.

Jordegenskaper, spesielt pH og organisk materiale, men også leirinnhold og nedbør, påvirker akkumulering og tap og varierer mellom regioner. Egenskapene til hvert PTE, spesielt binding/frigjøringssegenskapene, påvirker deres skjebne i miljøet, og dermed den risiko de kan medføre. Nedbør påvirker skjebnen og risikobildet for PTE. Time i Sørvest-Norge, området med høyest årlig nedbør, har det høyeste prosentvise tapet av PTE knyttet til dagens konsentrasjon i jord, spesielt med hensyn til Cd og Ni, som er grunnstoffer med lav Kd og lav bindingsaffinitet til jord. Derimot er Målselv og Stange områdene med lavest årlig nedbør og lave nåværende konsentrasjoner for de fleste PTE. Dette gir lite tap og stor prosentvis tilførsel av PTE i modellen. Stange er derfor den regionen med høyest antatt økning i jordkonsentrasjoner for mange PTE i de ulike scenarioene.

Tap av PTE via utvasking og avrenning var én størrelsesorden høyere enn fjerning via plantehøsting, bortsett fra Hg, hvor plantefjerning var mer relevant. Pågående klimaendringer kan forventes å resultere i økte flukser fra jord til vann, spesielt for de mest mobile PTE-ene. Ulike veier for PTE-transport (overflateavrenning, drenering og infiltrasjon) er sannsynligvis også påvirket av endringer i værmønstre. Høyere flomfrekvens vil trolig gi høyere PTE-flukser til overflatevann, samt midlertidig vannmetning. I sommerperioden forventes tørre perioder å bli lengre. Transport gjennom makroporene og sprekker i tørr jord, spesielt leirrike profiler, vil også resultere i raskere utvasking av jordprofiler, når det kommer nedbør. Lengre perioder med vannmetning kan påvirke spesiering av elementer som Hg og As, f.eks. metyleringen av Hg. Dette er ikke tatt hensyn til i modelleringen.

Miljørisiko – nåværende

De nåværende konsentrasjonene av PTE i jord (PEC_{jord}) er under de anslåtte estimert-ikke-effekt-konsentrasjon ($PNEC_{jord}$). Det indikerer at det ikke er noen miljørisiko knyttet til de vurderte PTE-ene, bortsett fra Ni. I alunskiferområdet ble $PNEC_{jord}$ for Ni overskredet, noe som indikerer risiko for terrestriske organismer ved direkte eksponering og ved sekundær forgiftning. Imidlertid er det sannsynlig at biotilgjengeligheten til Ni som stammer fra alunskifermineraler, er lavere enn fra menneskeskapte kilder. Dette er et forhold som ikke er vurdert i modellen.

De beregnede nåværende PTE-konsentrasjonene i overflatevann og sedimenter er utledet fra konsentrasjonene målt i jord. Bare Cd-konsentrasjonen oversteg de estimerte ingen-effektkonsentrasjonene i overflatevann ($PNEC_{overflatevann}$)- Det gjaldt spesielt i alunskiferområdet, men også i Time. Lav risiko for skadevirkninger forårsaket av Ni i overflatevann ble indikert for Målselv, Melhus og alunskiferregionen. For Zn ble det indikert en betydelig risiko for effekter på sedimentlevende organismer i alle regioner. Regionene der miljørisiko er indikert med hensyn til nåværende konsentrasjoner av noen PTE som overstiger de respektive PNEC-ene for land- og vannorganismer, er presentert i tabellsammendrag A.

Tabell A Oppsummering. Identifiserte risikoer for miljøeffekter av PTE på terrestriske og akvatiske organismer ved dagens konsentrasjoner i jord, overflatevann og sedimenter. Risikokarakteriseringsforhold (RCR = PEC/PNEC).

PTE	Risiko, jord (RCR)	Risiko, overflatevann (RCR)	Risiko sediment (RCR)
As			
Cd		Alunskifer (2.6), Time (1.3)	
Cr		Melhus (1.0)	
Cu			
Hg			
Ni	Alunskifer (1.1), Sekundær forgiftning: Alunskifer (2.3), Melhus (1.0)	Målselv, Melhus, Alunskifer (1-1.7)	Alunskifer (1.9)
Pb			
Zn			Alle regioner (1.3-2.2)

Akkumulering

For noen PTE er atmosfærisk bidrag alene tilstrekkelig til å forårsake akkumulering og økende konsentrasjoner i jord. Modellestimatene forutsier akkumulering av Hg i alle regioner, mens Pb akkumuleres i alle regioner bortsett fra Time, hvor mye nedbør er forventet å forårsake et høyere tap ved utlekking.

Med tillegg av PTE fra gjødsel, forventes økt akkumulering. Scenarioene og regionene som bidro betydelig til PTE-akkumulering er:

Organisk gjødsel kvalitetsklasse II (#2, se fotnote Tabell B) (forskrift – ML-verdier)

- As: Målselv, Melhus, Stange, Ås og Time
- Cd: Målselv, Melhus og Stange
- Cr: Målselv, Stange, Alunskifer, Ås og Time
- Cu, Pb, Hg og Zn: Alle regioner

Avløpsslam (#3, se fotnote Tabell B)

- Cd: Melhus, Stange
- Cr: Stange
- Cu. Hg og Pb: Alle regioner

Storfe- og grisegjødsel, maks. kons. (#4, se fotnote Tabell B)

- Cd og Cr: Stange
- Cu, Hg og Pb: Alle regioner
- Zn: Målselv, Melhus, Stange, Alunskifer og Ås

Alle scenarioer som fører til mer enn 10 prosent akkumulering etter 100 år er angitt i tabellsammendrag B.

Miljørisiko – 100 års perspektiv

I noen tilfeller er PTE beregnet å akkumulere til konsentrasjoner som forårsaker en miljørisiko i jord, overflatevann eller sedimenter i regioner der dagens konsentrasjoner er under bekymringsnivået:

Organisk gjødsel kvalitetsklasse II (#2)

- Cd: Stange (overflatevann)
- Cr: Målselv, Stange, Alunskifer, Ås og Time (jord)
- Hg: Alle regioner (Sekundær forgiftning), Time (jord)

Storfe- og grisegjødsel, maks. kons. (#4)

- Zn: Stange og Alunskifer (jord)

Scenarioer der miljørisiko ble estimert i et 100-årsperspektiv er vist i tabellsammendrag B.

Tabell B Oppsummering. Scenarier som predikerte økende PTE konsentrasjoner i jord (akkumulering) og risiko for terrestriske og akvatiske organismer etter 100 år.

PTE	Akkumulering >10% (jord)	Risiko jord	Risiko overflatevann	Risiko sediment
As	#2, fleste regioner			
Cd	#2 (Målselv, Melhus, Stange), #3 (Melhus, Stange), #0b, #4 (Stange),		#0a-10 (Alunskifer), #2 (Stange, Alunskifer)	
Cr	#2 (fleste regioner)	#2 (fleste regioner)	#2 (Melhus)	
Cu	#2, #3, #4, #7, #8, #9, #10, (fleste regioner)			#2 (Alunskifer og Time)
Hg	#0a, #1, #2, #6, #7, #8, #9 (alle regioner)	#2 (Time), Sekundær forgiftning (alle regioner)		
Ni		#0a-10 (Alunskifer), Sekundær forgiftning	#0a-10 (Alunskifer)	#0a-10 (Alunskifer)
Pb	#0a, #1, #2, #3, #4, #5, #6, #7, #8, #9 (fleste regioner)			
Zn	#2, #3, #4, #5, #6, #7, #8, #10 (fleste regioner)	#4 (Stange, Alunskifer)		#0a-10 (fleste regioner)

#0a: Atmosfærisk bidrag **#1**: Mineral P gjødsel **#2**: Forskrift org. gjødsel, kvalitetsklasse II **#3**: Avløpsslam **#4**: Storfe- og grisegjødsel (maks.) **#5**; Storfe- og grisegjødsel (gjennomsnitt) **#6**: Fiskeslam **#7**: Biorest (matavfall& husdyrgjødsel) **#8**: Biorest (matavfall) **#9**: Hestegjødsel **#10**: Fjørfegjødsel

Evaluering av estimerte konsentrasjoner i jordbruksvekster inkludert grønnsaker, frukt og bær og sopp

Estimert overføring av PTE fra jord til planter og konsentrasjoner i jordbruksvekster og grønnsaker, følger de samme trendene over tid som for jord ved årlig tilførsel av gjødselprodukter med ML-verdier som er angitt for kvalitetsklasse II i forskrift for organisk gjødsel. Inntak av As, Cd, Hg og Pb fra mat er allerede høyt i forhold til giftigheten og all økning av inntak av disse er uønsket. Disse grunnstoffene er derfor i fokus.

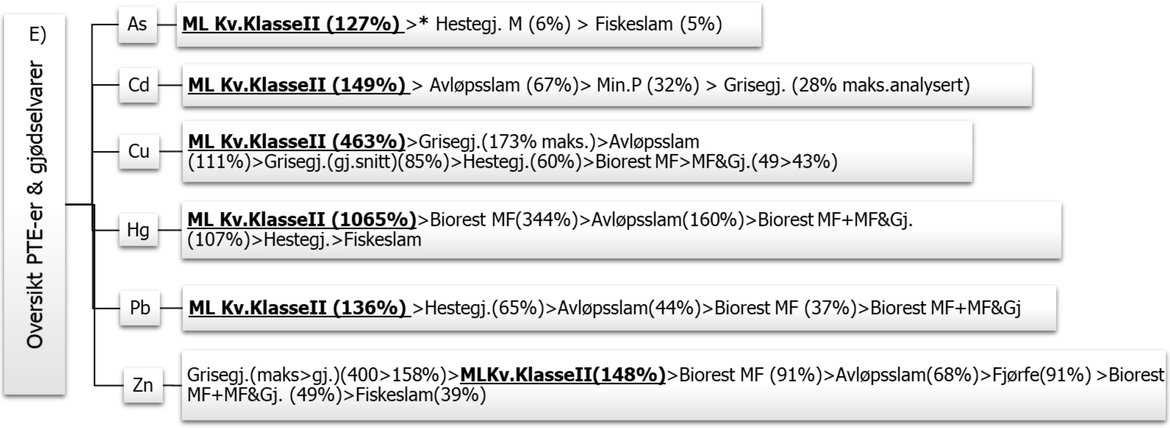
Konsentrasjonene av disse PTE-ene vil øke over tid for ett eller flere applikasjonsscenarioer. På grunn av de høye naturlige konsentrasjonene av mange av disse metallene i alunskiferjord, ble de høyeste konsentrasjonene av flere PTE i avlingene estimert for alunskiferområdet. For Cr ble den høyeste konsentrasjonen i avlinger estimert for caseområdet Melhus, mens for Hg og Pb ble de høyeste konsentrasjonene estimert for caseområdet Time.

Sammenligningen av grenseverdier i forskrifter for organisk gjødsel, viste at de høyeste grenseverdiene for Cd og Hg er de som er satt for kvalitetsklasse II i den norske gjødselvareforskriften (scenario vekstmedier), og for As og Pb er de høyeste grenseverdiene de som er satt for CE-merkede vekstmedier i EU-forordningen. Grenseverdiene for jordblandinger i forskrifter for organisk gjødsel, som ble brukt for jordblandinger i scenarioet som eksemplifiserer hjemmedyrking i jordblandinger, var like eller lavere enn disse grenseverdiene. Grenseverdiene som ble brukt i scenarioet for jordblandinger i scenarioet som eksemplifiserer urbant jordbruk, samt som dyrkingsmedier, kvalitetsklasse 0 etter den norske gjødselvareforskriften, var lavere enn grenseverdiene for jordblandinger for alle PTE-ene bortsett fra for Zn (lik).

Sammenligning av de estimerte konsentrasjonene av As, Cd, Hg og Pb i gulrot og potet dyrket i ulik jordbruksjord, viste at alunskiferjord ga høyest konsentrasjoner av As og Cd, mens jorda i Time ga høyest konsentrasjoner av Hg og Pb. Tilsvarende sammenligning ved dyrking i vekstmedier med PTE-innhold lik øvre grenseverdier etter henholdsvis norsk- og EU regelverk, viste at grenseverdiene i det norske regelverket ga høyere Cd- og Hg-konsentrasjoner i potet og gulrot enn grenseverdiene i EU-regelverket. For As og Pb var det grenseverdiene i EU-regelverket som ga høyest konsentrasjoner. Sammenligning av jordbruksjord og vekstmedier med maksimumskonsentrasjoner, viste at de høyeste grenseverdiene for vekstmedier ga høyere konsentrasjoner i gulrot og potet enn de høyeste verdiene som ble beregnet for jordbruksjord.

Sammenligning av estimerte og målte data

Samlet sett var det et samsvar mellom estimerte og målte konsentrasjoner av PTE i planter, til tross for noen få avvik. Riktig estimat av PTE-konsentrasjoner i avlinger vil kreve at de målte nivåene i jorda er representative for det undersøkte området, og at de valgte planteoverføringsfaktorene (TF) er representative for områdene. TF som ble brukt for Cd i gulrot, resulterte i en underestimering sammenlignet med de målte verdiene, og scenarioberegningen ble gjentatt med en høyere TF. Gitt de nevnte store variasjonene både i de faktiske jord- og avlingskonsentrasjonene og de mange påvirkningsparameterne, prosessene og faktorene, ansees de estimerte PTE-konsentrasjonene i planter til å være innenfor det forventede.



Gj.: gjødsel, ML Kvalitets KlasseII, MF: matavfall, *har brukt Upper-Bound-verdier for storefe- og grisegjødsel ga 6% økning og ikke inkludert.

Figur Sammendrag A En oversikt over PTE-er med økende PEC-jord i 100-årsperspektiv etter bruk av de valgte inputkildene i scenarioberegningene. Kun regionen med høyest økning vises.

Husdyr

Når det gjelder Cd, Hg og Pb, som er de stoffene som potensielt er mest giftige, er dagens nivåer i dyrefôr generelt langt under nivåene som vurderes å være av risiko for dyrehelsen. Ved vanlig praksis for bruk av organisk gjødsel og de tilknyttede PTE-nivåene i sammensatte dyredietter, forventes det at nivåene av disse grunnstoffene vil avta ytterligere (følger samme trend som beskrevet ovenfor). Imidlertid er det noen scenarioer som beregner en økning av Cd-, Hg- og Pb-nivåene i dyrefôr. Beregninger med maksimale nivåer for PTE og maksimal spredningsmengde tillatt i forskriften for organisk gjødsel i kvalitetsklasse II (#2), resulterte i økende konsentrasjoner over en 100-årsperiode, men de var likevel under nivåene som gir grunn for bekymring for dyrehelsen. Hg-innholdet i dyrefôr forventes også å øke ved bruk av biorest (matavfall) som gjødsel. Fordi Cd, Hg og Pb er giftige stoffer uten fysiologisk nyttige funksjoner, er det et viktig mål å holde nivåene så lave som mulig.

Det nåværende nivået av As i dyrefôr er også langt under nivået som er vurdert som maksimalt tolerabelt for dyr. For scenarioene med vanlig bruk av gjødsel, forventes det at opptak av As i dyrefôr og beitegras vil avta. Dersom de maksimale PTE-nivåene som er angitt i forskriften for organisk gjødsel i kvalitetsklasse II ble brukt i scenarioberegningen (scenario #2), ble det estimert en økning i As-konsentrasjonen, spesielt i regioner med nåværende lave As-konsentrasjoner, som i Stange. Imidlertid vil nivåene som forventes etter 100 år med gjødseltilførsel fortsatt være langt under nivået som gir bekymring for helserisiko hos husdyr.

I alle regioner er dagens nivåer av Cr og Ni i dyrefôr og beite langt under de maksimalt tolerable nivåene. For Ni ble det beregnet en nedgang i alle scenarioer. Tilsvarende ble det beregnet at Cr-nivåene i dyrefôr vil avta ytterligere, med unntak av scenario #2, som bruker de maksimalt tillatte nivåene for organisk gjødsel i kvalitetsklasse II, noe som innebar en økning i de fleste regioner. Økningen av Cr vil imidlertid ikke utgjøre en helserisiko for husdyr, da den for det meste forekommer i sin lavtoksiske trivalente tilstand.

For Cu, der maksimumsnivåene angitt i kvalitetsklasse II i forskriften for organisk gjødsel (#2) ble brukt i scenarioberegningen, resulterte det i økte nivåer i dyras diett. Med slik gjødsling vil beiteplantene i et 100-årsperspektiv i Stange og spesielt i alunskiferområdet, kunne inneholde forhøyede Cu-nivåer som anses å være skadelige for beitende sau (maksimalt tolerabelt kosthold 15 mg kg^{-1}). Nivåene anses ikke å utgjøre noen risiko for andre husdyr. I tillegg kan tilførsel av grisegjødsel (scenario #4) i alunskiferområdet, gi ytterligere økning av Cu-konsentrasjonen i beitegras, og nå nivåer som kan være skadelig for sau.

Bakgrunnsnivåene av Zn i de ulike regionene som vurderes, utgjør ingen helserisiko for dyrehelse. Bruk av organisk gjødsel med maksimumskonsentrasjonene (ML) angitt for kvalitetsklasse II i forskriften for organisk gjødsel (scenario #2), kan føre til en viss økning av Zn i alle regioner. Imidlertid vil den høyeste økningen av Zn i dyrefôr være forårsaket av bruk av grisegjødsel (scenario #4) i Stange (430 % økning) og i alunskiferområdet (160 %). Men selv etter 100 år med tilførsel av gjødsel i henhold til scenario #4, vil ikke beitedyr i Stange og alunskiferområdet være eksponert i for Zn-nivåer som gir bekymring. Bruk av grisegjødsel vil også føre til en økning av Zn-nivåene i jord og dyrefôr i andre regioner, men i mindre grad enn i Stange og alunskiferområdet.

Økningen av Zn- og Cu-nivåer gjennom bruk av grisegjødsel er et resultat av det høye Zn- og Cu-innholdet i grisefôr. Dyrs eksponering for disse grunnstoffene i nivåer over fysiologiske behov, kan potensielt indusere problemer med utvikling av bakteriell resistens, men det anses som lite sannsynlig at denne situasjonen oppstår under forholdene vurdert i de utførte scenarioene. Risikoen for at de estimerte Zn- eller Cu-nivåene i scenarioene for gjødsling med grisegjødsel kan føre til problemer med mikrobiell resistens mot disse stoffene, og eventuell ko-resistens mot antimikrobielle legemidler i dyr som spiser de gjødslete vekstene og i deres miljø, anses derfor som lav.

Mennesker

Bruk av organisk gjødsel med maksimumskonsentrasjonene (ML) angitt for kvalitetsklasse II i forskriften for organisk gjødsel (scenario #2), ble estimert til å gi en økning i konsentrasjonene av As, Cd, Pb og Hg i jordbruksvekster (hvete, gulrøtter og poteter) i enkelte regioner (Målselv, Melhus, Stange og Ås). Konsum av disse vekstene vil føre til økt eksponering for metallene via kosten. Siden inntak av As, Cd og Pb fra mat allerede er høyt i den norske befolkningen, er det ikke ønskelig med en ytterligere økning. For Hg vil bidraget fra konsum av jordbruksvekster være lite, sammenlignet med bidraget fra fisk og annen sjømat.

Ifølge de modellerte scenarioene forventes det at også dyrking i jordblandinger og vekstmedier fører til en økning av PTE-konsentrasjoner i grønnsaker og frukt i forhold til dagens nivåer, spesielt når det gjelder As, Cd, Hg og Pb.

I en studie som undersøkte konsekvensene av urbant jordbruk i København, Danmark, ble potensiell helserisiko fra eksponering for tungmetaller i de produserte produktene evaluert (Warming og Hansen 2013, Warming et al. 2015). Analyser viste at den høyest forurensede jorden inneholdt 21.8 mg kg^{-1} DW (middel- og maks. Som konsentrasjon i alunskifer 21 og 66 mg kg-1 DW), henholdsvis 2,6 (middel- og maks. Cd-konsentrasjon i alunskifer 1,2 og 4,4 mg kg-1 DW, henholdsvis 591 (middel- og maks. Pb-konsentrasjon i Sørvest-Norge henholdsvis 27 og 96 mg kg-1 DW) og 1298 mg kg-1 tørrvekt (DW) (middel- og maks. område Zn-konsentrasjon i Norsk jordbruksjord er henholdsvis 38-110 og 110-360 mg kg-1 DW) As, Cd, Pb og Zn. Den største risikoen for mennesker identifisert i denne studien, var eksponering for Pb fra direkte jordinntak, noe som var spesielt bekymringsfullt for barn.

Analyser viste at jorden med høyest innhold av As, Cd, Pb og Zn var henholdsvis 21,8, 2,6, henholdsvis 591 og 1298 mg kg^{-1} tørrvekt (TS). Gjennomsnitt- og maksimalverdiene i norsk landbruksjord for As er 21-66 mg kg^{-1} TS i alunskiferjord, for Cd 1,2 og 4,4 mg kg^{-1} TS i alunskiferjord, og for Pb 27 og 96 mg kg^{-1} TS i Sørvest-Norge. For Zn er gjennomsnitt- og maksimalverdiene i norsk jordbruksjord henholdsvis i området 38-110 og 110-360 mg kg^{-1} TS. Den største risikoen for mennesker identifisert i denne studien var eksponering for Pb fra direkte jordinntak, noe som var spesielt bekymringsfullt for barn.

Usikkerheter og kunnskapshull

Som del av prosjektet ble det gjennomført en sensitivitetsanalyse som viser hvordan usikkerhet i de ulike inputparameterne i modellen slår ut på resultatene. For alle PTE-ene hadde de nåværende konsentrasjonene i jord (bakgrunnskonsentrasjonen) og Kd størst innflytelse på resultatene. Kd ble estimert basert på pH i jord (unntatt Cr og Hg hvor fast Kd ble brukt), og pH hadde stor innvirkning på de estimerte konsentrasjonene. I estimering av PTE-nivåer i et 100 års perspektiv, bidro tilførselen av PTE fra luft eller med gjødsel betydelig til resultatene, mens det hadde mindre effekt i kortere perioder (≤ 10 år). For estimering av PTE-konsentrasjoner i avlinger var TF svært viktig, og for beregningen av $PEC_{overflatevann}$ hadde Kd og fortynningsfaktoren størst betydning.

De identifiserte relevante datahullene og kjente vurderingssvakhetene inkluderer:

- Det er få tilgjengelige analyser som viser dagens konsentrasjoner av PTE i jord, overflatevann og avlinger, og det er ingen harmonisert prøvetakings- og analyseprosedyre for slike prøver. De nåværende PTE-konsentrasjonene i jord er en av de viktigste faktorene (høy sensitivitet) for resultatet av risikoevalueringen. Mangel på tilstrekkelige data er dermed et av de viktigste kunnskapshullene.
- Fordampning av Hg fra jord er ikke inkludert i modellene som er brukt i denne vurderingen, på grunn av kunnskapshull og mangel på relevante data. Denne usikkerheten kan ha påvirket den estimerte høye økningen av Hg i jord, også med hensyn til atmosfærisk bidrag alene.
- Det er svært få tilgjengelige analyser for dagens konsentrasjoner av PTE i ulike gjødselvarer.

- Det er ingen tilgjengelige data for spesieringsformene for Hg, Cr og As- i gjødselprodukter, og svært lite kunnskap om deres skjebne og giftighet i miljøet.

Andre faktorer som gir usikkerhet i konklusjonene, inkluderer:

- Bruk av median- og gjennomsnittsverdier av PTE i stedet for å utføre en fullstendig sannsynlighetsvurdering
- Det er stor variasjon i jordbrukspraksis og avlingsnivå, og for denne vurderingen ble det valgt et typisk vekstskifte for hvert av caseområdene. Alternative vekstskifter ble beregnet, men resultatene viste at variasjonen i PTE-konsentrasjoner mellom vekstskifter var lav, typisk 5 %, slik at valg av vekstskifte ble vurdert som ubetydelige for modelleringen
- Noen av de fastsatte miljøtoleransegrensene (PNECs) er basert på begrensede datasett. For As, Hg og Cr, spesielt for sedimentlevende organismer, er de beregnede PNEC-ene derfor forbundet med en større usikkerhet.
- For mennesker er forbruket av lokalproduserte eller hjemmedyrkede grønnsaker eller sopp ikke kjent.

Abbreviations and definition

AF	Assessment factor
Alum shale	Soil samples classified as alum shale in Stange and other areas is treated as a separate case, hereafter called case area alum shale
As	Arsenic
AVS	Acid volatile sulfides is an operational defined parameter indicating those sulfides, which are readily extracted by the cold extraction of sediment in approximately 1 M HCl acid
BCF	Bio-concentration factor
BLM	Biotic ligand models
BMDL	Benchmark dose lower confidence limit
BW	Body weight
CEC	Cation exchange capacity
Cd	Cadmium
Cr	Chromium
Cr(tot)	Total Chromium
Cu	Copper
da	Decare (1000 m^2)
DOC	Dissolved Organic Carbon
DW	Dry weight
EC	European Commission
ECx	Effect Concentration (for x% effect)
ECB	European Chemicals Bureau
ECHA	European Chemicals Agency
EFSA	European Food Safety Authority
Engineered soil	Manufactured soil consisting of specified ratios of sand, silt, clay, and organic amendments
EQS	Environmental quality standards
ERA	European Risk Assessment
ERM	Environment Resources Management
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
Fertiliser	Products whose main task is to supply nutrients to plants and are suitable for annual application (see also 3.1.1)
Fertiliser products	The term include both fertilisers and soil improvers
FW	Fresh weight
Growing medium	A substrate for root development, in which plants are grown
ha	Hectare (10.000 m^2)

HBGV	Health-Based Guidance Value (TDI/TWI BMDL or similar)
HC$_5$	The fifth percentile, with 50% confidence, of a species sensitivity distribution
Hg	Mercury
K$_d$	Soil and pore-water partitioning or distribution coefficient. Partition coefficient specifically for un-ionized compounds and distribution coefficient for sum un-ionized and ionized compounds
Kp$_{susp}$	Partition Coefficient water/suspended solids
Kp$_{sed}$	Partition Coefficient water/sediment
LCx	Lethal Concentration (x% affected)
LOEC	Lowest observed effect concentration
ML	Maximum limit
N	Nitrogen
NFSA	Norwegian Food Safety Authority
NGU	Geological survey of Norway (Norges geologiske undersøkelse)
Ni	Nickel
NIVA	Norwegian Institute for Water Research
NOEC	No observed effect concentration
NRC	National Research Council
OC	Organic Carbon
P	Phosphorus
Pb	Lead
PEC	Predicted environmental concentrations
PEC$_{sw}$	Predicted environmental concentrations surface water
PEC$_{sed}$	Predicted environmental concentrations sediment
PNEC	Predicted no-effect concentration
PNEC$_{sed}$	Predicted no-effect concentration sediment
PNEC$_{soil}$	Predicted no-effect concentration soil
PNRC$_{sw}$	Predicted no-effect concentration surface water
PTEs	Potentially toxic elements
PTMI	Provisional tolerable monthly intake
RAR	Risk assessment report
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals (EU regulation of chemicals)
RCR	Risk Characterisation Ratio
SEM	Statistical extrapolation method
Soil improvers	Products whose main task is to improve the chemical, physical and biological condition of the soil
SOM	Soil organic matter, also often expressed only as organic matter (OM)
SSB	Statistics Norway (Statistisk sentralbyrå)
SSD	Species Sensitivity Distribution
TDI	Tolerable Daily Intake

TF	Transfer factor
TGD	Technical guidance document (issued by European Chemicals Bureau (ECB 2003)
TWI	Tolerable Weekly Intake
US EPA	United States Environmental Protection Agency
VKM	The Norwegian Scientific Committee for Food and Environment (Vitenskapskomiteen for mat og miljø)
WC	Water content
WHO	World Health Organization
Yr	Used for year and years
Zn	Zinc

Background as provided by the Norwegian Food Safety Authority

The potentially toxic elements arsenic (As), cadmium (Cd), Chromium Cr(tot) (Cr(III) and Cr(VI)), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni) and zinc (Zn) are present as natural elements in soil. They can also be present as contaminants in fertilising materials. With repeated applications of fertilising products over time, these elements may accumulate in soil, resulting in negative health and environmental effects.

There are three Norwegian regulations on marketing of fertilising products. In both the national regulation on marketing of fertilising and liming material, and in the Norwegian regulation implementing regulation (EC) No 2003/2003 on EC fertiliser, there are maximum levels for cadmium (Cd) in phosphorus (P) fertilisers. The maximum level is 100 mg Cd kg^{-1} P. There are no maximum levels for other heavy metals in these two regulations. When it comes to the regulation on marketing of organic fertilising products, there are maximum levels for the following potentially toxic elements in fertilising products and soil: Cd, Cr, Cu, Pb, Hg, Ni and Zn. EU have adopted a new regulation on fertilising product (EU) 2019/1009, and this regulation will replace regulation (EC) No 2003/2003 in July 2022. This new regulation has limit values for As, Cd, Cr/Cr(VI), Cu, Pb, Hg, Ni and Zn. The limit values differ between different product function categories.

Terms of reference as provided by the Norwegian Food Safety Authority

The Norwegian Food Safety Authority would like VKM to give their opinion on several questions related to the potentially toxic elements arsenic (As), cadmium (Cd), Chromium (Cr, Cr(III) and Cr(VI)), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni) and zinc (Zn) in Norwegian agricultural soil.

- What do we know about the levels of these elements in agricultural soil in Norway today?
- Describe the fate (mobility) of these elements within and in close proximity to agricultural soil after the application of fertilising products containing these elements to agricultural land and transfer to the affected organisms in Table 1?
- What level of these elements in agricultural soils would give the risk of negative effects on the selected affected organisms found in Table 1?
- What do we know about the current and future (up to 100 years) exposure to these elements for the affected organisms in Table 1, both when it comes to exposure levels and the sources for the exposure?
- What do we know about the risk for humans that are high consumers of locally grown vegetables?

Table A: Affected organisms

Affected organism	***Negative effects**
Plants - Agricultural plants for food and feed - Farmed/Cultivated mushrooms	- Reduced germination/growth and crop - Reduced germination/growth and crop
Animals - Soil organisms - Aquatic organisms - Domestic animals for food production, eating forage like grass and/or other feed from fields	- Ecotoxicology (environmental risk) - Ecotoxicology (environmental risk) - Reduced animal health
Humans – Whole population and subgroups, e.g. humans eating locally grown vegetables	Exposure/intake, not toxicological effects*

*****The need of assessment of human exposure depends on the results of the assessment plant and animals and may be excluded for one or more of the elements.

Assessment

1 Introduction

1.1 Framework for the assessment

As outlined in the terms of reference, VKM has been tasked with answering several generic, broad and long-term questions on potential impacts of selected metals and arsenic (Potentially Toxic Elements – PTEs) in fertilisers and soil improvers used in agricultural soils, and engineered soil and growing media in Norway. The assessment asked by the Norwegian Food Safety Authority (NFSA) will be used by NFSA to evaluate if today's and suggested maximum limits (MLs) in relevant regulations give sufficient protection in short and long-term perspective.

To assess the resulting concentrations in soils, runoff (surface water), and plants/crops, VKM has selected five regions including North-, Mid-, Southeastern-, and Southwestern Norway in order to account for regional differences. In addition, alum shale areas in Hedmark have been considered as a separate case area. The selected regions have been characterised in terms of soil properties, present concentrations of PTEs in agricultural soil, precipitation and infiltration rates, and current agricultural practice (i.e., application of fertilisers and what crops are grown locally), as well as atmospheric deposition.

The changes in PTE concentrations in a 100-year perspective have been modelled using state-of-the art modelling techniques. Relevant data sources, assumptions, and conclusions from the modelling and assessment are presented in a transparent manner. Please note, however, that complex data modelling as that performed in this report is subject to a considerable degree of uncertainty, particularly the 100-year predictions. Over time, factors such as agricultural practice, temperature, precipitation, soil quality etc. might change and highly influence fate and transfer processes.

Uncertainty for the present-state stems from the lack of relevant data (for e.g., soil quality, PTE content, soil sorption of PTEs, transfer factors for PTE into crops) and from variability in the data (e.g., median values for soil quality and PTE content are used to represent large regions, content of PTEs in some fertilisers have been poorly documented, and soil sorption of PTEs in the literature are extremely variable). Moreover, the model processes will never mimic nature completely. Cross-checks with measured present-state data in surface waters and in crops have been done, where possible, and suggest that the modelling results are reasonably robust.

To assess the potential risk of estimated PTE concentrations to soil organisms, plants, and aquatic organisms, exposed both directly and via the food-chain, "safe" levels have been estimated based on the toxicity data for relevant species and state-of-the art regulatory methods. In cases, where the lack of data contributes notably to the uncertainty, safety factors have been introduced to be on the conservative side. We know from experience that “safe” levels that have been estimated based on limited data are often conservative.

To assess the potential risk from PTE in dietary exposed farm animals and humans, a similar approach has been used. Also here, limited access to relevant data on PTE occurrence, transfer factors from soil to plants, intake assessment and tolerable levels are affected by uncertainty.

While the assessment in sum intends to give a broad and relevant long-term view on impacts from PTEs in fertilisers, the results must be viewed, consideration the quality of the underlying data and the model input parameters. Key relevant weaknesses to calculations and assessments are flagged in more detail where relevant, and a separate sensitivity analysis has been conducted for some of the most critical input data.

1.2 Circular economy and biobased fertiliser, soil improvers and growing media

Circular economy is a principle for economic activity that aims to keep resources in the economy, if possible. This is to be achieved by e.g., reducing the use of raw materials and generation of waste to a minimum. Circular economy also aims at reusing, also outside their original purpose (recycling), and this includes the recycling of nutrients and organic matter from organic waste to biobased fertilisers, soil improvers and growing media.

Due to a continuously increasing global population, urbanisation, and economic growth, there is a rising demand for food, and thus for plant nutrients such as nitrogen (N) and phosphorus (P) (Nizami et al., 2017). Particularly, the increasing need for P has gained much attention and raised concern (Cordell et al., 2009). Considering the shortage of P (EC, 2014), the decreasing quality of phosphate rock, increase in production costs, geopolitical unsecure access to P, and EU’s dependence on import (De Ridder et al., 2012), recycling of nutrients and particularly P was recognised early as an urgent issue by the EC. This is also reflected in the fact that the fertiliser regulation was the first in the EU’s circular economy package. The EU expect that bio-waste will replace up to 30% of the inorganic fertilisers that are currently in use (Hansen, 2018). In addition, recovery and recycling of nutrients will also prevent that fertilising nutrient become pollutants (Scholtz, 2017).

Livestock manure, sewage sludge, food waste and fish sludge are high-volume bioresources, which are easily available in many countries and secondary raw materials for nutrients and organic matter. Today, these bioresources are only partly utilised sustainably in bio-based fertiliser products. Different processes and technologies are required for transforming some of these bioresources into products for use, e.g. in agriculture or urban-home gardening. The most common areas of application today, i.e. composting and use of biowaste as feedstocks for anaerobic digestion (AD), are continuously increasing. In addition to the production of bio-based fertiliser products, AD processes replace uncontrolled greenhouse gas (GHG) emissions by the production of methane under controlled conditions. Biogas production from high volume bioresources has become an important political goal related to the need for cuts in GHGs and the exploration of means to obtain digestate for the safe application in food production.

While manure is applied to agricultural crops worldwide, especially in regions with a high density of livestock production, the use of other alternative bioresources such as sewage sludge is restricted due to regulations (in Norway FOR-2003-07-04-951).

With a fast-growing global population that is expected to reach over 9 billion by 2050, an increase of the food production is extremely important. In this context, it is deemed beneficial to reduce the climate footprint by eating more locally produced food. For many people and their families, the desire to cultivate their own food leads to a substantial interest in urban farming and the home cultivation of vegetables, herbs, berries and fruits. To ensure sustainability and reduce human exposure through the consumption of home-grown or locally bought vegetables grown in market gardens, it is essential to know the content of PTEs and organic contaminants in growing media and engineered soil, their transfer rates and the plant uptake efficiency to frequently eaten vegetables. Additionally, the cultivation of edible fungi on substrates that contain PTEs might cause an extra exposure pathway for consumers of mushrooms ("mushroom lovers") in comparison to the general population.

The new Farm to Fork (F2F) Strategy (EC, 2020) aims to make the EU food system fair, healthy and environmentally friendly, and includes ambitious and concrete targets with respect to fertilisers, organic farming, pesticides and antimicrobial resistance that are aspired to be achieved by 2030. It is expected that the EU's "circular economy package", including Green Deal and the F2F strategy will boost the emergence and commercialisation of biobased fertilisers. However, one of the bottlenecks and questions raised by professionals as well as the public is whether products from recycled secondary raw materials cause negative effects/impact on the environment, human and animal health in a short- and long-time perspective? This risk assessment, which is delivered upon a request by the NFSA, contributes to enhance the knowledge, and points out in particular critical knowledge gaps, which must be filled to allow answering the key questions.

1.3 Occurrence and properties of potentially toxic elements

1.3.1 Introduction

Natural soil contains all the elements that are considered in this evaluation. However, the levels may increase because of an increased use of biobased fertilisers, soil improvers and growing media. The soil serves as a habitat for organisms that provide key ecosystem services in the recycling of organic material, in particular carbon and nitrogen. With contribution from soil dwelling organisms, bacteria and fungi, to be sustainable use of fertilisers must ensure that soil functions do not deteriorate over time.

The fate and effects of PTEs in soil depend on their inherent properties (discussed in detail for each element below), soil properties (i.e., key characteristics such as organic matter content, pH, and cation exchange capacity), local temperatures, precipitation rates and patterns, among others. Across Norway, the receiving soil habitats, essentially agricultural soils, vary for all these parameters, and explains the range of scenarios that has been selected for further assessment in advanced long-term modelling.

The modelling takes into account that, after addition to soil, several removal processes will contribute to reduce soil concentrations of PTEs, including leaching, erosion, and plant uptake processes. These processes act as vectors to expose other recipients, including aquatic organisms due to erosion/leaching, and livestock and humans as due to the consumption of grown crops.

This report provides relevant modelling results for different scenarios that are considered to be representative of Norwegian agricultural soils based on relevant/conservative input for the various fertiliser products; their planned or intended use, their content of potential toxic elements, and influence of local environmental conditions.

Future changes to relevant model input parameters due to climate change is briefly discussed. The consequences for soil leaching, particularly, the erosion part, is difficult to predict using state-of-the-art modelling tools. A semi-quantitative approach that makes use of simple and generic modelling results therefore serves as a proxy for the influence of climate change.

Further, the report discusses PTEs in fertilisers in the context of urban agriculture. The current trend of using rooftops and other available urban locations for homegrown crops has increasing relevance for households in the future.

1.3.2 Arsenic (As)

Arsenic (As), a metalloid with atomic number 33, is the twentieth most abundant element in the earth’s crust with concentration 1.7 mg kg^{-1} (Wedepohl, 1995). As with other metalloids, As has semiconductor properties and occurs in nature in various oxidation states, mainly +V and +III, but also 0 and –III. Arsenic has chemical similarities with phosphorus (P) and acts as an analogue in various biological processes such as uptake in plants and microorganisms and in chemical behaviour in soils. However, the soil chemistry of As is more diverse than that of P as As exists in more than one oxidation state, forms bonds with sulphur (S) and carbon (C) more readily, and undergoes biotransformation’s (Wenzel, 2013). The As in the global soil reservoir is 4-5 orders of magnitude less than the amount of As stored in earth’s crust and 25-30 % of the As present in the oceans (Wenzel, 2013). Arsenic in soils has increased due to various anthropogenic activities consisting of inputs from mining, smelter activities, coal combustion, fertilisers, lime, pesticides, defoliants, manure from animals fed As as feed additive or treated with As-containing remedies, and recycling of As-contaminated compost and sewage sludge. Furthermore, wood preservation with chromated Cu arsenate have been widely used and resulted in widespread but very local As accumulation in soils around the treated wood.

The global mean concentration of As in soils is about 5-7.5 mg kg^{-1} with a common range between 0.1 and 55 mg kg^{-1} (Matschullat, 2000). Higher As concentrations are found at regional or local areas, attributed to geogenic anomalies or anthropogenic activities.

Seafood may contribute significantly to daily As intake. Arsenic in seafood is largely in organic form (arsenobetaine) that is much less toxic than inorganic forms (Ufelle & Barchowsky, 2019). Arsenic is generally not regarded as an essential nutrient. However, several studies indicate that it may have a beneficial function in ultra-trace amounts (NRC, 2005).

1.3.3 Cadmium (Cd)

Cadmium (Cd), atomic number 48, is present in the continental crust at 0.1 mg kg^{-1} (Wedepohl, 1995). It is a non-essential metal that is naturally present in all soils as a divalent cation (Cd(II)). Its typical concentrations in soils ranging from 0.1-1 mg kg^{-1}. The current Cd concentrations in soils are somewhat higher than geogenic values because of additions from anthropogenic activities through atmospheric deposition and the use of P-fertilisers and sewage sludge contaminated with Cd. Main industry products using Cd are rechargeable batteries, PVC stabilizers and pigments (Smolders & Mertens, 2013).

The typical Cd concentrations in soil are considered too low to affect the soil chemistry but Cd can influence the ecosystem function at trace levels because of high toxicity and bioavailability (Smolders & Mertens, 2013).

Cadmium commonly occurs in zinc (Zn) minerals at a typical ratio Cd:Zn 1:200, generally higher in sedimentary rocks than in igneous rocks (Smolders & Mertens, 2013).

Risk of soil Cd to humans occurs at soil Cd concentrations well below those required to cause explicit effects in plants and soil biota. Human health effects are related to exposure of Cd via the food chain, i.e. consumption of Cd contaminated crops such as cereals and potatoes, but also offal from animals and seafood. Local soil Cd is a potential risk to people who use the same soil to grow major food for an appreciable time of their life.

1.3.4 Chromium (Cr)

Chromium (Cr), atomic number 24, occurs as stable forms in trivalent Cr(III) and hexavalent Cr(VI) species. Other oxidation states can transiently exist in living organisms. The trivalent form is the major form in nature. Hexavalent Cr has strong oxidising properties and is produced almost entirely by industrial processes (Gonelli & Renella, 2013). Chromium (VI) is spontaneously reduced to Cr(III) when present in a soluble form.

Chromium is naturally present in all rock types, with particularly high concentrations in serpentine rock and soils. Its mean concentration in the continental crust is 126 mg kg^{-1} (Wedepohl, 1995), whereas the concentration range in soils is usually between 0.5 and 250 mg kg^{-1} (Gonelli & Renella, 2013). Chromium in natural soils from weathering of the parent rock is present mostly as insoluble $Cr(OH)_3$ or as Cr(III) adsorbed to soil colloids. The Cr(VI) is typically associated with oxygen as chromate (CrO_4^{2-}) or dichromate ($Cr_2O_7^{2-}$) oxyanions (Gonelli & Renella, 2013). The Cr(III) is less mobile, less toxic and mainly bound to organic matter in soil and aquatic environments. The relation between Cr(III) and Cr(VI) strongly depends on pH and oxidative conditions, but in most cases, the Cr(III) is the dominating species (Kotaś & Stasicka, 2000).

Chromium is used on a large scale in metallurgic industry, including production of stainless steel and electroplating due to its high corrosion resistance and hardness. It is also used in production of paints and pigments, leather tannery, wood preservation, Cr chemical production, and pulp and paper production. Wastes such as sludge, fly ash, slag and fluid from Cr industries may pollute the environments (Gonelli & Renella, 2013). The wastes have also been employed as fill material at numerous locations where leaching of Cr(VI) from the soils into the groundwater poses a considerable health concern (Salunkhe et al., 1998).

Chromium (III) is essential for humans and animals and Cr deficiency can have detrimental effects on the metabolism of glucose and lipids (NRC, 2005). The essentiality of Cr for metabolism in plants has not been definitely proven (Gonelli & Renella, 2013). Chromium (VI) is toxic to the biota and is a carcinogen and may cause death to animals and humans in larger doses (NRC, 2005). Chromium (III) sorbs strongly to soils (Bartlett & Kimble, 1976) (Table 5.1.1.1-1), while Cr(VI) is much more mobile (Barceloux, 1999). Thus, it would be preferable to assess the risk of Cr for separate species. However, all input data relates to total Cr, thus this was not possible.

1.3.5 Copper (Cu)

Copper (Cu) has atomic number 29. The mean concentration of Cu in the continental crust is 25 mg kg^{-1} (Wedepohl, 1995), and concentrations in soils typically vary between 2 and 50 mg kg^{-1} (Oorts, 2013). Copper mainly occurs in its divalent state (Cu(II) and has high affinity for binding to organic matter. The solid-liquid partitioning of Cu in soil is largely controlled by the soil pH and the organic matter content, with higher solubility at low pH and low organic matter content (Oorts, 2013). Copper has been used by man at least 10,000 years but more than 95 % of all Cu ever mined and smelted has been extracted since 1900 (Oorts, 2013). The main use of Cu is in electrical applications (65 %) and constructions (25 %). Other uses are tools in transport means, ammunition, coins, sculptures, musical instruments and cookware. The widespread use has resulted in significant anthropogenic emissions, which has caused increased concentrations of Cu in the environment (Hong et al., 1996). Local concentrations of Cu far above natural background values occur because of agricultural practices such as sludge application, Cu fungicides, manure from livestock fed high Cu levels, and industrial activities such as mining.

Copper is an essential trace element for all living organisms and can influence soil ecosystem functioning. In animals and humans Cu deficiency can elicit anemia, and bone, nerve, skin/hair, reproductive and cardiovascular disorders (Davis & Mertz, 1987). Copper toxicity to terrestrial organisms strongly depends on its bioavailability in soils and the sensitivity of the organisms. Poisoning of Cu through the food chain to vertebrates and humans is mainly considered of limited risk due to a strong regulation of internal concentrations of this element in plants and soil-dwelling invertebrates (Oorts, 2013).

1.3.6 Lead (Pb)

Lead (Pb) with atomic number 82, is averagely present in the continental crust at 14.8 mg kg^{-1} (Wedepohl, 1995). The mean Pb concentration in uncontaminated soils worldwide has been estimated to be 17 mg kg^{-1} (Steinnes, 2013a). Lead is among the elements that have been most extensively used by man over time. This led to extensive pollution of surface soils associated with mining and smelting and use of the metal. In modern times, the primary use of Pb has been production alkyl Pb compounds for anti-knock agents in gasoline, as pigments in paints, in car/tractor batteries, in ammunition and in fishing equipment. The contamination is mainly on a local scale, but release of Pb to the atmosphere from various high temperature processes has led to surface contamination on the regional and even global scale (Steinnes, 2013a).

Lead in soils exists predominantly in the Pb(II) oxidation state. It is particularly strongly bound to humic matter in organic-rich soil and to iron-oxides in mineral soil and is rather immobile in the soil unless present at very high concentrations (Steinnes, 2013a).

Lead is not known to be an essential element for man or animals and does not participate in any known beneficial biochemical functions (NRC, 2005). On the other hand, Pb is listed as a top toxic substance, and effort to phase out the use have significantly lowered blood Pb levels in the general population (Ufelle & Barchowsky, 2019).

1.3.7 Mercury (Hg)

Mercury (Hg) with atomic number 80 has a low abundance in the continental crust, in mean 0.04 mg kg^{-1} (Wedepohl, 1995). However, it has aroused substantial attention, first because of its numerous applications and more recently because of its toxicity (Steinnes, 2013b). Metallic Hg is in liquid state at room temperature. It is the only PTE for which evaporation is a significant removal factor from soil.

There is evidence that Hg was used, primarily for medicinal purposes, for more than 3,500 years ago in Egypt, China and India. The invention of scientific instruments such as the barometer and thermometer in the seventeenth and eighteenth centuries introduced the metallic Hg into scientific research, where it more recently has found a great number of new applications. During the twentieth century, Hg was largely applied in pharmaceuticals, agricultural chemicals, paints, measuring instruments and electrical components, dental products, as well as industrial application of Hg as cathode in chlor-alkali process (Steinnes, 2013b). Commercial production of Hg is made almost entirely from cinnabar, HgS. The environmental pollution of Hg is strongly related to the global cycling of elemental Hg vapour (Hg^0). The atmospheric Hg is derived from natural degassing of the Earth's crust, through volcanic eruptions and from evaporation from oceans and soils. However, anthropogenic sources are estimated to contribute more than the natural ones and consist mainly of emissions from metal mining and smelting, coal combustion, municipal incinerators, and chlor-alkali industries (Steinnes, 2013b; Ufelle & Barchowsky, 2019).

In soils the original Hg sources are the minerals constituting the rocks forming the soil parent material. The atmospheric Hg deposition to surface soils has become exceedingly important with the increasing contributions from anthropogenic activities. In the case of agricultural soils, the use of fertilisers (commercial fertilisers, manure, sewage sludge), lime, and Hg-containing fungicides may sometimes increase the Hg load substantially (Steinnes, 2013b). In the soils, Hg normally occurs as Hg^0 and various forms of Hg(II), generally strongly bound to organic matter and sulphides. The Hg-content is generally higher in organic-rich soils than in mineral soils. Under reducing conditions organic Hg compounds, particularly methyl Hg, may be formed in soils, and enter food chains.

No essential biological function of Hg is known. All chemical forms are toxic to humans and animals. Mercury compounds have characteristic toxicokinetic and health effects that depend on oxidation state and associated organic species (Ufelle & Barchowsky, 2019). Mercury vapour is much more hazardous than the liquid form. Inorganic Hg may show acute kidney toxicity. Methylmercury can elicit chronic effects in humans and animals living at the top of the food chain (Ufelle & Barchowsky, 2019).

1.3.8 Nickel (Ni)

Nickel (Ni), with atomic number 28 is averagely present in the continental crust at 56 mg kg^{-1} (Wedepohl, 1995). Nickel is naturally present in all rock types, but particularly high concentrations are found in serpentine rocks and soils, similarly as Cr (Gonelli & Renella, 2013). The normal Ni oxidation states are 0 or +2, although the +1 and +3 states can exist under certain conditions. Nickel in compounds is usually divalent. Reported background concentrations of Ni in soils range between 3 and 48 mg kg^{-1} – the lowest values in soils formed on sandy materials and higher values in in soils originating from volcanic rocks. Far higher concentrations may occur in soils originating from igneous ultramafic rocks. Nickel has a relatively high affinity for soil organic matter, and Ni solubility strongly depends on pH with very little solubility in alkaline soil (Gonelli & Renella, 2013).

Anthropogenic sources of Ni have resulted in a significant increase in the Ni content of soils. Nickel has a broad range of applications in modern industry, mainly in the production of stainless steel together with Cr. Thus, emissions of Ni from metal processing, as well as fumes from combustion of coal and oil have caused a great increase of Ni in the environment. Furthermore, the use of sewage sludge and phosphate fertilisers may also be important sources of Ni in agricultural soils (Gonelli & Renella, 2013). The dispersion of Ni has led to environmental concern, because relatively low concentrations are essential for living organisms, and excessive concentrations may be toxic for all organisms (NRC, 2005; Ufelle & Barchowsky 2019).

1.3.9 Zinc (Zn)

Zinc (Zn), with atomic number 30 is averagely present in the continental crust at 65 mg kg^{-1} as part of rocks or Zn-rich ores located all over the world (Wedepohl, 1995). Economically important ores contain typically 5-15 % Zn, primarily as zinc sulphides. The use of Zn in industrial production today constitutes of galvanisation purposes, brass production and other alloys, motor vehicle tyres, rubber, paints, cosmetics and others (Mertens & Smolders, 2013).

Zinc is naturally present in all soil types in typical background concentrations 10-100 mg kg^{-1}. However, far higher concentrations may occur due to high Zn in soil parent material, large application of sewage sludge, use of manure from animals fed high Zn levels, deposits in Zn mining areas or atmospheric deposits from Zn smelters as well as from natural processes such as volcanic activities or forest fires (Mertens & Smolders, 2013). In general, soils with a high clay content are associated with higher background Zn concentrations than sandy soils due to their higher native Zn concentration and their higher capacity to adsorb and retain Zn. Zinc in soil is present in the +II oxidation state and show pH-dependent binding sites of oxyhydroxides and organic matter and at high concentrations by ion exchange reactions on clay minerals. In general, soil solution of Zn increases fivefold per unit pH decrease (Mertens & Smolders, 2013). Zinc deficiency for agricultural crops is found in about 1/3 of wordwide soils due to low total Zn concentrations or low bioavailability due to high pH or other factors (Mertens & Smolders, 2013). Soil deficient of Zn may hurt the crops and create Zn deficiency in humans and livestock. Zinc toxic soils are less widespread than deficient ones. Risk of Zn toxicity is primarily manifested by effects in soil dwelling organisms; plants, invertebrates and soil microorganisms (Mertens & Smolders, 2013).

2 Literature search

Literature search was performed for topics which were of particular important for the risk evaluation and there other well accepted documents were not available, e.g. text books, EFSA, ECHA, EU dossier reports etc.). The search platform, searching words and number of hits are given in Table 2-1.

Table 2-1. Overview of searching platform, keywords and number of hits.

	Keywords	
Topic: Kd, TF and BCF plant uptake		# of hits
DTU FindIt	"BCF" AND "Arsenic" AND "review"	2
	"heavy metals" AND "soil-plant" AND review	114
	"heavy metals" AND "soil-plant" AND BCF	36
	"heavy metals" AND "soil-plant" AND BCF NOT rice	22
	Hg OR mercury AND BCF AND review	8
	Hg OR mercury AND BCF AND review NOT mushroom	4
	Hg OR mercury AND BCF AND north*	60
	Hg OR mercury AND BCF AND north* AND plant NOT rice	20
	Hg OR mercury AND "distribution coefficient" AND soil AND regression	3
	Hg OR mercury AND "distribution coefficient" OR Kd AND regression	16
	arsenic OR as AND plant uptake AND soil AND review	96
	arsenic AND "plant uptake" AND soil AND review	18
	"Arsenate and chromate retention mechanisms on goethite"	5
	Hg OR mercury AND bcf OR "bioconcentration factor" OR "plant uptake" AND Lettuce OR carrots OR potatoes OR grass OR cereal OR wheat OR barley OR rye NOT mushroom NOT plankton* NOT atmospher*	140
	(Hg OR mercury) AND (bcf OR "bioconcentration factor" OR "plant uptake") AND (Lettuce OR carrots OR potatoes OR grass OR cereal OR wheat OR barley OR rye) NOT mushroom NOT plankton* NOT atmospher*	75
	Cu OR copper AND BCF OR "plant uptake" AND review NOT cobalt	25
	title:(Cu OR Copper) AND title:(BCF OR "bioconcentration factor") AND abstract:(Cu OR Copper OR BCF OR "bioconcetration factor")	3
	title:(Cu OR Copper) AND title:(Kd OR "distribution coefficient") AND abstract:(Cu OR Copper OR Kd OR "distribution coefficient")	27
	(Pb OR Lead) AND title:(Kd OR "distribution coefficient") AND abstract:(Pb OR Lead OR Kd OR "distribution coefficient") AND (regression* OR review OR soil)	63
	(Cr OR chromium) AND title:(Kd OR "distribution coefficient") AND abstract:(Cr OR chromium OR Kd OR "distribution coefficient") AND (regression* OR review OR soil)	9
	title:"Cr(III)" AND title:"Cr(VI)" AND abstract:"Cr(III)" AND abstract:"Cr(VI)"	1
	title:(Ca OR Cadmium) AND title:(Kd OR "distribution coefficient") AND abstract:(Ca OR Cadmium OR Kd OR "distribution coefficient") AND abstract:soil	11
	(carrot* OR potatoe*) AND title:(BCF OR bioconcentration OR "plant uptake") AND abstract:("heavy metal*" OR "trace metal*" OR chromium OR Cr OR "Cr(III)" OR "Cr(VI)") AND (regression* OR review OR soil)	5
	title:(BCF OR "bioconcentration factor" OR "plant uptake" OR "transfer factor" OR tf) AND abstract:("heavy metal*" OR "trace metal*" OR HM OR TM) AND abstract:(soil* OR plant* OR carrot* OR potato*)	74

	Keywords	
	(Carrot* OR agave) AND (BCF OR "bioconcentration factor" OR TF OR "transfer factor") AND metal* AND (Cr* OR Chromium)	31
Topic TF and BCF edible mushroom		
Web of Science	(Hg OR mercury) AND ("Bioconcentration factor" OR bcf OR TF) AND edible AND mushroom AND review	4 (2 relevant)
	(Cd OR Cadmium) AND ("Bioconcentration factor" OR bcf OR TF) AND edible AND mushroom AND review	1
	(Pb OR lead) AND ("Bioconcentration factor" OR bcf OR TF) AND edible AND mushroom AND review	0
	(Pb OR lead) AND ("Bioconcentration factor" OR bcf OR TF) AND edible AND mushroom	42
	(Cd OR cadmium) AND ("Bioconcentration factor" OR bcf OR TF) AND edible AND mushroom	22
	(As OR Arsenic) AND ("Bioconcentration factor" OR bcf OR TF) AND edible AND mushroom	57
	(Cu OR copper) AND ("Bioconcentration factor" OR bcf OR TF) AND edible AND mushroom	45
	(Ni OR nickel) AND ("Bioconcentration factor" OR bcf OR TF) AND edible AND mushroom	20
	(Zn OR zink) AND ("Bioconcentration factor" OR bcf OR TF) AND edible AND mushroom	34
	(Hg AND Cd AND Cr AND Cu AND Hg AND Pb AND Ni AND Zn) AND ("Bioconcentration factor" OR bcf OR TF) AND edible AND mushroom	9
	(Hg AND Cd AND Cr AND Cu AND Hg AND Pb AND Ni AND Zn) AND ("Bioconcentration factor" OR bcf OR TF) AND edible AND mushroom	
	(Hg OR Cd OR Cr OR Cu OR Hg OR Pb OR Ni OR Zn) AND ("Bioconcentration factor" OR bcf OR TF) AND Agaricus bisporus	6
	(Hg OR Cd OR Cr OR Cu OR Hg OR Pb OR Ni OR Zn) AND ((oyster OR Pleurotus) AND mushroom) ("Bioconcentration factor" OR bcf OR TF) AND (cultivation AND substrate) (and related records – 2)	1
Topic TF and BCF and vegetables		
	(Hg OR Cd OR Cr OR Cu OR Hg OR Pb OR Ni OR Zn) AND ("Bioconcentration factor" OR bcf OR TF) AND (vegetable* OR tomato OR cucumber* OR bean* OR spinach OR lettuce OR radish OR onion OR cabbage)	338
	(Hg OR Cd OR Cr OR Cu OR Hg OR Pb OR Ni OR Zn) AND ("Bioconcentration factor" OR bcf OR TF) AND (vegetable* OR tomato OR cucumber* OR bean* OR spinach OR lettuce OR radish OR onion OR cabbage) AND review	2
	(Hg OR Cd OR Cr OR Cu OR Hg OR Pb OR Ni OR Zn) AND ("Bioconcentration factor" OR bcf OR TF) AND (vegetable* OR tomato OR cucumber* OR bean* OR spinach OR lettuce OR radish OR onion OR cabbage) AND garden*	21
Topics Hg in crops cultivated in field		
	(Hg OR mercury) AND concentration* AND crops AND field	109
	(Hg OR mercury) AND concentration* AND crops AND field NOT rice	80
	(Hg OR mercury) AND concentration* AND crops AND field NOT rice NOT high	27

Introduction on PTEs

Mainly based on relevant scientific textbooks, primarily chapters in Alloway BJ (ed) 2013: Heavy Metals in Soils. Environmental Pollution 22, 3rd ed. Springer.

Selection of Kds and TFs

Selection of Kds and TFs for the selected PTEs are based on literature research performed by Philip Gjedde, DTU student, with Prof. Stefan Trapp, as supervisor (Gjedde, 2020). Selection criteria for Kd and TFs are explained in section 5.1.1 and 6.2, respectively.

Fate processes erosion

The climate data that were used for the calculation of the soil water balance are interpolated precipitation and temperature maps, provided to NIBIO by the Norwegian Meteorological Institute (NMI). The evapotranspiration component was taken from NMI's weather data portal (www.senorge.no). Runoff (precipitation excess) was simulated by the PESERA model (described in Appendix IX).

Assessment environmental toxicity

Data sources and literature related to PNECs in surface water, sediment and soil is described in 7.1.1 and listed in Table 7.1.1-1.

Assessment farm animals

Mainly based on relevant scientific textbooks, primarily chapters in NRC 2005: Mineral Tolerance of Animals. 2nd rev. ed. National Research Council. The National Academies Press, Washington, D.C., as well as relevant scientific papers.

Microbial resistance to Cu and Zn search: (Cu OR Zn) AND microbial resistance.

Risk assessments human exposure

VKM and/or EFSA (European Food Safety Authority) have performed risk assessments on the human dietary exposures to the PTEs included in this report, hence we did not perform a literature search. Based on the search functions on the web pages of VKM (www.vkm.no) and EFSA (www.efsa.europe.eu) relevant risk assessments were identified and used in this report.

3 Regulations regarding fertilisers, soil improvers and growing media in Norway and the EU

3.1 Fertilisers, soil improvers, growing media and soil mixtures

3.1.1 Norway

Mineral fertiliser

According to Norwegian regulations, the concentration of Cd in mineral fertiliser should not exceed 100 mg Cd per kg phosphorus (mg Cd kg^{-1} P) (FOR-2003-07-04-1063). The other potentially toxic elements (PTEs) studied in this risk assessment are not included in the Norwegian regulations for mineral fertilisers.

Organic fertilisers and soil amendments

In Norwegian regulations, organic fertilisers/soil improvers are divided into four quality classes based on the content of the PTEs - Cd, Pb, Zn, Cu, Ni, Cr, and Hg (FOR-2003-07-04-951). Maximum level (ML) for As have also been suggested (Haraldsen et al., 2017), but is under review and currently not approved. The quality class determines the restrictions regarding application to soil. The different quality classes and corresponding maximum application to agricultural soils allowed are given in (Table 3.1.1-1). The maximum limit (ML) for the different PTEs in the different quality classes is given in Table 3.1.1-2.

Table 3.1.1-1. Quality classes for organic fertilisers/soil improvers and corresponding maximum application to agricultural soils allowed.

Quality class	Maximum application
0	No restrictions
I	40 tonnes DW ha^{-1} 10 $years^{-1}$
II	20 tonnes DW ha^{-1} 10 $years^{-1}$
III	No application

Table 3.1.1-2. Present ML for the different PTEs in the different quality classes for organic fertilisers and soil mixtures (FOR-2003-07-04-951). Suggested ML for As is included (Norwegian Agriculture Agency, 2018).

Quality class	**0**	**I**	**II**	**III**	**Engineered soil**
	mg kg^{-1} DW				
As[1]	5	8	16	32	8
Cd	0.4	0.8	2	5	1
Cr	50	60	100	150	100
Cu	50	150	650	1000	100
Pb	40	60	80	200	60
Hg	0.2	0.6	3	5	1
Ni	20	30	50	80	50
Zn	150	400	800	1500	150

[1]Suggested value

Growing media

Growing medium means a material used as a substrate for root development, in which plants are grown.

Growing media consists of basic substances of natural or artificial raw materials which are used individually or in a mixture, with or without additional nutrients or other additives, as a product for growing plants. Example of growing media is engineered soils for urban greening (mineral soil) and mixed growing media (organic soil).

Engineered soil is a manufactured soil consisting of specified ratios of sand, silt, clay, and organic amendments such as compost and designed for a specific application, such as construction of parks, green areas and similar locations.

Mixed growing media are potting soils in horticulture for production of vegetables, flowers etc. Most mixed growing media is organic, but lightweight mineral growing media also belong to this category.

In the present Norwegian regulation on organic fertilisers, it is defined that soil materials which can be contaminated with heavy metals or other environmental toxicants cannot be used for production of engineered soils (§ 10.8, FOR-2003-07-04-951). However, the severity of contamination is not defined in this regulation. The suggested limits for heavy metals for engineered soil in Table 3.1.1-2 is close to the Norwegian normative values in the pollution regulation, which is equivalent to class 1, according to Hansen & Danielsberg (2009) and close to the soil quality criteria for agricultural soil, allowing the application of organic waste in the present regulation on organic fertilisers (Table 3.2-1). In Hansen & Danielsberg (2009) it is stated that soil in condition class II (not to be mixed with quality classes for organic fertiliser products) in living areas can be used for growing vegetables (with exception of selected organic pollutants). The statement of Hansen & Danielsberg

(2009) is of concern for Cd and Hg, where class II has upper limit of 10 mg Cd kg^{-1} and 2 mg Hg kg^{-1}. At these soil concentrations plant uptake may be far beyond safe levels for these heavy metals in vegetables, given by The Norwegian Food Safety Authority.

The established soil normative values are used as guidelines for soil quality criteria for preliminary assessment of pollution in soils and as an assessment for handling of contaminated areas (Arp et al., 2017). The normative values are established for evaluation of contaminated ground, and not for risk evaluation of agricultural soil or growing media. It is uncertain if the health aspect including protecting farm animals and humans including vulnerable sub-populations and children eating soil, adequately assessed by using the established normative values established for contaminated ground and soil (Eggen et al., 2019).

In Norway, there has been large building construction activities in the cities in recent years, and at the same time, an increasing interest for cultivation of vegetables, berries and fruit for personal consumption. There is also a large interest for the use of recycled organic waste as composts and organic fertilisers. An important issue is, therefore, to ensure that criteria for engineered soils and mixed growing media is safe for cultivation of crops for human consumption.

Relevant scenarios are use of engineered soils in private gardens and where kitchen gardens or allotment gardens are established later for production of vegetables for personal consumption, or for local sale.

In this risk evaluation following worst-case scenarios related to growing media and engineered soils are included:

Scenario A. Engineered soil and organic fertilisers (Norwegian regulation) exemplifying private garden and growth for home consumption: Use of engineered soils in private gardens (Norwegian MLs Engineered soils, Table 3.1.1-2) followed by fertilising the soil with organic fertilisers Class II with maximum ML Class II for 1, 10 and 50 years (2000 kg DW ha^{-1} yr^{-1}). The vegetables are for home consumption. Bulk density of the soil is 1.2 mg m^{-3}.

Scenario B. Engineered soil and organic fertilisers (Norwegian regulation) exemplifying market garden and growth for sold on the local marked: Use of engineered soils in "allotment gardens" (Norwegian MLs Class 0, Table 3.1.1-2) followed by fertilising the soil with organic fertilisers Class II with maximum ML Class II for 1, 10 and 100 years (2000 kg DW ha^{-1} yr^{-1}). The vegetables are sold on local markets. Bulk density of the soil is 1.2 mg m^{-3}.

Scenario C. Organic growing media: Mixed organic growing media used for establishing beds in gardens, used in pots and containers and hobby greenhouses and use of Norwegian MLs organic fertilisers Class 0 (Sc. C1) and 2 (Sc. C2), and CE-growing media (Sc. C3) (Table 3.1.2-1). The vegetables are for home consumption. Bulk density of the growing media is 0.15 mg m^{-3}.

3.1.2 EU

Selling and applying fertilisers from recycled or organic materials across the EU single market has been difficult to do, due to the diverging national regulations. To improve this situation and facilitate market access, The European Parliament has approved new regulations for fertilisers from organic or recycled materials in the EU (EU 2019/1009) and Regulations EC No 1069/2009 (animal by-products regulation). The rules focus on potential toxic elements (PTEs), but also include limits for the organic contaminants - PAH and dioxin. The ML for the different PTEs in organic fertilisers is given in Table 3.1.2-1.

Table 3.1.2-1 shows MLs for selected PTEs for organic fertilisers, organic soil improvers and growing medium (EU 2019/1009). According to this regulation, "a growing medium shall be an EU fertilising product other than soil in situ, whose function is to grow plants or mushrooms. For this point, plants include algae."

Table 3.1.2-1. Limits for the different PTEs in CE-labelled organic fertilisers, organic soil improvers and growing medium given in the EU regulations (EU 2019/1009).

	Organic fertiliser	**Organo-mineral fertiliser**	**Organic soil improver**	**Growing medium**
	mg kg^{-1} DW	mg kg^{-1} DW	mg kg^{-1} DW	mg kg^{-1} DW
As (inorganic)	40	40	40	40
Cd	1.5	3[1)]	2	1.5
Cr(VI)	2	2	2	2
Cu	300	600	300	200
Pb	120	120	120	120
Hg	1	1	1	1
Ni	50	50	50	50
Zn	800	1500	800	500

[1)] If total P content given as P_2O_5 is 5% or more by mass, the limit value is 60 mg kg^{-1} P_2O_5 (26 mg kg^{-1} P)

3.2 Agricultural soil

Norway

In Norway, soils receiving organic fertilisers/soil amendments classified in quality classes I or II should not have PTE concentrations higher than those given in Table 3.2-1 (FOR-2003-07-04-951).

Table 3.2-1. Maximum content of PTE in soils receiving organic fertilisers/soil amendments classified in quality classes I or II (FOR-2003-07-04-951) and norm values for contaminated soil (Hansen & Danielsberg, 2009).

PTE	Soil receiving organic fertilisers	Normative values
	mg kg^{-1} DW	mg kg^{-1} DW
Cd	1	1.5
Cr(tot)	100	50
Cr(VI)		2
Cr(III)		50
Cu	50	100
Pb	50	60
Hg	1	1
Ni	30	60
Zn	150	200

EU

According to the EU regulations, soils receiving sewage sludge should not have PTE concentrations higher than those given in Table 3.2-2 (EC, 1986). The regulation also say that necessary steps should be taken to ensure that those limit values are not exceeded because of the use of sludge.

Table 3.2-2. Maximum content of PTE in soils receiving sewage sludge (EC, 1986).

PTE	mg kg^{-1} DW
Cd	1-3
Cr(tot)	
Cu	50-140
Pb	50-300
Hg	1-1.5
Ni	30-75
Zn	150-300

3.3 Food and feed

Maximum limits (MLs) for PTE concentrations in crops, and edible mushroom are given in Table 3.3-1 and Table 3.3.2. The values are the same for Norway (FOR-2015-07-03-870) and EU (1881/2006) except for Cd in barley and wheat. The ML values for Cd in barley and wheat have recently been changed, but still not implemented in the Norwegian regulation.

Table 3.3-1. Maximum limits for PTE concentration in crops and mushroom, given in fresh weight (FW), according to EU regulation 1881/2006 and amendments. ML for grass is given with 88 % dry matter according to FOR-2002-11-07-1290.

Crop	As	Cd	Cr	Pb	Hg	Ni	Zn
	mg kg^{-1} FW						
Barley; oat		0.050[1]		0.20			
Wheat (except wheat germ, gluten and bran)		0.10[1]		0.20			
Potato (peeled)		0.10		0.10			
Carrot		0.10		0.10			
Wild fungi		0.50		0.80			
Common mushroom, oyster mushroom and Shiitake mushroom				0.30			
Cultivated fungi		0.050					
Shiitake mushroom and Oyster mushroom		0.15					
Grass	2	1.00		30	0.1		

1)Values from latest consolidated version of EU 1881/2006 (as of 01.01.2022) which are still not implemented in the Norwegian regulation (FOR-2015-07-03-870).

Table 3.3-2. Maximum limits for Hg and Cu concentrations in crops according to the pesticide regulation (EU 396/2005 and amendments).

	Hg	Cu
	mg kg^{-1}	
Wheat	0.01	10
Carrot	0.01	5
Potatoes	0.01	5

4 Description of selected agricultural regions and common agricultural practice

Soil and climatic conditions, and thereby agricultural practices, vary considerably throughout Norway. To account for these regional differences, the risk assessment has been performed for five major agricultural regions (Figure 4-1), which includes from north to south:

- Northern Norway, represented with Målselv municipality in Troms as a case area.
- Trøndelag (Mid-Norway), with Melhus municipality as a case area.
- Hedmark region, with Stange municipality as a case area. Soil samples classified as alum shale in Stange and other areas is treated as a separate case, hereafter called case area alum shale.
- Southeastern Norway, represented with Ås municipality in Akershus as a case area.
- Southwestern Norway, represented with Time municipality in Rogaland as a case area.

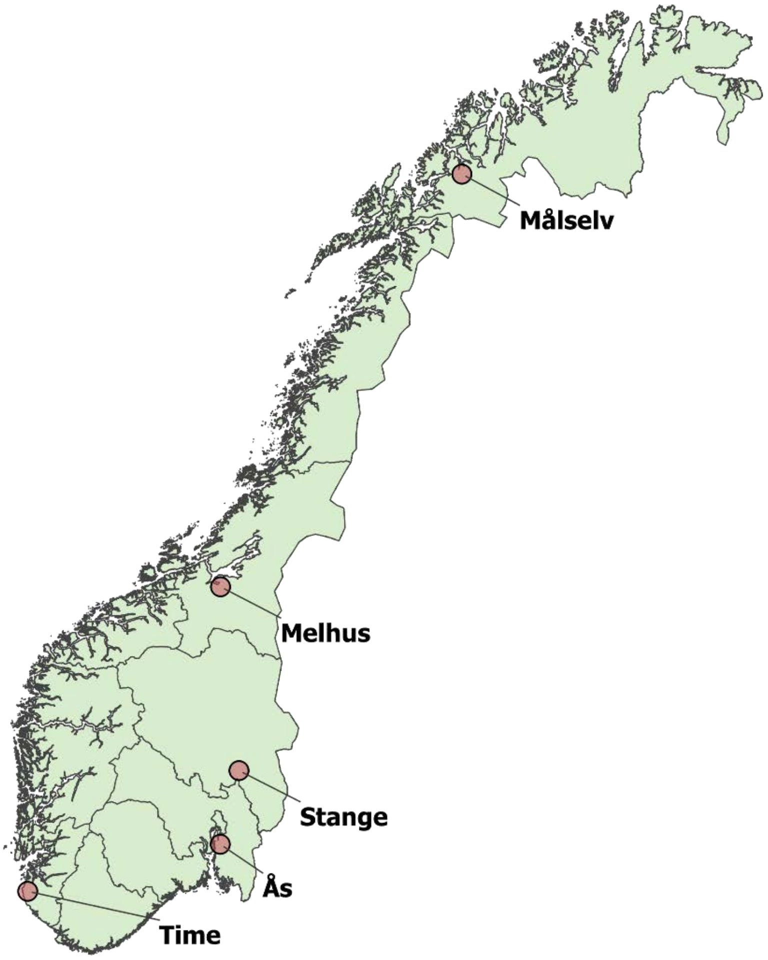


Figure 4-1. Regions included in the risk assessment. Northern Norway, the region Troms, represented with Målselv municipality as a case area, Trøndelag (Mid-Norway), with Melhus municipality as a case area, Hedmark region, with Stange municipality as a case area. Soil samples classified as alum shale in Stange and other areas is treated as a separate case, hereafter called case area alum shale. Southeastern Norway, represented with Ås municipality in Aksershus as a case area, and Southwestern Norway, represented with Time municipality in Rogaland as a case area.

4.1 Geogenic soil in the selected regions

Surficial deposits (till, gravel, soil) in Norway are largely the result of the latest Quaternary period, with its episodes of glaciation and deglaciation. Most of the agricultural soil has been developed on these glacial deposits and on post-glacial clay-rich marine deposits below the highest coastline. The marine influence on soil can be recognised up to an altitude of ca 200 metres above sea level.

High values of As, Cr and Ni are mostly found in soil overlaying volcanic rocks in Trøndelag and Finnmark. Pelitic rocks (e.g. black shales and alum shales) mainly in Hedmark, southeastern Norway and Rogaland may have elevated As concentrations (Andersson et al., 2011). The bedrock in Norway is very heterogeneous, and it is difficult to specify accurate delimitation of areas with elevated background levels. The same applies to the surficial deposits which often reflects the local bedrock. The mapping of the soil's geochemistry in Norway has a low coverage/resolution, compared to our neighbouring countries, Sweden, and Finland. Finland, for example, has a sampling density of 1 sample/km^2 covering the whole country. Below, is a short geological description of each region covered by this report.

4.1.1 Northern Norway (Troms, Målselv)

The bedrock of Troms is dominated by terranes belonging to the Upper and Uppermost Allochthons (Figure 4.1.1-1). The Váddás Nappe is characterised by mica schists, marble, quartzite and amphibolite, the Nordmannavik Nappe by garnet-kyanite gneisses, mylonites and sagvandite and Lyngsfjellene Nappe by gabbro and metasedimentary rocks. The Lower and Middle Allochthons are partly composed of feltspathic metasandstones and schists (Ramberg et al., 2008). Surficial soil deposits in Troms are mainly till and occur as a thin and discontinuous layer, Figure 4.1.1-2. Large parts of Troms are also dominated by exposed bedrock. Contour maps, of the 8 elements covered by this risk assessment, are shown in Figure 4.1.1-3. The maps are based on Aqua Regia digested soil samples (mainly till) from 496 observations loosely distributed in a sample grid of one sample per 36 km^2 (Reimann et al., 2011). Comparing the concentration levels in the till with the national land use-based soil quality criteria (TA2553/2009; Hansen and Danielsberg, 2009), the 100%-il of Cd and Hg is far below health-based soil quality criteria class 1 (out of 5). All the other elements have their 95%-il concentrations far below class 1 soil (except Cr, which is slightly higher). However, the Cr maximum concentration measured in this survey are below class II soil (<200 mg kg^{-1}).

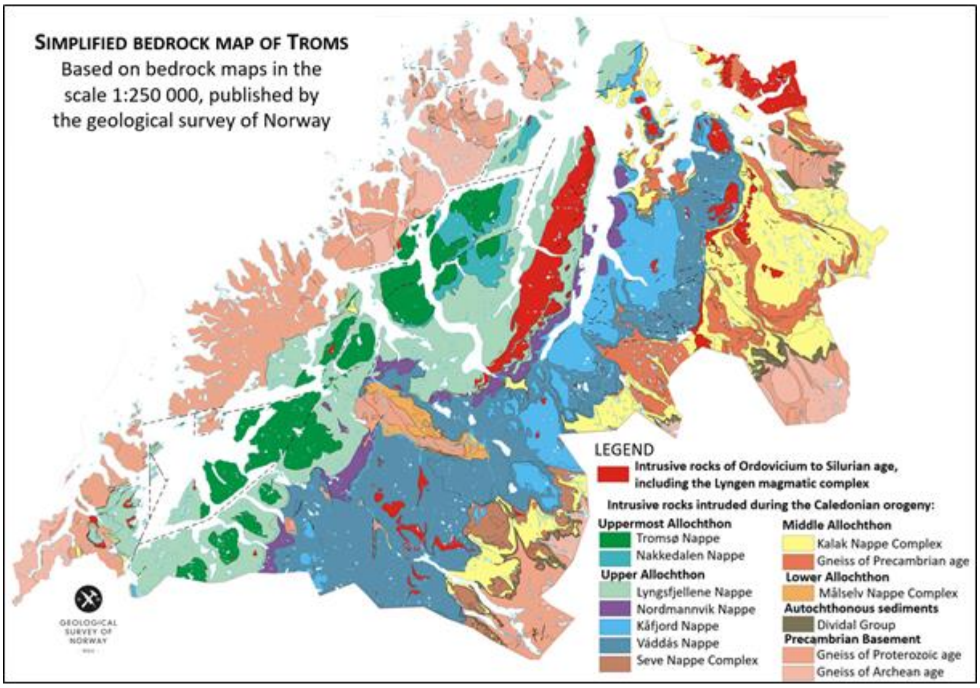


Figure 4.1.1-1. Simplified bedrock map of Troms.

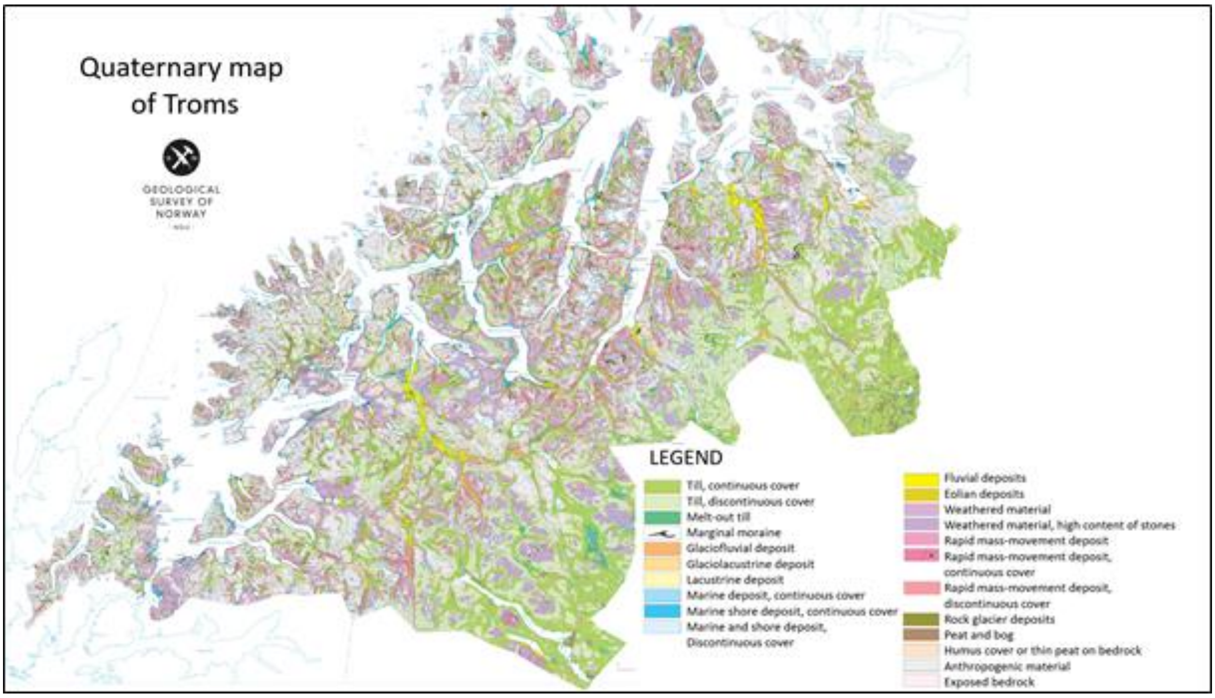


Figure 4.1.1-2. Quaternary map of Troms, scale 1:310 000, modified after Sveian et al., 2005.

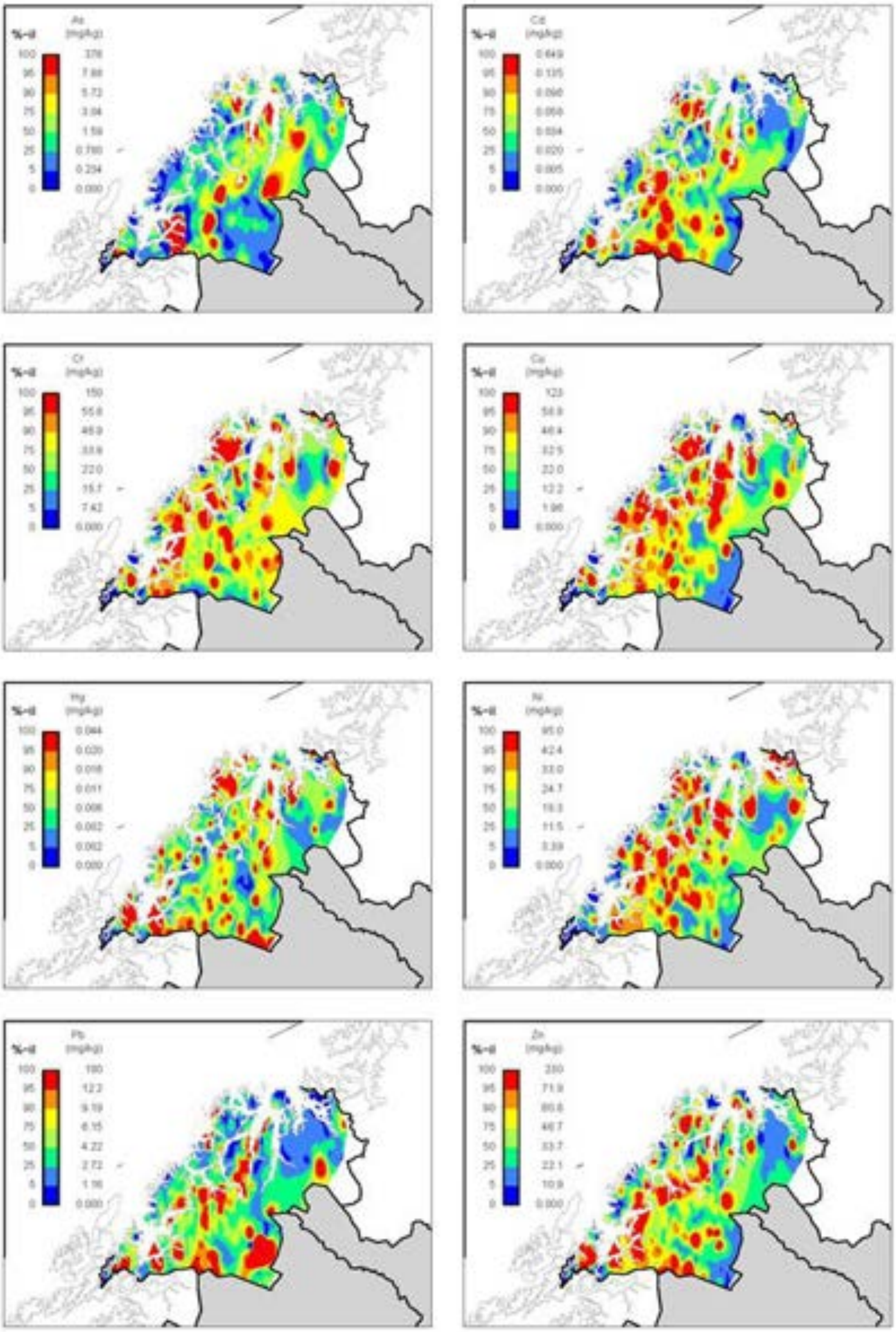


Figure 4.1.1-3. Elemental distribution in mineral soil in Troms of the potential toxic elements As, Cd, Cr, Cu, Hg, Ni Pb and Zn following an Aqua Regia digestion. Data is downloadable from www.NGU.no geochemistry database.

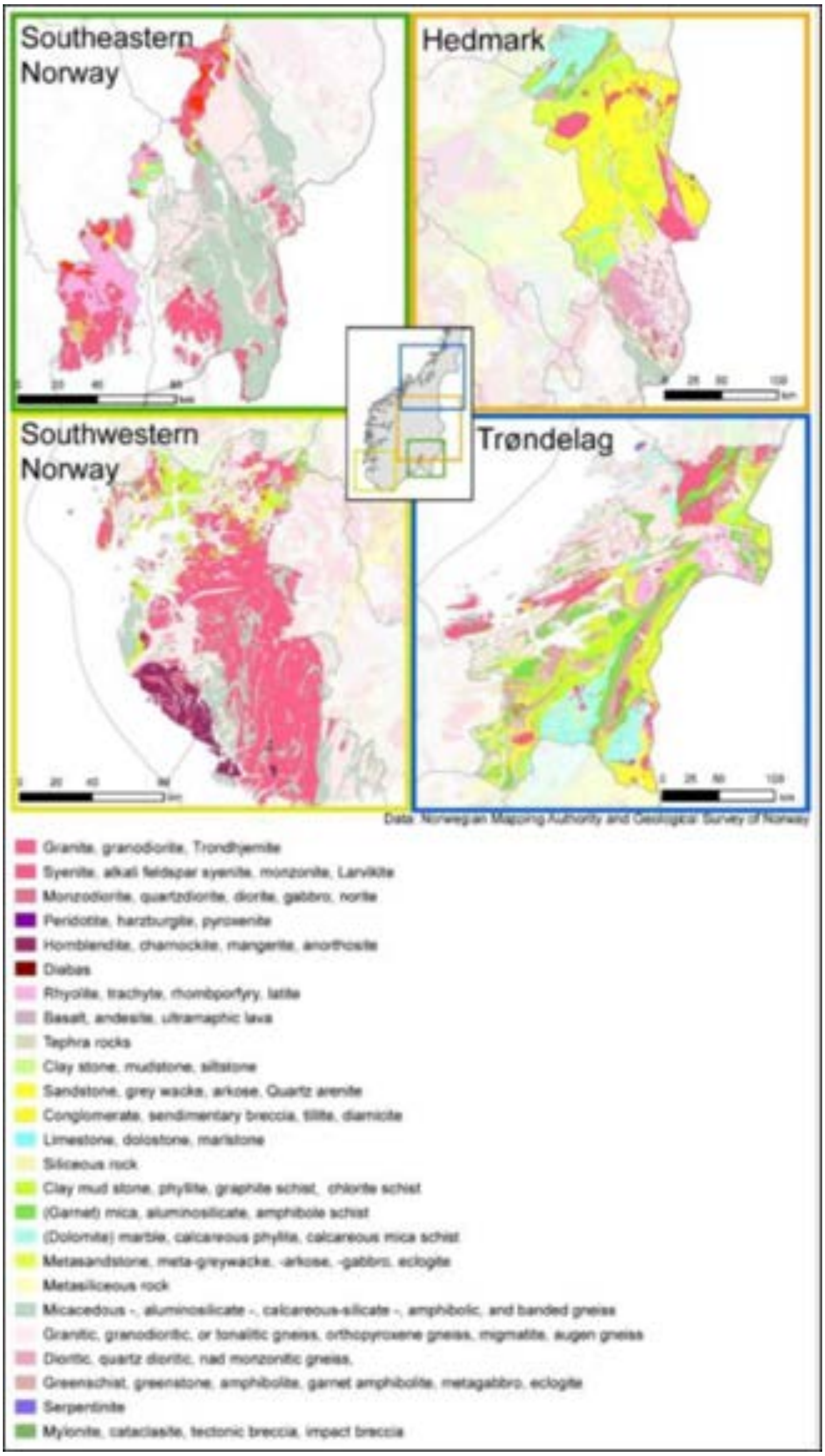
4.1.2 Trøndelag (Mid-Norway, Melhus)

Trøndelag (Figure 4.1.2-1) is a county in Mid-Norway and comprises Caledonian metamorphic and magmatic rocks, in addition to basement granitoid gneisses that are locally influenced by the Caledonian orogeny. Around the Trondheim fjord, the bedrock is overlain by thick layers of clay and other sediments deposited from saltwater predominate. In the remaining areas, the main soil type is moraine. Analysis of overbank sediments show higher HNO_3-extractable Cr and Ni concentrations and low As, Pb and Zn concentrations in the entire Trøndelag County, compared to the national mean (Ottesen et al., 2000).

Contour maps, of the 8 elements covered by this risk assessment, is shown in Figure 4.1.2-2. The maps are based on Aqua Regia digested soil samples (mainly till) from 1 214 observations loosely distributed in a sample grid of one sample per 36 km^2 (Finne et al., 2014; Flem et al., 2020).

Comparing the concentration levels in the till with the national land use-based soil quality criteria (TA2553/2009; Hansen and Danielsberg, 2009), the 100%-il of Cd and Hg are below health-based soil quality criteria class 1 (out of 5). Chromium, Cu, Ni and Zn show high concentrations in area such as Løkken, Røros, Skorovas and Grong, which are known mining areas for sulphide ores. Chromium and Ni are also elevated in areas with greenstone, Figure 4.1.2-1 and 4.1.2-2.

Arsenic is enriched in areas dominated by metasedimentary and mafic igneous rocks belonging to the Trondheim Nappe complex, relative to the granitic rocks that dominates in Roan, Grong-Olden, Agdenes, Trollheimen and Dovrefjell. The most prominent As anomalies occur in the eastern parts of the Støren Nappe, southeast of Trondheimsfjorden, and the Gjersvik Nappe in the northeast of Trøndelag County. Generally, Pb shows low concentrations in Trøndelag, where most of the area can be classified as clean soil, or class 1 soil, which should have <60 mg kg^{-1} Pb (TA2553/2009; Hansen and Danielsberg, 2009), Figure 4.1.2-2.



Data: Norwegian Mapping Authority and Geological Survey of Norway

Figure 4.1.2-1. Simplified geological bedrock map of southeastern Norway (Østlandet including Østfold, Akershus, Vestfold), Hedmark, southwestern Norway (including Rogaland County and Vest-Agder), and Trøndelag.

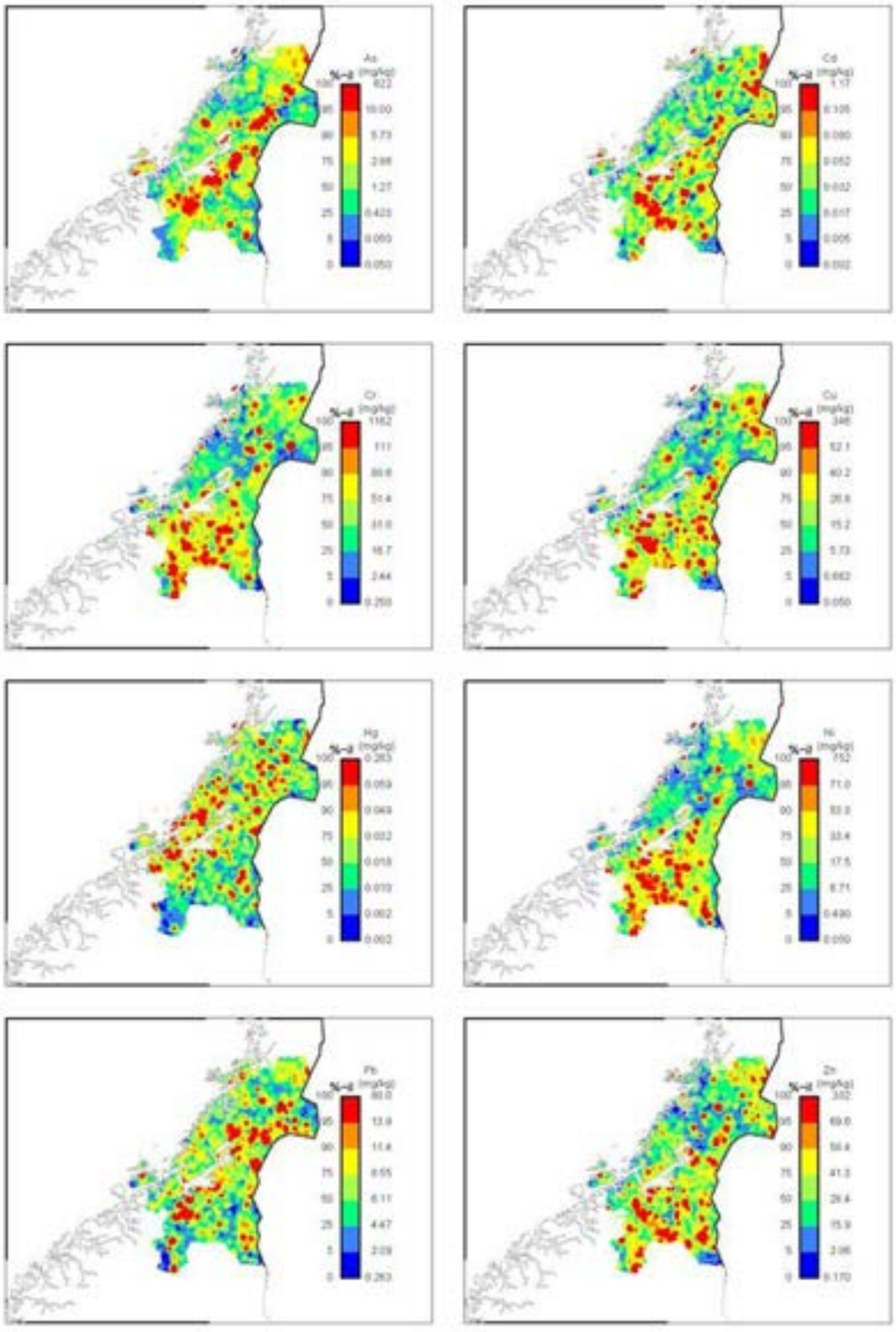


Figure 4.1.2-2. Contour maps, showing the elemental distribution in mineral soil in Trøndelag County, Mid Norway, of the potential toxic elements As, Cd, Cr, Cu, Hg, Ni, Pb and Zn following an Aqua Regia digestion. Data is downloadable from www.NGU.no geochemistry database.

4.1.3 Hedmark (Stange, including alum shale area)

Southern parts of Hedmark comprises the same Proterozoic basement as Østlandet, here mainly dominated by granites, gneisses, and sandstones (Figure 4.1.3-1). The soil is mainly moraine. Further north, around Lake Mjøsa, the bedrock is dominated by slate, limestone, quartzite, and sandstones of mainly Cambrian to Silurian age. The soil consists mainly of continuous thick moraine. Overbank sediments from this area show relatively high concentrations of As, Cu, Ni and Zn compared with the national mean (Ottesen et al., 2000). As elevated concentrations of Zn is found, it is also expected that high geogenic concentrations of Cd is present. The Mjøs region also have some historical prospecting operations on Pb. The area north of Lake Mjøsa (Østerdalen) is dominated by thrust nappes composed of Neoproterozoic sandstones and shales. Overbank sediments from this area are generally low in PTEs.

Stange municipality (focus area with alum shales)

Stange, which is located at the east side of Lake Mjøsa (Fig. 4.1.3-1), is selected as a focus area in Hedmark. The autochthonous rocks in the area are primary augen granite gneiss, tonalite, quartz diorite, mica schist, metasandstone, and quartzite. Stange's largest farms have moraine soil above Cambrian-Ordovician slate and limestone. Although the main part of the fine-grained particles in the moraine are of local origin, mostly larger rocks, that is mainly sparagmite sandstone and quartzite, originating from the hills in the north (Dahl et al., 2017). Overbank sediments from Stange show concentrations of Zn twice as high or more than the national mean (Ottesen et al., 2000) and it is, thus, expected to find high concentrations of Cd as well. Clay stone, limestone, and mud stone might contain alum shales, these usually contain elevated levels of PTEs.

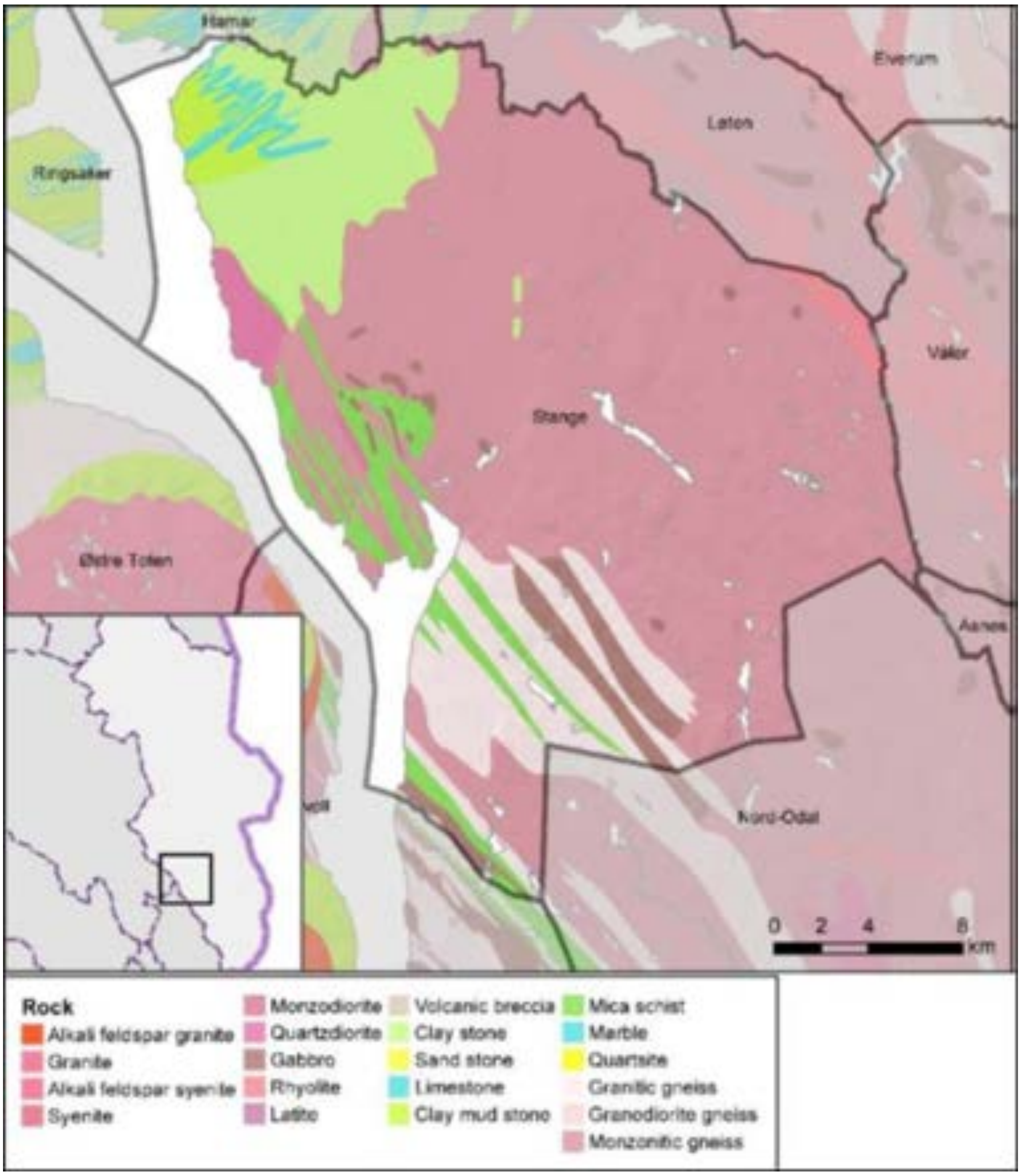


Figure 4.1.3-1. Simplified geological bedrock map of Stange municipality. The clay stone, limestone, and clay mud stone might contain alum shales.

4.1.4 Southeastern Norway (Ås in Aksershus)

The southeastern region (Akershus, Vestfold, Østfold) is part of the Permo-Carboniferous Oslo Rift, which consists of extrusive and igneous rocks (Permo-Carboniferous) and smaller areas of Cambrian to Silurian sedimentary rocks (Figure 4.1.2-1, upper left). The Oslo Rift is approximately 60 km broad and stretches more than 220 km, from Langesund in the south to the Mjøsa area in the north. It is surrounded by granitoid gneisses of Proterozoic age (Ramberg et al., 2008). The Oslo Rift is dominated by granites, syenites, and monzonites. The soils in this area are glacial deposits of varying thickness. Clay, formed in seawater, is common in the bottom of valleys and in the outer parts of Vestfold, which has been below the highest coastline. It is common to find precipitation of iron- and manganese oxides on soils and rocks in streams and lakes in the Oslo Field. These precipitations usually contain PTEs, such as Zn, Pb, Cd, and Mo (Ottesen et al., 2000). In the southeastern part of the region, the soil consists of mainly marine sediments, with elements of glacial deposits. Soil in the northeastern part of the region (Romerike) is dominated by marine sediments, with elements of glaciofluvial deposit. Overbank deposits in this area show relatively low As, Cr, Cu, Ni, Pb and Zn concentrations, compared with the national HNO_3-extractable mean (Ottesen et al., 2000). It is well known that Cd easily substitutes Zn, and low Zn concentrations indicate low Cd concentrations (e.g., Kullerud 1953).

4.1.5 Southwestern Norway (Time in Rogaland)

The southwestern region consists mainly of Proterozoic basement gneisses with Caledonian thrust nappes in the west, composed of Precambrian metamorphic and magmatic rocks. Anorthosites and granitoid gneiss dominate in the south, while mica schists and phyllites (Cambrian and Ordovician), in addition to Precambrian granites, amphibole and charnockite, can be found in the northern part of the southwestern region (Figure 4.1.2-1, bottom left). The number of surficial deposits is sparse in the area, except at Jæren, which has thick deposits of till and marine deposits. The Jæren area is low in Cr and Cu, but enriched in As, Pb and Zn. (Ottesen et al., 2000). Due to high Zn concentrations, it is also expected that Cd concentrations are high in this area. In the southern part of the region, analyses of HNO_3–extract of overbank sediments show low concentrations of all the PTEs covered by this report.

4.2 Common agricultural practice and use of fertilisers and soil products in selected agricultural regions

Data on agricultural areas and crops grown in the selected municipalities were obtained from Statistics Norway (SSB) database for the year 2019.

Data on agricultural areas and crops grown in the selected municipalities were obtained from Statistics Norway (SSB) database for the year 2017. In addition, for each of the four counties where the selected municipalities are located, data on the mean amount of lime applied in the years 2010-2014 were obtained from the NFSA (NFSA, 2015). Data on mean amount of sewage sludge applied during 2008 - 2017 were obtained from SSB.

In this risk assessment, we used the value of recommended mineral P application from the local agricultural extension service for the different crops in each of the regions (Table A-VI-5). For cereals, the application ranged from 11 - 18 kg P ha^{-1} yr^{-1} (comparable to 25 - 41 kg P_2O_5 ha^{-1} yr^{-1}). For potato and carrot, it was, on mean, 34 and 24 kg P ha^{-1} yr^{-1} (comparable to 78 - 55 kg P_2O_5 ha^{-1} yr^{-1}), respectively. These values are somewhat higher than those used in the risk evaluation by Six and Smolders (2014), who used 21 kg P_2O_5 ha^{-1} yr^{-1} for cereals and 45 kg P_2O_5 ha^{-1} yr^{-1} for potato. Current manure application practice is based on information provided by the local agricultural extension service.

4.2.1 Northern Norway (Målselv in Troms)

Målselv municipality is located along the river Målselv in Troms and Finnmark County in northern Norway. The area of agricultural land is approximately 2800 ha, of which approximately 2600 ha is tilled land. Agricultural land covers some less than 1 % of the municipality. Grass production cover approximately 90 % of the agricultural land, whereas potato- and vegetable production cover approximately 7 % and 0.8 % of the tilled land, respectively. Dominant soil types in Målselv are loamy fine sand and loamy medium sand.

The usual crop rotation is 4-15 years with ley (mean 7-8 years), after which the ley is ploughed and reseeded. The ley is usually harvested twice per year. Manure is applied together with Yara compound fertiliser NPK 25-2-6 or Yara NS 27-0-0.

A normal crop rotation in which potato is included is 1.-4. year potato and 5.-8. year ley, whereas a crop rotation in which vegetables (swede or Målselv turnip) are included is 1. year vegetables and 2.-5. year ley. For potato, swede and turnip Yara compound fertiliser NPK 12-4-18 is most commonly used with an addition of polysulphate for potato and swede.

4.2.2 Trøndelag (Mid-Norway, Melhus)

Melhus municipality is in Gauldalen in southern Trøndelag. The area of agricultural land is approximately 6900 ha, of which approximately 6400 ha is tilled land. Agricultural land covers 10 % of the municipality. Melhus has a wide variation in agronomic practices. Approximately 50 % of the agricultural land is used for grain, 1 % for potato and vegetables, and the rest is used for grass and whole crop silage production. Dominant soil types in Melhus are silt loam, loamy fine sand, clay loam, and loam.

Usual crop rotation at the bottom of the valley is 1.-3. year barley and 4. year oats, whereas on the hillsides, the usual crop rotation is five years with ley, after which the ley is ploughed and reseeded with grain as cover crop and harvested as whole crop for silage. Grain is typically fertilised with Yara compound fertiliser NPK 22-3-10.

Grass is usually harvested twice per year. Manure is applied in the spring, and after the first harvest, together with mineral fertiliser. Yara compound fertiliser NPK 25-2-6 is applied in the spring and mineral N fertiliser after the first harvest. Whole crop is fertilised with manure.

4.2.3 Hedmark (Stange, including alum shale area)

The counties of Hedmark and Oppland both have large areas with alum shale. Alum shale soil generally contain higher amounts of both total and easily extractable Cd, Cu, Ni and Zn than non-alum shale soils (Jeng & Bergseth, 1992). The selected municipality, Stange, is located east of Lake Mjøsa in Hedmark county. The area of agricultural land is approximately 9300 ha, of which approximately 8850 ha is tilled land. Agricultural land covers 15 % of the municipality. Grain and oilseed production cover approximately 70 % of the agricultural land, whereas potato and vegetable production cover approximately 6 % of the agricultural land. Dominant soil types in Stange are loam, sandy loam, and loamy medium sand.

The usual crop rotation alternates between barley and spring wheat, but with barley grown more often than spring wheat. When manure is applied, it is typically pig manure in combination with Yara compound fertiliser NPK 25-2-6 and Opti-NS. Without manure, Yara compound fertiliser NPK 22-3-10 or 20-4-11 is used. A normal crop rotation in which potato and carrot are included is 1. year potato, 2. year carrot, 3. year grain, 4. year potato, 5.-7. year grain. For carrot and potato, Yara compound fertiliser NPK 12-4-18 is commonly used.

4.2.4 Southeastern Norway (Ås in Akershus)

Ås municipality is located in Akershus county of southeastern Norway. The area of agricultural land is approximately 3950 ha, of which approximately 3880 ha is tilled land. Agricultural land covers 38 % of the municipality. Grain and oilseed production cover approximately 81 % of the agricultural land, whereas grass production cover 12 % and potato and vegetable production cover 1.7 %. Dominant soil types in Ås are silt loam, clay loam, and loam.

The usual crop rotation is alternating barley, wheat (both spring and winter wheat), and oats, but with barley and wheat grown more often than oats. The typical chemical fertiliser for grain is Yara compound fertiliser NPK 22-3-10. In addition, mineral N fertiliser is applied to wheat.

4.2.5 Southwestern Norway (Time in Rogaland)

Time municipality is located in the coastal lowland area of Rogaland County in southwestern Norway. The area of agricultural land is approximately 8000 ha, of which approximately 4200 ha is tilled land. Agricultural land covers 37 % of the municipality. Grass production cover 97 % and grain production cover 2.6 % of the agricultural land. Dominant soil types in Time are loamy medium sand and sandy loam.

The usual crop rotation is five years with ley, after which the ley is ploughed and reseeded. The ley is usually harvested three times per year, and the total yield is typically 10-13 tonnes DW per ha. Manure is applied in the spring and after the first harvest, together with mineral N fertiliser. After the second harvest, only mineral fertiliser or a combination of manure and mineral fertiliser is applied.

5 Fate of potentially toxic elements in soil

5.1 Influencing parameters

The fate of potentially toxic elements (PTEs) in soil is influenced by runoff, leaching, and adsorption. Uptake of contaminants into plants that are harvested and removed from the field also results in loss from soil and included in the fate prediction. A contaminant's physicochemical properties, soil properties, and climatic conditions will affect these fate processes. Volatilization is only relevant for Hg. Therefore, the important processes to focus on are adsorption, leaching, runoff, and removal via plant uptake.

5.1.1 Distribution coefficients, Kd

5.1.1.1 Selection of Kds for risk assessment modelling

Sorption to soil is a key factor for prediction of the fate of PTEs as it governs removal processes such as leaching, and uptake in plants.

Sorption processes are represented by concentration ratio (distribution) of a compound between soil (solid phase) and soil water (water phase), and this ratio is referred to as the distribution coefficient, Kd (typical unit L kg^{-1}). The Kd-value for PTEs in soils is difficult to predict, as it depends on the chemical and physical composition of the soil (e.g. organic matter content, texture and pH) and speciation (chemical form and charge) of the PTE as well as changes that occur over time (ageing processes), as explained in section 5.1.1.2.

For long-term simulations of PTE fate in soil, Kd is the central and most sensitive parameter. Sorption processes determine leaching and runoff rates ($k_{leaching}$, k_{runoff}), and uptake into and removal via plants (k_{plant}). Therefore, Kd value strongly affects the removal rate from soil and will, for a given input, determine whether PTEs will accumulate in soil over time or not. The Kd values will also determine transfer of PTEs to surface water, forage and food, and, thus, exposure of aquatic organisms, humans and farm animals via water, crops and forage.

In a risk assessment of Cd (VKM, 2019), a thorough comparison of alternative sources of Kd-values was made, and finally using the Smolders data (Smolders, 2013) who derived a regression based on data from four papers and using *in situ* measurements of soil-pore water concentrations of Cd which is expected to be more realistic. In the risk assessment of sewage sludge (VKM, 2009), default values were selected for all heavy metal. In the risk assessment of Cu and Zn in pig and poultry manure (VKM, 2014b), regressions suggested by Degryse et al. (2009) were used.

Due to the lack of empirical Kd values obtained from studies of Norwegian soil, Kd values were collected from literature and predicted from empirical regressions, if regressions were available. Soil parameters that strongly influence Kd of PTEs are pH, soil organic matter (SOM; commonly expressed only as OM or as organic carbon, OC), clay content and cation exchange capacity (CEC).

A literature search was conducted to retrieve Kd-values and regressions for the prediction of Kd-values (Gjedde, 2020). For most PTEs, multiple Kd-values and regressions were found.

Sheppard (2011) derived robust regressions for the prediction of Kd from soil properties, covering the PTEs As, Cd, Cu, Cr(III), Cr(VI), Pb, and Ni. The application domain (range of soil pH and organic carbon) of all these regressions covers the properties of the Norwegian soils used for the current assessment; the regressions are thus considered applicable to calculate the Kd. Sauvé et al. (2000) derived regressions for Cd, Cu, Pb, Ni and Zn (Table 2, 3 and 4) and shows mean Kd-values for As, Cr Cd, Cu, Hg, Ni, Pb and Zn (Sauvé et al. 2000). These two sources cover all PTEs under consideration. Another comprehensive source is the Soil Screening Guidance (US SSG) by the US EPA (1996), which contains ranges and median Kd-values derived from different literature references for As, Cd, Cr(III), Cr(VI), Cu, Pb, Hg, Ni and Zn. Yet another comprehensive source is the "Oppdatering av stoffdata for forbindelser i forurenset grunn" edited by the Norwegian Geotechnical Institute NGI (2016). The document contains Kd-value suggestions for As, Cd, Cr(III), Cr(VI)(tot), Cu, Pb, Hg, Ni and Zn. In comparison to the scientific literature, Kd values in this source are rather high. The values from NGI (2016) are intended to assess contaminated sites, where pollution typically occurred a long time ago, often decades, allowing time for ageing, and occasionally as metallic particles. This may explain the choice of high Kd-values. For consideration of aging, see section 5.1.1.2. Additional sources for individual PTEs are available, both agency reports and scientific papers, see appendix III.

Kd-values for all PTEs under investigation were found, and Kd can be chosen from various sources. The Kd-values and regressions were tested and compared. For the conditions of the Norwegian soils, the regressions by Sheppard (2011) gave lower Kd estimates than those in Sauvé et al. (2000), for all PTE where the outcome could be compared. There is one exception, and that is the Kd of Cd, where the regression(s) by Sauvé et al (2000) give(s) lower Kds which are more in compliance with a (new) comprehensive regression developed by Smolders (2013). The regression of Smolders (2013) has been chosen for the Kd of Cd, because it has previously been used in recent Cd risk assessment. Interestingly, the regressions derived by Sauvé et al. (2000) applied to the Norwegian soils gave for all PTEs, much lower Kds than the mean listed in Table 1 of that source. This can be explained by the properties of the soils: the mean pH of Norwegian soils considered in this study ranges from 5.66 to 6.13, while the pH-values of the soils shown in Sauvé et al. (2000) range from <4 to >8. The Norwegian soils have thus a pH near the lower end of the range, and low pH for all heavy metals leads to low Kd. Thus, when compared to the range of Kd-values from literature, the Kd of the investigated Norwegian soils is expected to be at the lower end.

For the choice of Kd for the subsequent risk assessment, the following criteria were applied:

i) Comprehensiveness: it is preferable to use one literature source that covers many PTEs over several sources that cover less or only one PTE. This leads to a more harmonized assessment, and reduced efforts due to less sources. It is preferable to use a regression over a default value because regressions allow an adaption of the Kd to the conditions at side.

ii) Soil Kd is a key variable in the risk assessment. Lower Kd means higher leaching and thus higher risk for the neighbouring aquatic systems. Hence, for a conservative risk assessment, a lower Kd is preferable with respect to aquatic systems. However, it should be considered that more leaching also means less long-term accumulation in soil, i.e. lower long-term risk for the terrestrial pathways (soil organisms, plant uptake, animal feed).

i) Lower Kd values should also be chosen due to relatively low pH value of the Norwegian soils investigated in this study. Their pH is moderately acidic, which leads to comparatively low Kd-values, compared to the range of Kd-values available from literature. On the other hand, organic carbon of Norwegian soils is comparatively high (Appendix V).

ii) Applicability: only regressions and Kd-values that are applicable and appropriate for Norwegian soils were selected. This means, the input data need to be available, and the regression range needs to cover the soils under consideration. Thus, the regressions chosen to have as input data that are solely pH, clay content and organic matter or organic carbon content, because these data are available for the studied Norwegian soils. Other parameters, such as total metal content (e.g., Sauvé et al. 2000), dissolved organic carbon (Bengtsson and Picado, 2008) or cation exchange capacity CEC (Braz et al. 2013) may also affect adsorption, but were not available for the soils under consideration.

iii) Realistic conditions. Kd can be determined by various methods, e.g., by spiking with the element under consideration and shaking for several hours. The measurement of in-situ distribution is more realistic, i.e., by extraction of soil pore water from soils, because it considers to some extent - aging (increasing adsorption with time) of soils. Sheppard (2011) based the Kd-regressions on studies using pore water extraction, and the regressions were tested versus soil samples from Scandinavia (Sweden). In contrast, the data pool from Sauvé et al. (2000) also contains data from spiking experiments.

iv) Careful documentation of input data for regressions. As an example, pH value of soils can be measured in various ways. A common method is to add distilled water to the soil and measure pH in the developing paste. Alternatively, pH can be measured by adding dilute (0.01 M) $CaCl_2$. The pH then is about ½ unit lower. In the study of Sheppard (2011), the regressions were derived by relation to pH (H_2O), while the different methods to determine pH were not differentiated in Sauvé et al. (2000), which adds some uncertainty to the regressions. Hence, this is another advantage of the Sheppard study.

Taken point i) to vii) into consideration, the regressions by Sheppard (2011) were first choice and were chosen where available. The next best alternative were the regressions derived by Sauvé et al. (2000), where pH (Table 2) or pH and soil organic matter SOM (Table 3) serve as input data. If neither a regression by Sheppard (2011) nor by Sauvé et al. (2000) was available for a PTE, as was the case for Hg, Kd was taken from the US EPA Soil screening guidance, Chapter 5 (1996, Table 43). Due to the available input data, no differentiation between Cr(III) and Cr(VI) could be made, and then the Kd-value for Cr(III) is the more realistic, because Cr(VI) in soil is rapidly reduced in the presence of organic matter (Butera et al. 2015). Measured data in fertilisers and soil and transfer factors (TFs) for uptake of Cr into plants (section 6.2.1) are only available for total Cr, thus, Kd for total Cr has been used (US EPA, 1996). Table 5.1.1.1-1 shows the equations or default Kds chosen for the risk assessment modelling, in addition to Kd for Cr(III) and Cr(VI).

Table 5.1.1.1-1. Selected Kd regressions or default Kd-values for PTE. All values L kg^{-1} DW. Unit clay is %, OrgC is % (g 100 g^{-1}). pH refers to pH in distilled water, except in the regression of Cd (taken from Smolders 2013). Kd-values in the referenced studies are measured by extracting in situ soil pore water.

Element	Regression	Reference
As	log Kd (As) =2.39+0.085 pH	Sheppard (2011)
Cd	log Kd (Cd) = -0.94+0.51 pH(CaCl2)+0.79 log orgC(%)	Smolders 2013
Cr(III)	log Kd (Cr(III)) = 1.61 + 0.290 pH + 0.381 log orgC(%)	Sheppard (2011)
Cr(VI)	Kd (Cr(VI)) = 9.4 L kg^{-1}	Sheppard (2011)
Cr(VI)	Kd (Cr(VI)) = 37 L kg^{-1}	US EPA (1996)
CrTOT	Kd (Cr) = 850 L kg^{-1}	US EPA (1996)
Cu	log Kd (Cu) =2.47+0.0656 pH+0.00726 clay(%)	Sheppard (2011)
Pb	log Kd (Pb) =1.96+0.276 pH+0.294 log orgC(%)	Sheppard (2011)
Hg	Kd (Hg) = 8946 L kg^{-1}	Sauvé et al. (2000)
Ni	log Kd (Ni) =0.816+0.229 pH	Sheppard (2011)
Zn	log Kd (Zn) = 0.62 pH-0.97	Sauvé et al. (2000)

5.1.1.2 Significance of PTE-aging processes in soil

The irreversible sorption (i.e. aging) of PTEs in soils is mostly distinguished during the first two years after application (Johnson et al. 2001). Due to ageing, PTEs bind faster with time. Ageing is initially (i.e. the first two years), the fastest (Johnson and Weber 2001). Even though it goes on for the next decades, the increase in irreversible sorption slows down. Using in situ Kd-values, i.e. soil pore water extracted from soils in the field that have been contaminated over a longer time periods (the last decades), ageing is intrinsically considered in Kd-value. This is not the case when Kd is determined by spiking experiments, e.g., in shaking experiments or similar. Hence, in the selection of Kd-values, soil pore water extraction data were preferably chosen. No further calculation of ageing was done. As ageing and thus, increased adsorption will inevitably occur during a 100-years period, ageing processes give an additional margin of safety for the risk assessment.

5.1.2 pH and organic matter in soils

The pH measurements of Norwegian agricultural soils (taken from NIBIO Soil database) are performed with distilled water (pH (H_2O)). For converting to calcium chloride (pH ($CaCl_2$)), the following correction factor is used:

$$\text{pH } (CaCl_2) = \text{pH } (H_2O) - 0.5 \qquad \text{(Eq. 1)}$$

The pH of Norwegian agricultural soils is mostly in the acidic range. The mean values for the five municipalities and different Norwegian regions are all in the range 5.8 - 6.2 as pH (H_2O) and 5.3 - 5.7 as pH ($CaCl_2$) (data from NIBIO Soil database pH (H_2O) values between 3.8 and 8.2) (Table AV-1). Considerable variations in pH are typical for all the regions, and there are small differences in means over time (pH ($CaCl_2$) 5.2-5.7).

The cold, humid climate in Norway is the main reason for the relatively high content of SOM (also referred to as mould) (Table AV-2). The mean content of SOM is highest at Stange/Hedmark (6.5%) and lowest at Time/Rogaland (4.1%). Assuming that SOM is equal to 1.724 x soil organic carbon (SOC) (Scheffer & Schachtschabel 1998), a SOM of 4.1% is equivalent to about 2.4% organic carbon (OrgC, ref Table 5.1.1.1-1).

5.1.3 Precipitation and air temperature

Climate - current and historic change

Norway’s land mass covers several climatic zones and shows a large variation in both temperature and precipitation. While the southern and western coastal zones are temperate with cold or warm summers (Subpolar oceanic (Cfc) and Warm summer continental (Cfb), respectively) (Köppen in FAO, 2006), the larger part of the inland is continental, with warm summers (Köppen Dfb). Central (mountain areas) and northern Norway also comprises areas with tundra climate.

Annual precipitation in Southeastern Norway ranges between 500 and 800 mm, while locally, the annual precipitation can be as low as 300 mm. Summers are warm and, depending on the distance to the coast, winters are generally below zero for prolonged periods. Temperatures in Central Norway are somewhat lower, as is the annual precipitation. Climate in agricultural areas of Trøndelag is similar to that of Southeastern Norway, and partially moderated by the influence of the North Atlantic Drift. Western Norway receives much larger quantities of rainfall, with typical values ranging between 1200 and 1500 mm and local mean annual totals at 2000 mm or more. Temperatures in the temperate West, especially Southwest of Norway are more moderate than in continental Norway.

Climate change as an ongoing process can be illustrated in several ways. In the context of this study, changes in normal period averages for some of the key climate quantifiers were analysed. A climate normal period is 30-years, which is the smallest time frame that is wide enough to cover typical weather dynamics. Presented here are comparisons between the

World Meteorological Organisation’s standard reference, the 1960-1990, normal period, and the most recent for which data were available (1980-2010).

Precipitation is characterised by two quantifiers in this section: annual total precipitation depth (P, mm) and the mean precipitation depth per rain day (P_d, mm).

Table 5.1.3-1 Changes in mean annual precipitation (P) and precipitation per rain day (Pd) for the study areas for two normal periods.

	normal	**Ås**	**Melhus**	**Stange**	**Time**	**Målselv**
P	1960-1990	834	852	574	1414	660
	1980-2010	930	914	626	1505	667
	difference	11.5%	7.3%	9.1%	6.4%	1.1%
P_d	1960-1990	4.87	4.42	4.02	6.88	3.68
	1980-2010	5.85	4.39	4.02	6.85	3.45
	difference	20.1%	-0.7%	0.0%	-0.4%	-6.3%

P_d is a parameter that is indicative of erosivity of precipitation, showing the degree of concentration at time. As a proxy value for the driving forces behind solid and solute transport, it is therefore, more indicative than annual precipitation depth. For Southeastern Norway (Ås), we see that the percentual increase in P_d is twice that of annual precipitation (Table 5.1.3-1). This means that, we do not only get more rainfall, but also that it occurs more concentrated. This is not the case for the other regions in Norway. Some municipalities show clear seasonal trends. However, all five municipalities are receiving a larger part of the annual precipitation in the winter period, while the summer and autumn periods are receiving a smaller share of the annual precipitation. Absolute negative changes in precipitation depth are only observed in autumn in the municipalities of Melhus and Time.

Temperatures have risen gradually over the course of the 60 years for which data were available here (Figure 5.1.3-1).

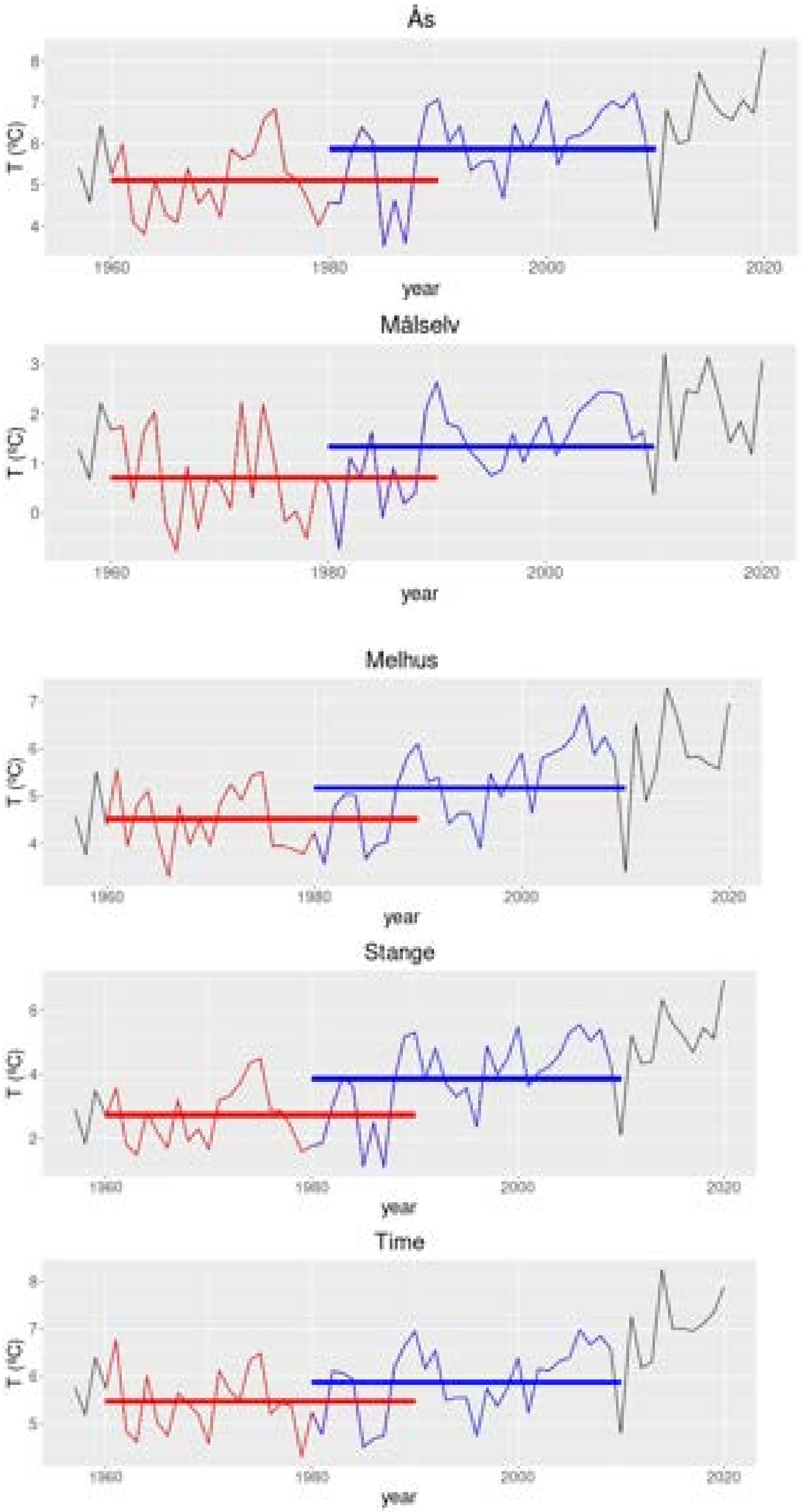


Figure 5.1.3-1. The development of mean annual temperatures in the different municipalities. The horizontal lines depict the mean temperature for the normal periods 1960-1990 (red) and 1980-2010 (blue).

Climate changes in the 21st century

Climate change in Norway during the 21st century is characterised by a continued, steady increase in overall temperatures and growing volumes of precipitation. The predictions presented here are taken from the report "Klima i Norge 2100" (Hanssen-Bauer *et al.*, 2015). The values showed the medians of ensemble model results for two climate change scenarios: RCP4.5 (moderate implementation of measures) and RCP8.5 (no measures).

Not only will there be an increase in annual total precipitation, but the differences will also be more pronounced during the spring and summer (Table 5.1.3-2).

Table 5.1.3-2. Percent increase in annual and seasonal precipitation for Norway for the intermediary (4.5) and worst-case (8.5) Representative Concentration Pathways (RCP).

	RCP4.5	RCP8.5
annual	8	18
winter	5	16
spring	12	13
summer	12	16
autumn	7	16

Regionally, the trends diverge somewhat. Increases in summer rain amounts are largest in Trøndelag, while those in winter are largest in northern and southeastern Norway. Coastal regions will show the largest absolute increases in precipitation volumes.

Besides the overall increase, precipitation will occur more concentrated at time. Table 5.1.3-3 shows the percentual changes in the number of days with intensive rainfall (intensive rainfall is a locally specified quantity, defined as the amount of daily rainfall with an expectancy of 0.5%).

Table 5.1.3-3 Percent increase in number of days with intensive rainfall for Norway for the intermediary (4.5) and worst-case (8.5) Representative Concentration Pathways (RCP).

	RCP4.5	RCP8.5
annual	49	89
winter	73	143
spring	65	91
summer	59	98
autumn	49	111

Here, there is also large variations from region to region; with the largest increases in Trøndelag and northern Norway. Overall, especially winter rain is going to be more torrential.

In the coastal and lowland regions, the general trend is that snowfall will be more erratic, start later and melt earlier due to the general rise in temperatures.

The consequences of these changes in precipitation volume, pattern and intensity on runoff generation and discharge in rivers has also been evaluated by the Norwegian center for climate (Norsk Klimasenter). The hydrological model "Hydrologiska Byråns Vattenbalansavdelning" (HBV; Bergström, 1976) was used to estimate the changes in runoff volumes and intensities for the mentioned climate scenarios.

Table 5.1.3-4. Percent increase in annual and seasonal runoff for Norway.

	RCP4.5	**RCP8.5**
annual	3	7
winter	26	44
spring	8	7
summer	-23	-26
autumn	8	17

Table 5.1.3-4 shows that the annual runoff is likely to increase. This increase is divided unequally over the seasons, with a decrease in the summer months. The increased precipitation during these months in combination with the higher temperatures and atmospheric CO_2 concentrations will lead to higher evapotranspiration rates. The marked increase in winter runoff is likely to be ascribed to intermittent snowfall and melting periods, alternated with rain in the absence of frost. Most of the country-wide trends apply to all municipalities in this report, except for Ås. Southeastern Norway is the only region where autumn runoff is less likely to increase by a significant amount.

Without a model study, it is unclear whether the amount of particle and solute transported through the tile drain systems will increase. If the overall increase in precipitation can be ascribed to the increase in torrential rainfall events, the effect on tile drainage might be limited. On the other hand, farmers currently experience shortcomings in their drainage networks, and many consider a smaller spacing between tile drains when new systems are installed, or old ones maintained.

There is no readily available answer to the question what these dynamics entail for sediment and solute transport from agricultural soils. The simulations required are too complex at the scale of this study and fall outside the scope of the current study. However, abroad conclusion can be drawn by combining process understanding with the most important changes in the remainder of the 21st century.

Runoff will increase, and so will the amount of sediment and solute from agricultural soils. It is important to realise that the increasing frequency of high intensity rain showers is more relevant for agriculture's impact on aquatic ecosystems than the non-episodic changes. Not only are torrents more erosive than low-intensity rainfall, but they also increase the instantaneous hydrological connectivity of the hillslope-river system. When large volumes of excess water are generated in a short period of time, a hydrological shortcut is created. In this situation, there is an increased likelihood that particles and solute will be transported from their origin to river or lake in one single event. This study could not investigate what this will mean for instantaneous concentrations.

Soil properties are in equilibrium with climatic conditions. Long-term trends in weather patterns can therefore be expected to result in changes in soil properties as well; either gradually or as state-shifts (Hirmas *et al.*, 2018). Evidence of such changes is yet to be established for mineral soils, but state shifts with regard to soil hydraulic properties for more organic soils are already being observed (Robinson *et al.*, 2018).

5.2 Removal processes from soil

Mobilization and transportation of PTEs are processes that are dynamic in time and space. PTEs are removed from soil by overland flow and infiltration, erosion, or by interaction with vegetation or atmosphere. Rainfall is often, the main driver behind these processes. Precipitation will first infiltrate and generate overland flow, after the soils capacity to take up water is exceeded. When soil moisture values within the soil profile are sufficiently high, water will start to move from superficial to deeper layers in soil profile through the soil matrix. The presence of macropores can increase the magnitude of these downward transport process exponentially. The ratio between matrix and macropore flow, therefore, determines much of the dynamics of PTE transport towards the saturated zone.

In this study, infiltration/runoff ratios have been estimated for each of the municipalities, to best represent transport by overland flow and leaching.

5.2.1 Leaching and Runoff

The previously used equation for the loss rate by leaching k_{leach} required the calculation of soil-water partition coefficient $K_{soil\text{-}water}$ in the unit ($m^3 \times m^3$). This is non-elegant, because it requires unnecessary calculation steps and a separate definition of bulk density. The loss rate from leaching was, thus derived from the mass balance, as follows.

The change of chemical mass loss through leaching water is

$$\frac{dm}{dt} = -Q\,C_w \qquad \text{(Eq. 2)}$$

where m is chemical mass (mg PTE), Q is infiltrating water ($L\ a^{-1}$) water flow and Cw is concentration in soil water [$mg\ L^{-1}$]. By definition, Kd = $C_{soil}\ Cw^{-1}$, where C_{soil} is concentration in (dry) soil, ($mg\ kg^{-1}$ DW), Kd is ($L\ kg^{-1}$), and thus

$$\frac{dm}{dt} = -Q\,C_{soil}/K_d \qquad \text{(Eq. 3)}$$

C_{soil} = m/M, where M is soil mass in kg. We get

$$\frac{dC_{soil}}{dt} = -Q/M \times C_{soil}/K_d \qquad \text{(Eq. 4)}$$

Soil mass M is replaced with Area (m^2) multiplied by depth (m) mulitiplied by density ($kg\ m^{-3}$), and for a unit area of 1 m^2 follows:

$$\frac{dC_{soil}}{dt} = -Q/(area \times depth \times density \times K_d) \times C_{soil} \qquad \text{(Eq. 5)}$$

Q now is precipitation P (L/a) times fraction infiltrated F_{infilt} (- or L/L), hence

$$\frac{dC_{soil}}{dt} = -F_{infilt}\, P/(area \times depth \times density \times K_d) \times C_{soil} = -k\, C_{soil} \qquad \text{(Eq. 6)}$$

The loss rate k_{leach} (a^{-1}, per year) can now be derived as

$$k_{leach} = F_{infilt}\, P/(area \times depth \times density \times K_d) \qquad \text{(Eq. 7)}$$

Unit check $L\ a^{-1}\ m^{-2}\ m^{-1}\ m^{3}\ kg^{-1}\ kg\ L^{-1}$ remains 1 a^{-1} (per year) is fine.

The present risk assessment differentiates between infiltration (leaching) and runoff water. The loss from soil with runoff water can be calculated in a similar way to the loss with infiltration water, if the concentration ratio between soil solids and runoff water equals the Kd. Then, the loss from soil with runoff (equation derived as before), k_{runoff} (a^{-1}) is

$$k_{run-off} = F_{run-off}\, P/(area \times depth \times density \times K_d) \qquad \text{(Eq. 8)}$$

where F_{runoff} is the fraction of precipitation that is running off the soil via surface flow.The total loss rate due to infiltration and runoff with soil water k_{loss} (a^{-1}) is then

$$k_{loss} = F\, P/(area \times depth \times density \times K_d) \qquad \text{(Eq. 9)}$$

where F is the sum of F_{infilt} and F_{runoff} (- or L L^{-1}).

5.2.2 Erosion

Soil erosion is the detachment and transport of soil particles. Erosion is one of several processes by which agriculture has a negative impact on water quality. Erosion processes can be classified according to the nature of their detachment mechanism. Sheet, or inter-rill, erosion is the result of unconcentrated overland flow. Gully erosion is soil loss due to soil structure failure in talwegs, where overland flow tends to concentrate. On Norwegian agricultural soils, gullies' dimensions are usually sufficiently small for them to be filled up again by normal tillage operations. They are therefore classified as ephemeral gullies. Internal erosion is the loss of soil particles from within the soil matrix. This can either be suffusion (loss of smaller particles through a matrix of coarser material), piping, or erosion along macropores. Internal erosion is a significant mechanism on Norwegian agricultural soils because of the omnipresent tile drains. Suffusion will be referred to as drain erosion from here on. Finally, streambank erosion can be assumed to be a significant source of soil loss at the catchment level.

In this study, sediment fluxes to recipient water were calculated as the result of erosion processes mentioned here. Sheet, drain and gully erosion rates were derived from existing models, developed for Norwegian agricultural soils (Kværnø et al., 2020). Streambank erosion was estimated by comparing modelled annual soil loss rates with (catchment scale) measured annual loads (JOVA programme). Sediment transport rates and subsequent annual loads per municipality to the freshwater system (SDR: sediment delivery rate) were estimated by the following sediment balance:

$$SDR = a*IC*E_{SHEET} + b*L_{GULLY} + c*E_{DRAIN} + d*E_{BANK}$$

Here, E is erosion (tonne year^{-1}), separated by detachment mechanism and multiplied by a combined scaling and transport factor (a, b, c, and d). IC is and index of sediment connectivity.

The detailed mass balance calculation and its constituent terms is elaborated in Appendix IX. The calculations were carried out for Melhus, Stange, Ås and Time municipality, but could not be done for Målselv. The latter municipality does not yet have a soil map, and this is a prerequisite for the estimation of sheet erosion risk.

Annual soil flux rates range from an estimated 0.12 10^3 ha^{-1} (Stange) to 2.39 10^3 ha^{-1} (Time). The distribution of annual flux levels over different regions is largely explained by the main driver behind soil loss: excess precipitation. At Time, with its wet climate, excess annual precipitation levels differ from the other regions by an order of magnitude. Stange and Målselv have little excess precipitation. The relative importance of soil loss through the tile drain system in these areas can therefore be assumed to be higher than in the other regions. The estimated losses from gully and streambank erosion are very homogeneous throughout the country.

Table 5.2.2-1. Results of the water balance elements and sediment calculations for the five municipalities.

Muni-cipality	**Area**	**P**	**ET**	**Q**	**E_{sheet}**	**$E_{drainage}$**	**E_{gully}**	**E_{bank}**	**E_{tot}**	**runoff ratio**	**Infiltr. ratio**
	ha	mm			10^3 kg ha^{-1}					%	%
Målselv	335642	667	316	26	-	-	-	-	-	4	49
Melhus	70206	943	454	75	1.76	0.186	0.03	0.01	1.98	7	54
Stange	93570	609	376	24	0.07	0.003	0.04	0.01	0.12	4	34
Ås	37151	909	449	83	1.32	0.198	0.03	0.01	1.97	9	41
Time	60610	1542	593	452	2.35	0.014	0.03	0.01	2.39	29	32

NB: The erosion values in this Table are soil flux rates, i.e. rates of sediment delivered to recipient water bodies.

5.2.3 Removal via uptake in harvested plants

Uptake of PTEs by plants plays a role both in the removal of PTEs from the soil (estimate of annual loss of PTEs from soil via harvested plants) and in transfer of PTEs to the food chain (exposure to humans and farm animals). In this section, calculation of removal of PTEs from soil via harvest of crops is addressed and plant uptake and selection of transfer factors (TF) is addressed in section 6.2.

If plant biomass is harvested and transported from the field, then removal via plants can be calculated by plant removal rate, $k_{plant\text{-}removal}$ (year^{-1}), according to equation 14.

$$k_{plant-removal} = \left(\frac{CP \times C_{plant}}{DEPTH_{soil} \times RHO_{soil} \times C_{soil}}\right) \qquad \text{(Eq. 14)}$$

Where

$k_{plant\text{-}removal}$ = plant removal rate [yr^{-1}]

CP = crop production [kg DW·m^{-2}·yr^{-1}]

C_{plant} = concentration in plant [mg·kg^{-1}·DW]

$DEPTH_{soil}$ = soil depth [m]

RHO_{soil} = bulk density of soil [kg·m^{3}]

C_{soil} = concentration in soil [mg·kg^{-1} DW]

With C_{plant}/C_{soil} = TF (transfer factor soil-to-plant) follows

$$k_{plant-removal} = \left(\frac{CP \times TF}{DEPTH_{soil} \times RHO_{soil}}\right) \qquad \text{(Eq. 14a)}$$

To consider the crop rotation, the equation is modified to

$$k_{plant-removal} = \left(\frac{\sum_{i=1}^{N}(CP_i \times TF_i \times n_i/N)}{DEPTH_{soil} \times RHO_{soil}}\right) \qquad \text{(Eq. 14b)}$$

where CP_i is the production of crop i, TF_i is the transfer factor soil-to-plant for crop i, n_i is the frequency of crop i in the rotation (with $0 \le n_i \le N$), and N is the number of years that this particular crop rotation scheme lasts before it restarts (N is 4 to 8 years). For each crop rotation, other n_i are entered. The sum of all n_i is equal to N at a site. Yield production for the crops in the different regions used in the calculations is presented in Table 5.2.3.-1.

Table 5.2.3-1. Crop production (crop yield) for different crops produced in the selected regions, given in kg FW biomass ha^{-1} yr^{-1}. Data provided by the local agricultural extension service. For prediction of $k_{plant\text{-}removal}$, FW was calculated to DW using the water content of different crops, as presented in Table 6.2.1-1.

Crops	**Location**	**Crop yield (tonnes yield FW ha^{-1} yr^{-1})**
Potato	Målselv	22.5
Swede	Målselv	30
Turnip	Målselv	10
Grass	Målselv	25
Barley	Melhus	3.8
Oat	Melhus	3.6
Grass	Melhus	30
Wheat	Stange	5.6
Barley	Stange	5.1
Carrot	Stange	40
Potato	Stange	30
Wheat	Ås	6.8
Barley	Ås	5.8
Oat	Ås	5.2
Grass	Time	57.5
Carrot	Time	60
Potato	Time	45

An overview of input data used in the calculation of removal of PTE via harvesting plants is shown in Table AIII-1 in appendix III. The concentrations in agricultural crops, C_{plant}, are calculated using bioconcentration factors soil-to-plant, i.e. constant transfer factors (TF; mg PTE per kg plant to mg PTE per kg soil). This means that plant concentrations are proportional to soil concentrations (Tables 8.1.1-1 to 8.1.8-1). This approach assumes that the concentrations of trace metals in plants or different parts of the plant (stem, leaf, grain etc.) are proportional to the total concentration in soil. TFs vary for different plant species and with each PTE. The basis for selection of TFs used in this risk assessment is detailed in section 6.2.

$$C_{plant} = Csoil \times TF_{plant} \qquad \text{(Eq. 15)}$$

Where
C_{plant} = concentration of PTEs in plants (wheat, oats, barley, potato, grass, carrot, garden fruits, root vegetables, leafy vegetables) [mg kg^{-1} DW]
C_{soil} = total concentration of PTEs in soil [mg kg^{-1} DW]
TF_{plant} = crop-specific TF for uptake of PTEs from soils into plants [mg PTE kg^{-1} DW plant to mg PTE kg^{-1} DW soil]

6 Hazard identification

This chapter includes information about the soil concentrations of PTEs in selected case areas, predicted PTE input to the soil via different sources and output of PFE via transport from soil to water and uptake in crops and selection of TFs.

6.1 PTE concentration in soil, input and loss

This section covers PTE concentrations in agricultural soil, atmospheric contribution, measured concentrations of PTEs in mineral- and organobased fertilisers, soil improvers and growing media, estimated input of PTEs to soil via these sources and estimated loss of PTE from soil. Both commercial mineral products and organic based products from circulated secondary raw materials including as sewage sludge, digestate based on food waste and cattle/pig manure as substrates, fish sludge and manure are included.

6.1.1 Present PTE concentration in agricultural soil

There are few available soil data for PTEs at individual municipalities included in this risk evaluation. The estimated median soil concentrations of PTEs (Table 6.1.1.-1) which is used for PEC-calculations in this risk assessment, are therefore based on data from the regions and not only from individual municipalities.

The PTE concentrations in agricultural soil used in different municipalities and regions are presented in Appendix I, along with the number of analyses and their reference. Table 6.1.1-1 gives an overview of median concentrations of all PTEs in the regions studied.

Median PTE concentrations in present agricultural soil (Table 6.1.1-1 and Appendix I) were below the maximum content of PTE in soil receiving organic fertilisers/soil amendments classified in quality classes I or II (FOR 2003-07-04-951), except for Ni at alum shale (Table 3.2-1).

Table 6.1.1-1. Median PTEs concentrations (mg kg^{-1} DW) in agricultural soil for the selected focus regions and used as present PEC_{soil} (See Appendix I for all data).

Regions		**Northern Norway**	**Mid-Norway**	**Hedmark**	**Alum shale**	**South-eastern Norway**	**South-western Norway**
		Soil concentration (mg kg^{-1} DW)					
Munici-palities		**Målselv**	**Melhus**	**Stange**	**Alum shale[1]**	**Ås**	**Time**
PTEs	As	1.6	3	1.1	15	2.7	2
	Cd	0.082	0.1	0.13	0.84	0.21	0.19
	Cr	25	36	14	19	27	9.3
	Cu	14	20	12	43	11	11
	Hg	0.025	0.033	0.03	0.038	0.04	0.069
	Ni	13	23	12	51	14	3.6
	Pb	6	9.6	8.1	20	16	23
	Zn	46	55	43	110	81	36

[1] Alum shale from different municipality

6.1.2 Potential sources for PTE to agricultural soil, urban- and home farming

VKM has previously performed risk assessments related to contaminants and fertilisers and soil improvers, heavy metals and organic contaminants in sewage sludge (VKM, 2009), Cu and Zn in pig and poultry manure (VKM, 2014b) and Cd in mineral P fertilisers (VKM, 2019, Amundsen et al. 2000).

The recycling of organic resources for fertilisers, soil improvers and growing media is increasing, and both the food safety and environmental authority, need knowledge about potential risks of PTEs in these soil and fertiliser products.

6.1.2.1 Selected input sources and application cases

Selection of input sources, application practice and number of fertilisers and soil improvers applied, and PTE concentrations, were discussed with NFSA. NFSA's need for evaluation of today's MLs and known measured maximum concentrations of PTEs in different organic based fertilisers and soil improvers was included in the risk assessment. Based on the suggestions by NFSA and expert group, the scenarios listed in Table 6.1.2.1-1 were evaluated in the present assessment. The atmospheric contribution, which was included in all scenarios but also evaluated as a separate source (#0a), was a worst-case scenario and based on estimated upper limit of excess of PTE influx over 200 years (Table 6.1.2.3-1). Mineral P fertilisers was also evaluated as a separate source (#0b) and in combination with atmospheric contribution (#1). Lime products were included in all scenarios (#1-#10). Since the contribution from lime is shown to be very low (Erstad, 1992), liming products were not included as a separate scenario.

While mineral P fertilisers, cattle and pig manure were applied according to common practise and thus varied for the different crop rotations and regions, a suggested limitation for P application (30 kg P ha^{-1} yr^{-1}) and a maximum dry weight application (2000 kg DW ha^{-1} yr^{-1}) was used as application rate for fish sludge, digestates and poultry manure (#6-8,#10) and sewage sludge and horse manure (#3,#9), respectively, and did not account for crop rotations and was same for all regions. The suggested limitation of 30 kg P ha^{-1} yr^{-1} is the maximum suggested P limitation in the proposal for a new fertiliser regulation (Norwegian Agriculture Agency, 2018). Evaluation of the Norwegian organic fertiliser regulation quality class II (2000 kg DW ha^{-1} yr^{-1} and ML for selected PTEs given in Table 3.1.1-2) was also same for all regions (#2). The sources and applied PTE concentrations in different input schemes and scenarios are presented in Table 6.1.2.1-1 and 6.1.2.1-2 and discussed in section 6.1.2.2.

Table 6.1.2.1-1. An overview of selected fertiliser and soil improver input sources, chosen amount applied and PTE concentrations in the input sources. Scenario #2 is an evaluation of the regulation for Norwegian organic fertiliser quality class II (based on maximum amount and concentration). Except atmospheric contribution and mineral P fertiliser (#0a and #0b), all scenarios include atmospheric contribution and lime application.

Input scheme	**Input source**	
#0a	Atmospheric contribution	Based on estimated upper limit of excess of PTE influx over 200 yr[1]
#0b	Mineral P fertilisers (without atm. contr.)	Present practice given by the agricultural extension service for the given crops[2]. PTE conc.: from NFSA[3] and Yara[4]
#1	Mineral P fertilisers	Present practice given by the agricultural extension service for the given crops[2]. PTE conc.: from NFSA[3] and Yara[4]
#2	Regulation organic fertilisers	Application rate: max. quality class II (2000 kg DW ha^{-1} yr^{-1})[5]. PTE conc.: max ML quality class II[6]. Application rate in all municipality independent of crop
#3	Sewage sludge	Application rate: Same as #2. PTE conc.: mean concentration[7]
#4	Manure[14] (cattle & pig)	Application rate: Present practice given by agricultural extension service[2]. PTE conc.: max. conc. in manure[8]
#5	Manure[14] (cattle & pig)	Application rate: Present practice given by agricultural extension service[2] PTE conc.: mean conc. in manure[8]
#6	Fish sludge	Application rate: Suggested limitation for P, [9]. PTE conc.: mean conc. in fish sludge[10]
#7	Digestate (food waste & manure)	Application rate: Same as #6. PTE conc.: mean conc. in digestate[11]
#8	Digestate (food waste)	Application rate: Same as #6. PTE conc.: mean conc. in digestate[12]
#9	Horse manure	Application rate: Same as #2. PTE conc.: mean conc. in horse manure[13]
#10	Poultry manure	Application rate: Same as #6. PTE conc.: mean conc. in poultry manure[8]

[1] Data from Table 6.1.2.3-1, [2] Based on information given by agricultural extension service, except in Stange with higher amount of pig manure (70 kg P ha^{-1} yr^{-1}), [3] NFSA Report 2017, [4] info sent from Yara, pers.comm. 2021. [5] Table 3.1.1-1. First, suggested ML for As was not included in the scenario. [6] Table 3.1.1-2. [7] SBB sewage sludge

data [8]PTE max and mean concentration from Daugstad et al., (2012). [9]Suggested P limitation Norwegian Agriculture Agency, 2018, [10]Collected data from fish sludge, [11]Collected data from digestate based on co-substrate food waste & manure, [12]Collected data from digestate based on only food waste, [13]Collected data from non-controlled composted horse manure.[14] Scenarios with pig manure were included also in cases where it was not given by the extension service.

6.1.2.2 PTE concentrations and selection of input data for selected fertilisers and soil improvers

An overview of mean PTE concentrations in fertilisers and soil improvers is presented in Table 6.1.2.2-1. For some products (fertilisers and soil improvers), chemical analyses of the selected PTEs were scarce. Hg and As are less commonly measured for (Hg missing for cattle, pig and poultry manure, and As missing for sewage sludge and digestate), and for some sources below limit of quantification (LOQ). In liming products, Zn was not included in the analysis (Erstad, 1992).

The number of PTE analyses for the different products varied highly and an overview of number of samples analysed and higher than LOQ is shown in Table 6.1.2.2-1. In upper bound (UB) calculations, levels below the LOQ are substituted with the LOQ; in lower bound (LB) calculations levels below the LOQ were substituted with zero (Nøstbakken et al., 2021). For fertiliser products were analyses from one source were used, upper-Bound-values was used (cattle, pig and poultry manure from Daugstad et al., 2012).

The number of available analyses for some of the selected fertiliser products were very low and a minimum numbed of four was chosen, even such a low number is surely questionable. The number and variation of analyses for some elements and fertiliser products are shown in a boxplot in Figure 6.1.2.2-1.

Table 6.1.2.2-1. Concentrations of PTEs in the different fertilisers and soil improvers included in the risk assessment (minimum, maximum, mean, median). The number of samples analysed and samples with concentrations above LOQ (As < 0.8 mg kg^{-1} DW, Pb < 0.7 mg kg^{-1} DW and Ni < 1 mg kg^{-1} DW) are shown. The upper-bound LOQ values has been used. For sewage sludge, only weighed mean and median concentrations for the year 2018 are given. Data from each wastewater treatment plant is given as mean values. n.a.=not analysed; Hg not analysed for in cattle, pig and poultry manure, and As not analysed for in digestate and sewage sludge.

PTE	Input source	Min.	Max.	Mean	Median	n analysed	n > LOQ
As	Cattle manure[1,7]	0.8	0.8	0.8	0.8	7	***0***
	Pig manure[1,7]	0.8	0.8	0.8	0.8	14	***0***
	Poultry manure[1,7]	0.8	0.9	0.8	0.8	12	***1***
	Horse manure[2]	0.6	2	1.2	1	6	5
	Fish sludge[3]	0.6	3.2	1.7	1.6	28 +11	28+11
	Digestate (FW+M)[4]					*n.a.*	
	Digestate (FW)[5]					*n.a.*	
	Sewage sludge[6]					*n.a.*	
Cd	Cattle manure[1]	0.1	0.2	0.1	0.1	7	7
	Pig manure[1]	0.1	0.7	0.3	0.2	14	12
	Poultry manure [1]	0.1	0.3	0.2	0.2	12	12
	Horse manure[2]	0.1	1.2	0.5	0.4	12	9
	Fish sludge[3]	0.3	2.4	0.8	0.7	28+21	28+21
	Digestate (FW+M)[4]	0.1	0.8	0.4	0.4	49	49
	Digestate (FW)[5]	0.1	0.9	0.5	0.5	10	8
	Sewage sludge[6]			0.6	0.6		
Cr	Cattle manure[1,7]	1	1.2	0.6	0.3	7	3
	Pig manure[1,7]	0.3	5.2	1.3	0.3	14	5
	Poultry manure[1]	0.3	3.6	1.7	1.4	12	12
	Horse manure[2]	1.9	31	14.1	14	12	12
	Fish sludge[3]	1.5	16	6.0	4.8	28+20	28+20
	Digestate (FW+M)[4]	2.7	11.3	5.5	5.2	49	49
	Digestate (FW)[5]	13	13.9	13.4	13.2	4	4
	Sewage sludge[6]			16.9	13.5		
Cu	Cattle manure[1]	27	67	39	37	7	7
	Pig manure[1]	47	185	95.4	83.5	14	14
	Poultry manure[1]	28	128	64.5	50.5	12	12
	Horse manure[2]	11	329	47	17	12	12
	Fish sludge[3]	12	36	21.5	22	28+17	28+17
	Digestate (FW+M)[4]	49.6	73	61.3	61	49	49
	Digestate (FW)[5]	35	102	68.2	62	10	10
	Sewage sludge[6]			164.8	145.0		
Hg	Cattle manure					*n.a.*	
	Pig manure					*n.a.*	
	Poultry manure					*n.a.*	
	Horse manure[2]	0.011	0.110	0.058	0.050	11	8
	Fish sludge[3]	0.000	0.260	0.068	0.042	28+21	20
	Digestate (FW+M)[4]	0.038	0.360	0.106	0.086	49	49
	Digestate (FW)[5]	0.550	0.690	0.620	0.620	4	***1***
	Sewage sludge[6]			0.3	0.3		
	Cattle manure[1]	1	4.3	1.5	1	7	***1***
	Pig manure[1]	1	7	1.8	1	14	3

PTE	Input source	Min.	Max.	Mean	Median	n analysed	n > LOQ
Ni	Poultry manure[1]	1.8	5.6	3.4	3.1	12	12
	Horse manure[2]	3.7	20	9.7	9.5	11	7
	Fish sludge[3]	0.5	24	4.1	1.7	28+21	28+18
	Digestate (FW+M)[4]	1.9	17.1	7	6.9	49	49
	Digestate (FW)[5]	1	3	2.3	2.8	4	3
	Sewage sludge[6]			12.9	10.8		
Pb	Cattle manure[1,7]	0.7	0.7	0.7	0.7	7	***0***
	Pig manure[1,7]	0.7	0.7	0.7	0.7	14	***0***
	Poultry manure[1,7]	0.7	1.4	0.8	0.7	12	4
	Horse manure[2]	0.5	72.2	12.2	3.1	11	8
	Fish sludge[3]	0.2	3	1.2	1	28+20	28+18
	Digestate (FW+M)[4]	2.2	10.4	4.8	4.6	49	49
	Digestate (FW)[5]	3.8	8.7	6.8	7.9	4	3
	Sewage sludge[6]			13.8	11.4		
Zn	Cattle manure[1]	140	220	184.3	190	7	7
	Pig manure[1]	250	1542	636.6	545	14	14
	Poultry manure[1]	140	760	357.4	310	12	12
	Horse manure[2]	70	240	118.6	110	12	12
	Fish sludge[3]	169	1300	499.3	446.5	28+21	28+21
	Digestate (FW+M)[4]	204	312	265.2	265	49	49
	Digestate (FW)[5]	150	864	446.1	386	10	10
	Sewage sludge[6]			391.1	354.0		

[1]Daugstad et al., (2012), [2]Data given from producer of commercial products of horse compost, [3]Mean concentrations of collected data from NIBIO projects (mean values for 28 samples from a single smolt hatchery count as one sample). The mean concentrations include one sample which was a mixture of fish sludge and polluted wood waste, [4]Mean concentrations in liquid digestate from Greve biogass plant. [5]Mean concentrations of collected data from different NIBIO projects for liquid digestate. [6]Weighed mean and median concentrations for 2018, Kostra data, SSB; [7]Upper-Bound values for dataset from Daustad et al., (2012) were used.

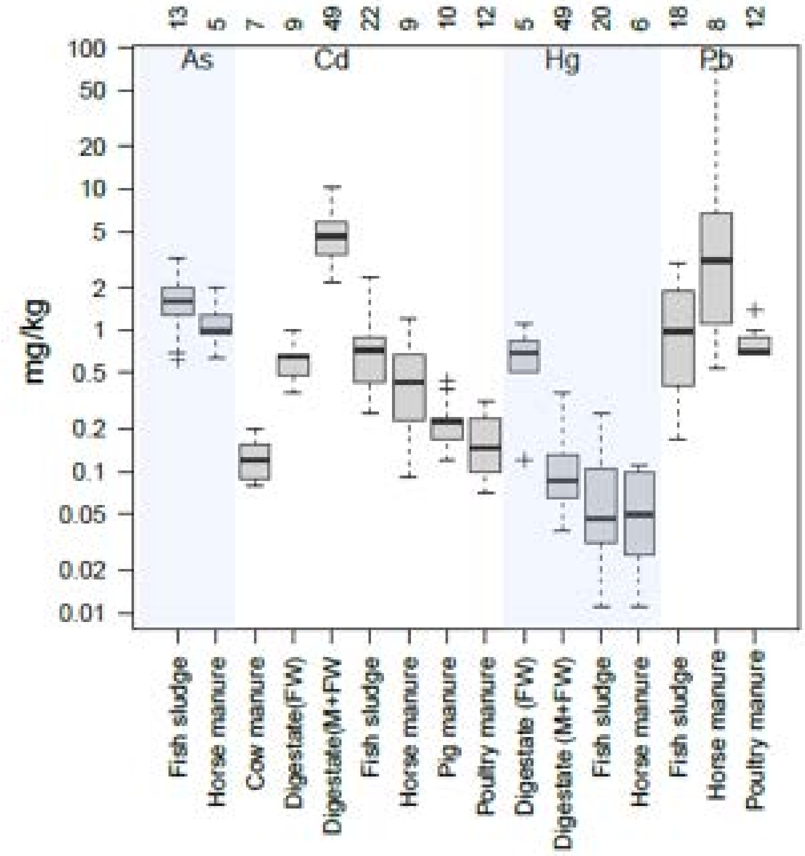


Figure 6.1.2.2-1. Boxplots comparing the distribution of As in fish sludge and horse manure, Cd in cow manure, digestate (FW), digestate (M+FW), fish sludge, horse manure, pig manure and poultry manure, Hg in digestate (FW), digestate (M+FW), fish sludge and horse manure and Pb in fish sludge, horse manure and poultry manure. The box shows the interquartile range, with a thick horizontal line at the median. The whiskers show the non-outlying data, while outliers are shown as crosses. Number of analyses from each group is given along the top axis. Note the logarithmic scale of the y-axis of the plot.

6.1.2.2.1 Mineral P fertilisers

NFSA has conducted a survey of Cd content in mineral fertiliser products (NFSA, 2017). The concentrations of Cd per kg P in different types of mineral fertiliser varied from <2 mg Cd kg^{-1} P up to 160 mg Cd kg^{-1} P (n=48). Two products had a higher Cd content than the ML value, and the products were withdrawn from sale. From this dataset it seems that one of the production sites has a general higher Cd concentration. For instance, in the commonly used NPK 23-2-10, Cd concentration varied from 25 mg Cd kg^{-1} P when produced in Porsgrunn to 82 mg Cd kg^{-1} P when produced in Glomfjord. Three other Yara NPK products produced in Glomfjord (NPK 8-3-18, NPK 23-2-10, NPK 20-4-11) were in the range of 82-85 mg Cd kg^{-1} P. In the risk assessment of ML for Cd in mineral P fertilisers (VKM, 2019), Cd concentrations of Yara NPK 22-3-10 and NPK 25-2-6 (25 and 27 mg Cd kg^{-1} P, respectively), were used for grain and grass, whereas NPK 12-4-8 (50 mg Cd kg^{-1} P), was used for potato and carrot (Table AVI-1).

There is an increasing trend in Cd-concentration in mineral fertilisers in Norway - e.g. the mean mg Cd kg^{-1} P from 1993 to 2005 was in the range of 4 to 9, while for 2017 and 2020 the concentrations were 24 and 30 mg Cd kg^{-1} P, respectively (Yara, personal reference). This is as expected, since an increasing part of mineral fertiliser production will be based on P rock with higher content of impurities such as Cd. Thus, in the present assessment, we choose to use the highest measured Cd concentration in Yara's NPK fertiliser from NFSA report (2017), 85 mg Cd kg^{-1} P.

For the other PTEs, the concentration in NPK 8-5-19 mikro (fullgjødsel) and NPK 25-2-6 (fullgjødsel), data given by Yara (2021, personal reference) where used (Table AVI-2).

According to the fertiliser recommendations (NIBIO fertiliser handbook[1]), the amount of applied P should be adjusted according to soil P status, and P fertiliser should not be used when soil P status is very high (P-AL (plant available P) >14). Here, recommended P fertiliser application without adjustment for soil P status is used for calculating Cd input to soil with mineral P fertiliser. Different mineral fertilisers are used for different crops, and, by combination with manure, mineral fertilisers with lower P concentration are used.

Applied amounts of P with mineral fertilisers to each of the crops and case areas in the scenarios are given in Table AVI-5.

6.1.2.2.2 Lime products

Mean PTE concentrations of 16 different Norwegian lime products of various origins (Erstad, 1992) were used in the risk assessment (Table AVI-3). Mean amounts of lime applied to the agricultural area within each of the case areas are given in Table 6.1.2.2.2-1. Mean values for 2010-2014 of total lime application within each of the four counties where selected municipalities are located were used. Total application was divided by the agricultural area in the county to give mean application per ha and year.

Table 6.1.2.2.2-1. Mean application of lime products in each of the selected case areas presented as kg^{-1} ha^{-1} yr^{-1}.

Municipality	**Ås**	**Stange**	**Time**	**Melhus**	**Målselv**
Applied lime [1)] (kg^{-1} ha^{-1} yr^{-1})	130	90	330	220	60

[1)]Mean total application in the respective counties for 2010-2014 (NFSA, 2015) divided by the agricultural area in the county.

6.1.2.2.3 Sewage sludge

For the years 2017-2019, approximately 112.000 tonnes DW sewage sludge was collected yearly in Norway, where 54% were applied on agricultural fields, 11% on urban areas, 17%

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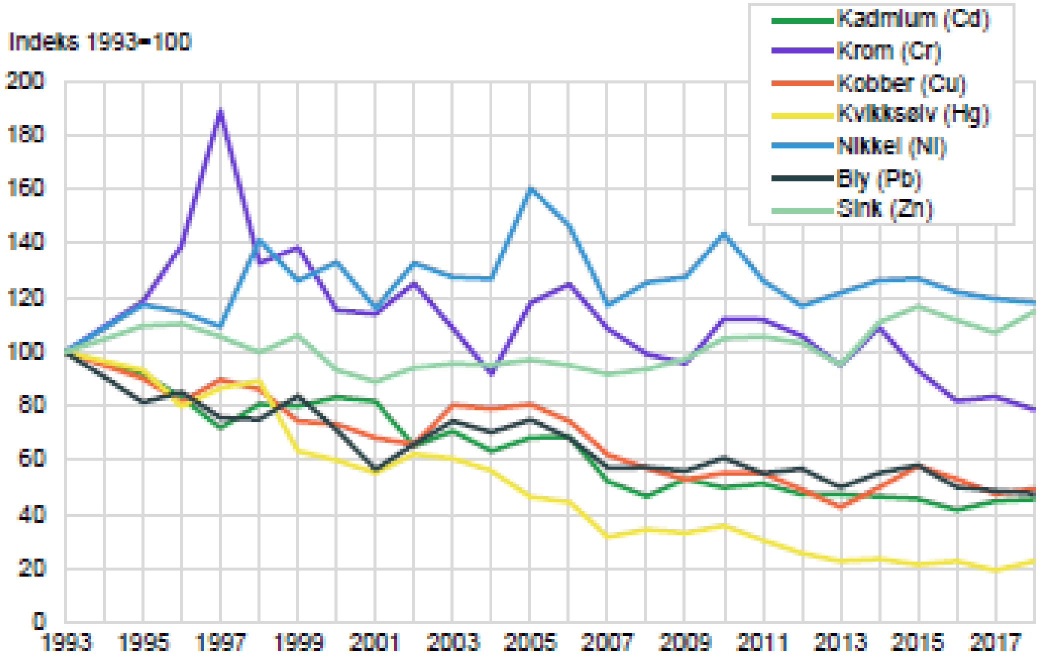
[1] https://www.nibio.no/tema/jord/gjodslingshandbok?locationfilter=true (in Norwegian)

were used for engineered soils and 18% had another use/placement (SSB database). The regional differences are, however, large. For example, 46% of the sewage sludge applied on agricultural fields were applied in Oslo/Akershus, whereas no application on agricultural fields in the counties Sogn og Fjordane, Møre og Romsdal, Nordland, Troms and Finnmark were report. In Oslo/Akershus, approximately 20% of agricultural fields receive sewage sludge during a 10-year period, providing the application of 20 tonnes DW ha^{-1}.

Mean PTE concentrations in sewage sludge have decreased considerably the last decades for Hg, Cd, Pb and Cu, while for Zn, Ni and Cr the mean concentrations in 2018 were not significantly different from the concentrations in 1993 (Figure 6.1.2.2.3-1).



[1] Tall for 1994 eksisterer ikke og er i figuren kun «trukket» i form av direkte linje fra året 1993 til 1995.

Kilde: SSB - Avløp, SESAM (Miljødirektoratet), KOSTRA (SSB) og Altinn (Miljødirektoratet)

Figure 6.1.2.2.3-1. Relative changes in mean PTE concentrations in Norwegian sewage sludge from 1993 to 2018 (1993 = 100) (Berge & Sæther 2019).

Mean PTE concentrations in sewage sludge for the year 2018 (Berge & Sæther 2019), is shown in Table 6.1.2.2-1.

The amount of sewage sludge allowed for application is regulated regarding heavy metal concentration. The maximum sewage sludge application allowed according to current regulations is 20 tonnes DW ha^{-1}10 yr^{-1} for sludge in quality class II and 40 tonnes DW ha^{-1} 10 yr^{-1} for sludge in quality class I. The commonly applied amount is 20 tonnes DW ha^{-1} 10 yr^{-1}. The present assessment includes an application of maximum amount quality class II, 20 tonnes DW ha^{-1}10 yr^{-1} (Table 3.1.1-1) with the weighted mean concentration of PTEs in sewage sludge for the year 2018 (Berge & Sæther 2019) (#3) (Table 6.1.2.2-1).

6.1.2.2.4 Manure (cattle, pig, horse, and poultry)

Concentrations of PTEs in cattle and pig manure presented in Daugstad et al. (2012) show large variations. The mean PTEs concentration (dry weight (DW) basis), with variation for different manure types and concentrations with a normalized DW content are presented in Table 6.1.2.2-1. The measured maximum (#4) and mean (#5) PTEs values in data from Daugstad et al. (2012) were included as separate fertiliser schemes. For grass and cereals, we have calculated with amounts of applied manure based on today's practice given by agricultural extension service. To illustrate a tentative situation using manure as the main nutrient source for potato and carrot, we calculated with larger amounts than given by agricultural extension service. Applied amounts of manure in the calculations are given in Table AVI-5.

Contribution of PTEs via application of manure depend on livestock density, and which is highly variable between different regions of Norway. Specifically, high livestock density is found in the region where Time is located, whereas Ås is in a region with low livestock density. As a result, scenario with manure is not included at Ås. The regions with Stange, Melhus and Målselv have a significant number of animals and scenarios with manure are included in the risk assessment. Rogaland county (Time) has a high share of Norway's number of both cattle, pig, poultry and sheep. For example, Rogaland has 17% of the number of cattle and 28% of pigs in Norway. In comparison, Akershus (Ås) has only 2% of cattle and 4% of pigs in Norway. More information about the number of animals in the different regions of this risk assessment is shown in Table AVI-9. It is expected that in the future, the main part of manure will be applied locally, even though more manure may be redistributed from region with high livestock density to regions with low livestock density to reduce the P surplus in the regions with high livestock density.

6.1.2.2.5 Digestate and compost

The concentrations of PTEs in digestate and compost vary widely depending on the type of input materials, the origin as well as, treatment process itself (Kupper et al. 2014). Green waste refers to organic waste from private gardens and public green areas (Brändli et al. 2005), while bio-waste refers to both green waste and food- and kitchen wastes, including restaurants, caterers and shop premises and similar waste from food processing plants (European Union, 2008). PTEs are not degraded and PTEs are thus either slightly increasing or stable since organic matter content are reduced during the biological transformation processes (anaerobic digitation and aerobic degradation). Input substrates with high PTEs will reduce the quality of end product and should be avoided. In the present assessment, digestate based on food waste alone and food waste in combination with manure are evaluated.

6.1.2.2.6 Fish sludge

Fish sludge is a mixture of feed residues and faeces of farmed fish. The current amount of collected fish sludge is quite small, because it is mainly collected from the smolt production. Yearly collected fish sludge is calculated to 102 tonnes P and 3219 tonnes carbon, which

constitute about 1.4% of carbon in the total sludge production from Norwegian farmed fish (Broch & Ellingsen 2020). This can be compared to the total amount of P in excreted manure, which is calculated to 12 000 tonnes P per year (Bye et al. 2020).
Furthermore, collecting fish sludge is only imposed on expansion of existing smolt production facilities or establishment of new facilities according to Pollution Regulations in Norway. However, the collected amount of fish sludge is assumed to increase rapidly with the ongoing trend of moving post-smolt production and salmon farms on land, in addition to development of closed production units in the sea. The use of fish sludge as fertiliser is, therefore, in the starting pit and is expected to increase as the amount of collected fish sludge increases. Data on the content of PTEs in fish sludge comes from different open reports (Brod & Øgaard, 2021; Brod 2021; Brod et al. 2017; Ytrestøyl et al. 2016) and from some on-going projects to which access has been granted.

6.1.2.3 Atmospheric contribution through atmospheric deposition

Regular Nationwide moss surveys performed in Norway since 1977 (Steinnes et al., 2016; Berg et al., 1994; Berg et al., 1995) and monitoring of wet deposition (Bohlin-Nizzetto et al., 2018, 2019, 2020) shows a declining tendency of input of PTEs via atmospheric deposition. As described by Eggen et al. 2019 (VKM, 2019), the bioactivity is often not taken into consideration when calculating 'atmospheric deposition'. Additionally, the atmosphere will always reflect local dust sources, in addition to long-range atmospheric input from anthropogenic sources. This was well demonstrated by a survey that sampled mineral soil C-horizon, organic soil O-horizon, and terrestrial moss (*Hylocomium splendens*) along a 100-km transect, over two mineral deposits in southern Norway; the Nordli Mo deposit, with surface exposure of molybdenite (MoS_2), and a sandstone-hosted Pb-mineralization with surface exposures of sphalerite (Flem et al., 2018). Results demonstrated that moss reacts strongly to the presence of local Pb mineralization (Flem et al., 2018), as local 'dust' overprints any other Pb sources. Thus, in this report, the methodology suggested by Fabian et al. (2017) for estimating diffuse atmospheric deposition at the continental to regional scale is used. For a given chemical element, it compares the statistical distribution of the element concentration in topsoil to that of the bottom soil. A quantitative estimate of the diffuse external input of the PTEs, covered in this report, is derived from the lower end of the statistical distribution where a constant input has largest impact.

Estimated values of influx are given in Table 6.1.2.3-1 based on data from the Baltic Soil Survey (BSS). The BSS provides a database of more than 40 chemical elements in agricultural soils from an area of 1,800 000 km^2, including the northern European countries of western Belarus, Estonia, Finland, northern Germany, Latvia, Lithuania, Norway, Poland, north-western Russia, and Sweden (Reimann et al., 2003). Topsoil and bottom soil can be compared either statistically or graphically as shown for As in Figure 6.1.2.3-1, (Fabian et al., 2017). Excess Hg is estimated based on data from Trøndelag, Norway, (Finne et al, 2014 a, b; Flem et al., 2020, Flem et al., 2021). This is because the BSS project data base do not provide data for Hg. To calculate the upper limit of the total influx per ha and year into agricultural soil, the total excess mass of the element is divided by the volume (V) sampled. Using a bulk dry soil density of 1200 kg/m^3 and a soil depth of 25 cm (which was the sampling depth of topsoil at the Baltic Soil Survey), this corresponds to 3000 t soil ha^{-1}. Assuming a 200-year period of influx, the yearly elemental diffuse flux to the soil surface is calculated in Table 6.1.2.3-1. This value depends on an assumed plough depth, time of cultivation, and soil density, which in turn is highly dependent on organic content. The estimated influx values listed in Table 6.1.2.3-1 must be considered as upper limit values, because the low-concentration ends of the investigated cumulative probability functions, in addition to external influx, may also be strongly shifted by biosphere adjustments. For example, plants strive to avoid Zn deficiency and thus accumulate a minimal amount of Zn also in their surrounding topsoil (Reimann et al., 2019b). The estimates given in Table 6.1.2.3-1 might also be influenced by agricultural practices. The true input through diffuse contamination will thus be at most equal or lower than the value in Table 6.1.2.3-1.

Table 6.1.2.3-1. Estimated upper limit of total excess of PTE influx over 200 years as mg kg^{-1} and mean influx a year during the last 200 years as mg kg^{-1} yr^{-1}. See text for details for the calculation of the total influx as g ha^{-1} yr^{-1}.

Element	**Excess mg kg^{-1}**	**Mean yearly input mg kg^{-1} yr^{-1}**	**Excess g ha^{-1} yr^{-1}**	**Reference**
As	0.2	0.0010	2.4	
Cd$^{1)}$	0.028	0.0001	0.34	Reimann et al., 2019a
Cr	2.5	0.013	30	
Cu$^{2)}$	1	0.005	12	Reimann et al., 2019b
Hg	0.03	0.0002	0.36	
Ni	1.4	0.007	17	
Pb$^{3)}$	3.3	0.016	40	Fabian et al., 2017
Zn$^{2)}$	5	0.0250	60	Reimann et al., 2019b

[1]Reimann et al., 2019a; [2] Reimann et al., 2019b; [3] Fabian et al., 2017

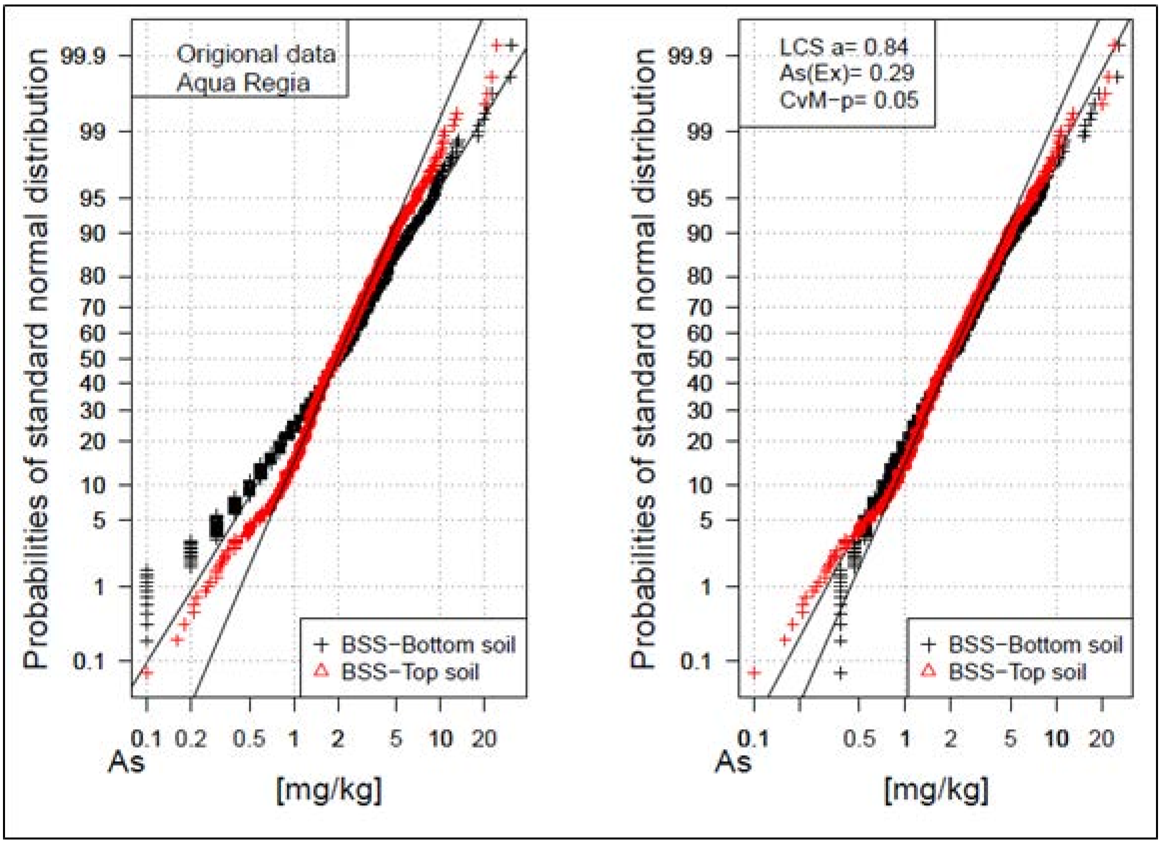


Figure 6.1.2.3-1. Excess As (As(Ex)) in agricultural top soil estimated to 0.29 mg kg^{-1} based on quantiles and to 0.2 mg kg^{-1} graphically.

The Norwegian Institute for Air Research (NILU) monitors PTEs in precipitation at five sites in Norway: Birkenes, Hurdal, Kårvatn, Svanvik and Karpdalen. Reported total wet deposition of As, Cd, Cr, Cu, Hg, Ni, Pb and Zn is given in Table 6.1.2.3-2 for the three last monitoring years, Bohlin-Nizzetto et al. (2018, 2019, 2020). The monitoring stations at Svanvik and Karpdalen, located east in Finnmark close to the Russian border, is influenced by the Ni-mining, ore roasting plant and Ni-smelter at the Russian side of the border. The high registration of Ni in precipitation at these two sites is probably not representative for the Northern Norway region. The measured Cu concentration at Birkenes shows an increase from 19.3 g ha^{-1} yr^{-1} in 2018 to 86.7 g ha^{-1} yr^{-1} in 2019, there is no clear explanation of this increase (private communication, Wenche Aas, NILU).

In Table 6.1.2.3-1, the excess of PTEs in topsoil compared to bottom soil concentration is estimated as mg kg^{-1}. The excess of the elements is assumed to be added equally throughout the last 200 years for simplicity when relating the excess amount to g ha^{-1} yr^{-1}, even though the NILU monitoring programs and the moss surveys shows decreasing trends of atmospheric deposition of all elements (Bohlin-Nizzetto et al. 2020; Steinnes et al., 2016). The concentrations given in Table 6.1.2.3-1 is therefore an upper limit estimate for atmospheric deposition. The concentrations given in Table 6.1.2.3-2 is on the other hand, a lower limit estimate for atmospheric deposition as contribution from air and aerosols, dry deposition, are not included (Bohlin-Nizzetto et al. 2018, 2019, 2020).

Table 6.1.2.3-2. Total wet deposition of PTEs in 2017-2019 at Birkenes (Agder county, South Norway), Hurdal (Viken county, Eastern Norway close to Hedmark), Kårvatn (Møre and Romsdal county, south of Trøndelag county), Svanvik and Karpdalen is both located east in Finnmark close to the Russian border.

Monitoring station	Year	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
		g ha^{-1}yr^{-1}							
Birkenes	2019	1.21	0.27	1.78	86.7	0.0766	2.97	8.42	58.5
Birkenes	2018	1.29	0.30	0.900	19.3	0.0819	2.41	8.08	54.0
Birkenes	2017	1.84	0.36	2.01	46.2	0.114	3.90	13.1	56.1
	Mean	**1.45**	**0.31**	**1.56**	**50.73**	**0.09**	**3.09**	**9.87**	**56.20**
Hurdal	2019	-	0.37	-	-	-	-	5.13	51.3
Hurdal	2018	-	0.17	-	-	-	-	4.60	39.6
Hurdal	2017	-	0.12	-	-	-	-	3.53	39.3
	Mean		**0.22**					**4.42**	**43.40**
Kårvatn	2019	-	0.10	-	-	-	-	3.93	37.5
Kårvatn	2018	-	0.060	-	-	-	-	3.07	37.7
Kårvatn	2017	-	0.050	-	-	-	-	1.72	20.7
	Mean		**0.070**					**2.91**	**31.97**
Svanvik	2019	2.24	0.31	1.36	194	-	141	3.50	15.1
Svanvik	2018	3.75	0.26	1.12	127	-	111	3.84	18.1
Svanvik	2017	4.88	0.36	1.02	137	-	112	3.42	17.0
	Mean	**3.62**	**0.31**	**1.17**	**152.67**		**121.33**	**3.59**	**16.73**
Karpdalen	2019	1.52	0.18	1.49	105	-	71.6	5.10	31.3
Karpdalen	2018	3.35	0.29	2.06	102	-	104	3.66	37.7
Karpdalen	2017	2.80	0.21	1.12	89.0	-	70.5	2.69	17.3
	Mean	**2.56**	**0.23**	**1.56**	**98.67**		**82.03**	**3.82**	**28.77**

National ‘atmospheric deposition’ has been monitored by sampling and analysis of terrestrial moss (*Hylocomium splendens*) since 1977 (Steinnes et al., 2016). In accordance with the monitoring of PTEs in precipitation done by NILU, the monitoring program by moss also shows, as already stated, a decreasing trend for most elements (Appendix Tables AVII1 – AVII3). Especially Pb, a significant decreasing tendency from 2011 to 2016, reported a shift in median Pb concentration from 1.54 mg kg^{-1} to 0.05 mg kg^{-1} (Steinnes et al. 2011, 2016). Steinnes et al. 2016 reports a national median value of 0.13 mg As kg^{-1}, 0.08 mg Cd kg^{-1}, 0.7 mg Cr kg^{-1}, 4.2 mg Cu kg^{-1}, 0.05 mg Hg kg^{-1}, 1.1 mg Ni kg^{-1}, 0.05 mg Pb kg^{-1} and 31 mg Zn kg^{-1} by ‘atmospheric deposition’. The last three years' growth of the moss is used for analysis, the yearly deposition is those accessed by dividing the reported numbers by three giving 0.043 mg As kg^{-1} yr^{-1}, 0.027 mg Cd kg^{-1} yr^{-1}, 0.2 mg Cr kg^{-1} yr^{-1}, 1.4 mg Cu kg^{-1} yr^{-1}, 0.02 mg Hg kg^{-1} yr^{-1}, 0.37 mg Ni kg^{-1} yr^{-1}, 0.017 mg Pb kg^{-1} yr^{-1} and 10.3 mg Zn kg^{-1} yr^{-1}. These numbers seem generally high, compared to the estimated excess abundance of PTE in soil given in Table 6.1.2.3-1. This is probably due to reflection of e.g., local dust sources. Atmospheric deposition will show variations both at local and regional scale in addition to yearly variations depending on dominating wind directions and rain and snow conditions. Historically local industry, e.g., metal smelters/processers have had a strong local impact, however, as the moss surveys show this has been reduced significantly and are no longer recognisable. Thus, and due to lack of regional/local data of topsoil and bottom soil, the same estimate for atmospheric input has been used for all regions. Table 6.1.2.3-3 gives a summary of estimated diffuse contamination by the three methods discussed above.

Table 6.1.2.3-3. Summary of estimated atmospheric diffuse contamination by moss, comparison of top soil and bottom soil concentration by CDF analysis (Table 6.1.2.3-1) and by wet deposition (Table 6.1.2.3-2).

	[1]Moss	CDF-analysis	CDF-analysis	wet deposition
	mg kg^{-1} yr^{-1}	mg kg^{-1} yr^{-1}	g ha^{-1} yr^{-1}	g ha^{-1} yr^{-1}
As	0.04	0.001	2.4	1.5-3.6
Cd	0.03	0.00014	0.34	0.07-0.3
Cr	0.23	0.0125	30	1.2-1.6
Cu	1.40	0.005	12	51-153
Hg	0.02	0.00015	0.36	0.09
Ni	0.37	0.007	17	3.1-121
Pb	0.02	0.0165	40	2.9-9.9
Zn	10.33	0.025	60	17-56

[1] Steinnes et al., 2016

6.1.3 Calculation of PTEs input to soil

The PTE contribution (given as g PTE ha^{-1} yr^{-1}) was calculated based on the applied amount of fertilisers and soil improvers (given as kg or tonnes per ha and year) (Table A-VI-5) and measured PTE concentrations in the fertilisers and soil improvers (given as g PTE kg^{-1} or tonn^{-1}). PTE concentrations were mean values of analysis made available for the project group, published reports and papers, and for sewage sludge, the data was from Statistic Norway (SSB) (Table 6.1.2.2-1, Table AVI-1 and 2). For evaluation of the Norwegian organic fertiliser regulation quality class II, the maximum levels (MLs) given in Table 3.1.1-2 was used. Atmospheric contribution (see section 6.1.2.3, Table 6.1.2.3-1) and lime products were included as PTE sources in each of the evaluated schemes (#1-10). Atmospheric contribution (#0a) and mineral P fertilisers (#0b and #1, without and with atm. contribution, respectively) were also evaluated as separate sources for PTEs.

All fertiliser schemes (#1-#10) were evaluated for all case areas, except for cattle or pig manure which is rarely applied in Ås (Southeastern Norway) and mineral P fertilisers for grass production in Time where often no mineral P fertilisers are used. For the fertiliser schemes cattle and pig manure (#4 and 5), basically cattle manure was applied in the scenarios for Målselv, Melhus and Time and pig manure for Stange. However, to address an application of Zn and Cu via pig manure also in other areas, pig manure application was also evaluated with respect to Zn and Cu in Målselv, Melhus and Time.

Climate influences annual crop yield. As illustrated in Table 5.2.3-1, annual yield for different crops produced in the selected regions are presented, which influence the demand for fertilisers in the regions. The regional differences in yields also affect the calculated removal of PTEs from soil via crop harvesting (section 5.2.3). This was taken in account by including crop rotations of relevance for each case area (Table AVI-8) and annual yields for the different crops (Table 5.2.3-1). Generally, the input PTE at Målselv is lowest (selected crop rotation with only grass and lower biomass production) and highest at Stange (selected crop rotation with cereals, potato, and carrot).

The following application rates for the different scenarios were:

- Mineral P fertilisers (#1), and cattle and pig manure (#4 and #5 for maximum and mean measured PTE values, respectively): applied amounts related to present practice for the given crops in the different regions,
- Poultry manure (#10), digestates (#7 and #8), and fish sludge (#6): applied based on a suggested limitation for P (30 kg P ha^{-1} yr^{-1}),
- Horse manure (#9) and sewage sludge (#3): applied based on maximum allowed amount dry weight (2000 kg DW ha^{-1} yr^{-1}) for quality class II in Norwegian regulation for organic fertilisers and soil improvers.

Application of atmospheric contribution was based on a worst-case estimated upper limit of total excess of PTE influx over 200 years (Table 6.1.2.3-1).

The number of chemical analyses available for the fertilisers and soil improvers are generally low (section 6.1.2.2). The lowest number used was n=4 for digestate based on food waste (#8) for Cr, Hg, Ni and Pb. There were no data available for As in sewage sludge (#3) and the digestates (#7 nor #8). Data for Hg in cattle, pig and poultry manure is also lacking. We have no analysis available for Cr(VI), only of total Cr, and this must be kept in mind during interpretation of the data. The problem with lack of data is further discussed under data gaps in Chapter 13.

Since the atmospheric contribution and fertilisers applied is based on a suggested limitation for P (30 kg P ha^{-1} yr^{-1}) (fish sludge, digestates and horse manure) was the same in all case areas, the only regional difference was mean application rate of lime products (application rates statistics collected by NFSA). The contribution of lime products in different regions is shown in Figure 6.1.3-1.

The estimated PTE inputs for the different scenarios is shown in Table AVI-6a. The estimated atmospheric contribution is the dominating source for some PTEs to soil and, therefore, the input values without atmospheric contribution is shown as well (Table AVI-6b). The PTE inputs by different scenarios and case-areas are visualised – also as input without atmospheric contribution for As, Cr, Hg, Pb - in Figures 6.1.3-1 to 6.1.3-9.

Atmospheric PTE contribution comes both from wet and dry precipitation. The amount added through dry precipitation is not possible to calculate with the data available.

Since different application rates have been used, it is difficult to compare the different fertiliser scenarios without having that in mind. In addition, it is only for pig and cattle manure a measured maximum concentration was evaluated, all other based on mean values. It was decided by NFSA to use 30 kg P ha^{-1} y^{r-1}, but in a previous risk assessment, a higher application rate of manure, 70 kg P ha^{-1} yr^{-1}, as a realistic worst case was included. A realistic worst case with 70 kg P ha^{-1} yr^{-1}, might be the case for other organic fertilisers as well. In order to show the effect of application rates and selection of mean and maximum values, a comparison of different fertilisers, application rates and use of mean and maximum measured values is present for Hg and case-area Time (highest present Hg concentration in agricultural soil but lowest percent increase over time) in Table 6.1.3-1. As shown in the table, both the selected application rate of fertilisers and use of mean or maximum (or 95%-tile) PTE concentration, influence the input of PTEs highly.

Table 6.1.3-1. Comparison of input of Hg, given as g Hg ha^{-1} yr^{-1}, with different applications rates (30 and 70 kg P ha^{-1} yr^{-1}, 2000 kg DW ha^{-1} yr^{-1}) of fish sludge, digestates, horse manure and sewage sludge at Time case-area. Scenarios in **bold** are those which are included in the evaluation.

	Application rates	**Mean measured Hg conc.**	**Max. measured Hg conc.**
		Application rate (g Hg ha^{-1} yr^{-1}	
Fish sludge	**30 kg P ha^{-1} yr^{-1}**	**0.443**	0.679
Fish sludge	70 kg P ha^{-1} yr^{-1}	0.555	1.105
Digestate (FW&M)	**30 kg P ha^{-1} yr^{-1}**	**0.649**	1.342
Digestate (FW&M)	70 kg P ha^{-1} yr^{-1}	1.034	2.651
Digestate (FW)	**30 kg P ha^{-1} yr^{-1}**	**2.061**	2.253
Digestate (FW)	70 kg P ha^{-1} yr^{-1}	4.330	4.778
Horse Manure	30 kg P ha^{-1} yr^{-1}	0.746	1.094
Horse Manure	70 kg P ha^{-1} yr^{-1}	1.261	2.073
Horse Manure	**2000 kg DW ha^{-1} yr^{-1}**	**0.476**	0.580
Sewage sludge	**2000 kg DW ha^{-1} yr^{-1}**	**0.960**	1.120
Sewage sludge	30 kg P ha^{-1} yr^{-1}	0.771	0.881
Sewage sludge	70 kg P ha^{-1} yr^{-1}	1.319	1.575

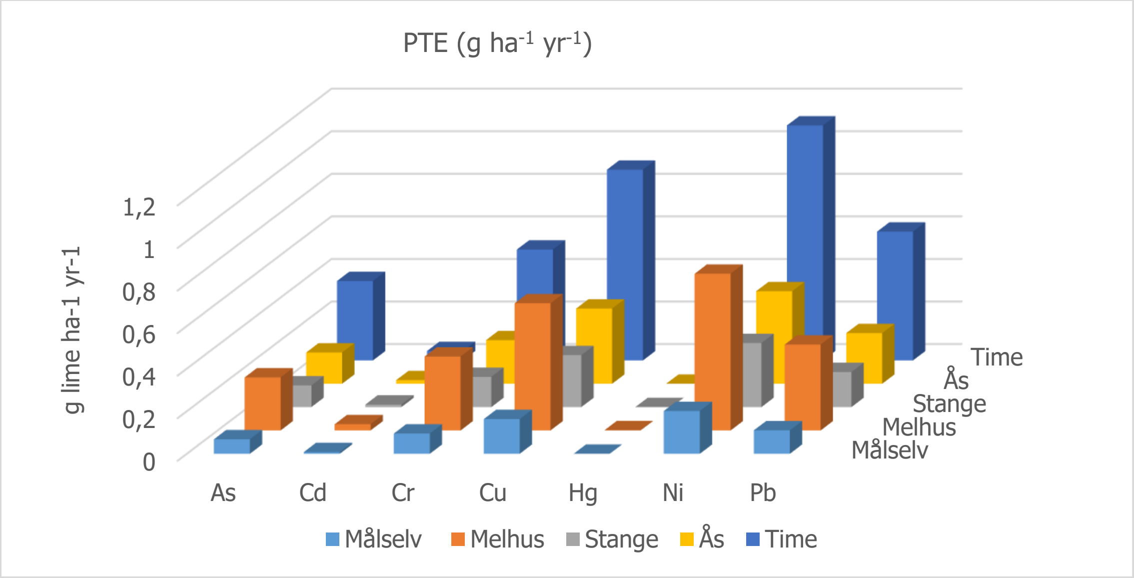
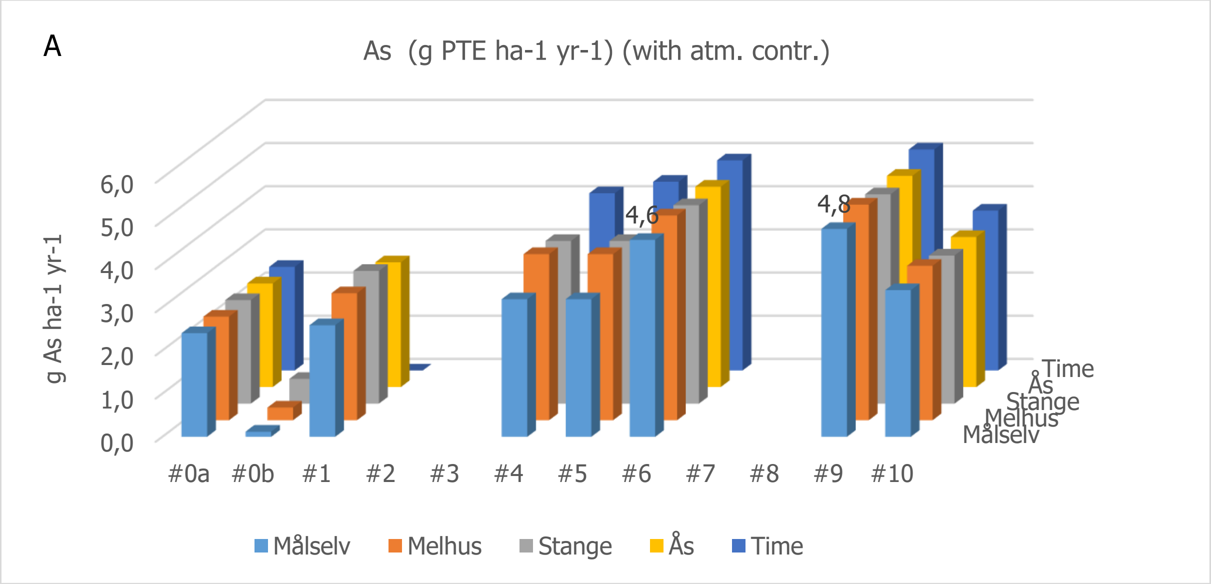


Figure 6.1.3-1. Input of selected PTEs, except Zn, via lime products in the different regions.



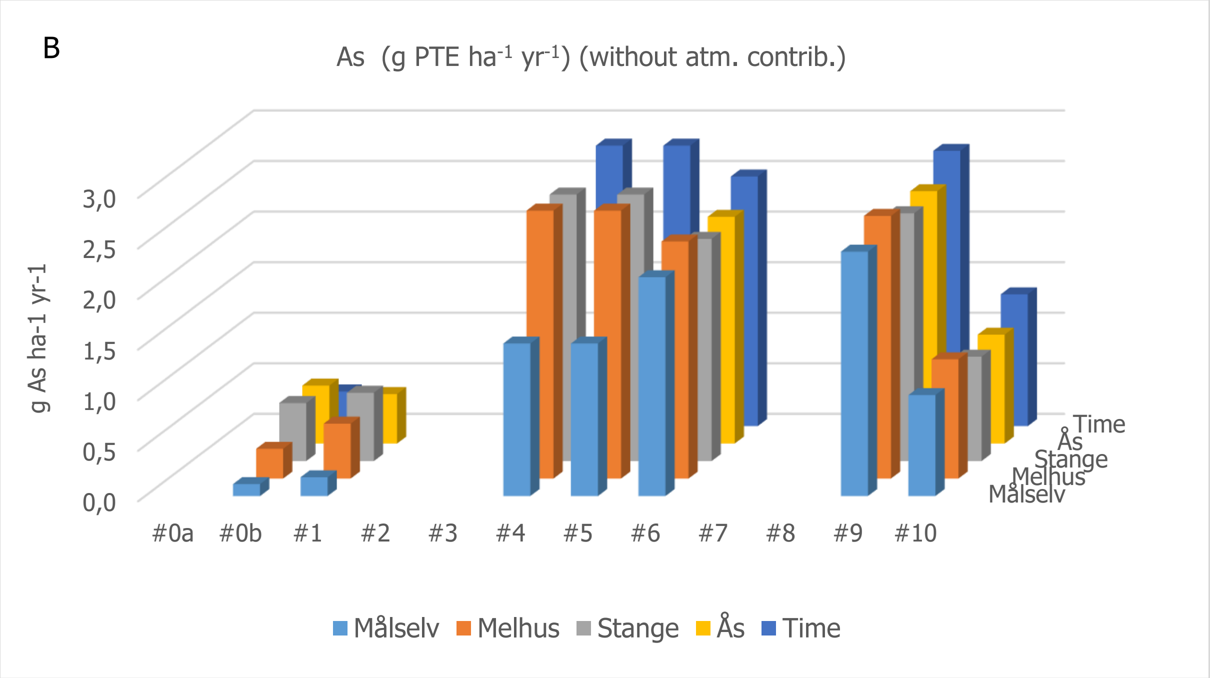


Figure 6.1.3-2. Input of As via selected input schemes, given as g ha^{-1} yr^{-1}, in all regions. (A) Input values including atmospheric contribution, (B) Input values excluding atmospheric contribution. Scenario #2, evaluation of suggested ML quality class II organic fertilisers is not shown (input 34.6 - 40.4 g ha^{-1} yr^{-1}). Lime products are included in all scenarios. As analyses of sewage sludge (#3) and digestate (#7 and #8) were not available and these input schemes are not included in the figures, nor the PTE contribution from lime products.

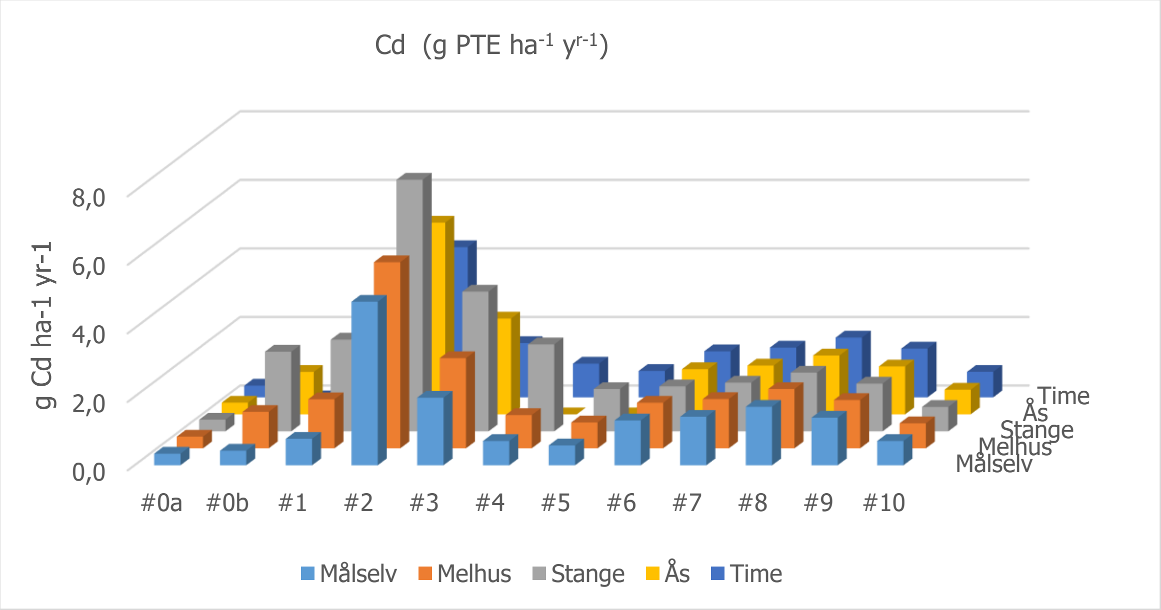


Figure 6.1.3-3. Input of Cd via selected scenarios, given as g ha^{-1} yr^{-1}, in all regions. Atmospheric contribution and lime products are included in #1-#10.

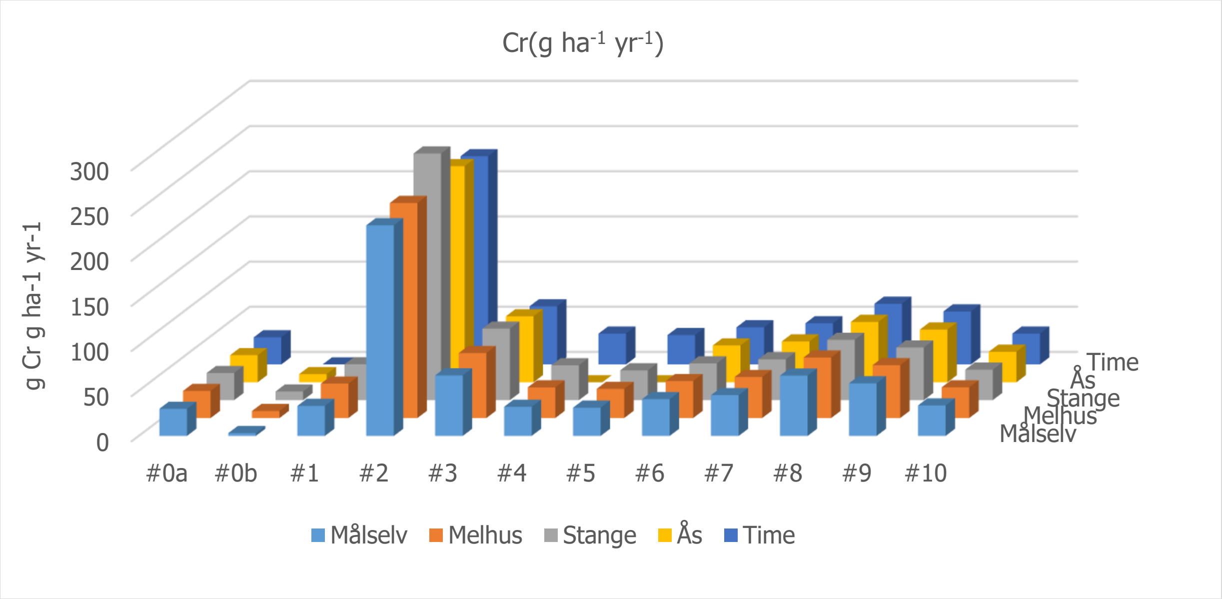


Figure 6.1.3-4. Input of Cr via selected scenarios, given as g ha^{-1} yr^{-1}, in all regions. Atmospheric contribution and lime products are included in #1-#10.

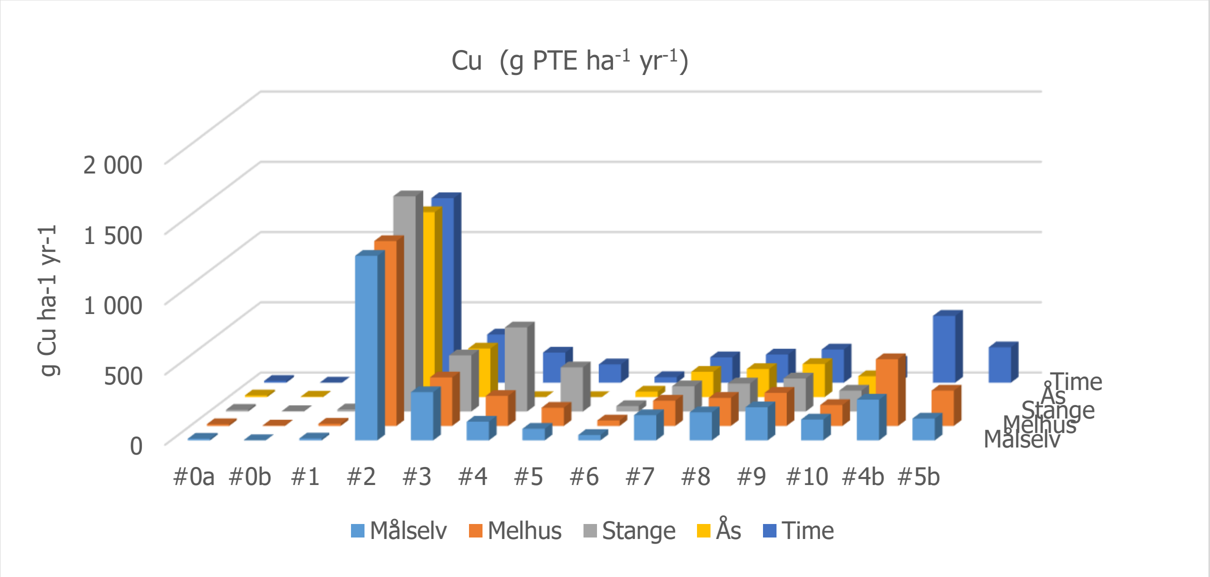


Figure 6.1.3-5. Input Cu via selected schemes, given as g ha^{-1} yr^{-1}, in all regions. Atmospheric contribution and lime products are included in #1-#10. The evaluation of Cu and Zn in pig manure applied in Målselv, Melhus and Time were performed as an extra calculation of evaluation of scenario #4 and #5 and is shown as #4b and #5b.

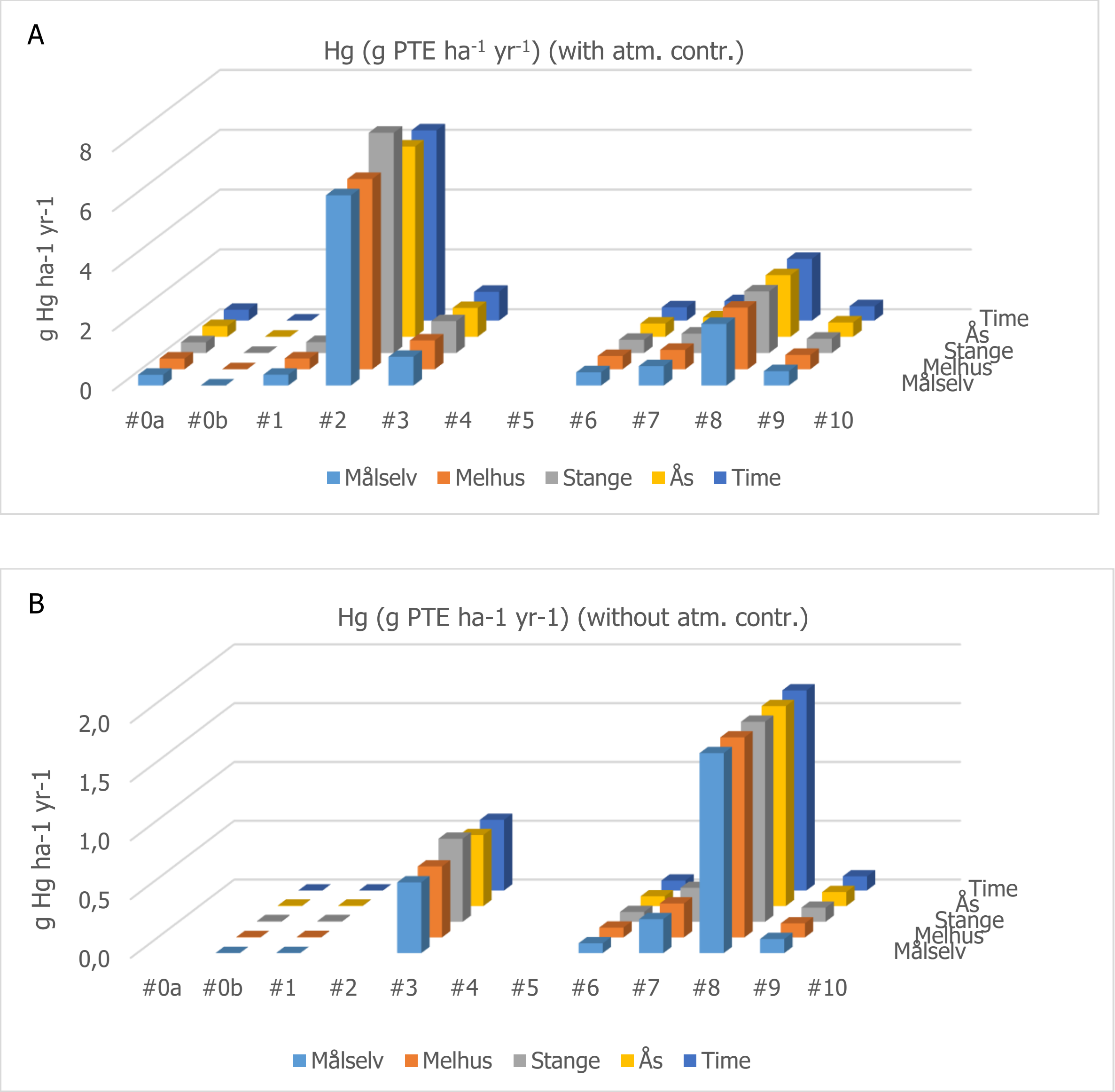


Figure 6.1.3-6. Input Hg via selected schemes, given as g ha^{-1} yr^{-1}, in all regions. (A) Atmospheric contribution is included, (B) Atmospheric contribution is not included, but lime products are. Scenario #2 is not shown. Hg analyses of cattle, pig and poultry manure (#4, 5, 10) were not available and these schemes are not included in the figures, nor the PTE contribution from lime products.

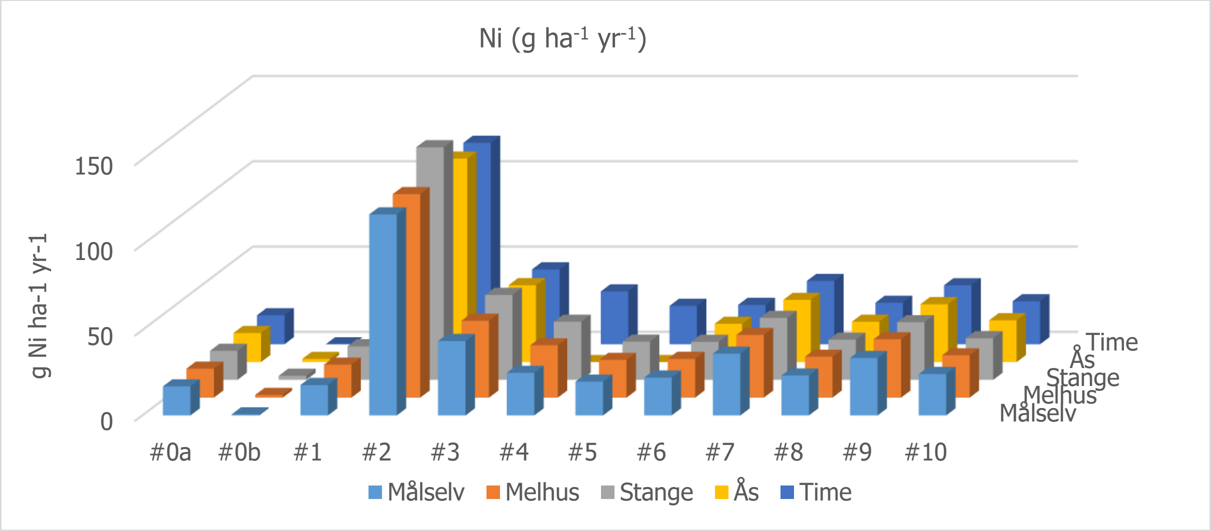
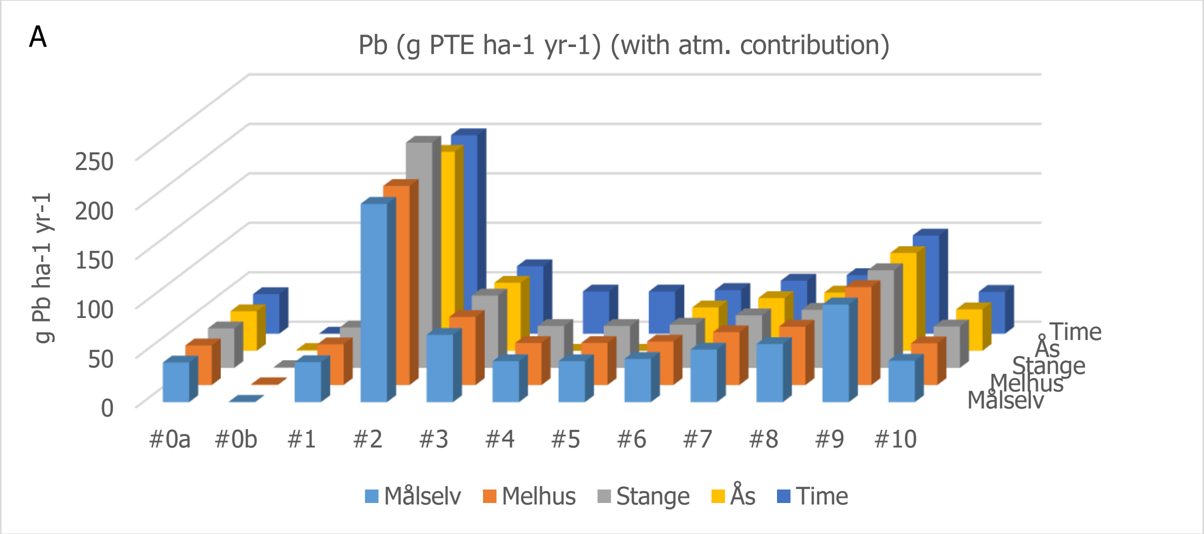


Figure 6.1.3-7. Input Ni via selected schemes, given as g ha^{-1} yr^{-1}, in all regions. Lime is also included.



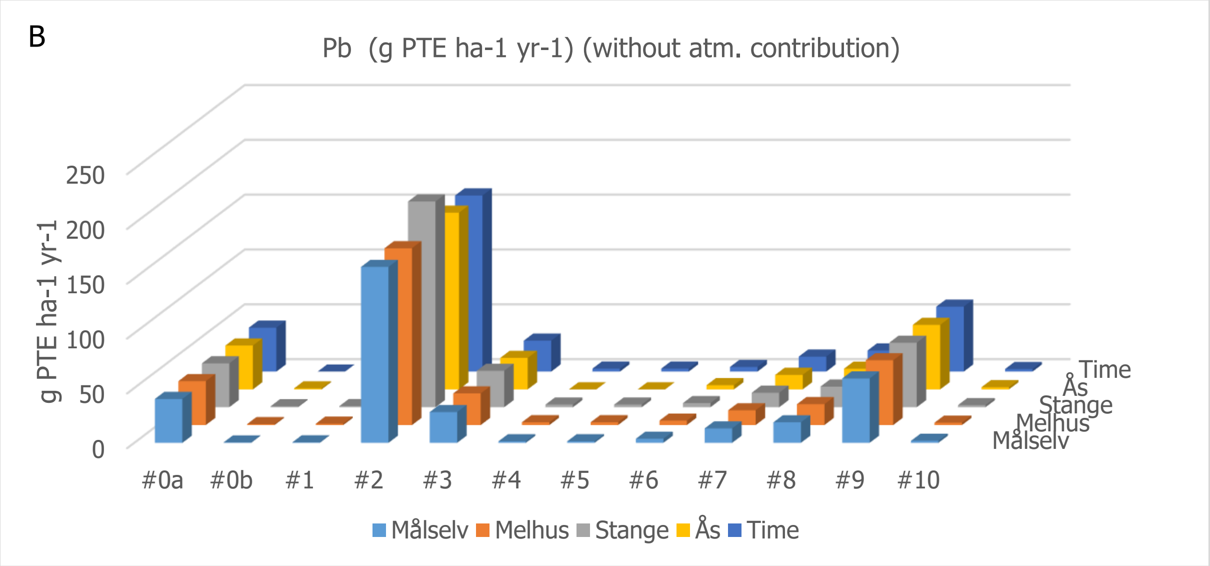


Figure 6.1.3-8. Input Pb via selected schemes, given as g ha^{-1} yr^{-1}, in all regions. (A) Atmospheric contribution included in #1-10 (B) Atmospheric contribution not included. Lime products are included in alle scenarios.

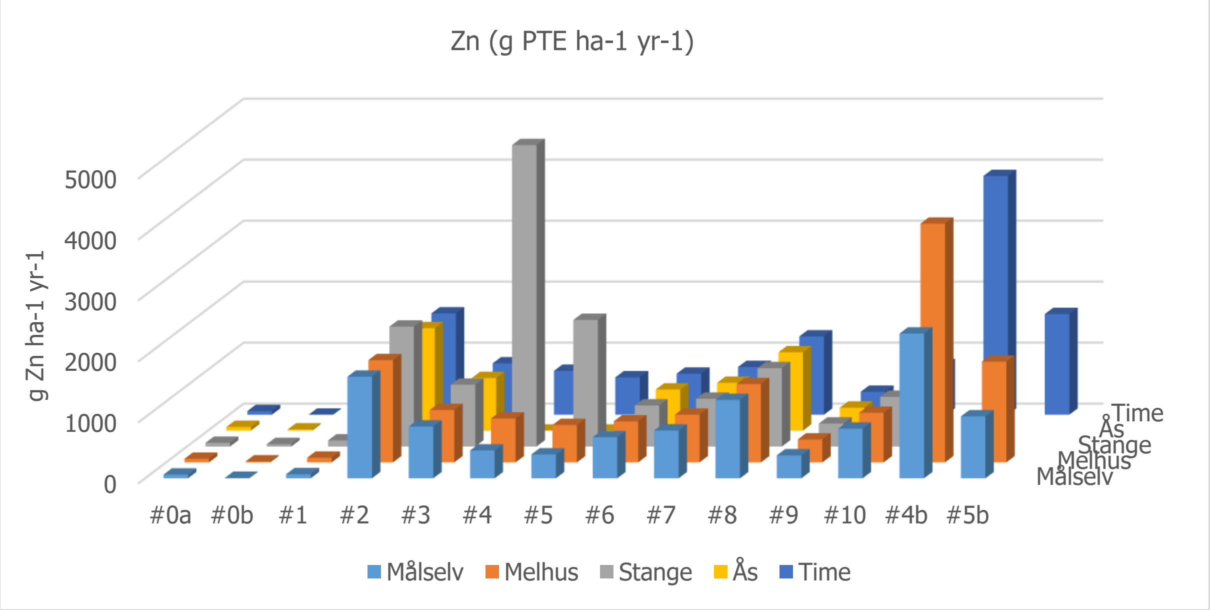


Figure 6.1.3-9. Input Zn via selected schemes, given as g ha^{-1} yr^{-1}, in all regions (only crop 1). Atmospheric contribution and lime products are included in #1-#10. The evaluation of Cu and Zn in pig manure applied in Målselv, Melhus and Time were performed as an extra calculation of evaluation of scenario #4 and #5 and is shown as #4b and #5b.

6.1.4 Loss of PTE from soil via leaching and plant harvesting

Predicted loss of PTE per ha per year

The loss from soil by plants can be calculated by

$$\text{loss (g yr}^{-1}) = k_{\text{plant-removal}} \times m_{\text{Soil}}(t) \qquad \text{(Eq. 16)}$$

where $k_{\text{plant-removal}}$ is the loss rate constant (yr^{-1}, see section 5.2.3) and $m_{\text{soil}}(t)$ is the amount of PTE in soil at time t (m_{soil} is C_{soil} x area x depth x density).

The same way, loss with water from soil is calculated:

$$\text{loss (g yr}^{-1}) = k_{\text{loss}} \times m_{\text{Soil}}(t) \qquad \text{(Eq. 17)}$$

where k_{loss} is the loss rate constant for loss with runoff and leaching (a^{-1}, see section 5.2.1)

Table 6.1.4-1 shows the predicted loss in g ha^{-1} year^{-1} via plant harvesting, and runoff and leaching to the water recipient for all regions and alum shale the first year. Present soil concentrations were used. Hence, input scenarios do not play a role.

For Cu as for all selected PTEs, the loss by leaching and runoff is larger than the loss by plant uptake for all sites. Plant uptake is most relevant for the conditions at Målselv, Melhus and Stange, but is of minor relevance elsewhere where the loss due to leaching and runoff dominates. The loss at Time is particularly high, which has the highest precipitation, highest runoff, and lowest Kd for Cu.

Cd shows a similar pattern, highest initial amount is in the alum shale. Loss is mostly by leaching and runoff water, plant uptake plays a very minor role, crop rotation is not affecting overall loss, which is highest for the conditions at Time.

Zn is present in the highest amounts in agricultural soil among selected PTEs. Otherwise, the pattern is rather as discussed for Cu and Cd: loss due to leaching and runoff dominates, in particular at Time, and only for Målselv, Melhus and Stange plant uptake is also relevant.

More about PTE in soils see section 8.1.

Loss of PTEs from soil via runoff and leaching, and via plant uptake and harvesting is presented as g PTE ha^{-1} yr^{-1} in Table 6.1.4-1.

The same data are given as % related to present PTE in agricultural soil (g PTE ha^{-1}) and as % to added PTE (g ha^{-1} yr^{-1}) via maximum allowed amount organic fertilisers and soil improvers and ML according to quality class II (scenario #2) in section 8.1 (Figure 8.1-1 and 8.1-2, respectively).

Table 6.1.4-1. Calculated loss of the selected PTEs in agricultural soil. PTEs present in agricultural soil (given as g PTE ha^{-1}), input of PTEs to soil via application of maximum amount organic fertilisers and soil improvers and ML quality class II (#2), and loss of PTEs, separated in loss via runoff /leaching and plant harvesting, given as g PTE ha^{-1} yr^{-1}.

		Unit	**Målselv**	**Melhus**	**Stange**	**Alum shale**	**Ås**	**Time**
As	Present in soil	g PTE ha^{-1}	3780	7163	2756	37587	6774	5018
	Input soil (#2)	g PTE ha^{-1} yr^{-1}	34.6	34.9	40.4	40.4	34.9	34.8
	Runoff/leaching		7.7	20.9	3.1	42.9	15.1	38.3
	Plant removal		0.29	0.25	0.09	1.26	0.36	1.28
	Sum loss soil		8.0	21.2	3.2	44.1	15.4	39.5
Cd	Present in soil	g PTE ha^{-1}	194	239	326	2105	527	477
	Input soil (#2)	g PTE ha^{-1} yr^{-1}	4.8	5.4	7.3	7.3	5.6	4.4
	Runoff/leaching		2.3	2.2	1.3	8.1	4. 5	24.0
	Plant removal		0.09	0.04	0.14	0.92	0.16	0.78
	Sum loss soil		2.4	2.3	1.4	9.1	4.6	24.8
Cu	Present in soil	g PTE ha^{-1}	33079	47752	30070	107749	27597	27597
	Input soil (#2)	g PTE ha^{-1} yr^{-1}	1313	1315	1532	1532	1316	1313
	Runoff/leaching		54.5	116.2	29.1	104.4	46.5	199.3
	Plant removal		13.3	9.6	12.0	43.0	8.2	37.3
	Sum loss soil		67.8	125.7	41.1	147.4	54.6	236.6
Cr	Present in soil	g PTE ha^{-1}	59070	85954	35081	47610	67738	23332
	Input soil (#2)	g PTE ha^{-1} yr^{-1}	233.2	238.1	273.1	273.1	239.3	230.5
	Runoff/leaching		104.7	243.6	38.1	51.7	144.4	159.6
	Plant removal		1.0	0.3	0.3	0.4	0.4	1.3
	Sum loss soil		106	244	38.4	52.1	145	161
Hg	Present in soil	g PTE ha^{-1}	59.07	78.79	75.17	95.22	100.35	173.11
	Input soil (#2)	g PTE ha^{-1} yr^{-1}	6.36	6.36	7.37	7.37	6.36	6.36
	Runoff/leaching		0.010	0.021	0.008	0.010	0.020	0.112
	Plant removal		0.001	0.009	0.007	0.009	0.018	0.010
	Sum loss soil		0.011	0.030	0.015	0.019	0.038	0.122
Ni	Present in soil	g PTE ha^{-1}	30716	54915	30070	127796	35123	9032
	Input soil (#2)	g PTE ha^{-1} yr^{-1}	117.82	119.29	136.35	136.35	119.25	118.10
	Runoff/leaching		357.49	772.79	170.09	722.89	383.61	378.66
	Plant removal		3.25	0.73	0.82	3.46	0.66	3.21
	Sum loss soil		360.74	773.52	170.91	726.35	384.27	381.87
Pb	Present in soil	g PTE ha^{-1}	14177	22921	20297	50116	40141	57702
	Input soil (#2)	g PTE ha^{-1} yr^{-1}	200.43	201.20	227.65	227.65	201.16	200.60
	Runoff/leaching		4.53	8.04	2.87	7.08	11.51	71.52
	Plant removal		0.30	0.18	0.30	0.74	0.46	4.10
	Sum loss soil		4.83	8.23	3.17	7.82	11.97	75.62
Zn	Present in soil	g PTE ha^{-1}	108689	131318	107749	275638	203213	90317

		Unit	Målselv	Melhus	Stange	Alum shale	Ås	Time
	Input soil (#2)	g PTE ha^{-1} yr^{-1}	1667	1677	1966	1966	1680	1660
	Runoff/leaching		473	429	153	392	544	1260
	Plant removal		58	56	54	139	132	160
	Sum loss soil		531	485	208	531	675	1420

6.2 Uptake and transfer of PTEs into crops

Uptake of contaminants by plants from soil and growing media is a possible exposure pathway of contaminants for animals and humans. For exposure of animals and humans, the contaminants must be transferred to the edible parts of plants that is consumed or leached to drinking water.

Plant uptake of inorganic elements is variable and depends on a number of parameters, among them - soil properties (especially pH, soil organic matter, SOM, and texture, and thus K_d value), properties of the plant itself (species, plant parts, age etc.) (McLaughlin et al., 2011; Yang et al. 1995; He and Singh 1994), the properties of the elements and whether it is an essential plant nutrient and thus regulated by the plant.

Urban farming and home cultivation of vegetables.

There is an increasing interest for homegrown vegetables and urban farming, e.g. kitchen gardens, pots and containers in small gardens, balconies and roofs. While there are regulations of organic fertilisers and soil improvers (section 3) for cultivation of crops, there are no specific regulations for home gardening or urban farming. Compared to agriculture crops, homegrown and urban grown vegetables, are eaten by a smaller portion of the population (subgroup), by a neighbourhood, kindergarten or families, and in high amount during the summer months. For this subgroup, especially children, this is an exposure route that needs to be considered.

Harvesting of peat is known to cause climate gas (CO_2) emissions, because it results in fast decomposition of the peat material. As a measure to reduce climate gas emission, replacing peat with other substrates in growing media has become an important issue. Compost based on different kinds of organic waste are alternatives for peat. While peat used for growing media is assumed to have low content of contaminants including PTEs, the replacing substrates might have a higher content (ref Table 6.1.2.2-1). Also engineered soil might have residues of contaminants.

The NFSA ask for more knowledge of potential exposure of PTEs in subgroups via eating locally or home-grown vegetables, and an evaluation of the Norwegian MLs of PTEs in engineered soil, organic fertilisers and soil improvers quality class 0 and 2, and the European CE-labelled growing media have also been performed in the present assessment.

Cultivation of mushrooms

Edible mushroom lovers (another subgroup population) will have a higher exposure than the rest of the population. People collecting edible mushrooms in nature will have a temporarily exposure period in the summer and early autumn, while for people eating commercially cultivated mushrooms, the exposure will be more continuous.

Growing edible mushrooms on recycled biobased residues, such as agro-industrial residues (Philippoussis, 2009), is well recognised. Particularly, oyster mushrooms - one of the most widely produced mushroom species in the world - are well-known as an aggressive colonizer of a wide array of substrates (Fernandes et al., 2015). Even harvested common reed from constructed wetland in southern Sweden has been tested as substrate for cultivation of oyster mushroom with success (Hultberg et al., 2018). There is an increasing focus on enhanced human exposure related to the presence of contaminants in recycled substrates, and thus edible mushrooms is included in this risk evaluation. Although, there is much literature on content and TFs of elements, including heavy metals, in wild mushrooms, only a few highly relevant studies of cultivated mushrooms were found (Koutrotsios et al., 2020; Sakellari et al., 2019; Gucia et al., 2012). Oyster mushroom (*Pleurotus ostreatus*) and white button mushrooms, Champignon (*Agaricus bisporus*) are very popular mushrooms for cultivation.

In the present assessment human exposure via agricultural crops, vegetables grown in relation to urban farming and cultivated edible mushrooms, is addressed. Cereals, potatoes, carrots, and grass are the main food and forage crops and included in the assessment.

6.2.1 Plant uptake pathways and influencing factors on uptake

Plants take up PTEs by several pathways:

- with the transpiration water from soil (advective)
- by direct adsorption from soil pore water (diffusive)
- due to wet and dry deposition from air
- by soil particle erosion (by rain splash or wind) with subsequent deposition on plant surfaces, like leaves
- by enzymatic processes, that facilitate uptake, or exclude toxic or unwanted elements.

Enzymatic regulation always happens for essential elements, such as those that are needed by plants in their metabolism (Marschner 1995, McLaughlin 2011). Among the PTEs under consideration, Cu, Ni and Zn count to the essential elements. Plants cannot grow without these elements, which on the other hand are toxic, at high concentrations. Hence, plants target a homeostatic concentration in the cytosol (McLaughlin 2011), independent from the concentration in the soil solution.

Arsenate, As(V), is not essential, but it is chemically similar to phosphate, and taken up by the same transport system (Marschner 1995). With the exception of Cu, Ni, Zn and arsenate, the other PTEs are non-essential, and uptake is most likely a passive process, i.e. not driven by plant enzymes. However, non-essential elements may be taken up through the same pathways as nutrients if the molecules are similar in charge and diameter (McLaughlin 2011). The more soluble the PTE, the more relevant is uptake with transpiration water. Hence, low Kd-values correlate with high TF. For Cd and Zn, uptake with water is the most relevant process, and comparatively high TF are resulting, while for Pb which is stronger adsorbed, uptake with soil particles also plays a significant role, and TF values are low. Attachment of soil particles to leaves means that even for completely insoluble heavy metals, a minimum transfer can be observed.

This minimum transfer with resuspended soil particles is independent of the chemical properties, as it depends on a purely physical transport mechanism. It does, however, depend rather much on the height and shape of the crops. Literature values for soil attached to plant surfaces show large variability, and for lettuce a mean of 0.26 g g^{-1} DW soil attached to leaves has been measured using radioactive tracers (Li et al. 1994). Lettuce has a special shape that supports the collection of particles. Contrary, grains are quite well protected against particle deposition, but can be polluted with soil dust during harvest. With potatoes and carrots, soil attachment is obviously possible, but the amount of heavy metal transfer with attached soil depends largely on the kind of processing after harvest. Hence, the process occurs for all crop types and affects the transfer of PTEs with soil particles to plants. A typical mean value of 1% attached soil (FW) has been chosen earlier for risk assessment purposes (Kulhánek et al. 2004, Jeffries and Martin 2009). Dry weights of fruits and vegetables in Table G-1, US SSG (US EPA 1996) range from 3.9% to 54%, corresponding to a numerical minimum TF of 0.0004 to 0.005, DW-based.

Shape and geometry of crops are manifold: root crops, tubers, leaves, and grains are harvest products. Hence, also the relevance of uptake pathways and resulting TF vary considerably. Moreover, soil properties (particle size, Kd), environmental conditions (temperature, precipitation, evaporation) and agricultural management practices (including application of fertiliser) differ for each crop. A large variation of the quantitative uptake of PTEs into crops is resulting, which leads to a high variability of TF, accompanied by large uncertainty of the calculated uptake of PTEs into plants. To account for this variability, a separate TF-value was collected for each crop from the scientific literature. Different to the estimation of Kd-values, no regressions were used, even though these would allow an adaption to site-specific conditions. This was for two reasons: first, the available number of regressions between soil or plant properties and TF is rather small, and for several combinations of PTE and plant, no regression has ever been established (as far as we know). Second, a valid regression would require a high number of input parameters, due to the diverse and varying uptake processes, and these data are not readily available.

Selection of TFs for agricultural crops

Thus, for each PTE, a constant but plant specific TF was collected. With eight relevant PTEs and six crop species (plus mushrooms), 48 TF values are required, plus those for the urban gardening (tree fruits, leafy vegetables). Similar to the procedure for collection of Kd-values, a literature search was conducted to retrieve TF-values for the investigated PTEs and for six crops - barley, oats, wheat, carrots, potatoes and grass, plus mushrooms (where available). The search and results are documented in Appendix III. For most PTEs, multiple sources of TF-values were found, and between 5 and 10 relevant scientific documents are listed in appendix III which contain relevant TF-values, usually for more than one PTE and more than one crop.

To select the most appropriate TF-values, the following considerations were made:

i. Comprehensiveness: *it is preferable to use one source that covers many PTEs and many crops* over a high number of different sources that cover less or only one PTE and crop. This, *because TF is always derived by the same methodology, which leads to a more harmonized assessment*, and also due to the reduced effort with less sources.
ii. The crop under consideration must be covered, or at least, TF must be for a rather similar crop. For example, very few TF-values for oats were found, and for the missing values, TF of barley was chosen as replacement.
iii. Higher TF means higher human exposure and higher exposure of animals with animal feed. Hence, for a conservative risk assessment, a higher TF is on the safe side. However, it needs to be considered that more plant uptake also means less long-term accumulation in soil. Thus, higher TF-values were *not* preferably chosen.
iv. Applicability: only those TF values which are applicable and appropriate for Norwegian agricultural conditions were selected. This excludes, for example, TF-values of cereals from Southeast Asia, where the environmental conditions differ significantly, and where rice is grown in paddy fields.
v. Realistic conditions. TF can be determined by various methods, such as by pot experiments in laboratory, or by greenhouse experiments, or in field experiments. The field experiments represent the conditions closest to agricultural reality. *Measurements of the concentration ratio between plants and soil in situ and at harvest were thus preferred.* These field values include deposition from air, which can be insignificant (1- 5%, Cd) or highly relevant (30%, Pb) (Legind et al. 2012), depending on the PTE. This was mostly due to a lack of site-specific data, but also due to the relative remoteness of Norwegian agricultural areas, which makes the crops less suspect to PTE deposition from air.
vi. Clear documentation. For unknown reason, many scientists do not report their units. The TF can be determined based on fresh weight, or on dry weight. For example, if the water content of the harvested product is 10%, the outcome differs by a factor of 10 and thus, the unit cannot be ignored. Hence, only TF values from studies that clearly state methodology and units were chosen. In the case of Novotna et al. (2015), the co-author Ondrej Mikes was contacted to verify that the TF refers to dry plant material (air-dried, in this case).
vii. Consistency. If a reported TF-value differed largely from all other reported TF-values, it was considered suspect and not used.

Taking these points into consideration, the median TF-values by Novotna et al. (2015) were first choice and chosen where available.

Novotna et al. (2015) analysed samples of potato, hop, maize, barley, wheat, rape seed, and grass (1st and 2nd cut) from 66 agricultural sites for Cd, Cr, Cu, Mo, Ni, Pb and Zn. The authors developed regressions (which require input data not at hand), but give also mean, median, minimum and maximum TF values plant-to-soil. The median values were chosen for our purpose (Novotna et al. 2015). If no value from this source was at hand, TF-values were taken from the US Soil screening guidance (US EPA 1996, appendix G Background Discussion for Soil-Plant-Human, Table G-2, Summary Table of Empirical Bioconcentration Factors for Metals). The values in this table are the geometric mean of 1 – 71 studies. This source was also chosen in section 5.1.1, as best alternative if no Kd-regression was available, hence this choice supports comprehensiveness and consistency.

Though the database is good for TF-values of total Cr, it is insufficient for Cr(III) and Cr(VI). The assessment of plant uptake, thus, can only be done for total Cr. However, the NGI (2017) source lists separate values for TF for Cr(III) and Cr(VI) in roots and stem, but the values are identical, and these values have their origin back in 2005 (Naturvårdsverket, 2005) and seems not verified later.

Table 6.2.1-1 shows the plant-specific TF-values chosen for the risk assessment modelling. The values are for dry weight.

Table 6.2.1-1. Selected TF-values from literature for crops, primary from Novotna et al. (2015), US EPA (1996, in italic) and Legind and Trapp (2010), and % DW in plants used for the present risk evaluation. Unit is mg kg^{-1} crop (DW) to mg kg^{-1} soil (DW, where given). Dry weight content (%) used for conversion between dry and fresh weight for cereals (grains of barley and wheat), carrots, grass and potato are shown (NFSA, 2020).

TF (DW based)	Barley	Wheat	Grass (1st cut)	Carrot	Potato	Ref. source
% DW	85	85	20	11	24	
As	*0.026*	*0.026*	*0.036*[1]	*0.008*	*0.004*	US EPA
Cd	0.11	0.17	0.23	None (*0.064*)	0.29	Novotna (carrots, US EPA)
Cr(tot)	0.003	0.003	0.008	None (0.005)	0.005	Novotna, carrot same as potato
Cu	0.15	0.14	0.19	None (0.20)[2]	0.24	Novotna (carrots, US EPA)
Hg	*0.0854*	*0.0854*	*0.008*	*0.014*	*0.002*	US EPA
Ni	0.01	0.008	0.05	None (*0.008*)	0.02	Novotna (carrots, US EPA)
Pb	0.006	0.005	0.01	0.011	0.008	Novotna, carrot from Legind and Trapp, 2010

TF (DW based)	Barley	Wheat	Grass (1st cut)	Carrot	Potato	Ref. source
Zn	0.32	0.31	0.25	None *(0.044)*	0.19	Novotna, except carrots = US EPA

[1]TF of leafy vegetables was chosen for grass; [2]Mean TF Cu for cereals, grass and potato (Novotna et al. 2015)

TFs for vegetables for home cultivation and urban farming

The list of vegetables with relevance for cultivation in kitchen gardens, in pots and containers in the garden or on balconies is very wide. However, to simplify this, root vegetables (represented by carrot, radish etc), leafy vegetables (represented by lettuce, spinach etc.), potato and garden fruits were selected since there were available TFs (on DW basis) in the two literature sources already used for estimation of uptake in agricultural crops (US EPA, 1996; Novotna et al., 2015). In addition, TFs from Legind and Trapp (2010) and Samsøe-Petersen et al. (2002) were used. An overview of TFs applied for uptake in vegetables and garden fruits grown for home cultivation and urban farming is presented in Table 6.2.1-2.

Table 6.2.1-2. Selected TF-values on DW basis from literature for root vegetables, potato, and leafy vegetables. TFs for garden fruits is included when available.

	TF (mg kg^{-1} DW)							
	As	**Cd**	**Cr(tot)**	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**
Root vegetable	0.008[1]	0.064[1]	0.005[2]	0.2[5]	0.014[1]	0.014[1]	0.011[4]	0.044[1]
Potato	0.004[1]	0.29[2]	0.005[2]	0.24[2]	0.002[1]	0.002[2]	0.008[2]	0.19[1]
Leafy vegetables	0.036[1]	0.364[1]	0.008[3]	0.44[3]	0.008[1]	0.032[1]	0.045[4]	0.25[1]
Garden fruits	0.002[1]	0.09[1]	n.d.	n.d.	0.01[1]	0.06[1]	n.d.	0.046[1]

[1]US EPA (geometric mean based on one and up to 71 studies use. Median values were not given), [2]Novotna et al., 2015 (median values were selected); [3]Samsøe-Petersen et al., 2002; [4]Legind and Trapp, 2010; [5]Mean TF Cu for cereals, grass and potato (Novotna et al. 2015).

TFs for cultivated mushrooms

Elements found to bioaccumulate in mushrooms are Cd, Cu, Hg and Zn (Sakellari et al., 2019; Koutrotsios et al., 2020; Kojta et al., 2012; Chojnacka et al., 2013), while the elements Cr, Ni and Pb which in the literature have very low TFs (BCFs)<1, were excluded (regulated) (Saellari et al, 2019). Uptake and accumulation of elements in mushrooms is known to be influenced by several factors including type of elements, species, substrate they are growing on, and fungal lifestyle (Koutrotisios et al., 2020).

Most literature on uptake of elements, including PTEs, are based on collected wild edible mushrooms. Three studies with relevance to cultured edible mushroom, Oyster mushroom (*Pleurotus ostreatus*, *P. eryngii*) cultivated on different kinds of agro-industrial waste, were used for selection of TFs (summarised in Table 6.2.1-3, Sakellari et al., 2019; Koutrotsios et al., 2020; Siwulski et al. 2019). TFs were determined by comparing highest measured PTE concentration in mushroom dividing by the comparing PTE concentration in the cultivation material. For Hg, TFs between 16 ± 6 and 220 ± 110 (kg DW / kg DW) for caps and stipes, respectively, has been reported (Falandysz and Gucia, 2008). The mean TF for caps (16) was selected for calculating $PEC_{mushroom}$. A few other studies and TFs based on collected mushroom is also included in the table, e.g. TFs from Parasol Mushroom (*Macrolepiota procera*) (Champignon family, also cultivated) and Champignon (*Agaricus bisporus*) (Alonso et al. 2003; Gucia et al., 2012; Falandysz et al., 2007).

Table 6.2.1-3. Selected TFs for Cd, Cu and Zn for edible mushroom applied in the risk assessment were based on maximum measured concentration in Oyster mushroom (mg kg-1 DW) and corresponding concentrations in the growth substrate (mg kg-1 DW) (Koutrotsios et al., 2020). Selected TF for Hg was based on measurements of Parasol mushroom grown wild (Falandysz and Gucia, 2008).

	Mushroom	**Selected TFs (conc. mushroom /conc. substrate)**
Cd	Oyster mushroom (*P. ostreatus*)	5.2 (0.62/0.12)
Cu		5.6 (39.1/7.0)
Zn		7.7 (118.3/15.4)
Hg	Parasol mushroom, *Macrolepiota procera*, Champignong family	16

7 Hazard characterisation

In order to assess the risk of adverse environmental effects posed by application of fertilisers containing the potential toxic elements - arsenic (As), cadmium (Cd), chromium (Cr(III) and Cr(VI)), copper (Cu), lead (Pb), mercury (Hg), Ni (Ni) and zinc (Zn), the maximum concentration of these elements that is not expected to cause toxic effects need to be established for the exposed environmental compartments (soil, surface water and sediment). These concentrations are referred to as Predicted No Effect Concentrations (PNEC).

7.1 Environmental toxicity

7.1.1 PNEC derivation

In the current risk assessment, PNECs are derived for each PTE in surface water ($PNEC_{sw}$), sediment ($PNEC_{sed}$), and soil ($PNEC_{soil}$). For PTEs that are likely to cause toxic effects at higher food chain levels due to ingestion of organisms from lower trophic levels that accumulate substances, PNEC for secondary poisoning has also been derived.

Methods for derivation of PNECs for environmental risk assessment have been internationally harmonised and compiled into manuals, such as the Technical Guidance Document (ECB, 2003) that was developed for risk assessment of existing and new industrial chemicals in the European Union. This document will be referred to as TGD in the current report.

The PNEC values are usually determined based on results from single species laboratory tests or, in few cases, established effect and/or no-effect concentrations from model ecosystem tests. The available effect data are screened for reliability and relevance according to specific criteria. The laboratory toxic effect studies of substance concentration ranges are expressed as effect concentrations (EC_x) or, if the effect is lethality, LC_x, where x shows the level of effect (e.g. LC_{50} is the concentration causing lethality in 50% of the tested population). In long term tests for sub-chronic or chronic effects, the results are often expressed as EC_{10}, meaning 10% effect on the studied endpoint or as NOEC, which is the highest tested concentration without a statistically significant effect.

PNEC is calculated from, the lowest L(E) C_x or NOEC value in the selected set of data, which is divided by an assessment factor (AF). The AF reflects the degree of uncertainty in extrapolation from laboratory toxicity test data for a limited number of species, to the 'real' environment. The size of the AF depends on the confidence with which a PNEC can be derived from the data. This confidence increases, if data are available on the toxicity to organisms at several trophic levels, taxonomic groups and with lifestyles representing various feeding strategies. Thus, lower assessment factors can be used with larger and more relevant datasets. For example, if the data contains only short-term $L(E)C_{50}$ values for one representative of each group of fish, invertebrates and algae ("Base-set"), $PNEC_{sw}$ is calculated as the lowest $L(E)C_{50}/1000$. When chronic, long-term NOECs are available for, at least, three species representing algae, invertebrates and fish, an assessment factor 10 is applied on the lowest NOEC to calculate PNEC for surface waters as NOEC/10.

The PTEs that are addressed in the present report occur naturally in the environment and some of them are essential for organisms. This represents a specific challenge when PNEC is derived using the assessment factor approach, because toxic effects may occur at concentrations slightly above background concentration, and the PNEC derived using the recommended assessment factor may become lower than the natural background concentration.

If a large dataset from long-term tests for different taxonomic groups is available, statistical extrapolation methods based on the species sensitivity distribution (SSD) may be used to derive a PNEC. (Posthuma et al, 2001). The general requirement in TGD is that, the dataset contains at least 10 NOECs (preferably more than 15) for different species covering at least 8 taxonomic groups. When several NOECs for the same species and test endpoint are available, the geometric mean of these is normally used in the analysis.

SSDs are constructed using a cumulative plot of logarithmically transformed NOECs against rank as-signed percentiles for each value to which a statistical distribution is fitted. Usually a log-normal model is used, but also other models may be used to obtain the best fit. From the selected model, the fifth percentile (HC_5 or median fifth percentile (HC_5-50), i.e., HC_5 directly from the curve) is extrapolated. Finally, an AF in the range of 1-5 is used to calculate PNEC from the HC_5 as PNEC = HC_5/AF. Criteria for selecting the appropriate AF are included in the TGD.

In the environment, organisms are exposed to PTEs mainly as ions dissolved in the surrounding water phase. Interactions from various abiotic factors in the water, affect the chemical speciation of the elements in water by forming complexes that are less available for uptake by the organisms. The most important factors in this respect are dissolved organic carbon, water hardness (mainly calcium content) and pH. Furthermore, the uptake of metal ions in the organism is affected by the concentration of other cations that competes for binding to the receptor at the site of uptake (e.g. gills in fish). Due to the effects of abiotic factors, the toxicity of metals to aquatic organisms differs between waters depending on their chemical composition. The same applies to toxicity in sediments and soil, where the porewater is an important route for exposure for sediment- and soil dwelling organisms.

Based on laboratory studies of toxicity of metals to organisms exposed in media of different chemical composition, models have been developed to quantitatively describe the effect of abiotic factors on the toxic responses. Such models are known as Biotic Ligand Models (BLM) (Di Toro et al. 2001).

For PTEs where BLMs are available, site specific or regional aquatic PNECs can be calculated. For some metals, BLM models have been used to derive a generic environmental quality standard for the bioavailable concentration, ($EQS_{bioavailable}$), with an option to calculate a local EQS for specific set of abiotic factors that affects the bioavailability. A software tool to perform these calculations has been developed by ARCHE and WCA under the name Biomet (http://www.arche-consulting.be/en/home/). Biomet contains toxicity databases of NOEC values for aquatic organisms used for calculation of in the RARs (Cu, Zn, Pb) and in the ECHA (European Chemicals Agency) dossiers (Ni). BLM models and the algorithm for SSD analysis are integrated in the Biomet tool. The statistical extrapolation model (Aldenberg & Slob, 1993) is used in the analysis of SSD. The necessary input parameters to run the models are pH, dissolved organic carbon (DOC) and calcium (Ca). The output from the model is HC_5, which can be used for calculating $PNEC_{sw}$ with an appropriate assessment factor.

In sediments, organic carbon and Acid Volatile Sulfide (AVS) are known to control the toxicity of cationic metals toward sediment-dwelling organisms (DiToro et al., 1992), and normalisation of toxicity data with regard to these variables are often used to reduce the intraspecies variation of NOEC values.

Abiotic factors also affect the chemical speciation and biological availability of PTEs in soils. The major factors in this respect are pH, organic carbon (OC), clay content and cationic exchange capacity (CEC). A model for calculating $PNEC_{soil}$ for specific abiotic conditions has been developed by ARCHE (https://www.arche-consulting.be/tools/soil-pnec-calculator/). The calculated PNEC values are based on reliable chronic toxicity data for terrestrial organisms (plants, invertebrates, and microbial processes) from the same databases used in the EU RARs and ECHA Dossiers. Bioavailability correction of the toxicity data is performed using:

- a leaching-ageing factor (an empirically derived factor used to account for the reduced toxicity of metals observed in the field compared to the same total concentration of metal in laboratory toxicity tests with soluble metal salts) and,
- normalisation of toxicity thresholds (NOECs) towards soil properties based on regression of toxicity data with these soil properties.

The soil properties required for calculation of site specific PNECs are cation exchange capacity (CEC), % organic carbon, % clay and pH.

The normalised NOEC-values are subjected to an analysis of the Species Sensitivity Distribution analysis (SSD). PNEC is calculated and can be expressed both as total concentrations in soil PNEC total and (if a background concentration is given) as the added concentration ($PNEC_{add}$).

In this report, regional $PNEC_{sw}$ have been based on HC_5, calculated using the Biomet tool and appropriate assessment factors for Cu, Ni, Pb and Zn.

The Soil PNEC Calculator has been used in calculation of regional $PNEC_{soil}$ for Cu, Ni, Pb and Zn.

Data sources/literature

PNECs in surface water, sediment and soil for most of the elements addressed in the present risk assessment, are available from various comprehensive risk assessment reports. In these reports, available ecotoxicity data are compiled, assessed for relevance, and used to predict safe (PNEC) levels according to criteria and principles described in technical guidance documents (ECB, 2003; ECHA, 2016). European environmental quality standards (EQS) have been established under the Water Framework Directive, using similar criteria as for PNEC (EC 2011). The information and data used for deriving PNECs for the present risk assessment have been extracted from European Risk Assessment Reports, Environmental Quality Standard Substance Data Sheets and REACH Registration Dossiers. Sources for each element are listed in Table 7.1.1-1.

Table 7.1.1-1. Data sources for PNEC derivation for all metals assessed for PTEs in this report.

Reference	Document	Reference used in text
EC (2007)	European Risk Assessment Report. Cadmium metal and cadmium oxide.	RAR-Cd
EC (2005)	European Risk Assessment Report, chromium trioxide, sodium chromate, sodium dichromate, ammonium dichromate, potassium dichromate.	RAR-Cr
ECHA (2008)	European Voluntary Risk Assessment Report, Copper and copper compounds.	RAR-Cu
EC (2008)	European Risk Assessment Report. Nickel and nickel compounds.	RAR-Ni
EC (2010)	European Risk Assessment Report Zinc metal.	RAR-Zn
LDAI (2008)	European Voluntary Risk Assessment – Lead.	RAR-Pb
EQS (2005a)	Environmental Quality Standards (EQS) Substance Data Sheet (6), Cadmium and its compounds.	EQS-Cd
Euro Chlor (1999)	Risk Assessment for the Marine environment.	RAR-Hg
EQS (2005b)	Environmental Quality Standards (EQS) Substance Data Sheet (25), Nickel and its compounds. First draft.	EQS-Ni
EQS (2005c)	Environmental Quality Standards (EQS) Substance Data Sheet (21) Mercury and its Compounds.	EQS-Hg
EQS (2005d)	Environmental Quality Standards (EQS) Substance Data Sheet (20). Lead and its compounds. Final draft.	EQS-Pb
EQS (2011)	Environmental Quality Standards (EQS) - Nickel	EQS-Ni (b)
ECHA (2021a)	Substance Registration Dossier, Arsenic,	ECHA Dossier-As

Reference	Document	Reference used in text
ECHA (2021b)	Substance Registration Dossier, Cadmium	ECHA Dossier-Cd
ECHA (2021c)	Substance registration Dossier, Chromium	ECHA-Dossier-Cr
ECHA (2021d)	Substance Registration Dossier, Nickel	ECHA Dossier-Ni
ECHA (2021e)	SubstanceRegistration Dossier, Mercury.	ECHA Dossier-Hg
ECHA (2021f)	Substance registration Dossier, Zinc	ECHA Dossier-Zn
ECHA (2021g)	Substance Registration Dossier, Lead.	ECHA Dossier-Pb

7.1.2 PNEC Arsenic (As)

For As, the information on environmental toxicity and PNEC-values have been extracted from the ECHA Dossier-As.

7.1.2.1 *Aquatic environment* PNEC_{sw}

When As is deposited directly into aerobic surface waters, it forms As(III) species, i.e. arsenite. Arsenite is thermodynamically unstable in most environments, and therefore tends to oxidize to dissolved As(V) species, i.e. arsenates.

Available ecotoxicity data on the effects of As on aquatic organisms are based on dissolved elemental As concentrations. Reliable chronic NOEC and EC10 values were identified for 27 freshwater species representing fish, invertebrates, algae and aquatic plants. The reliable data were based on tests with inorganic As(III) and As(V) compounds. The chronic toxicity values (NOEC or EC_{10}) varied from 4.6 µg L^{-1} (*Pediastrum duplex*) to 6403 µg L^{-1} (*Chlorella sp.*) (both algae). For other taxonomic classes, the lowest NOECs are - fish (*Oncorhynchus mykiss*): 234 µg L^{-1}, invertebrates (*Cyclopoida*): 40 µg L^{-1} and macrophytes (*Lemna disperma*): 292 µg L^{-1}. The dataset met the criteria for using SSD for calculation of PNEC_{sw}. The HC_5 from the SSD was 16.8 µg L^{-1}. An assessment factor 3 was applied to derive **PNEC_{sw} = 5.6 µg L^{-1}** (ECHA dossier-As).

The available data did not allow for a conclusion on the effect of specific water parameters, including hardness, pH, phosphate level, on the toxicity of As to aquatic organisms. Therefore, the generic PNEC has been used for all the regions in the present risk assessment.

7.1.2.2 Fresh water sediment $PNEC_{sed}$

No chronic sediment toxicity tests were identified for As. In the absence of chronic whole sediment toxicity tests, PNECsed was calculated using the equilibrium partitioning method. This method uses the PNECsw for aquatic organisms and the sediment/water partitioning coefficient as inputs using the procedure described in the TGD. For As, PNECsw = 5.6 µg L-1 and Kpsed = 4786 L kg-1 (Allison & Allison, 2005) gives a PNECsed value of 27 mg kg-1

7.1.2.3 Terrestrial environment PEC_{soil}

Background As concentrations in the soils used for the terrestrial ecotoxicity tests ranged between 0.6 and 240 mg kg-1 DW (dry weight), with a median value of 4.4 mg kg-1 DW. These background concentrations are significant compared to the lowest reliable NOEC and EC10 values for effects of inorganic As substances to terrestrial organisms. Therefore, an added approach was selected for the risk assessment of As in soil. All NOEC and EC10 values are based on added As concentrations, without considering the natural background levels in the soil. In essence, this added risk assessment approach assumes that species are fully adapted to the natural background concentration. Thus, only the anthropogenic added fraction should be regulated or controlled.

Reliable chronic toxicity data are available for the long-term effect of As on 19 terrestrial species or microbial endpoints, covering 3 taxonomic groups (13 terrestrial plants, 4 invertebrates and 2 microbial endpoints). A total of 101 reliable EC10 or NOEC values, ranging between 6.9 and 704 mg added As kg-1 dry weight (DW), were selected for derivation of a PNECsoil. All results were from tests using soluble pentavalent As substances (Na2HAsO4 and Na3AsO4).

The bioavailability and toxicity of As to most soil dwelling organisms was significantly affected by the properties of the tested soils. Toxicity to terrestrial invertebrates and most plants decreased with higher clay content of the soil. Sheppard (1992) reviewed reported toxicity thresholds for plants and calculated a geometric mean value of 40 mg kg-1 in sands and loams and 200 mg kg-1 in clay soils. The deviation of a single geometric standard was 3.6-fold above and below these values, which suggests a PNECsoil, plants of 11 mg kg-1.

The NOEC or EC10 values were normalised to reasonable worst-case soil properties (10% clay, pH 7) and analysed for SSD. The lowest species mean NOEC (5.0 mg kg-1) was found among the invertebrates (Enchytraeus albidus). In tests with microorganisms, the lowest NOEC was 53 mg kg-1 (dehydrogenase activity). The dataset includes 13 species of plants, where species mean NOEC varied from 5.3 mg kg-1 (Phaseolus vulgaris) to 143 mg kg-1 (Triticum aestivum). The HC5 was 5.8 mg kg-1. An assessment factor 2 was applied to derive a PNECsoil add = 2.9 mg kg-1. This reasonable worst-case PNEC will be used for all the Norwegian regions in the present risk assessment. The present concentration of As in the selected case areas range from 1-3 mg kg-1 in Målselv, Melhus, Stange, Ås and Time. In the alum shale area, the present concentration is 15 mg kg-1 due to the specific geochemical composition of the black shale, and therefore may be assumed to represent the ambient background concentration of that area. Since the fraction of the As in soil that can be attributed to anthropogenic input is not known the PNECsoil has been calculated as PECsoil present + PNECadd, where PNECadd = 2.9 mg kg-1, The calculated PNECs are shown in Table 7.1.2.3-1.

Table 7.1.2.3-1. $PNEC_{soil}$ for As for all Norwegian scenarios, calculated with the $PNEC_{add}$ approach (taking present background concentrations into account).

Region	**Background**	**PNEC**
	mg As kg^{-1}	mg As kg^{-1}
Målselv	1.6	4.5
Melhus	3	5.9
Stange	1.1	4
Alum shale	15	17.9
Ås	2.7	5.8
Time	2	4.9

7.1.2.4 Secondary poisoning

The ECHA dossier-As has reviewed bioaccumulation studies of As in earthworms. A total of 53 soil-earthworm bioaccumulation factors (BAF) ranged from 0.01 - 0.93 with a median of 0.22, indicating that earthworms in all of the assessed studies, accumulated As to levels much lower than those measured in the associated soils. The median BAF soil-earthworm value of 0.22 was selected for the chemical safety assessment.

Regarding the As uptake in terrestrial organisms, earthworms seem to accumulate more than small mammals. Thus, biomagnification of As in terrestrial food chains up to the level of small mammals does not appear to be significant, including herbivores and omnivores (there are no sufficient data for insectivores), as BAF values were higher at lower trophic levels.

7.1.3 PNEC Cadmium (Cd)

Cadmium is a naturally occurring element with a ubiquitous distribution pattern in the environment. Cd is non-essential and toxic at very low exposure levels.

For Cd, information on environmental toxicity relevant for risk assessment has been extracted from EU RAR-Cd, EQS-Cd and ECHA Dossier-Cd.

7.1.3.1 Aquatic environment $PNEC_{sw}$

A wealth of data exists on the toxic effects of Cd to freshwater organisms. Only studies that presented no observed effect concentrations (NOEC or EC_{10}) for chronic toxicity were included as a basis for $PNEC_{sw}$ and EQS.

Nineteen tests of chronic effects of Cd on fish and amphibians were selected for derivation of aquatic $PNEC_{sw}$. In general, toxicity is most pronounced in soft water. Reproduction parameters are most sensitive to Cd. The lowest reported chronic effect concentration for fish was 0.8 µg L^{-1} in Atlantic salmon (*Salmo salar*) reproduction test.

Twenty-two chronic toxicity tests in invertebrates were selected to derive NOEC. Certain Cladocera (e.g., *Daphnia* and *Ceriodaphnia*), appear to be particularly sensitive to Cd. Most chronic lowest-observed effect concentration (LOEC) values of *Daphnia,* range between 1 and 10 µg L^{-1}. The lowest LOEC value was found in a reproduction test with *Daphnia magna*, where the mean number of young per adult after 21 days of exposure was reduced at 0.29 µg L^{-1} (LOEC). The NOEC in this test was 0.16 µg L^{-1}.

Eight tests with 6 species of plankton algae and one plant (*Lemna paicicostata*), were selected. The data show that Cd can affect primary producers in the 1-10 µg L^{-1} range. Algae are likely to be most sensitive to Cd at nutrient-limiting conditions and low cell density. With one exception, all tests were performed in artificial media, some of which had a very similar composition as freshwater samples. The lowest NOEC (0.85 µg L^{-1}) was found for growth of the diatom *Asterionella formosa*.

The RAR-Cd considered the diversity of the data to be large enough to use the SSD approach for calculation of PNEC. For species where many NOECs were available, geomean values were calculated for effect concentrations representing the same endpoint and test medium. Effect concentrations for 28 species and 16 different families including warm- and cold-water fish, amphibians, crustaceans, algae, and higher plants) were included in the SSD analysis. The HC_5 was 0.38 µg L^{-1}. A generic PNEC was derived from the HC_5-50, including an assessment factor (AF = 2), to account for the remaining uncertainty, which gives a generic $PNEC_{sw} = HC_5/2 = 0.19$ µg L^{-1}.

The generic $PNEC_{sw}$ is based on toxicity tests in various aquatic media, which differ with respect to pH, hardness, and organic carbon content. Hence, the generic $PNEC_{sw}$ (0.19 µg L^{-1}) might not be protective for aquatic environments with very low hardness. The RAR therefore, suggests using specific, refined PNECs for regional risk assessments in areas with soft water. A water hardness correction equation of the United States Environmental Protection Agency, (US EPA, 2001) was used to calculate the HC_5 as a function of water hardness. All NOEC values were converted at a reference hardness of 50 mg $CaCO_3$ L^{-1}, and the HC_5 was recalculated. Based on the hardness-normalized HC_5, and using an AF of 2, the $PNEC_{sw}$ was calculated to be 0.08 µg Cd L^{-1} at hardness 40 mg $CaCO_3$ L^{-1}.

In an addendum to the European Union RAR, the issue of risk characterisation of Cd in very soft waters (hardness below 40 mg $CaCO_3$ L^{-1}) has been addressed. The report concluded that no further adjustment of the PNEC in very soft water is necessary and the previously agreed PNEC of 0.08 µg L^{-1} is proposed for waters with hardness of 2.7 - 40 mg $CaCO_3$ L^{-1} and dissolved organic carbon concentrations of above 2 mg C L^{-1} (EC, 2008). In Norwegian surface waters, the hardness level is generally low. A survey of 1006, mostly pristine, lakes in Norway showed a medium value of only 4 mg $CaCO_3$ L^{-1} and 90% of the lakes had a hardness less than 18 mg $CaCO_3$ L^{-1} (Skjelkvåle et al., 2001). Surface waters in agricultural areas are likely to show slightly higher hardness levels, but still, in most cases, less than 50 mg $CaCO_3$ L^{-1}. Thus, a $PNEC_{sw} = 0.08$ µg Cd L^{-1} will be used for risk assessment in all Norwegian regions in the present Risk Assessment.

7.1.3.2 Fresh water sediment PNEC$_{sed}$

Sediment-dwelling organisms may be exposed to Cd in the sediment via uptake across respiratory surfaces and body walls from the porewater, or by ingestion of sediment. In aerobic sediments, the availability of Cd for biological uptake is mainly affected by the content of organic carbon and Fe and Mn-hydroxides. In anaerobic sediments, acid-volatile sulphides reduce bioavailability and toxicity by binding and immobilising Cd as insoluble sulphide. Only limited relevant data on the toxicity of Cd to freshwater benthic organisms were found in the review performed for the RAR-Cd. Seventeen tests were selected as a basis for PNEC estimation. These data refer to tests in which uncontaminated sediment was spiked with Cd^{2+} salts. Only one of the sediments toxicity tests available within the dataset can be considered as a real chronic test. This is a test in freshwater sediments spiked with Cd, which showed a NOEC of 115 mg kg^{-1} dry weight on the abundance of chironomids (*Chironomus salinarius*) after 14 months (Hare et al., 1994). This NOEC was used for PNEC calculation, with an AF of 50. The choice of an AF of 50 instead of 100 is justified by the number of acute toxicity data, showing minor differences between species. Thus:

$PNEC_{sed}$ = 115 mg kg^{-1}/50 = 2.3 mg Cd kg^{-1} DW

7.1.3.3 Terrestrial environment (PNEC$_{soil}$)

In the ECHA Dossier-Cd, the dataset on chronic toxicity data for terrestrial organisms used in the RAR-Cd has been extended to include 21 tests with microflora, 9 invertebrates and 15 plants.

The data selected for derivation of PNEC for organisms that are exposed to Cd in soil include NOECs from long-term tests with microorganisms, plants, and soil fauna. The tests with microorganisms were performed on the native microflora in soil, where effects of Cd on important element-cycling processes (e.g., respiration, ammonification, or nitrification) or enzyme activity were studied. For plants, endpoints include seed germination or growth of roots or shoots. Various earthworms and springtails were used as representatives of the soil fauna in tests, where effects on growth or reproduction were investigated.

For microorganisms, 21 tests were selected for PNEC derivation. The NOECs varied from 3.6 mg kg-1 in a test on respiration to 3600 mg kg-1 in a test on N2 fixation.

Among the 9 selected species in tests with soil fauna, the NOECs ranged from 5 mg Cd kg-1 (cocoon production in Eiseina fetida) to 50.5 mg Cd kg-1 (reproduction in Folsomia candida). For plants, 15 species were selected. The lowest NOEC (1.8 mg Cd kg-1) was found in a test where effects on root length of Picea sitchensis was studied. The highest NOEC in tests with higher plants was 80 mg Cd kg-1 (growth of Cucurbita pepo). In the ECHA Dossier-Cd, SSD analyses were performed separately on microorganisms and plants + invertebrates. The HC5 for microorganisms was 2.3 mg kg-1. For combined plants and invertebrates, the HC5 was 3.6 mg kg-1. When all organism groups were analysed together, HC5 was 2.4 mg L-1. ECHA Dossier-Cd suggests basing PNECsoil on HC5 for microorganisms (2.3 mg kg-1) with AF 1.

Thus, PNECsoil = 2.3 mg kg-1. This generic PNECsoil has been used for all the Norwegian regions in the present risk assessment.

No separate PNEC for plants was calculated in the RAR-Cd, where the effect concentrations from toxicity tests with plants were pooled with those from microorganisms and soil fauna for deriving PNECsoil. Later, VKM (2019) made an analysis of the sensitivity distribution of NOECs from tests with plants. The dataset included 60 NOECs from 14 species. The SSD analysis of the data showed a HC5 of 2.79 mg Cd kg-1. To allow comparison with the generic PNECsoil for terrestrial organisms, the same AF (1) is proposed for derivation of PNECsoil, plants.

Hence: PNECsoil, plants = HC5/1 = 2.8 mg Cd kg-1.

7.1.3.4 Secondary poisoning in mammals, PNEC$_{soil,\ secpois}$

The median Cd Bioconcentration Factors (BCF, L kg^{-1} WW) decreases in the order - algae > invertebrates > vertebrates and, water-fish Cd Bioaccumulation Factors (BAF's) are about 40 L kg^{-1} WW with maximum values around 600 L kg^{-1} WW. Soil-earthworm BAF values are about 15 (dry weight concentration ratio) with values up to 150. All BCF and BAF values exhibit pronounced decrease with increasing concentrations in the environment. The PNECoral for birds and mammals is 0.16-0.3 mg kg^{-1} food, respectively, based on chronic feeding studies. A large risk for secondary poisoning is predicted for earthworm eating mammals in the terrestrial environment using this PNEC value. The median BAF and typical soil concentrations predict food Cd concentrations that are about 15-fold above the PNECoral. This predicted risk at ambient concentrations is ascribed to overestimated bioavailable Cd, based on feeding studies where metal salts were mixed with laboratory diets. An alternative approach for terrestrial wildlife was proposed based on measured tissue residues in field collected samples and on renal thresholds. About 20 studies were compiled and critical soil Cd concentration was derived to protect wildlife from reaching renal thresholds. This critical soil Cd concentrations is 0.9 mg kg-1 DW and is triggered by data on moles and shrews (both carnivorous) dwelling in acidic soils. This critical soil Cd concentration is below the PNECsoil derived from direct toxicity tests (plants, invertebrates and microbial processes), confirming the general knowledge that Cd is more toxic to mammals than to plants or invertebrates (RAR-Cd).

PNEC$_{soil,\ secondary\ poisoning}$ = critical soil concentration = **0.9 mg Cd kg^{-1}** soil, dry weight.

7.1.4 PNEC Chromium (Cr)

Chromium, as Cr(III) compounds, is an essential element in animal nutrition, functioning mainly in glucose metabolism and possibly in fat metabolism. It is non-essential for plant growth, although it is essential for some microbes, possibly as a cofactor for specific enzyme systems. Cr(VI) compounds are not thought to be nutritionally useful forms of Cr. Due to the high mobility (bioavailability) in biological systems and powerful oxidizing properties of Cr(VI) compounds, they are considered to be more toxic to biological systems than Cr(III) forms (RAR-Cr).

For Cr, information on environmental toxicity relevant for risk assessment has been extracted from the RAR-Cr, EQS Datasheet-Cr and the ECHA Dossier-Cr.

7.1.4.1 Aquatic environment (PNEC$_{sw}$)

The European RAR-Cr includes a review of data on the toxicity of Cr(VI) on aquatic organisms. The compiled data on chronic effects for derivation of PNEC include NOEC or EC10 values for 3 species of algae and cyanobacteria, 4 macrophytes, 7 invertebrates, 9 fish and one amphibian. For those species where several tests cover the same endpoint, the geomean of the NOECs or EC10s have been calculated. The NOECs varies from 4.7 µg L-1 for reproduction of the cladoceran Ceriodaphnia dubia to 3500 µg L-1 for growth and mortality of fish (Poecilia reticulata).

The dataset was considered adequate for SSD-analysis, and HC5 was calculated according to an equation for log-normal distribution. The resulting value for 50% confidence level in the HC5 was 10.2 µg L-1. An AF 3 was considered appropriate, which gives a **PNEC$_{sw}$ of 3.4 µg L^{-1} for Cr(VI).**

For Cr(III), available data on toxicity is insufficient to calculate a PNEC from an SSD analysis. The lowest available long-term NOEC is from a test on Daphnia magna in soft water (NOEC = 47 µg L-1). Applying an assessment factor of 10 this NOEC gives a tentative **PNEC of 4.7 µg L^{-1} for Cr(III).** The ECHA Dossier-Cr reports a PNECsw= 6.5 µg L-1 for Cr(III), but the basis for this is not explained in the dossier.

In the present risk assessment, PNECsw for Cr(VI) will be used for assessment of Cr in surface water.

7.1.4.2 Fresh water sediment (PNEC$_{sed}$)

Reduction of Cr(VI) to Cr(III) is expected to occur in anaerobic sediments. Strong adsorption of insoluble Cr(III) species formed to sediment is likely at pH levels that is typically found in the environment. In general, once Cr(III) is scavenged from the water column, it becomes part of the sediment matrix and is thus, less available for uptake from biota. In the RAR-Cr, it was concluded that there is insufficient data available to derive a PNEC from studies on sediment dwelling organisms. As an alternative, the PNEC$_{sed}$ may be calculated from PNEC$_{sw}$ using the sediment/water partition coefficient, Kd$_{sed}$ 31623 (Allison & Allison, 2005). Since any Cr(VI) is likely to be reduced to Cr(III) under the conditions found in most sediments, PNEC$_{sw}$ for Cr(III), (4.7 µg L^{-1}) should be used. This gives **PNEC$_{sed}$ = 149 mg kg^{-1}**. The ECHA dossier-Cr reports a PNEC$_{sed}$ = 206 mg kg^{-1} for Cr(III), but the basis for this is not explained in the dossier.

7.1.4.3 Terrestrial environment (PNEC$_{soil}$)

Most Cr in soil is in the trivalent form, and is complexed with mineral structures in the form of mixed Cr(III) and Fe(III)oxides. Cr(VI) tends to be reduced to Cr(III) in soil with high organic matter content (Ertani et al. 2017).

Cr(III) has generally been shown to be less toxic than Cr (VI) to soil organisms. Since Cr(III) adsorbs more strongly onto soil than Cr(VI), adsorption will also contribute to make Cr(III) less toxic than Cr(VI). Tests on plants exposed to Cr(III) in the form of chromic sulphate in alkaline soil, have been reported to reduce the growth of wheat at 100 mg kg^{-1}, but NOEC could not be obtained from the study. For invertebrates, a NOEC of 32 mg Cr kg^{-1} dry soil has been found for effects on reproduction in earthworms (*Eisenia andrei*). Several tests of effects of Cr(III) on microbial soil processes have been performed. In the RAR-Cr, SSD analysis was performed on NOEC values from 30 tests, showing a HC_5 of 5.9 mg kg^{-1}.

Applying an assessment factor of 10 to the lowest NOEC for invertebrates gives a **$PNEC_{soil}$ for Cr(III) of 3.2 mg Cr kg^{-1} DW**.

According to the Technical Guidance Document, an equilibrium partitioning approach can be used in the derivation of $PNEC_{soil}$. In RAR-Cr, this was done for Cr(III) using $K_{soil\text{-}water}$ = 1200 m^3 m^{-3} (acidic conditions) and $K_{soil\text{-}water}$ = 22500 m^3 m^{-3} (neutral/alkaline conditions). The $PNEC_{soil}$ for Cr(III) was estimated as follows: $PNEC_{soil}$ = 3.3 mg kg^{-1} wet weight for acidic conditions and 62 mg kg^{-1} wet weight for other conditions. The $PNEC_{soil}$ estimated for Cr(III) for acidic conditions using the equilibrium partitioning method is in good agreement with the values obtained above, using available toxicity data.

The RAR-Cr notes that there are many natural soils where the levels of total Cr are above the PNECs derived here. Again, the main form of Cr needs to be considered. In natural soils, majority of Cr will be present as low solubility Cr(III) complexes, where bioavailability is limited. The derived PNECs may not be appropriate for such situations.

The present background concentrations in the Norwegian regional soils are a factor 3-10 higher than the calculated $PNEC_{soil}$. This indicates that, PNEC based on NOECs from tests in soils spiked with inorganic Cr(III) salts are not applicable for risk assessment in soils with Cr accumulated over many years. A tentative solution is to consider the proposed PNEC = 3.2 mg kg^{-1} as $PNEC_{soil\ add}$. This appears to be a reasonable approach as the NOEC on which the PNEC is based was obtained in a test on earthworms in an artificial soil with an insignificant background concentration of Cr. The Cr was added as $Cr(NO_3)_3$ and NOEC is referred to the added concentration of Cr. The Dutch Maximum Permissible Concentration (MPC) for Cr in soil (Crommentuijn et al. 1995) is also based on a NOEC for effect of Cr(III) on earth worms. In this case, the NOEC was 38 mg kg^{-1}, which, with an AF=10, gives a Maximum Acceptable Addition, MPA = 3.8 mg kg^{-1}. The background concentration of Cr in soils with or without minor anthropogenic influence in the Netherlands, was estimated at 100 mg kg^{-1}. This would give MPC = 103.8 mg kg^{-1} which was truncated to 100 mg kg^{-1}.

In the present risk assessment, the PNEC suggested in RAR-Cr is taken as $PNEC_{add}$ to which an appropriate background concentration should be added to obtain a tentative PNEC. The present concentrations of Cr in the selected case areas varies from 9.3 mg kg^{-1} (Time) to 36 mg kg^{-1} (Melhus). These concentrations are not natural background concentrations, but are influenced by anthropogenic inputs, including Cr from fertilisers. Nevertheless, using the present PEC_{soil} as background concentration in calculation of regional PNECs allows an assessment of the risk posed by future changes in $PEC_{soil.}$ Thus, the $PNEC_{soil}$ has been calculated as PEC_{soil} present + $PNEC_{add,}$ where $PNEC_{add}$ = 3.2 mg kg^{-1}, The calculated PNECs are shown in Table 7.1.4.3-1.

Table 7.1.4.3-1. $PNEC_{soil}$ for Cr for all Norwegian scenarios, calculated with $PNEC_{add}$ approach (taking present background concentrations into account).

Region	Background (mg Cr kg^{-1})	PNEC (mg Cr kg^{-1})
Målselv	25.0	28.2
Melhus	36.0	39.2
Stange	14.0	17.2
Stange, Alum shale	19.0	22.2
Ås	27.0	30.2
Time	9.3	12.5

7.1.4.4 Secondary poisoning

According to the RAR-Cr, uptake of Cr(VI) from water, sediment and soil has been shown for a wide range of organisms. The bioconcentration factor for fish is, however usually very low (~1 L kg^{-1}). Based on chronic toxicity studies on birds, a NOEC in food of 166 mg kg^{-1} was calculated for Cr(VI). Applying an assessment factor of 10 gives a PNEC for secondary poisoning of 17 mg kg^{-1} food. A PNEC for soil was not calculated in the RAR-Cr. The ECHA dossier-Cr concludes that bioconcentration and biomagnification of trivalent Cr is not an issue for both water and soil organisms.

7.1.5 PNEC Copper (Cu)

Copper is an essential nutrient and therefore each species needs to maintain an optimal range of internal concentration to fulfil specific functions of metabolism. Cu concentrations below this range causes deficiency, while higher concentrations may lead to toxic effects (RAR-Cu).

For Cu, information on environmental toxicity relevant for risk assessment has been extracted from RAR-Cu.

7.1.5.1 Fresh water environment ($PNEC_{sw}$)

In the risk assessment of Cu, the selection criteria for toxicity data included information on abiotic factors in the test medium. However, background concentration of Cu in the test media was not used as a selection criterion. The selected data included 139 chronic NOEC values for 27 species, representing algae, macrophytes, invertebrates and fish. Among algae, the green alga *Pseudokirchneriella subcapitata* showed the lowest species NOEC (geometric mean value of 54 µg L^{-1}). NOECs for invertebrates ranged from 6 µg L^{-1} (snail, *Juga plicifera*) to 54.3 µg L^{-1} in amphipod *Hyalella azteca*, (geometric mean value). Among fish, the lowest NOEC was found for rainbow trout (*Oncorhynchus mykiss*, 11.6 µg L^{-1}, geometric mean value) and the highest for *Noemacheilus barbatulus* (120 µg L^{-1}).

The NOECs were derived from tests under various conditions in terms of abiotic factors in the test media, and it was observed that factors such as DOC, pH and hardness affected the toxicity of Cu. BLM-models were developed for algae, invertebrates and fish and were used to normalise all NOECs to the same set of abiotic parameters.

After normalisation of all individual NOEC values towards typical conditions for pH, hardness and DOC occurring in representative EU surface waters, regional HC_5 was calculated for six European scenarios. The resulting HC_5 ranged from 11-27 µg L^{-1} (log-normal distribution).

The Biomet tool includes BLM-models for Cu and has been used to calculate $PNEC_{sw}$ for selected rivers in Norwegian regions that are used in the present risk assessment of PTEs. The bioavailable fraction of Cu under the conditions in the selected regional rivers was between 4 and 17%, and the HC_5 varied from 5.8 µg L^{-1} in Målselva to 24.4 µg L^{-1} in Orreelva (Time). Most of the variation appears to be explained by DOC concentration.

The RAR does not conclude on the AF to be used for calculation of $PNEC_{sw}$ for Cu, but provided solid arguments that suggest low AF as presented. In the ECHA Dossier, AF=1 has been used, which means that **PNEC= HC_5**. The abiotic factors used for calculation of HC_5 and $PNEC_{sw}$ for Cu are shown in Table 7.1.5.1-1.

Table 7.1.5.1-1. $PNEC_{sw}$ for Cu and abiotic parameters used for calculation of HC_5 for Cu in rivers in the selected Norwegian regions.

Region	River	pH	DOC	Ca	$Cu_{background}$	HC_5	$PNEC_{sw}$
			mg L^{-1}	mg L^{-1}	µg L^{-1}	µg Cu L^{-1}	µg Cu L^{-1}
Målselv	Målselva	7.65	1.12	8	0.65	5.8	5.8
Melhus	Nidelva	7.23	2.47	4	0.65	13.7	13.7
Stange	Glomma	7.25	3.47	5	1.39	21.0	21.0
Alum shale	Glomma	7.25	3.47	5	1.39	21.0	21.0
Ås	Glomma	7.25	3.47	5	1.39	21.0	21.0
Time	Orreelva	7.81	5.38	20	1.53	24.4	24.4

7.1.5.2 Fresh water sediment ($PNEC_{sed}$)

Long-term exposure tests with the oligochaete *Tubifex tubifex* showed NOEC values ranging from 18.3 to > 5883 mg Cu kg^{-1} DW for growth and reproduction endpoints. For *Chironomus riparius,* bounded NOEC values ranged between 54.4 and 1417 mg Cu kg^{-1} DW for growth endpoint.

In tests with amphipod *Hyalella Azteca,* the observed differences in bounded NOEC values ranged between 59 and 3158 mg Cu kg^{-1} DW for survival endpoint and between 21.8 and 1,531 mg Cu kg^{-1} DW for growth endpoint. Investigation of the mitigating effect of specific sediment characteristics on chronic toxicity of Cu towards *H Azteca* and other organisms in the database (i.e. amphipod *Gammarus pulex* and oligochaete *Lumbriculus variegatus*) resulted in the conclusion, that both OC and AVS seemed to control the chronic toxicity of Cu towards sediment-dwelling organisms.

The highest NOEC values have been observed for sediment with the highest AVS/OC combination (i.e. 17.5 mmol AVS kg^{-1} dry weight and 6.97% OC). The lowest values were observed for low AVS/OC sediment (i.e. 0.21 mmol AVS kg^{-1} dry weight and 2.83% OC.)

To use the whole dataset of long-term toxicity tests for derivation of $PNEC_{sed}$, the NOECs should be normalised based on OC and AVS in sediments. Normalisation based on AVS concentrations measured in sediment was, however, not possible, due to artefact occurring during SEM-AVS analysis. As an alternative, data from tests in sediments with AVS >0.77 mmol kg^{-1} dry weight were excluded and the remaining 62 chronic toxicity NOECs, representing 6 species were normalised for organic carbon before analysis of species sensitivity distribution (SSD). The HC_5 derived from SSD-analysis (log-normal model) was 1.741 mg Cu g^{-1} OC. It was concluded that, an AF = 1 is adequate for derivation of $PNEC_{sed}$ from HC_5. Hence, the OC normalised $PNEC_{sed}$ of 1.741 mg Cu g^{-1} OC. This corresponds to **$PNEC_{sed}$ of 87 mg Cu kg^{-1} DW** for a sediment containing 5 % organic carbon. This $PNEC_{sed}$ has been used for all regions in the present risk assessment.

7.1.5.3 Terrestrial environment ($PNEC_{soil}$)

Many toxicity data for soil-dwelling organisms representing invertebrates, plants and microbes have been compiled as a basis for $PNEC_{soil}$ calculation in RAR-Cu.

For plants, 67 individual high-quality NOEC's for 9 different species ranged from 18 mg kg^{-1} (*Hordeum vulgare)* to 698 mg kg^{-1} (*Lycopersicon esculentum)*.

For soil invertebrates, 108 individual NOECs from 10 different species were selected, ranging from 8.4 mg kg^{-1} for *Eisenia fetida* cocoon production to 1,460 mg kg^{-1} for *Folsomia candida* reproduction.

Data on microbial toxicity tests in which the native soil microbial community is exposed, generated 77 NOEC values for effects on functional parameters and two NOECs for microbial growth. In the total risk approach, NOEC or EC_{10} values range from 30 mg kg^{-1} (glucose respiration) to 2402 mg kg^{-1} (maize respiration).

Several studies have shown that Cu toxicity is generally larger in soils freshly spiked with Cu(II) salts than in soils contaminated with Cu in the field. This is the results of two processes: leaching and ageing. These two processes were studied in tests with soil from old, contaminated soils and freshly spiked soils. From the observations, it was concluded that there is sufficient justification to assume that toxicity under field conditions is less, compared to under laboratory conditions, and a reasonable worst case generic leaching-ageing factor (L/A) of 2.0 is proposed for all soils. This generic L/A factor was used on all individual $NOEC_{add}$ values of tests starting within 120 days after spiking, to generate aged $NOEC_{add}$

values. For $NOEC_{add}$ values of tests in soils that have equilibrated for more than 120 days after spiking, the L/A factor should be 1.0.

In order to normalise the NOECs that were derived from tests in different soil types, to the abiotic conditions in a specific soil, a program was initiated to develop regression functions for different species and abiotic factors. Toxicity tests with plants (*Hordeum vulgare* and *Lycopersicon esculentum*), invertebrates (*Folsomia candida* and *Eisenia fetida*) and three microbial processes were carried out in 19 European soils. The range of abiotic factors in the soils were: pH 3.0-7.5, organic carbon 0.4-33%, clay content 5-51 % and Cu-background 19-660 mg kg^{-1}.

Single linear and multivariate regressions between soil toxicity thresholds and various soil properties were analysed. Application of chronic regressions seemed to reduce the uncertainty associated with the effects assessment and could therefore be applied for normalising the NOEC values.

The statistical extrapolation method was used to calculate the median fifth percentile (HC_5) of NOECs using log-normal and log-logistic distributions. The SSD was performed on the pooled dataset including toxicity data for invertebrates, plants and microbes.

The HC_5 from the distribution of all NOECs without correction for ageing and without normalisation was 57.5 mg kg^{-1}. When ageing factor (2) was applied, HC_5 was 87.2. When both ageing factor and OC normalisation was included, the HC_5 for six European soils ranged from 25.3 mg kg^{-1} (Acid sandy soil, Sweden) to 172.8 (Peaty soil, The Netherlands).

The model for normalisation and ageing are included in Arche $PNEC_{soil}$ calculator, which was used to calculate the selected Norwegian regions. Here, AF=1 is used to calculate $PNEC_{soil}$ from HC_5. The results are shown in Table 7.1.5.3-1.

Table 7.1.5.3-1. Regional $PNEC_{soil}$ values for Cu in the Norwegian regions calculated on the basis of soil normalisation and aging by the Arche $PNEC_{soil}$ calculator.

	Målselv	**Melhus**	**Stange**	**Alum shale**	**Ås**	**Time**
PNEC mg Cu kg^{-1}	86	112	109	109	119	70

7.1.5.4 Secondary poisoning

There is overwhelming evidence to show the absence of Cu biomagnification across trophic levels in the aquatic and terrestrial food chains. Differences in sensitivity among species are not related to the level in trophic chain, but to the capability of internal homeostasis and detoxification. Field evidence has further provided evidence on the mechanisms of action of Cu in the aquatic and terrestrial environments, with no concern for secondary poisoning (RAR-Cu).

7.1.6 PNEC lead (Pb)

Lead is a naturally occurring element found in small amounts in the earth's crust. It is non-essential and toxic to aquatic and terrestrial organisms.

For Pb, information on environmental toxicity relevant for risk assessment has been extracted from the RAR-Pb, ECHA Dossier-Pb and EQS Datasheet-Pb.

7.1.6.1 Freshwater environment (PNEC$_{sw}$)

From the high-quality dataset, 69 individual NOEC/EC$_{10}$ values could be extracted from which 3% originated from algae species, 51% from invertebrates and 46% from fish.

Two individual EC$_{10}$ values were retrieved for 2 different algae species. The NOEC values for those freshwater algae were 30 µg L^{-1} for *Pseudokirchneriella subcapitata* and 99 µg L^{-1} (dissolved Pb) for *Chlorella kesslerii*.

35 individual NOEC/EC$_{10}$ values were retrieved for 7 different invertebrate species. The species mean NOEC values (as dissolved Pb) for freshwater invertebrates ranged from 6.3 µg L^{-1} for the amphipod, *Hyalella azteca* (single value for 3 different endpoints) to 168 µg L^{-1} for the cladoceran, *Daphnia magna* (single value).

32 individual NOEC/EC$_{10}$ values were retrieved for 8 different fish species. The NOEC values for freshwater fish range from 19.1 µg L^{-1} for carp, *Cyprinus carpio* (single value) to 70.5 µg L^{-1} for catfish, *Ictalurus punctatus* (single value). Most data on freshwater fish are available for fathead minnow, *Pimephales promelas.*

From the sensitivity distribution of the aquatic organisms belonging to different trophic levels (plotted with the individual chronic NOEC/EC$_{10}$ values), it seems that fish were less sensitive to the toxic effects of lead, compared to invertebrates.

SSD analysis of the geomean NOECs for 17 selected species gave a HC$_5$ = 8.0 (log-normal distribution). An assessment factor of 2 or 3 was suggested to account for the remaining uncertainty. This resulted in a PNEC$_{sw}$ value of 4.0 µg L^{-1} (AF=2) or 2.7 µg L^{-1} (AF=3).

Later, additional data has been added to the database of chronic NOECs, and BLM models have been developed which allows calculations of site specific or regional HC$_5$ values. In the ECHA Dossier-Pb, HC$_5$ for the most sensitive European scenario was 4.8 µg Pb L^{-1}. Due to the extended database and the use of BLM-models, an AF=2 is proposed, which gives PNEC$_{sw}$= 2.4 µg Pb L^{-1}. In the European Environmental Quality Standards (EQS, 2005d), the standard for freshwater (EQS=1.2 µg L^{-1}) is specified as the bioavalabile fraction of Pb, with the option to calculate local or regional EQS using a BLM model.

The Biomet tool has been used to calculate PNEC$_{sw}$ for selected rivers in the Norwegian regions that are used for the present risk assessment of PTEs. The bioavailable fraction of Pb in regional rivers were between 12 and 40% and HC$_5$ varied from 3 µg L^{-1} in Målselva to 16 µg

L^{-1} in Orrelva (Time). The site specific and PNECs for rivers in the Norwegian scenarios are shown in Table 7.1.6.1-1.

Table 7.1.6.1-1. Abiotic factors and calculated $PNEC_{sw}$ for Pb in the Norwegian regional scenarios.

Region	River	pH	DOC	Ca	Pb	$PNEC_{sw}$
			mg L^{-1}	mg L^{-1}	µg L^{-1}	µg Pb L^{-1}
Målselv	Målselva	7.65	1.12	8	0.06	3.0
Melhus	Nidelva	7.23	2.47	4	0.02	6.0
Stange	Glomma	7.25	3.47	5	0.2	8.6
Alum shale	Glomma	7.25	3.47	5	0.2	8.6
Ås	Glomma	7.25	3.47	5	0.2	8.6
Time	Orreelva	7.81	5.38	20	0.16	15.8

7.1.6.2 Freshwater sediment ($PNEC_{sed}$)

The high quality chronic freshwater sediment database contains Pb toxicity data for 7 different sediment dwelling species (*Tubifex tubifex*, *Ephoron virgo*, *Hyalella azteca*, *Gammarus pulex*, *Lumbriculus variegatus*, *Hexagenia limbata*, *Chironomus tentans*). Selected EC_{10} levels for Pb ranged from 573 mg Pb kg^{-1} (*Tubifex tubifex*; endpoint: reproduction) to 3390 mg Pb kg^{-1} (*Chironomus dilutus*; endpoint: survival). SSD analysis of the NOEC values showed HC_5 = 522 mg kg^{-1} DW. The RAR-Pb suggests an AF=3 which gives **$PNEC_{sed}$ = 174 mg Pb kg^{-1}** DW.

7.1.6.3 Terrestrial environment ($PNEC_{soil}$)

The dataset retrieved for derivation of $PNEC_{soil}$ includes 14 NOECs from 10 plant species, ranging from 65 mg kg^{-1} for *Hordeum vulgare* (oat) to 2207 mg kg^{-1} for *Triticum aestivum* (wheat).

For invertebrates, 12 NOEC or EC_{10} values were selected, ranging from 130 mg kg^{-1} for *Dendrobaena rubida* (earthworm) to 2207 mg kg^{-1} for *Folsomia candida* (springtail).

Test on microbial processes are multi-species tests, in which the native soil microbial community is exposed. There are 18 NOEC or EC_{10} values for functional parameters C- and N-mineralization. The NOECs vary from 96 to 4144 mg Pb kg^{-1}, both with respiration as endpoint.

An SSD-analysis of NOECs accounting for differences in Pb toxicity between spiked soils and field contaminated soils (assuming a background concentration of 15 mg kg^{-1} in those tests where background concentration was not reported and using a leaching/ageing factor of 4.2) shows a HC_5 = 333 mg Pb kg^{-1} DW. The HC_5 is based on 44 NOEC values. The RAR-Pb notes for Pb data richness is sufficiently large (soil/species), but those supporting Pb field data are limited. There are only 2 studies and no studies providing a LOEC. Therefore, an AF=2 to derive $\mathrm{PNEC_{soil}}$ from $\mathrm{HC_5}$ was proposed, Thus **$\mathrm{PNEC_{soil}}$ =333/2 = 166 mg Pb $\mathrm{kg^{-1}}$ DW**.

7.1.6.4 Secondary poisoning in terrestrial mammals and birds ($\mathrm{PNEC_{soil,\ secpois}}$)

In the RAR-Pb, $\mathrm{PNEC_{soil,\ secpois}}$ has been derived from a bioaccumulation factor (BAF) for earthworms and $\mathrm{PNEC_{oral}}$ for mammals and birds.

Bioaccumulation studies with earthworms in soil showed that measured BAFs are not significantly affected by Pb concentration in soil. Lead is rarely concentrated from the soil into organisms (BAF value higher than 1). The median BAF is 0.10 kg DW $\mathrm{kg^{-1}}$ WW (n=101).

BAF increased with decreasing pH and CEC, but was not correlated with soil organic matter content. The equation describing BAF on a wet weight basis (kg DW $\mathrm{kg^{-1}}$ wet weight) as a function of pH reads:

$\mathrm{BAF} = 13.9 \times \exp(-0.76 \times \mathrm{pH})$

This equation predicts that the median BAF of 101 data points above BAF = 0.10 kg DW $\mathrm{kg^{-1}}$ ww was found at pH 6.5. For the Norwegian regional soils, pH 5.66 (lowest) gives a BAF of 0.18.

$\mathrm{PNEC_{oral}}$ has been derived from feeding studies with mammals and birds. An SSD analysis was performed on $\mathrm{NOEC_{oral}}$ from 11 tests, ranging from 100 to 1100 mg $\mathrm{kg^{-1}}$ WW. The $\mathrm{HC_5}$ of the distribution was 49.1 mg Pb $\mathrm{kg^{-1}}$ WW.

Based on a BAF of 0.10 kg DW $\mathrm{kg^{-1}}$ WW and $\mathrm{HC_5}$ = 49.1 ($\mathrm{NOEC_{oral}}$), the concentration of Pb above which risk for secondary poisoning cannot be excluded ($\mathrm{PNEC_{soil,\ secpois}}$) can be calculated as 49.1/0.10 = 491 mg Pb $\mathrm{kg^{-1}}$. For the Norwegian regions used in the present assessment, pH values are below 6.5 and therefore the BAF should be adjusted using the equation above. Using the lowest pH from the regions, pH 5.6 (Målselv), gives a BAF=0.18 and a **$\mathrm{PNEC_{soil,\ secpois}}$ = 272 mg Pb $\mathrm{kg^{-1}}$**, which may be used for all the Norwegian regions. Thus, $\mathrm{PNEC_{soil,\ secpois}}$ is higher than $\mathrm{PNEC_{soil}}$ for direct exposure.

7.1.7 PNEC Mercury (Hg)

Mercury occurs naturally in soils from geological sources or because of natural events such as forest fires and volcanic eruptions. It is recognised as a non-essential, toxic, persistent, and mobile contaminant and becomes mobile because of volatility of the element and several of its compounds (Gworek et al. 2020).

For Hg, information on environmental toxicity relevant for risk assessment has been extracted from RAR-Hg, and EQS Datasheet-Hg.

7.1.7.1 Freshwater environment (PNECsw)

Mercury is a priority substance under the Water Framework Directive (2000/60/EC) and Environmental Quality Standards have been developed as described in EQS Datasheet-Hg. The lowest NOEC-values among freshwater organisms were for fish 0.5 µg L^{-1} (*Pimephales promelas*), invertebrates 0.62 µg L^{-1} (*Hyalella azteca*) and algae 20 µg L^{-1} (*Scenedesmus acuta*).

High-quality chronic effects data were available to derive an aquatic PNEC according to statistical extrapolation methodology (SSD). NOECs from 14 freshwater species and 15 saltwater species from 9 different taxonomic groups of fish, invertebrates and algae were included in the database for SSD analysis. A HC_5 = 0.142 µg Hg L^{-1} was calculated for combined freshwater and marine NOECs. It was suggested to use an AF=3 for derivation of PNEC, which gives a $PNEC_{sw\ add}$ = 0.047 µg L^{-1}. For risk assessment, the background concentration must be added to $PNEC_{sw\ add}$. The concentration of Hg in regional rivers are all below the detection limit 0.001 µg L^{-1}. The **$PNEC_{sw}$=0.048 µg L^{-1}** has therefore been used for the Norwegian regional scenarios.

7.1.7.2 Freshwater sediment ($PNEC_{sed}$)

Only one chronic NOEC for sediment dwelling organism was identified in the EQS Data Sheet-Hg. In a 28d test with *Chironomus riparius* larva in Hg_2Cl_2 spiked sediment, the NOEC was 930 mg kg^{-1}. The appropriate assessment factor for the derivation of a $PNEC_{sed}$ form this NOEC according to TGD is 100, resulting in a **tentative $PNEC_{sed}$ of 9.3 mg Hg kg^{-1} sediment DW**. This PNECs is also reported in RAR-Hg and ECHA Dossier-Hg.

7.1.7.3 Terrestrial environment ($PNEC_{soil}$)

A compilation of chronic effects of inorganic Hg on soil dwelling microorganisms and earth worms, is included in the ECHA Dossier-Hg. NOECs from eight tests on microbial processes range from 1.4 mg kg^{-1} (ATP) to 2406 mg kg^{-1} (phosphatase activity). The lowest NOEC for earth worms was 2.7 mg kg^{-1} (*Eisenia fetida*). No data on toxicity to plants is reported. The dataset does not fulfil the requirements for an SSD analysis according to TGD and a tentative $PNEC_{soil}$ must be calculated from the lowest NOEC using an assessment factor. As only two taxonomic groups are represented, the appropriate AF is 50 which gives a tentative $PNEC_{soil}$ = 1.4/50 = 0.028 mg kg^{-1} DW. This concentration appears extremely low in comparison with $PNEC_{sed}$ and is also lower than the background concentration in uncontaminated soils which is 0.03-0.1 mg kg^{-1} (Gworek et al. 2020).

A review of Hg toxicity to terrestrial biota by Mahbub et al. (2017) confirms that microorganisms have been observed to be the most sensitive indicators to Hg stress. Furthermore, it is concluded that there is a scarcity of accurate Hg toxicity information in terrestrial ecosystems which hinders establishment of a widely acceptable safe limit of soil Hg.

Studies of forest environments in Sweden have shown that the critical limit for Hg in soils can be set for organically bound Hg content rather than for free Hg ion concentration or total dissolved Hg concentration. Based on field and experimental studies indicating effects of Hg on respiration in soils, a tentative critical limit of 0.5 mg Hg kg-1 organic matter was suggested (Meili et al. 2003). In a review of impact of soil properties on critical concentrations of metals in soil, de Vries et al. (2007) emphasised derivation of critical free and total metal concentrations in soil solution. This approach assumes that impacts on plants, microorganisms, and soil invertebrates are mainly related to soil solution concentration and not to the soil solid-phase content. The review includes data from Lijzen et al. (2002) on toxicity to plants exposed to Hg in solutions. The NOECs in tests of 11 species varied from 0.1 µg L-1(Lolium perenne) to 100 µg L-1 (Nicotiana sp.). An SSD-analysis of the data showed a HC5 of 0.08 µg L-1. de Vries et al. (2007) also reports a HC5 of 0.02 µg L-1 based on results of NOECs from tests with soil organisms. The source of these data is, however, not accounted for.

Data on toxicity of Hg in tropical soil has been reported by Lima et al. (2019). Toxicity tests with plants exposed to Hg in soil showed an EC10 of 3.6 mg kg-1 for effect on emergency of oat (Avena sativa) and 22 mg kg-1 for effect on shot dry matter in common bean (Phaseolus vulgaris). These two species were selected as being the most sensitive among 11 species in an initial screening. In the tests, effects on soil microbial processes were also studied. Based on the results, a critical limit for Hg in tropical soil was derived as lowest EC10 divided by an AF of 10, which gives 0.36 mg kg-1.

In order to make it possible for comparison, the proposed critical values in Swedish forest soil and tropical soil with HC5-values reported by de Vries (2007), the latter may be converted from concentration in soil solution to concentration in soil using the Kdsoil=8946 L kg-1, selected for the present report. (Table 7.1.7.3-1).

The four critical concentrations or HC_5-values are in the same range and could be used as basis for a tentative $PNEC_{soil}$. A pragmatic solution is to use the mean value, 0.39 mg kg^{-1}. This is a factor 10 higher than the $PNEC_{soil}$ based on the lowest NOEC for effect on microbial processes with an AF of 50 (ECHA Dossier-Hg), but still lower than this NOEC.

Table 7.1.7.3-1. HC_5-values and critical concentrations of Hg considered for derivation of a $PNEC_{soil}$.

	Soil solution (µg L^{-1})	**Soil (mg kg^{-1})**
HC_5 plants	0.08	0.7[1]
HC_5 ecotoxicity	0.02	0.18[1]
Critical conc. Swedish forest	0.35	0,31[1]
Critical conc. Tropic soil	-	0.36

[1] Concentrations in soil calculated from concentrations in solution using Kd of 8946 (See Table 5.1.1.1-1)

Thus, a tentative **$PNEC_{soil}$ = 0.39 mg kg^{-1}** is proposed for this report.

7.1.7.4 Secondary poisoning

The EQS Data Sheet-Hg concludes that insufficient hazard data is available for a hazard assessment of secondary poisoning. However, long-term NOECs from feeding studies with inorganic Hg on birds and mammals were reported as 4 mg kg^{-1} DW, food (birds) and 7 mg kg^{-1} food (mammals).

Top predators such as birds and mammals which feed on fish or mussels that may contain up to 70-99% of organic Hg, which is deemed to be more toxic than inorganic Hg. Therefore, it is suggested to base the assessment for secondary poisoning of top predators on methylmercury (i.e. organic Hg or CH_3Hg or MeHg). The lowest NOECs for effects of methylmercury on birds and mammals are very similar (0.25 and 0.22 mg kg^{-1}, respectively). Thus, the NOECs for organic Hg are 16-32 times below that for inorganic Hg. This NOECs could, with appropriate assessment factors, and factors for bioaccumulation (BAF) be used to calculate $PNEC_{secpois\ sw}$ and $PNEC_{secpois\ soil}$, if the BAF in water and soil were known. However, there is a high degree of uncertainty regarding bioconcentration and biomagnification of Hg, and EQS Datasheet-Hg suggested to temporarily set the QS for methyl Hg for biota concentration only. Based on the NOEC of the most sensitive taxon and an assessment factor of 10 the resulting Quality standards (QS) is:

$QS_{secpois}$, food (=$PNEC_{secpois,\ food}$) = 22 µg methyl-Hg kg^{-1} food (prey tissue; WW)

Applying the same approach and assessment factor for inorganic Hg gives

$QS_{secpois}$, food (=$PNEC_{secpois,\ food}$) = 400 µg kg^{-1} inorganic Hg kg^{-1} food (prey tissue; DW).

Considerable uncertainty exists regarding the bioconcentration and biomagnification of Hg, and the tentative Quality Standards for Hg in food cannot be used to calculate $PNEC_{soil,\ secpois}$ as long as BAF (soil/prey) has not been established.

Secondary poisoning in the terrestrial food-chain has been assessed by Smit et al, (2000) as a basis for determining Maximum Permissible Concentration (MPC) of Hg in soil in the Netherlands. The calculations are based on geometric mean values of BAF measured in earthworms and NOEC values for chronic toxicity in birds and mammals, and the proposed added maximum permissible concentrations (MPA) were calculated at 0.56 mg kg^{-1} for inorganic Hg and 0.14 mg kg^{-1} for methyl-Hg. $PNEC_{soil,\ secpois}$ can be calculated by adding the background concentration to these MPA-values. Taking the present regional concentrations as background gives **$PNEC_{soil,\ secpois}$ at 0.17-0.21 mg kg^{-1} for methyl-Hg and 0.59-0.63 mg kg^{-1} for inorganic Hg** for the Norwegian regions.

7.1.8 PNEC Nickel (Ni)

Nickel is a naturally occurring element that is essential for several terrestrial species. Ni essentiality to aquatic organisms has only been confirmed for plants and (cyano) bacteria

For Ni, information on environmental toxicity relevant for risk assessment has been extracted from the RAR-Ni and ECHA Dossier-Ni.

7.1.8.1 Aquatic environment PNEC$_{sw}$

In the RAR-Ni, a large amount of data on chronic toxicity of Ni to aquatic organisms were identified. After an initial analysis of reliable data, it was concluded that the intraspecies variation of NOECs was affected by abiotic factors such as pH, DOC and hardness. It was therefore decided to develop BLM- models to allow normalisation of NOEC to specific water qualities. Such models were developed for algae, crustacean, and fish. The dataset of reliable NOECs was screened to remove those toxicity data with physico-chemical parameters outside the boundaries of BLMs for bioavailability normalisation. The remaining data were geomean NOECs from 8 species of algae, 2 higher plants, 15 invertebrates, 3 fish and 3 amphibians. The NOEC (geomeans) ranged from 6.8 µg L^{-1} (mollusc, *Lymnea stagnalis*) to 640 mg L^{-1} (amphibian, *Bufo terrestris*). An SSD analysis of these non-normalised NOECs showed a HC_5 = 5.6 µg L^{-1}.

The selected set of NOECs were normalised to six different European scenarios, and SSD analyses were performed for each scenario. In the most sensitive scenario, among five watercourses and lakes the HC_5 ranged from 7.3 µg L^{-1} (Lake Monate, Italy) to 19.4 µg L^{-1} (River Teme, United Kingdom). In The Netherlands ditch scenario with high hardness (260mg $CaCO_3$ L^{-1}) and DOC (12 mg L^{-1}) the HC_5 was 43.6 mg L^{-1}

The RAR(Ni) suggested that an AF=3 should be used to calculate $PNEC_{sw}$ from HC_5. Thus, the PNECs for the European scenarios range from 2.4 µg L^{-1} in Lake Monate to 14.5 µg L^{-1} in the ditch scenario of The Netherlands. Later, an $EQS_{bioavailable}$ = 4 µg L^{-1} has been derived using a BLM model, which allows calculation of local or regional EQS.

In the present risk assessment, the Biomet tool has been used to calculate BLM-normalised HC_5 for the Norwegian regions. The bioavailable fraction of Ni in regional rivers were between 36 and 99% and varied from 4 µg L^{-1} in Målselva to 11 mg L^{-1} in Glomma (Stange and Ås) (Table 7.1.8.1-1).

Table 7.1.8.1-1. Abiotic factors and calculated $PNEC_{sw}$ for Ni in the Norwegian regional scenarios.

Region	River	pH	DOC	Ca	Ni	$PNEC_{sw}$
			mg L^{-1}	mg L^{-1}	µg L^{-1}	µg Ni L^{-1}
Målselv	Målselva	7.65	1.12	8	0.47	4.0
Melhus	Nidelva	7.23	2.47	4	0.69	8.7
Stange	Glomma	7.25	3.47	5	0.71	11
Alum shale	Glomma	7.25	3.47	5	0.71	11
Ås	Glomma	7.25	3.47	5	0.71	11
Time	Orreelva	7.81	5.38	20	1.0	10

7.1.8.2 Fresh water sediment $PNEC_{sed}$

The RAR-Ni, that was published in 2008, identified a need for additional testing to provide robust data for the derivation of $PNEC_{sed}$. The testing program that was initiated provided additional data on toxicity to sediment-dwelling organisms. (Vandegehuchte et al, 2006). However, the results obtained from laboratory tests were not consistent with results from field recolonisation studies on Ni contaminated sediments. The latter showed that benthic re-colonisation was unaffected at Ni concentrations that is 10 times higher than the threshold levels derived from laboratory tests. It was concluded that the toxicity of Ni to benthic organisms in laboratory studies was more accurately explained by measured Ni concentrations in the overlying water than Ni in sediment phases. This hampered a straightforward calculation of a $PNEC_{sed}$ value and necessitated the development of an alternative approach.

An additional research program, described in the ECHA Dossier-Ni, was initiated to provide more appropriate conditions for testing of the effects of Ni on sediment dwelling organisms. The program evaluated the chronic toxicity of eight field collected Ni-spiked freshwater sediments to nine species of benthic invertebrates to create a robust database of chronic toxicity tests for Ni. The nine benthic organisms tested represent a variety of feeding strategies and taxonomic groups. The chronic toxicity tests covered different endpoints such as abundance, survival, growth, biomass, reproduction, fecundity and hatching, and resulted in four EC10-values and four unbounded NOEC values (one species was excluded from the evaluation). The data were initially used to populate SSD and to derive a reasonable worst-case PNEC (RWC-PNEC) for Ni. Thereafter, Ni toxicity to four species in three additional sediments (which also showed broad ranges of sediment parameters), was tested resulting in an SSD with eight EC_{10}-values.

The research identified Acid Volatile Sulfide (AVS) as the key parameter controlling Ni toxicity. Bioavailability models based on AVS were developed for six benthic organisms. The models were used to normalise the chronic ecotoxicity data to an AVS concentration of 0.8 µmol g^{-1}, which represents 10th percentile of its distribution in EU sediments. The normalized data were included in the SSD for HC_5 derivation. The resulting HC_5-value of 109 mg Ni kg^{-1}

DW, was estimated from the log-normal distribution. The HC_5 of 109 mg Ni kg^{-1} DW is a robust estimate of Ni toxicity in sediments at the 10th percentile of parameters controlling Ni bioavailability and represents RWC ecotoxicity value in the absence of necessary data for performing bioavailability correction (i.e. AVS data).

Based on the outcome of the testing program, previous laboratory studies, and corroborating field studies, Ni toxicity and behaviour in freshwater sediments has been well characterized and the remaining uncertainty is low. According to The ECHA Dossier-Ni, an AF of 1 is justified, given the robust sediment toxicity database. The resulting **$PNEC_{sed}$ is 109 mg Ni kg^{-1} DW.**

7.1.8.3 Terrestrial environment ($PNEC_{soil}$)

In the RAR-Ni, reliable and relevant NOECs from 11 species of plants, 6 invertebrates and 13 microbial species were selected for derivation of $PNEC_{soil}$.

For plants, the $L(E)C_{10}$/NOEC values ranged from 11 mg kg^{-1} for *Lycopersicum esculentum* to 1127 mg kg^{-1} for *Hordeum vulgare.*

For invertebrates, 37 individual NOECs (for 6 different species) were selected ranging from 36.4 mg kg^{-1} for *Folsomia candida* reproduction to 1140 mg kg^{-1} for *Eisenia fetida* reproduction.

For microorganisms, the selected NOEC or EC^{10} values comprise functional parameters (n=39), and microbial species (n=13). The functional parameters are based on the carbon cycle (n=27), nitrogen cycle (n=12), including denitrification and mineralization of specific substrates. Enzymatic parameters were also considered in the effects assessment. Six (6) different enzymatic processes were included in the dataset. In the total risk approach, NOEC or EC_{10} values range from 28 mg kg^{-1} (nitrification-mineralisation) to 2491 mg kg^{-1}.

Analysis of the data revealed that the toxic response is highly dependent on soil type and time between addition of soluble Ni to soils and measurement of toxicity (i.e. an ageing effect).

In summary, NOEC values were first corrected for the difference in Ni bioavailability between laboratory conditions (Ni freshly added as soluble salts) and field conditions, through application of a leaching-ageing factor (L/A factor). The second step is the correction of the aged NOEC values towards specific soil properties at a given site, since it is demonstrated that abiotic factors (i.e. soil properties) affect Ni toxicity in soil. This normalisation was based on the slopes of the organism specific regression models between toxicity thresholds and driving abiotic factors i.e. cationic exchange capacity (CEC) and pH.

Aggregation of the aged/normalised toxicity data was performed based on the calculation of species mean value for the most sensitive endpoint. Species sensitivity distribution were further constructed, for which a HC_5 value, and subsequently a $PNEC_{soil}$, could be derived.

SSD analysis of NOECs normalised for six European ecoregions were performed. An agricultural acidic sandy soil from Sweden with low pH and CEC showed the most sensitive response with a HC_5 = 8.6 mg kg^{-1}. The highest HC_5= 194 mg kg^{-1} was obtained with the Natural clay soil from Greece, characterised as high in pH, clay content and CEC.

Models for normalisation of Ni- toxicity to abiotic factors and ageing are included in The $PNEC_{soil}$ calculator from Arche and have been used to calculate $PNEC_{soil}$ for the Norwegian regions in the present risk assessment. The results are shown in Table 7.1.8.3-1.

Table 7.1.8.3-1. Regional $PNEC_{soil}$ for Ni in the Norwegian regions.

	Målselv	**Melhus**	**Stange**	**Alum shale**	**Ås**	**Time**
PNEC mg Ni kg^{-1}	31	48	46	46	42	23

7.1.8.4 Secondary poisoning

Secondary poisoning through the aquatic food chains has been assessed in EQS-NI(b). A bioconcentration factor of 270 and total PEC_{oral} value of 12.3 mg Ni kg^{-1} (birds) were used for derivation of quality standards for fresh water.

For the avian food chain, applying BCF of 270 L kg^{-1} to the total PEC_{oral} value of 12.3 Ni kg^{-1} yields a $PNEC_{secpois\ sw}$ of 46 µg Ni L^{-1} This concentration is nearly four times higher than the $PNEC_{sw}$ calculated for the six Norwegian regions. Given that the critical dissolved concentration of 46 µg Ni L^{-1} is based on 100% bioavailability, it is likely that the actual critical dissolved concentration is even higher. It can be concluded that, the risks associated with dietary Ni exposure to aquatic food chain is not the most sensitive pathway to be considered for Ni.

In the RAR-Ni, secondary poisoning in terrestrial food-chains was analysed for birds and shrew feeding on worms and isopods. The results from risk assessment on local sites showed that the shrew feeding on worms were at risk in soils exceeding 22.6 mg kg^{-1}. Thus, a **$PNEC_{secpois\ soil}$ value of 22.6 mg kg^{-1}** is used in the present risk assessment.

7.1.9 PNEC Zinc (Zn)

For Zn, information on environmental toxicity relevant for risk assessment has been extracted from the EU RAR-Zn and ECHA Dossier-Zn

7.1.9.1 Aquatic environment ($PNEC_{sw}$)

The data selected in RAR-Zn RAR for derivation of $PNEC_{sw}$ includes chronic NOEC values for 18 species representing algae, invertebrates and fish. Algae appears to be the most sensitive group with the lowest NOEC (geometric mean value) for the green alga *Pseudokirchneriella subcapitata* of 17 µg L^{-1}. Among the invertebrates, the NOEC range from 37 µg L^{-1} for the crustacean *Ceriodaphnia dubia* to 400 µg L^{-1} (zebra mussel, *Dreissena polymorpha)*. The fish, NOECs range from 44 µg L^{-1} (*Jordanella floridae*) to 660 µg L^{-1} *(Brachydanio rerio*)

An SSD analysis was performed including species mean NOECs for the 18 selected species. The HC_5 for log-logistic distribution was 15.6 µg L^{-1}. The RAR proposed an AF=2, which gives $PNEC_{sw}$=7.8 µg L^{-1}. However, this AF has been questioned in a recent work by Van Sprang et al. (2009) and UK has adopted an AF=1 in the proposal of regional Environmental Quality Standards for Zn. (WFD-UKTAG 2012). Since more toxicity data have been included in the dataset, the ECHA Dossier-Zn has calculated HC_5 to 20.6 µg L^{-1} and used AF=1 for calculation of a generic **$PNEC_{sw,\ add}$ = 20.6 µg L^{-1}**. It should be noted that the NOECs in the Zn database represent added Zn, i.e. a background concentration must be added to the PNEC (added) to obtain $PNEC_{sw}$.

The PNEC is based on NOEC values from tests performed in water with a range of abiotic factors, without normalisation using BLM modelling. However, a BLM model for Zn has been included in the Biomet tool, which allows calculation of site specific $PNEC_{sw}$. The site specific HC_{5_add} and PNECs for rivers in the Norwegian scenarios are shown in Table 7.1.9.1-1.

Table 7.1.9.1-1. $PNEC_{sw}$ for Zn and abiotic parameters used for calculation of HC_5 for Zn in rivers in the selected Norwegian regions.

Region	River	pH	DOC	Ca	Zn	HC_{5_add}	$PNEC_{sw}$
			mg L^{-1}	mg L^{-1}	µg L^{-1}	µg Zn L^{-1}	µg Zn L^{-1}
Målselv	Målselva	7.65	1.12	8	0.51	11.6	12.1
Melhus	Nidelva	7.23	2.47	4	0.48	15.6	16.1
Stange	Glomma	7.25	3.47	5	2.82	20.4	24.2
Alum shale	Glomma	7.25	3.47	5	2.82	20.4	24.2
Ås	Glomma	7.25	3.47	5	3.82	20.4	24.2
Time	Orreelva	7.81	5.38	20	2.5	40.3	42.8

7.1.9.2 Freshwater sediment ($PNEC_{sed}$)

The dataset on chronic toxicity of Zn to sediment dwelling organisms, which was compiled for the RAR-Zn, contains only four useful chronic NOEC values representing three species. The lowest NOEC is for the crustacean *Hyalella azteca* (488 mg kg^{-1} DW) and the highest for the oligochaete *Tubifex tubifex* (1101 kg^{-1} DW). These NOEC-values are expressed as added Zn concentrations. The number of species is small to apply SSD analysis. Therefore, the $PNEC_{add}$, sediment was derived from the lowest NOEC applying an AF=10. Hence, a $PNEC_{add,\ sed}$ of 49 mg kg^{-1} was proposed. Later, tests with additional species have been added to the dataset in the ECHA dossier-Zn, showing the lowest NOEC for *Gammarus pulex* (146 mg kg^{-1}). SSD analysis of the NOECs showed an HC_5=118 mg kg^{-1}. Considering the weight of evidence provided by the elements discussed in the chemical safety report, it was considered that the use of HC_5 from SSD, using statistical extrapolation techniques, is justified for PNEC derivation, and that no additional assessment factor needs to be applied. Consequently, the PNEC is set at the level of HC_5, which is considered as protective for EU freshwater ecosystems: **$PNEC_{add,\ sed}$= 118 mg kg^{-1} DW** ECHA Dossier-Zn (2021).

In the absence of measured background concentration of Zn in the river sediments, these values have been calculated from Zn concentration in the regional river waters, using a kp_{sed} (63096 L kg^{-1}) from Allison & Allison (2005). The results are shown in Table 7.1.9.2-1.

Table 7.1.9.2-1. $PNEC_{sed}$ for Zn and relevant background data for the Norwegian regional rivers. Zinc concentration in sediments were calculated as Zn(water) × kp_{sed}.

Region	River	Zn (water)	Zn (sed)	$PNEC_{sed}$
		µg L^{-1}	mg kg^{-1}	mg Zn kg^{-1}
Målselv	Målselva	0.51	32	150
Melhus	Nidelva	0.48	30	148
Stange	Glomma	3.82	241	359
Alum shale	Glomma	3.82	241	359
Ås	Glomma	3.82	241	359
Time	Orreelva	2.5	158	276

7.1.9.3 Terrestrial environment ($PNEC_{soil}$)

Data on toxic effects of Zn on microbial processes, plants and invertebrates obtained from tests in natural and artificial soils with characteristics (pH, clay content, organic matter content and background concentration of Zn) within boundaries of these 4 parameters in EU soils were reviewed in RAR-Zn.

The selected data included 97 NOECs for effects on microbial processes (C-mineralisation, N-mineralisation, and enzyme activity). The NOECs ranged from 17 to 1000 mg Zn kg^{-1} DW. For invertebrates, 27 NOECs representing three species were selected, ranging from 32 to 1000 mg Zn kg^{-1} DW. For plants, 29 NOECs representing 16 species were included, ranging from 32 to 400 mg Zn kg^{-1} DW. The large toxicity variation of Zn is partly due to variation in the bioavailability of Zn in soil caused by abiotic factors such as cation exchange capacity and soil pH. Furthermore, ageing processes reduce the available fraction of Zn in soil over time.

Models for normalisation of Zn-toxicity to abiotic factors and ageing are included in the $PNEC_{soil}$ calculator from Arche and have been used to calculate $PNEC_{soil}$ for the Norwegian regions in the present risk assessment. The results are shown in Table 7.1.9.3-1.

Table 7.1.9.3-1. Regional $PNEC_{soil}$ for Zn in the Norwegian regions.

	Målselv	Melhus	Stange	Alum shale	Ås	Time
$PNEC_{soil}$ mg Zn kg^{-1}	132	203	181	220	231	116

7.1.9.4 Secondary poisoning

The accumulation of Zn, an essential element, is regulated in animals from several taxonomic groups, such as molluscs, crustaceans, fish and mammals. In mammals, one of the two target species for secondary poisoning, the absorption of Zn from diet and excretion, are regulated. This allows mammals, within certain limits, to maintain their total body Zn level (whole body homeostasis) and to maintain physiologically required levels of Zn in their various tissues, both at low and high dietary Zn intakes. The results of field studies, in which relatively small differences were found in Zn levels of small mammals from control and polluted sites, are in accordance with homeostatic mechanism. These data indicate low bioaccumulation potential of Zn in both herbivorous and carnivorous mammals (RAR-Zn).

7.2 PTE toxicity in farm animals

7.2.1 Arsenic toxicity in animals

Arsenic (As) is considered as a poison, but major forms have a rather low toxicity. Some forms of organic As, particularly those found in seafood, are virtually non-toxic (NRC, 2005). Arsenic is generally not accepted as an essential element but possible As deficiency has been reported for various animal species at trace concentrations (e.g. < 12 µg kg^{-1} diet for rats and chicken; <35 µg kg^{-1} diet, for goats). The most consistent signs of the apparent deprivation have been depressed growth, impaired fertility and increased perinatal mortality observed in goat, pig and rat (NRC, 2005).

Furthermore, some forms of As have beneficial effects in supranutritional amounts. Due to antibiotic and anticoccidial properties, organic As were, in the past, used extensively as growth promoters for pig and poultry. Medical remedies based on As, have been used for treatment of parasite infections and cancers (NRC, 2005).

The absorption of As varies with chemical form, but generally organic As seem to be absorbed mainly by simple diffusion (NRC, 2005). Arsenobetaine, the main As compound in seaweed and other seafood, passes through the body into urine without biotransformation. A range of other As compounds are transformed to different species after absorption. The excretion of As in species is generally fast and no tissues significantly accumulate As, but elevated levels may be present in the liver and kidney after excessive As ingestion (Ufelle and Barcowsky, 2019).

The mechanisms involved in As toxicity include oxidative stress, altered methylation and altered metabolism of other essential minerals (NRC, 2005). The acute toxicity of As is determined by chemical form and oxidation state. Trivalent As (arsenite) is acutely more toxic than pentavalent As (arsenate). Some trivalent organic As species, such as monomethyl- and dimethylarsonous acids which are metabolites of inorganic As, are similarly or even more toxic than arsenite. Most pentavalent organic As species are relatively nontoxic (NRC, 2005).

Chronic oral As toxicosis in domestic animals has been rarely reported, but most usual signs are depressed growth, feed intake and feed efficiency, and in some cases - convulsions, uncoordinated gait and decreased haemoglobin (NRC, 2005).

Arsenic toxicity is influenced by factors that affect reactive oxygen metabolism. For example, ascorbic acid and α-tocopherol are shown to alleviate As toxicosis in rats (Ramanathan et al. 2003). The same applies to selenium, but here are also mechanisms involved, such as the level of methylation (NRC, 2005).

Maximal tolerable levels of As are somewhat unclear, but NRC (2005) indicated a 30 mg kg^{-1} diet for domestic animals. NRC (2005) also refers to an EU directive (2002) that sets the maximum As contents in products intended for animal feed at 2 mg kg^{-1} feed, with the exception of meals made from grass etc (4 mg kg^{-1}) and feedstuffs obtained from fish and other marine animals (10 mg kg^{-1}).

7.2.2 Cadmium toxicity in animals

Cadmium (Cd) is toxic to humans and various animals and is generally not considered an essential element. It has specific adverse effects on the kidney, and may induce hypertension and microcytic, hypochromic anaemia. However, in studies with rodents, chickens, and livestock, addition of low levels of Cd to their diets have been shown to increase weight gain (Bokori and Fekete, 1995). The basis of these effects is mainly unknown, but may result from antibiotic or pharmacological actions as observed with other trace elements, such as Zn and Cu. Furthermore, Cd is an essential element for the marine diatom, *Thalassiosira weissflogii*, where Cd is a cofactor for an isoform of carbonic anhydrase (CA). The enzyme is needed under conditions of low Zn – which is often the case in many marine environments (Lane and Morel, 2000). Higher plants have not been shown to require Cd for physiological purposes (NRC, 2005).

The bioavailability of Cd depends on its chemical form. Cadmium in ionic form and as salt, such as cadmium chloride, have the highest bioavailability. In general, Cd is not absorbed very efficiently. In freshwater, Cd is likely to be in free ionic form, whereas in foods, including those of animal origin, it generally exists in a complex with a variety of ligands, such as metallothionein (NRC, 2005). The bioavailability of Cd in animal tissues is usually less than for cadmium chloride (CdCl). However, the bioavailability of Cd in foods of plant origin may be somewhat higher than that of Cd salts (Prankel et al., 2004). The toxic effects of Cd are thought to be caused by free Cd ions. Cadmium bound to metallothionein is usually less active (NRC, 2005).

Animals with a high rate of feed intake appear to be affected at lower levels of dietary Cd than animals with lower feed intake. Thus, small animals with relatively high intake, compared with their body size may be more sensitive to Cd effects than larger animals (NRC, 2005).

The toxicity of Cd is also affected by the nutritional and physiological state of an animal. Deficiencies in Zn, Fe, Cu, Ca, or protein, increase the tissue accumulation and toxicity of Cd, and vice versa (NRC, 2005). Cadmium has been shown to be absorbed at higher rates in immature animals than in adults (NRC, 2005).

Even low exposure of Cd accumulates in the body. Primarily to prevent high levels in animal food products, WHO has set a 1 mg kg^{-1} upper limit in complete feeds for animals (IPCS, 1992).

Although Cd accumulation is greatest in the kidney, followed by liver, testes, pancreas and spleen, lower levels are also found in muscle and bone. The transfer of Cd to eggs and milk is very inefficient. Regardless of the level of Cd fed to animals, the concentration of Cd in meat, milk, and eggs is consistently lower, on a DW basis, than the level in the diet (NRC, 2005).

The maximum tolerable level of Cd is the dietary level that, when fed for a defined period, will not impair accepted indices of animal health or performance (NRC, 2005). Animals can tolerate acute exposure to 25 mg kg^{-1} Cd in the diet for few days (NRC, 2005). Indications of functional toxicosis in rodents, such as increased blood pressure, have been shown after a Cd intake of 1 mg kg^{-1} diet for several months (NRC, 2005). A chronic dietary level of 10 mg kg^{-1} is tolerated by poultry and livestock species. However, this level results in unacceptable levels in kidneys and liver, and, in some cases, also in muscles (NRC, 2005). Dogs can also tolerate 10 mg Cd kg^{-1} over several years (NRC, 2005).

The toxicity of Cd in water appears to be very similar to that in feed, and the total intake from both sources should be considered (NRC, 2005).

The upper limit for Cd in complete feeds for animals at 1 mg kg^{-1} diet has been set by WHO to protect consumers of animal products. In a review of potential contaminants in livestock feeds and proposed guideline levels for feed, MacLachlan et al. (2013) commented that advice on the maximum levels of exposure to Cd are challenging to develop. This is due to the accumulation of Cd with increasing duration of exposure, and slaughter of livestock usually occurs before steady-state concentrations are archived in tissues. Prankel et al. (2004) conducted a meta-analysis of feeding trials investigating Cd accumulation in livers and kidneys of sheep and suggested that preventing livers and kidneys of older animals from entering the human food chain would be an appropriate measure to decrease the risk from Cd in foods of animal origin. Prankel et al. (2004) suggested that sheep fed a concentration of Cd from plant origin at 1 mg kg^{-1} total feed DW (maximal limit in feed) would result in maximum residue levels in liver (0.5 mg kg^{-1} wet weight) at approximately 200 days of exposure. The corresponding maximum residue level in kidney (1.0 mg kg^{-1} wet weight) would be reached at approximately 150 days.

7.2.3 Chromium function and toxicity in animals

The essentiality of chromium (Cr) was shown by Schwartz and Mertz (1959) as involvement in glucose metabolism in rats. Later this mechanism was further described via Cr binding to an oligopeptide (chromodulin) which amplifies insulin receptor and enhances insulin action (NRC, 2005). In domestic animals, supplementation of organic Cr with low Cr concentration was shown to improve growth rate, milk production and feed intake, and reduces disease incidence (NRC, 2005).

The absorption of trivalent Cr is low – up to about 2 % (NRC, 2005). Certain organic forms of trivalent Cr appear to be more bioavailable than inorganic trivalent form. The hexavalent Cr is absorbed to a greater extent, but this occurs less likely because Cr(VI) is reduced in the environment to the more stable oxidation state Cr(III), and it is also mainly reduced to Cr(III) in the stomach.

Trivalent Cr has a low order of toxicity because of low intestinal absorption and limited entry to cells (NRC, 2005). Hexavalent Cr, which does not generally occur naturally, is several-fold more toxic than trivalent Cr. Absorbed Cr(VI) can cross cell membranes where it is reduced to Cr(III), whose intermediate compounds including free radicals, are believed to bind to intracellular macromolecules, including DNA (NRC, 2005).

Large doses of Cr(III) are required to produce signs of acute toxicosis. For chronic exposure, the maximum tolerable level for Cr(III) was set at 3000 mg kg^{-1} diet for chromic oxide, an insoluble form of Cr(III). For more soluble forms of Cr(III), the maximum tolerable level was set at 500 mg kg^{-1} for poultry and 100 mg kg^{-1} for mammalian species (NRC, 2005). However, studies of most farm animal species are lacking. Any increase in Cr concentration in edible tissue, except for kidney, should not represent a concern for human health (NRC, 2005).

7.2.4 Copper function and toxicity in animals

Copper (Cu) was first shown to be essential for growth and haemoglobin formation in laboratory rats by Hart and coworkers (1928). The authors showed that rats on a milk diet required Cu, in addition to iron to treat anemia (Hart et al. 1928). Subsequently, it became evident that Cu is a critical element in a range of metabolic pathways of great importance in practical husbandry and is affected by diets with deficient or toxic concentrations. In addition to anemia, which may occur in all species of animals and humans, Cu deficiency may also produce bone, nerve, skin/hair, reproductive, as well as cardiovascular disorders in several species (Davis and Mertz, 1987).

Copper functions as a co-factor in Cu-containing enzymes such as, amine oxidases, ferroxidases and superoxide dismutases (Turnlund 2006). Thus, many of the physiological functions of Cu can be predicted based on the biochemical roles of Cu containing enzymes (Prohaska 1997). In connective tissue formation, the Cu-containing enzyme, lysyl oxidase, is essential for cross-linking of collagen and elastin, which is necessary for proper maturation of connective tissue (Werman & David 1996). Thus, Cu plays a role in bone formation, skeletal mineralization, and integrity of the connective tissue in the heart and vascular system. Copper is involved in iron metabolism through ceruloplasmin and ferroxidase II proteins and possibly involved in the formation of bone marrow cells, and hence the production of red blood cells (Suttle 2010). Copper plays multiple roles in the central nervous system; it is required for myelin production through cytochrome c oxidase activity in phospholipid synthesis and in normal neurotransmission through Cu-proenzymes such as monoamine oxidase in the catecholamine metabolism (Suttle 2010). Furthermore, Cu also plays a role in immune functions. Cellular and humoral factors of the immune system are suppressed by Cu deficiency, including changes in T-lymphocytes, T-helper cells, B-cells, monocytes, and interleukin-2 (Failla & Hopkins 1998).

Copper plays a key role in managing oxidative stress. Cu and Zn are collectively essential elements of the cytoplasmic superoxide dismutase (SOD) which forms the first line of defense that converts reactive oxygen species (ROS) to the less toxic, hydrogen peroxide, which is further inactivated by Se-dependent glutathione peroxidase (Suttle 2010). Decreases in SOD activity, as a mineral deficiency, can lead to increased damage to lipids, proteins, and nucleic acids, which can induce cellular death via apoptosis.

Recent studies have advanced the understanding of the complex ways in which Cu is absorbed, transported, and incorporated into functional enzymes and proteins involved in energy metabolism, formation of connective tissue and defence against free radicals (Suttle 2010; NNR 2012). The absorption of Cu is basically regulated by the amount of Cu in the diet. However, it is shown that Cu absorption is inhibited at high dietary levels of Zn, as Zn induces the production of metallothionein, which chelates Cu (NNR 2012). Furthermore, the Cu absorption interacts with the uptake of molybdenum and sulfur due to shared carriers. This connection has been observed in most outbreaks of Cu deficiency, as well as poisoning disorders in grazing livestock, also in Norway. Clinical disorders of deficiency, as well as Cu poisoning may frequently occur in grazing ruminants. Sheep is particularly sensitive to Cu resulting to various deficiency symptoms in lambs, as well as poisoning due to Cu accumulation in the liver and release through haemolysis. Copper responsive disorder rarely occurs naturally in non-ruminants such as pigs and poultry (Suttle 2010). Chronic Cu poisoning may occur in pigs and poultry given Cu supplements as growth stimulants in proportions that are not suitably balanced with other minerals. Furthermore, Cu tolerance is also influenced by the composition of diet.

Copper deficiency is manifested in a wide range of signs in different animal species. Common signs in various animals, include anemia, growth depression, bone disorders, depigmentation of hair, wool and feathers, demyelination of the spinal cord, fibrosis of the myocardium, and diarrhea (Suttle 2010). Usually, depigmentation of the coat is the earliest clinical sign, whereas anemia usually develops only when deficiency is severe or prolonged (Van Paemel et al 2010).

Copper sulphate has been observed to quantitatively reduce some Gram-positive bacterial e. g. *Streptococcus* spp) populations in the gut. Investigations into the contribution of this antimicrobial property to growth promoting effects of Cu has produced inconsistent results (Van Paemel et al. 2010).

Liver and kidney are target organs for Cu toxicosis in all species. Particularly in young animals, excessive dose of Cu leads produced a reduction in the number of erythrocytes and anemia (NRC 2005). Sheep is particularly susceptible for Cu toxicosis, since Cu easily accumulates in the liver. At exceeded capacity of Cu storage, liver necrosis results to the release of Cu and Fe to blood and this is characterized by hemolysis, hemoglobinemia and hemoglobinuria.

Maximum tolerable levels for Cu given by NRC (2005) for pigs, poultry and horses, cattle and sheep are 250, 40 and 15 mg kg-1 DM, respectively.

7.2.5 Lead toxicity in animals

The efficiency of lead (Pb) absorption is significantly influenced by the chemical form, level of other dietary constituents, age and physiological state of the animal. The proportion of a dose of highly soluble Pb absorbed by adults may vary from less than 10 percent when ingested with a meal to 60-80 % after fasting (NRC, 2005). Calcium and phosphate are effective in reducing Pb absorption. Young animals absorb Pb more efficiently than older animals, and pregnancy, lactation or deficiency of iron or calcium also increase Pb absorption.

Most toxicological studies have used Pb acetate, which is one of the most soluble forms of Pb and does not mimic the bioavailability of several other chemical forms of Pb (NRC, 2005). In rat, the absorption of metal species has been shown to be 60-80 % of lead acetate under conditions of comparable particle sizes and reduced with increasing particle size, due to reduced surface-area-to-mass ratio (summarized in Høgåsen et al. 2016).

Lead enters the blood where more than 90 % is taken up by red blood cells and mostly bound to haemoglobin in the cells. The half-life of Pb in blood and other soft tissues of adult humans is about 1 month, but it is much longer in bone compartments (NRC, 2005).

Proposed toxic mechanisms for Pb include interaction with proteins and subsequent alteration of their functions, inhibition, or imitation of calcium action, replacement of Zn as an enzyme cofactor, or by causing oxidative stress (NRC, 2005).

Neurodevelopmental, cardiovascular, and haematological signs occur at lowest exposure levels, and renal, gastrointestinal, hepatic, and immunological signs occur at higher doses or lengths of exposure (NRC, 2005).

The toxicity of Pb-contaminated water to fish varies considerably, depending on species, water hardness, pH, salinity, and organic matter. Generally, Pb is less tolerable via water exposure than when consumed in diets. Rainbow trout are particularly sensitive. Young fish, animals and humans are more susceptible that mature individuals (NRC, 2005).

Among dietary factors influencing toxicity is calcium, which modulates Pb effect due to facilitated increase in renal excretion and reduced absorption of Pb. Also, iron and Zn have protective effect against Pb toxicity, possibly due to inhibition of its uptake (NRC, 2005). Cadmium on the other side, is shown to increase Pb deposition and toxicity (Phillips et al., 2003).

Lead accumulates in various tissues, such as kidney, brain, and liver, and more permanently in bones (NRC, 2005). Concentrations in muscle is relatively low. Recent data on Pb in milk from cattles accidently exposed to Pb through feed may indicate that Pb in cattle milk can be an issue of concern. Lead was found in milk above acceptable limit in animals with no clinical signs (Bernhoft et al. 2016). Lead may also transfer to egg yolk in Pb exposed laying hens (Mazliah et al., 1989).

Available toxicological data are too sparse to indicate a maximum tolerable level of Pb. In chickens and quail, slight but significant changes in growth and egg production occur with 1 mg kg^{-1} in the diet of lead acetate, and 0.5 mg kg^{-1} of soluble Pb appears to be a maximum tolerable level for chronic exposure in these species at low dietary calcium levels. At high dietary calcium, 100 mg kg^{-1} of Pb in diet is tolerated (NRC, 2005). In pigs, 25 mg kg^{-1} diet of lead acetate resulted in decreased growth. In adult ruminants 250 mg kg^{-1} Pb in diet is shown to be tolerated for several months without significant effects on performance (NRC, 2005). However, 1 mg kg^{-1} BW per day of lead acetate to calves orally exposed via water for up to 56 days resulted in increased mortality (Zmudzki et al., 1985). This dose corresponds to approximately 30 mg kg^{-1} total diet. In dogs, the same dose of lead acetate, 1 mg kg^{-1} BW per day resulted in increased blood pressure after 10 days (Fine et al., 1988). Reduced learning capability was shown in 10-15 months old lambs that were exposed in utero to Pb. Their mothers were fed lead acetate at 4.5 mg kg^{-1} BW in their diet during pregnacy (Carson et al., 1974). The sparse toxicity data show heterogenous effect levels, and data on neurodevelopmental effects in farm animals are particularly few. However, the legislation on Pb by EU Commission which also include the Norwegian legislation has set maximum limit of 30 mg Pb kg^{-1} in grass etc and 10 mg kg^{-1} in other feed. Based on available data these limits seem to protect animal health.

7.2.6 Mercury toxicity in animals

Absorption of mercury (Hg) is highly dependent on its chemical form. Gastrointestinal absorption of metallic Hg is only about 0.01 % in humans and animals (NRC, 2005). Absorption of inorganic Hg from the GI tract ranges between 1 and 40 %, depending on species, age, diet, intestinal pH, and the solubility of the source. The absorption is highest at young age, and active GI microbiota may convert inorganic Hg into organic Hg and thus increase the absorption (NRC, 2005). The absorption of organic Hg compounds is very efficient; methylmercury, the main form of organic Hg, is absorbed 90 % or higher in mammals and birds. Due to ruminal demethylation to inorganic Hg, methylmercury is relatively less absorbed in ruminants. Also, fish absorb methylmercury far more efficient than inorganic Hg from water and feed (NRC, 2005).

In the blood, inorganic Hg is present equally in plasma and erythrocytes, whereas methylmercury is mostly in erythrocytes. Methylmercury associates with thiol-containing amino acids through binding to sulfhydryl groups, and thus crosses cell membranes via the amino acid transport system. Inorganic Hg does not readily cross cell membranes, but ionic forms may form complexes with selenium (Se) that are more lipophilic and able to cross membranes (NRC, 2005).

The tissue distribution of Hg differs depending upon the form consumed. Inorganic Hg is primarily present in kidneys and liver. Methylmercury distributes readily to all tissues including the brain and muscles due to its ability to cross cell membranes. Methylmercury effectively crosses both the blood-brain barrier and placenta, whereas inorganic Hg crosses these barriers only to a limited extent. Hg from organic and inorganic sources is transported into milk, and organic Hg also into eggs (NRC, 2005).

Inorganic Hg can induce metallothionein and a large proportion of this Hg in liver and kidneys are protected against toxic effects via binding to this sulfhydryl-rich protein. Another protection is that Hg forms complexes with Se in the liver. The latter mechanism is considered particularly important in fish and marine mammals (Storelli and Marcotrigiano, 2002). Methylmercury interacts with Se to form bismethylmercury selenide, which is soluble and not stable and thus not considered to be a good detoxification mechanism. However, above a threshold concentration, a demethylation process takes place and inorganic Hg forms Hg selenide in liver (NRC, 2005).

Excretion of inorganic and metallic Hg is predominantly via urine and faeces. Methylmercury is excreted more slowly with major route via the bile to faeces. In the intestine, some of the methylmercury is converted into its inorganic form, which is the primary excreted form, whereas the remained methylmercury is resorbed and retained (NRC, 2005).

Mechanisms for the toxic effects of inorganic and organic Hg is similar with the difference in toxic signs due to the difference in their tissue distribution (NRC, 2005). The major mechanism is high-affinity binding of divalent mercuric ions to thiol or sulfhydryl groups of proteins, hydroxyl, carboxyl and phosphoryl groups. These results to decreased enzyme activities and impaired structural functionality and transport processes, as well as promotion of oxidative stress, lipid peroxidation, mitochondrial dysfunction, and changes in haeme metabolism. Furthermore, Hg interacts with selenium and calcium and inhibits their functions.

Accumulation of inorganic Hg in the kidney produce changes in renal function – a critical effect of its toxicity (NRC, 2005). Chronic exposure to inorganic Hg results in nephrotoxicity, progressive anemia, gastric disorders, tremor, inflammation, and other effects. Dose-response studies to accurately determine safe levels of inorganic Hg for farm animals and companion animals are generally lacking, but there is information from studies of symptoms, mechanisms, and tissue accumulation (NRC, 2005).

The easy transport of methylmercury into the brain and across the placenta makes the nervous system and foetus sensitive indicators for the effects of organic form (NRC, 2005). The most critical endpoint for exposure to organic forms of Hg is the nervous system, particularly, developing nervous system. Ataxia, muscle spasms, paralysis, impaired vision, loss of coordination, and hind limb crossing are common neurological signs of methylmercury exposure in animals (NRC, 2005). Changes in behaviour, decreased activity, and deficiencies in learning and memory also occur. Methylmercury may also cause reproductive effects in form of impaired sperm function, abortions, and malformations.

Selenium and Zn protect against nephrotoxic, and some other acute effects induced by Hg. Vitamin E decreases the toxicity of methylmercury, probably by protecting against oxidation (NRC, 2005).

Concerning maximum tolerable levels in animals, chronic consumption of diets containing soluble forms of inorganic Hg at 0.2 mg kg^{-1} is tolerated by poultry, pigs, as well as rodents (NRC, 2005). Studies on ruminants are lacking. Chronic consumption of methylmercury at 1 mg kg^{-1} diet is tolerated by poultry, and a dietary level of 2 mg kg^{-1} has been established by NRC as safe for pigs and ruminants.

Regardless of the form of Hg, dietary levels considered safe for animals may result to levels in animal products that represent risk for human consumers of meat, milk and eggs.

7.2.7 Nickel toxicity in animals

Nickel (Ni) is essential for lower forms of life, such as bacteria, fungi, algae, plants, and invertebrates, where it participates in hydrolysis and redox reactions, regulates gene expression and stabilize certain structures (Nielsen, 1998). In plants, Ni is essential for nitrogen metabolism. Nickel is generally not accepted as an essential element for higher animals, but Ni deprivation has affected normal growth and reproduction in higher animals (NRC, 2005).

In humans and animals, less than 10 % of dietary Ni is absorbed. Nickel seems to be homeostatically regulated by absorption from the gut. It is transported in blood principally bound to serum albumin. Most of the absorbed Ni is rapidly and efficiently excreted through the kidney, as well as in sweat (NRC, 2005).

Life-threatening toxicity of Ni through oral intake is low. Excessive intake of Ni may result to interference with absorption or use of essential elements, such as Cu, iron and Zn. Toxic effects such as alteration of cellular redox status, which can cause DNA, cellular membrane and protein damage, impaired cell cycles and abnormal cytoskeletal structure are suggested (Sutherland & Costa, 2002). Nickel may also be toxic by inhibiting enzymes involved in glucose, energy, and oxidative metabolism. Studies by dermal application, injection or inhalation have shown that Ni is a carcinogen and allergen to humans (NRC, 2005).

The acute toxicity of Ni is low, and no chronic toxicosis signs caused by oral intake have been reported for humans. With extended time of exposure, relatively high amounts of Ni are required before signs of toxicosis are seen in animals. Commonly reported signs include reduced growth, feed intake, and feed efficiency, haematological changes, kidney damage and impaired reproductive performance characterised by increased offspring mortality (NRC, 2005).

Nickel does not accumulate with age in any organ. But, overcoming homestatic mechanisms by addition of soluble Ni salts to drinking water or diet elevates tissue and blood Ni concentrations.

Maximum tolerable levels of Ni are suggested to be near 100 mg kg^{-1} diet for cattle, 250 mg kg^{-1} diet for poultry and pig. Because most animal feed contains <10 mg Ni kg^{-1} diet, Ni toxicity under normal environmental conditions is not a concern for domestic animals (NRC, 2005).

7.2.8 Zinc function and toxicity in animals

The biochemical role of zinc (Zn) is as an essential part of more than 300 enzymes involved in synthesis, metabolism and turnover of proteins, carbohydrates, lipids, nucleic acids and some vitamins. Well known Zn-containing enzymes include superoxide dismutase (SOD), alkaline phosphatase and alcohol dehydrogenase. Zinc is essential for several body functions and has three general physiological roles, namely - catalytic, structural, and regulatory. Zinc-dependent enzymes can be found in all known classes of enzymes (McCall et al. 2000) and Zn appears to be part of more enzyme systems than all the other trace elements combined. Zinc plays an important role in the structure of proteins and cell membranes. A structure resembling a finger, referred to as a Zn finger domain, stabilizes the structure of several proteins. Proteins with Zn-binding domains are estimated to represent approximately 10 % of the human proteome, and the same would be expected to be true in production animals (Andreini et al. 2006). Cell membrane integrity is also affected by Zn. Loss of Zn from biological membranes increases their susceptibility to oxidative damage and impairs their function (O'Dell 2000). Zinc plays a major role in regulating gene transcription, as Zn finger-containing transcription factors bind to DNA and affect the transcription of genes. Furthermore, Zn finger-containing transcription factors bind to regulatory DNA sequences called metal response elements (MRE) in the promotor region of genes and enhance or repress transcription.

Due to the many biochemical functions of Zn, symptoms of deficiency are varied and occur in several organ systems. A main symptom in most species is retarded growth, but species-specific symptoms are also found. For poultry, frayed feathers, shortened leg and wing bones, enlarged hock joint and reduced egg production and hatchability have been reported. Tucker and Salmon (1955) reported that Zn cures and prevents parakeratosis in pigs. During the next decade, the importance of Zn for growth and development in various species including humans applied to prenatal, as well as postnatal development (Hambidge et al. 1986). In all species, Zn deprivation is characterized by loss of appetite, retardation or cessation of growth and lesions of the integument and its outgrowths – hair, hoof, horn, wool, or feathers (Suttle 2010). However, well-defined cases of absolute clinical Zn deficiency are not common in animals and humans in European countries and North America (Hambidge et al. 1986; NNR 2012). In animals, the disease is mostly known from experimental conditions or diets containing for instance, high calcium or phytate, which reduce Zn absorption (Suttle 2010). In general, both Zn absorption and excretion are under homeostatic control (Pond et al. 2005).

A wide margin of safety exists between required Zn intake and the amount that will produce toxic effects. Livestock exhibit considerable tolerance to high Zn intakes. The extent of tolerance depends particularly on the species, but mainly on the nature of the diet. Pigs and poultry are more tolerant to excess Zn than ruminants, where large amounts may change rumen metabolism due to Zn toxicity on rumen microbiota (Pond et al. 2005).

Thus, Zn plays essential role in a wide array of processes including cell proliferation and animal growth, immune development and response, reproduction, gene regulation, and defence against oxidative stress and damage (Richards et al. 2010). The role of Zn in gene regulation is based on its incorporation into the structure of various transcription factors and hormone receptor proteins. Reflecting its role in gene regulation, Zn is required for the synthesis of a variety of enzymes and other proteins. The key structural proteins, collagen, and keratin, both require Zn for their synthesis (Suttle 2010). Collagen is the major structural protein of the extracellular matrix and connective tissues in internal tissue, including cartilage and bone.

Keratin is the major structural protein of the hoof and claw horn, skin, feathers, hair and beaks. Decreases in collagen and keratin synthesis and turnover rates in Zn-deficiency can lead to a variety of defects including bone abnormalities, decreased tissue strength and dermatit, and poor feathering (Suttle 2010).

In managing oxidative stress, Zn and Cu together are essential elements of the cytoplasmatic superoxide dismutase (SOD) which forms the first line of defence that converts reactive oxygen species (ROS) to the less toxic hydrogen peroxide, which are further inactivated by the Se-dependent glutathione peroxidase (Suttle 2010). Decreases in SOD activity, as in a mineral deficiency, can lead to increased damage to lipids, proteins, and nucleic acids, which can induce apoptotic cellular death. Zinc may manage oxidative stress in other ways as well, including through induction of metallothionein, and as a cofactor in p53 transcription factor, which mediates repair of DNA damaged by oxidative stress (Richards et al. 2010). Poor oxidative stress management in production animals can result in decreased performance, compromised immune function, increased morbidity and poor meat quality (Richards et al. 2010; Suttle 2010).

In livestock, reduced feed intake and growth retardation or cessation are the first effects of Zn deprivation. Appetite for solid foods is sensitive to Zn and may reflect the pivotal role of Zn in cell replication. Many of the adverse effects of severe Zn deficiency are secondary to loss of appetite. Deficiency is characterized by lesions of the integument and its outgrowths: hair, wool, and feathers. More explicitly, it leads to scaled skin in pigs (parakeratosis) and poor feathering in chicks. Bone growth is also affected, and impaired immunity is a general characteristic (Van Paemel et al. 2010).

High dietary Zn intake may have a preventive effect on diarrhea in piglets. It has been observed that these high supplementation levels support a large diversity of coliforms in weaned piglets and that they may reduce the pigs´ susceptibility to *E. coli* infections. These observations may contribute to the growth promoting effect of high dietary Zn in weaned piglets (Poulsen and Carlson, 2008).

Initial signs of Zn toxicosis in animals usually consist of reduced feed intake, growth rate, and other measures of performance or signs of secondary deficiencies of other minerals, such as Cu (NRC 2005).

Maximum tolerable levels for Zn given by NRC (2005) are: pigs: 1000 mg kg^{-1} DM, poultry, cattle and horses: 500 mg kg^{-1} DM, and sheep: 300 mg kg^{-1} DM.

7.2.9 Bacterial resistance

Several studies have described that soil bacteria and enteral bacteria in farm animals may develop resistance to trace elements such as Cu and Zn and simultaneous resistant to anti-microbial drugs (Baker-Austin et al. 2006; Seiler & Berendonk 2012; Bednorz et al. 2013; Yazdankhah et al. 2014; Starke et al. 2014; Becerra-Castro et al. 2015; Vahjen et al. 2015; Wales & Davies 2015; Ciesinski et al. 2018). However, there are also studies that do not show correlation between metal and antimicrobial resistance (Ghazisaeedi et al. 2020).

Resistance to Cu in bacteria, particularly enterococci, have been associated with resistance antimicrobial drugs such as macrolide antibiotics and vancomycin. Resistance to Zn have been associated with resistance to methicillin in staphylococci and Zn supplementation to animal feed may increase the proportion of multi-resistant *E. coli* in gut microbiota (Yazdankhah et al. 2014).

There is no available data demonstrating whether Cu/Zn-resistant bacteria may acquire antibiotic resistance genes to develop resistant abilities, or if antibiotics-resistant bacteria have greater ability for Cu/Zn-resistance than antibiotics-susceptible bacteria (Yazdankhah et al. 2014).

Data on dose-response relation for Cu/Zn exposure and resistance is also sparse. However, it is more likely that a resistance driven effect will occur at high trace element concentration than at more normal exposure levels.

VKM (2014b) addressed the topic of bacterial resistance related to the relatively high levels of Zn and Cu used in pig and poultry production. In such animals and their environment, the risk for development of bacteria resistant to Zn or Cu as well as to mentioned antibiotics could not be excluded. Furthermore, resistance genes and antibiotic resistant bacteria may be dispersed from wastewater and sewage sludge (VKM, 2020a, 2020b). The present opinion deals with adverse effects of PTEs in various organic fertilisers including manure from pigs/poultry and sewage sludge and do not discuss the possible dispersion of resistance genes and resistant bacteria via these animals' manure and sewage sludge. The focus is on the risk of elements such as Zn and Cu may create resistance problems via the fertilised soil into animals grazing or eating feed from such soil.

7.3 Dietary human exposure

VKM and EFSA have performed risk assessments of dietary exposures to the PTEs included in this report. The hazard characterisations below are based on these assessments. Established health-based guidance values, such as values for recommended intake and tolerable intake, are summarised in Table 7.3-1.

Table 7.3-1. Health-based guidance values for the recommended or tolerable intake of PTEs in humans.

Metal	Recommended intake	Tolerable intake (TDI/TWI)	Tolerable intake (BMDL)	
Arsenic			0.3 – 8.0 µg kg^{-1} BW per day	EFSA 2009
Cadmium		2.5 µg kg^{-1} BW per week		EFSA 2009
Copper	0.9-1.6 mg day^{-1}	5 mg day^{-1}		Nordic Council of Ministers 2014, EFSA 2015)
Chromium (III)	Not appropriate	0.3 mg kg^{-1} BW per day		EFSA 2014a, b
Chromium (VI)			1.0 mg kg^{-1} BW per day	EFSA 2014a
Lead			0.50 1.50 µg kg^{-1} BW per day	EFSA 2010
Mercury		Inorganic Hg: 4.0 µg Hg kg^{-1} BW per week MeHg: 1.3 µg Hg kg^{-1} BW per week		EFSA 2012
Nickel		13 mg kg^{-1} BW per day		EFSA, 2020
			Acute: LOAEL 4.3 µg kg^{-1} BW	EFSA, 2020
Zink	5-12 mg day^{-1}			Nordic Council of Ministers, 2014
	7.5-16.3 mg day^{-1} (adults)			EFSA 2014c

7.3.1 Arsenic (As)

The toxicity of As depends on the chemical form of the element, with inorganic As (arsenate and arsenite) being more toxic than organic As compounds. Arsenobetaine is assumed "to be of no toxicological concern", while specific information of the toxicity of arsenosugars and arsenolipids are not available (EFSA, 2009). Inorganic As is carcinogenic, but not genotoxic; As does not directly induce DNA damage, but many potential mechanisms for As induced carcinogenicity are described, such as - indirect genetic damage caused by oxidative stress (EFSA, 2009). For inorganic As, EFSA have established a $BMDL_{01}$ range of 0.3 – 8.0 µg kg^{-1} BW per day for lung, skin and bladder cancers, and skin lesions (EFSA, 2009).

In the general European population, the largest contributors to total As exposure are "fish and seafood", and "cereals and cereal products", and a major contributor is "vegetables, nuts, pulses including carrots, tomato and leafy vegetables" (EFSA, 2009). The food groups "grains and grain-based products (excluding rice)", "drinking water" and "rice" are the main contributors of exposure to inorganic As (EFSA 2021). In some countries, "vegetables and vegetable products", and "fish and other seafood" are also large contributors (EFSA 2021). The mean exposure level to inorganic As in the European population is: 0.07 – 0.61 µg kg^{-1} BW per day for infants, toddlers and other children, 0.04 – 0.21 µg kg^{-1} BW per day for adolescents, and 0.03 – 0.15 µg kg^{-1} BW per day for adults (EFSA, 2021).

7.3.2 Cadmium (Cd)

The toxicity of Cd is well described, and the chronic toxic effects are mainly in kidney and bones (EFSA, 2009). EFSA established a tolerable weekly intake (TWI) for Cd based on an increased risk of reduced kidney function in adults following long-term dietary exposure (EFSA, 2009). The TWI was set at 2.5 µg Cd kg^{-1} BW per week (EFSA, 2009). In 2010, the Joint FAO/WHO Expert Committee on Food Additives (JECFA) established a PTMI (provisional tolerable monthly intake) of 25 µg kg^{-1} BW per month (FAO/WHO, 2010), corresponding to a weekly intake of approximately 5.8 µg Cd kg^{-1} BW. Following the JECFA evaluation, EFSA compared the two approaches and that their approach was appropriate and reaffirmed the TWI of 2.5 µg Cd kg^{-1} BW per week (EFSA, 2011). VKM agrees with the EFSA approach and uses a TWI of 2.5 µg Cd kg^{-1} BW per week.

VKM have earlier assessed the exposure to Cd in the Norwegian population and concluded that exposure of the Norwegian adult population to Cd is comparable to the exposure of the adult European population (VKM, 2015). In 2012, EFSA estimated the dietary Cd exposure in the European population (EFSA, 2012). For adolescents, adults, the elderly and the very elderly, the mean middle bound exposures ranged from 1.63 - 2.20 µg kg-1 BW per week. Infants, toddlers, and other children had mean middle bound exposures of 2.74 - 3.96 µg Cd kg-1 BW per week. Weighing the estimated exposures for each group by the percentage of the number of years they contribute to a mean lifetime of 77 years, a mean lifetime exposure was estimated. The mean middle bound lifetime dietary exposure to Cd was calculated to be 2.04 µg Cd kg-1 BW per week. In Europe, grains and grain products, vegetables and vegetable products, and starchy root tubers are the food groups that contribute most to dietary Cd exposure (EFSA, 2012). At a more detailed level, the foods contributing most to the dietary Cd exposure across all age groups are potatoes, bread and rolls, fine bakery wares, chocolate products, leafy vegetables, and aquatic molluscs.

7.3.3 Chromium (Cr)

Chromium exists in several valence states. The most prevalent being Cr(III) and Cr(VI) (see introduction part 1.3.4). The trivalent Cr(III) is the most stable and most prevalent. The role of Cr as an essential nutrient is debated, and even though some countries have given minimum intake requirements, EFSA (2014a) and the Nordic Council of ministers (2012) concluded that based on available data, it is unclear if Cr is an essential element and did not establish a minimum requirement intake (Nordic Council of Ministers, 2014, EFSA 2014a).

Chromium is predominantly present as Cr(III) in food and as Cr(VI) in drinking water (EFSA 2014b). Chromium (III) is poorly absorbed, and the oral toxicity is considered to be low. Based on reproductive effects at high concentrations, EFSA established a TDI of 0.3 mg Cr(III) kg^{-1} BW per day (EFSA 2014b).

IARC classified Cr(VI) as a human carcinogen (Group 1), causing lung and nasal cancers based on occupational studies and causes cancer in rodents after oral exposure (EFSA 2014b). As Cr(VI) is both genotoxic and carcinogenic, EFSA used MOE approach in the assessment of Cr(VI), a $BMDL_{10}$ of 1.0 mg kg^{-1} BW per day as a reference point and considered a MOE > 10 000 to be of low concern (EFSA 2014b). This indicates that the exposure from food and drinking water below 0.1 µg kg^{-1} BW per day should be of low concern.

7.3.4 Copper (Cu)

Copper is an essential element and a component of several enzymes. It is also an important role in the regulation of intracellular reduction and oxidation reactions. According to the Nordic nutrient recommendation (Nordic Council of Ministers, 2014) the minimum required intake level for adults is 0.9 mg day^{-1} while EFSA proposed recommended intakes of 1.6 mg day^{-1} for men and 1.3 mg day^{-1} for women (EFSA 2015). Although Cu deficiencies in humans are rare, it has been reported in premature babies given milk formulae and in individuals recovering from chronic diarrhoea. Low Cu intake has also been associated with colorectal cancers, possibly related to increased ROS formation in the human gut with low Cu concentration (NCM 2014).

Intake of high levels of Cu is associated with acute toxicity, predominantly as gastrointestinal disturbances such as vomiting, diarrhea and stomach pain. Acute intoxications have occurred following consumption of drinking water from Cu tubes in areas with soft water containing 3.7 mg Cu L^{-1} and above (review in NCM, 2014). EU Scientific Committee for Food Safety proposed an upper safe intake levels increasing from 1 mg day^{-1} for 1-3 year olds to 5 mg day^{-1} for adults based on the lack of liver toxicity after chronic exposure to Cu (SCF 2003).

7.3.5 Lead (Pb)

The toxic effects of Pb are mainly in the central nervous system and kidney (EFSA, 2010). EFSA have established three BMDLs based on developmental neurotoxicity in young children, cardiovascular affects in adults, and nephrotoxic effects in adults. The corresponding BMDLs ($BMDL_{01}$) for the effects are 0.50 µg Pb kg^{-1} BW per day, 0.63 µg Pb kg^{-1} BW per day, and 1.50 µg Pb kg^{-1} BW per day (EFSA, 2010).

The main contributors to the dietary exposure to Pb for the European population are cereals, vegetables and tap water. Specifically, cereal products, potatoes, cereal grains (except rice), cereal-based mixed dishes, leafy vegetables and tap water are the main food contributors (EFSA, 2010). In the adult European population, the mean dietary exposure ranges from 0.36 - 1.24 µg Pb/kg BW per day (EFSA, 2010). In children aged 1 – 3 years, the mean dietary exposure is 1.10 – 3.10 µg Pg/kg BW per day, while in children aged 4 – 7 years, the mean exposure is 0.80 – 2.61 µg Pb/kg BW per day (EFSA, 2010).

7.3.6 Mercury

The toxicity of mercury depends on its chemical form. Inorganic mercury is toxic to the liver, nervous system and immune system, and affects reproduction and development. Methylmercury is neurotoxic and causes developmental effects (EFSA, 2012). EFSA have established TWIs for inorganic mercury and methylmercury and assessed the dietary exposure to mercury. For inorganic mercury, EFSA established a TWI of 4 µg kg^{-1} BW per week (expressed as mercury), based on kidney toxicity (EFSA, 2012). The TWI for methylmercury was established at 1.3 µg kg^{-1} BW per week (expressed as mercury), based on neurodevelopmental effects in prenatally exposed children (EFSA, 2012).

Human exposure to inorganic mercury and methylmercury is mainly dietary, where fish and other seafood is the main contributor to the exposure to both forms (EFSA, 2012). In 2014, VKM published an Opinion on the Benefit-risk assessment of fish and fish products in the Norwegian diet (VKM, 2014a). The assessment included exposure to mercury, and exposure to mercury through the consumption of fish and fish products were estimated for 2-year-olds, adults and pregnant women. For 2-year olds, the mean lower bound exposure to mercury was 0.50 µg kg^{-1} BW per week, while the mean upper bound exposure was 0.51 µg kg^{-1} BW per week. For adults, the mean lower bound exposure to mercury was 0.29 µg kg^{-1} BW per week, and the upper bound exposure was 0.30 µg kg^{-1} BW per week. The exposure to mercury in pregnant women were lower than for adults; the mean lower bound and upper bound exposures to mercury were both 0.17 µg kg^{-1} BW per week.

7.3.7 Nickel (Ni)

Nickel may be present in various forms, but in food and water total Ni is generally measured. EFSA has recently published an updated risk assessment of Ni in food and water (EFSA 2020) and established a TDI of 13 µg kg^{-1} per day for oral exposure to Ni based on reproductive effects in rats and a standard uncertainty factor of 100 (EFSA,2020). The critical effect was post-implantation loss of embryos. EFSA also identified a risk of acute oral exposure to Ni. Persons sensitized to Ni may experience flare-up reactions in the skin after acute oral exposure. A LOAEL of 4.3 µg kg^{-1} B was found. EFSA stated that a MOE of 30 would indicate low risk. EFSA further indicated that estimated mean intake was below the TDI, but the 95 percentiles may exceed the TDI for younger age groups, and hence may raise a health concern for younger age groups, but also specified that critical reproductive effects occur only at older age.

7.3.8 Zinc (Zn)

Zinc plays crucial roles in many enzymes involved in normal cellular turnover of molecules such as proteins, lipids, carbohydrates, and nucleic acids, as well as functions of immune system, DNA synthesis and regulation of oxidative stress (Nordic Council of Ministers 2014, EFSA 2014c). The recommended intake levels of Zn are in the range of 5-16 mg day^{-1} depending on age and gender (EFSA 2014c, Nordic Council of Ministers, 2014).

The toxicity of Zn is low. Ingestion of > 50 mg Zn day^{-1} has been associated with decreased enzyme activity of Cu-dependent enzymes and more severe signs of deficiencies in Cu metabolism and immune toxicity has been associated with ingestion of > 150 mg day^{-1} (Nordic Council of Ministers, 2014). No upper intake level was set by neither EFSA nor Nordic Council of Ministers.

8 Exposure assessment

8.1 Modelling soil environmental concentration (PEC_{soil})

Long-term simulation of PTEs contribution through organobased and mineral fertilisers and soil improvers, their fate in the environment and further exposure to soil, surface water and sediment living organisms, and farm animal and human through crops, is important knowledge for the authorities in establishing sustainable and safe regulations of nutrient resources.

In this evaluation, predicted soil concentrations, PEC_{soil}, over 100 years have been calculated using the same equation (Eq. 20), as applied in previous risk assessment performed by VKM (ERM, 2000 in Amundsen et al., 2000; VKM, 2019).

$$PTE_{soil}\ (t) = PTE_{soil}(0) \cdot e^{-(k_p+k_l)t} + (\frac{I}{k_p+k_l}) \cdot (1 - e^{-(k_p+k_l)t}) \qquad \text{(Eq. 20)}$$

Where

PTE_{soil} = concentration of each PTEs in soil at time t (mg kg^{-1} DW)
PTE_{soil} (0) = present (initial) concentration in soil at time t = 0 (mg kg^{-1} DW)
I= input of a given PTE (mg kg^{-1} yr^{-1})
k_p= $k_{plant\text{-}removal}$, removal of a given PTE by plants (yr^{-1}) (Eq. 14)
k_l= $k_{leaching}$, removal of a given PTE from the plough layer by leaching and runoff (yr^{-1}) (Eq. 7)

This equation is based on PTE input (section 6.1.3), PTE leaching rate from soil ($k_{leaching}$) (section 6.1.4, Eq. 17), PTE removal rate via uptake and harvesting of plants and removed from the field ($k_{plant\text{-}removal}$) (section 5.2.3., Eq. 14), and present concentration of PTE in agricultural soil (PTE_{soil} (0)).

It follows information about the input data for estimating PEC_{soil} over time. The input parameters used for predicting PEC_{soil} for each region are presented in Table 8.1-1.

Crop rotation. Description of the selected crop rotations and yields (kg ha^{-1}) in different regions is presented in Table AVI-8, and application of mineral P fertilisers (#0b,1) and cattle and pig manure (#4,5) in Table AVI-5 (also described in section 4.2). This information is also part of the calculation of PTE removal from soil via harvesting (Eq. 14b). Initially, two crop rotations were included for Målselv (crop rotation 1 grass and 2 vegetables and grass), Melhus (crop rotation 1 cereals and 2 grass), and Time (crop rotation 1 grass and 2 vegetables and grass). The resulting concentrations in soil, surface water and other recipients varied less than 1% with different crop rotation schemes. Hence, with respect to the large number of scenarios, PTEs, and six regions included in the predictions, results are only shown and evaluated for one crop rotation scheme.

Soil depth: A soil depth of 0.2 m is used in ECHA (2016) and was selected because this range usually has a high root density of crops and represents the ploughing depth.

Soil quality parameters: pH, SOM, clay content and soil density dry weight values were derived from the NIBIO soil data bank (Table AV-1-3).

Kd values were collected from literature and predicted from empirical regressions, except for Hg and Cr, where fixed Kd values were used (Table 5.1.1.1-1 and section 5.1.1).

Comparing Kds in different regions, Time and Målselv with the lowest mean pH (pH < 5) and low organic matter (4.1-5.6 % SOM), have generally lower Kd-values than the other regions. For Cu, where both the percentage of clay and pH influence Kd, Ås (22% clay) has the highest Kd (1079) and Time (8% clay) is the lowest (762). Melhus has the highest Kd for all PTE except Cu.

Loss processes: The higher precipitation and water that is infiltrating or running off, the more PTEs are removed from soil by leaching and runoff. The highest loss by this process is seen for Time (Table 8.1-1), which therefore also has the highest loss rate of all regions for all PTEs. For most PTEs and regions, loss by uptake into plants and harvesting is about one order of magnitude smaller. Loss through plants is most relevant for mercury (similar loss by plant uptake and leaching plus runoff) and Zn. For the latter, it is still 3 - 8 times smaller than loss through leaching and runoff (Figures 8.1-1 and 8.1-2).

Table 8.1-1. Summary of input values for the exposure modelling; present-state PTE concentrations, soil properties, soil-water distribution coefficients (Kd), as well as precipitation and infiltration parameters. These values were used for estimating soil PTE concentrations over time, reflecting processes of leaching, runoff and transfer to crops and forage. Please note that for Hg, evaporation is a significant removal process that is not considered by the model used.

	Region		**Troms**	**Trønde-lag**	**Hedmark**		**South-eastern Norway**	**South-western Norway**
	Municipality		Målselv	Melhus	Stange	Alum shale	Ås	Time
Background	As	mg kg DW^{-1}	1.6	3.0	1.1	15	2.7	2.0
	Cd		0.082	0.10	0.13	0.84	0.21	0.19
	Cr		25	36	14	19	27	9.3
	Cu		14	20	12	43	11	11
	Hg		0.025	0.033	0.033	0.038	0.04	0.069
	Ni		13	23	12	51	14	3.6
	Pb		6.0	9.6	8.1	20	16	23
	Zn		46	55	43	110	81	36
Soil porperties[1]	pH ($CaCl_2$)[1]		5.66	6.19	6.10	6.10	6.13	5.79
	SOM[1]	%	5.56	6.35	6.54	6.54	5.45	4.12
	OC	%	3.27	3.74	3.85	3.85	3.21	2.42
	Clay content[1]	%	17.00	17.00	15.53	15.53	22.65	8.18
	Soil dry density[1]	kg m^{-3}	1181.4	1193.8	1252.9	1252.9	1254.4	809.1
Prec. Infiltr.	Precipitation[2]	mm yr^{-1}	674	943	609	609	909	1542
	Fraction Infiltration[3]	F	0.49	0.54	0.34	0.34	0.41	0.32
	Fraction Runoff[3]	F	0.04	0.07	0.04	0.04	0.09	0.29
As	K_{dsoil}	L kg^{-1}	743	824	810	810	815	762
Cd			125	259	239	239	214.3	115
Cr			850	850	850	850	850	850
Cu			915	990	953	953	1079	805
Hg			8946	8946	8946	8946	8946	8946
Ni			129	171	163	163	166	139
Pb			4715	6866	6541	6541	6319	4690
Zn			346	738	649	649	677	417

[1] from NIBIO Soil databank. Limitation for selecting parameters is described in Appendix V. [2]Precipitation values taken from www.senorge.no. [3]Infiltration and runoff fractions are based on the method described in Appendix IX.

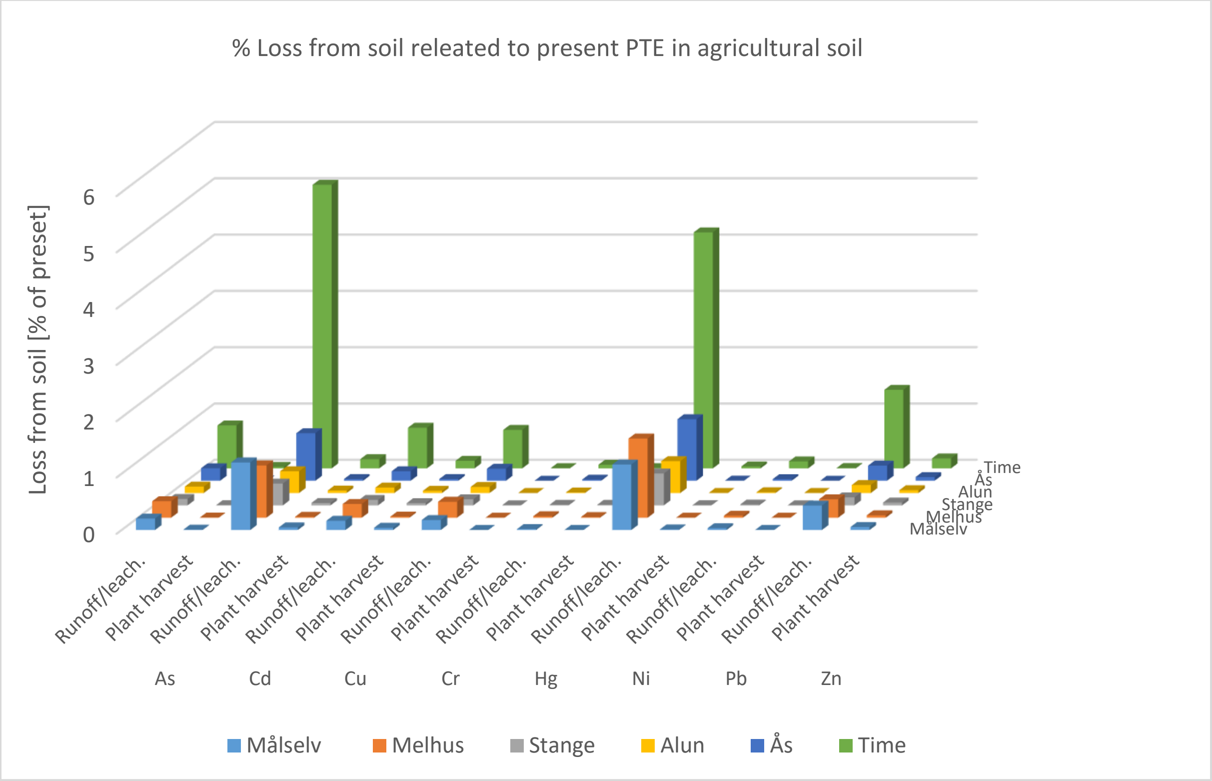


Figure 8.1-1. Loss of PTEs from soil via runoff and leaching, and via plant uptake and harvesting, given as percent (%) loss of total amount present in top soil (0.2 m) per year.

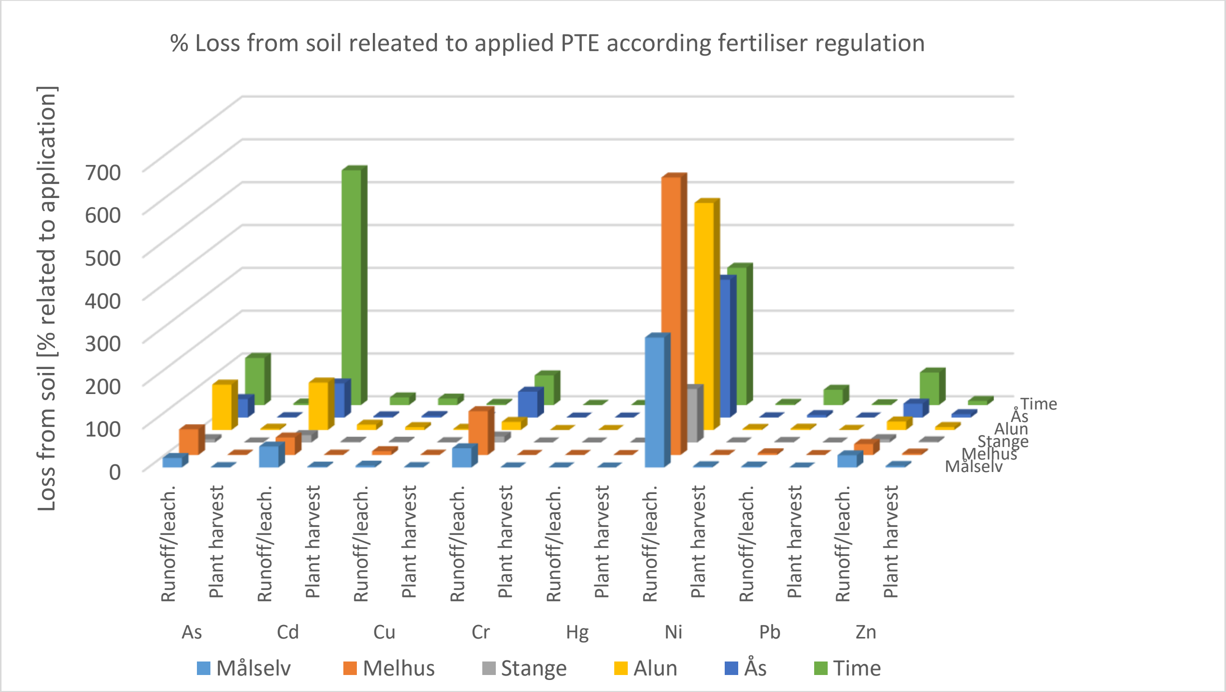


Figure 8.1-2. Loss of PTEs from soil via runoff and leaching, and via plant uptake and harvesting, given as percentage (%) of annual input of PTE via application of maximum

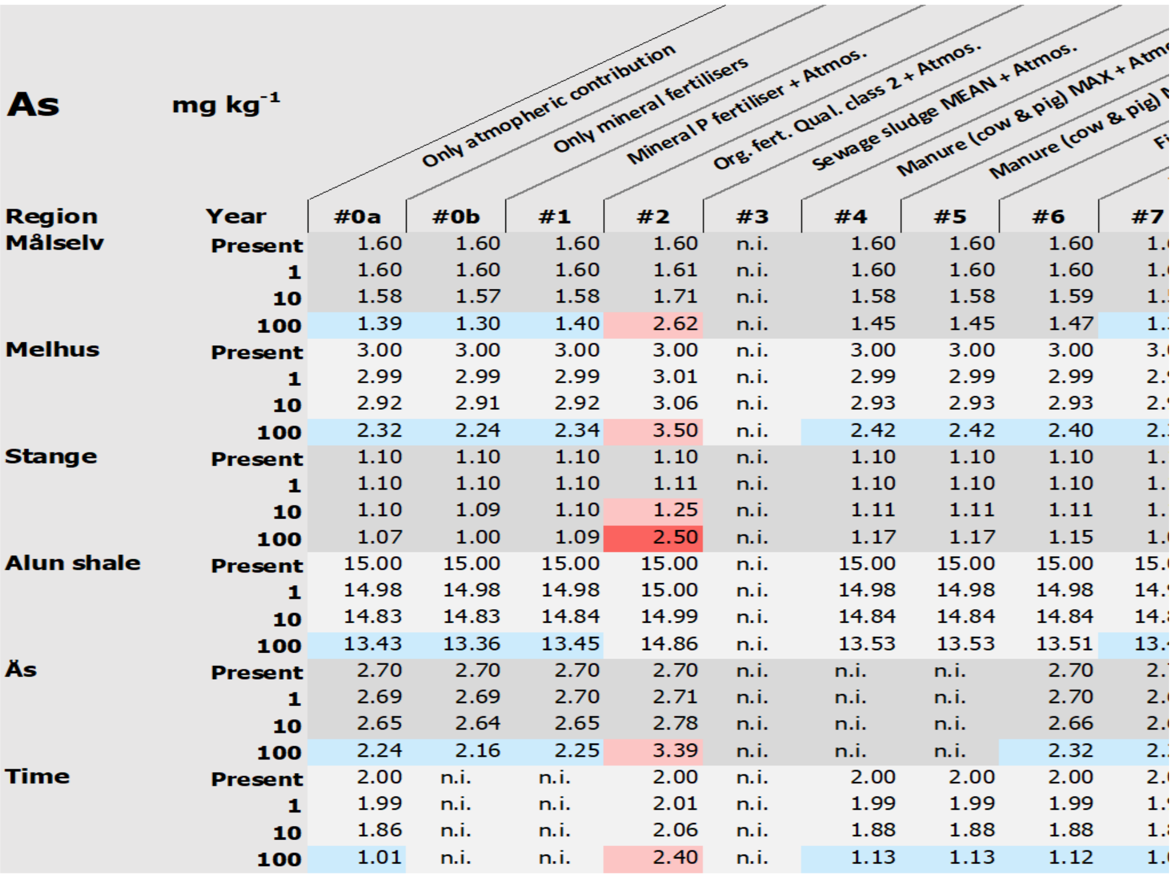
amount fertilisers and soil improvers and MLs for PTEs as an evaluation of the regulation quality class II (#2).

8.1.1 PEC_{soil} for arsenic (As)

The present mean concentrations of As in soil, is between 1.1 mg kg^{-1} DW (Stange) and 3.0 mg kg^{-1} (Melhus) in all regions except in the alum shale region, where the present concentration is 15 mg kg^{-1} DW. In most scenarios, the PEC_{soil} shows decreasing concentration of As over time, but application of fish sludge (#6) and manure (#4,5,9 and 10) causes a slow accumulation in Stange (Table 8.1.1-1).

There is currently no ML for As in the Norwegian regulation for organic fertilisers. However, ML is suggested, and an additional estimation of the suggested ML was performed on request. The suggested ML caused an increase in PEC_{soil} over time in all regions, except alum shale (Table 8.1.1.-1). Highest increase was estimated in Stange (appr. 130% after 100 years, from 1.1 mg kg^{-1} DW to 2.5 mg kg^{-1} DW), followed by Målselv (appr. 65%) and Ås, Time and Melhus (in the range of 17-26%).

Table 8.1.1-1. PEC_{soil} (mg kg^{-1} DW) for As up to 100 yr.



As	**mg kg^{-1}**	Only atmopheric contribution	Only mineral fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atm	Manure (cow & pig)	Fi	
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**
Målselv	**Present**	1.60	1.60	1.60	1.60	n.i.	1.60	1.60	1.60	1.
	1	1.60	1.60	1.60	1.61	n.i.	1.60	1.60	1.60	1.
	10	1.58	1.57	1.58	1.71	n.i.	1.58	1.58	1.59	1.
	100	1.39	1.30	1.40	2.62	n.i.	1.45	1.45	1.47	1.
Melhus	**Present**	3.00	3.00	3.00	3.00	n.i.	3.00	3.00	3.00	3.
	1	2.99	2.99	2.99	3.01	n.i.	2.99	2.99	2.99	2.
	10	2.92	2.91	2.92	3.06	n.i.	2.93	2.93	2.93	2.
	100	2.32	2.24	2.34	3.50	n.i.	2.42	2.42	2.40	2.
Stange	**Present**	1.10	1.10	1.10	1.10	n.i.	1.10	1.10	1.10	1.
	1	1.10	1.10	1.10	1.11	n.i.	1.10	1.10	1.10	1.
	10	1.10	1.09	1.10	1.25	n.i.	1.11	1.11	1.11	1.
	100	1.07	1.00	1.09	2.50	n.i.	1.17	1.17	1.15	1.
Alun shale	**Present**	15.00	15.00	15.00	15.00	n.i.	15.00	15.00	15.00	15.
	1	14.98	14.98	14.98	15.00	n.i.	14.98	14.98	14.98	14.
	10	14.83	14.83	14.84	14.99	n.i.	14.84	14.84	14.84	14.
	100	13.43	13.36	13.45	14.86	n.i.	13.53	13.53	13.51	13.
Ås	**Present**	2.70	2.70	2.70	2.70	n.i.	n.i.	n.i.	2.70	2.
	1	2.69	2.69	2.70	2.71	n.i.	n.i.	n.i.	2.70	2.
	10	2.65	2.64	2.65	2.78	n.i.	n.i.	n.i.	2.66	2.
	100	2.24	2.16	2.25	3.39	n.i.	n.i.	n.i.	2.32	2.
Time	**Present**	2.00	n.i.	n.i.	2.00	n.i.	2.00	2.00	2.00	2.
	1	1.99	n.i.	n.i.	2.01	n.i.	1.99	1.99	1.99	1.
	10	1.86	n.i.	n.i.	2.06	n.i.	1.88	1.88	1.88	1.
	100	1.01	n.i.	n.i.	2.40	n.i.	1.13	1.13	1.12	1.

8.1.2 PEC_{soil} for cadmium (Cd)

The present concentration of Cd in soil varies from 0.08 mg kg^{-1} DW in Målselv to 0.84 mg kg^{-1} DW in the alum shale area.

Increasing concentrations are predicted for the scenario evaluating the regulation of organic fertilisers and soil improvers (#2) in Målselv (70%), Melhus (86%) and Ås (3.3%). In Stange accumulation reaches 150% in 100 years. Lower rates of accumulations are predicted also for several other scenarios including mineral fertilisers (#0b – without atmospheric contribution, #1 – with atmospheric contribution) (23-32%, respectively), manure (#4) (28%) and food waster digestate (#8) (8%) in Stange. The model predicts decreasing concentration of Cd with time in all regions with only atmospheric contribution (#0a), fish sludge (#6), digestate (#7 and #8), compost horse manure (#9) and poultry manure (#10). In the alum shale region, Ås and Time all input scenarios show a decreasing temporal trend in PEC_{soil}.

Table 8.1.2-1. PEC_{soil} (mg kg^{-1} DW) for Cd.

Cd	**mg kg^{-1}**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082
	1	0.081	0.081	0.081	0.083	0.082	0.081	0.081	0.082	0.082	0.082	0.082	0.081
	10	0.074	0.074	0.075	0.091	0.080	0.075	0.075	0.078	0.078	0.079	0.078	0.075
	100	0.032	0.034	0.042	0.139	0.071	0.041	0.037	0.055	0.058	0.065	0.057	0.041
Melhus	**Present**	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
	1	0.099	0.100	0.100	0.101	0.100	0.099	0.099	0.100	0.100	0.100	0.100	0.099
	10	0.092	0.095	0.097	0.113	0.101	0.095	0.094	0.096	0.097	0.098	0.097	0.094
	100	0.048	0.068	0.078	0.186	0.110	0.065	0.059	0.075	0.078	0.086	0.077	0.059
Stange	**Present**	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130
	1	0.130	0.130	0.131	0.132	0.131	0.130	0.130	0.130	0.130	0.130	0.130	0.130
	10	0.126	0.134	0.135	0.153	0.140	0.134	0.129	0.130	0.130	0.131	0.130	0.127
	100	0.096	0.160	0.171	0.323	0.217	0.167	0.125	0.127	0.131	0.140	0.130	0.108
Alun shale	**Present**	0.840	0.840	0.840	0.840	0.840	0.840	0.840	0.840	0.840	0.840	0.840	0.840
	1	0.837	0.837	0.837	0.839	0.838	0.837	0.837	0.837	0.837	0.837	0.837	0.837
	10	0.806	0.814	0.815	0.833	0.821	0.815	0.809	0.810	0.810	0.811	0.810	0.807
	100	0.557	0.622	0.633	0.784	0.678	0.628	0.586	0.589	0.592	0.602	0.591	0.569
Ås	**Present**	0.210	0.210	0.210	0.210	0.210	n.i.	n.i.	0.210	0.210	0.210	0.210	0.210
	1	0.208	0.209	0.209	0.210	0.209	n.i.	n.i.	0.209	0.209	0.209	0.209	0.208
	10	0.194	0.197	0.198	0.214	0.203	n.i.	n.i.	0.197	0.198	0.199	0.198	0.195
	100	0.097	0.120	0.130	0.236	0.162	n.i.	n.i.	0.122	0.125	0.133	0.125	0.107
Time	**Present**	0.190	n.i.	n.i.	0.190	0.190	0.190	0.190	0.190	0.190	0.190	0.190	0.190
	1	0.181	n.i.	n.i.	0.183	0.181	0.181	0.181	0.181	0.181	0.181	0.181	0.181
	10	0.115	n.i.	n.i.	0.134	0.121	0.118	0.117	0.119	0.120	0.121	0.120	0.116
	100	0.005	n.i.	n.i.	0.053	0.020	0.013	0.010	0.017	0.018	0.022	0.018	0.010

>50% Loss

10-50% Loss

10-100% Acc.

>100% Acc.

8.1.3 PEC_{soil} for chromium (Cr)

The present concentrations of Cr in soil range from 9.3 mg kg^{-1} DW at Time to 36 mg kg^{-1} DW at Melhus.

A temporal increase in PEC_{soil} is found if maximum amount of organic fertilisers and soil improvers (2000 kg DW ha^{-1} yr^{-1}) with MLs according to quality class II is applied (#2) in

Målselv, Stange, alum shale and Time. The highest accumulation is from 14 - 23 mg kg^{-1} DW (63%) after 100 years in Stange. Except for the sewage sludge, all other scenarios show a decreasing temporal trend of PEC$_{soil}$.

Table 8.1.3-1. PEC$_{soil}$ (mg kg^{-1} DW) for Cr.

Cr	**mg kg^{-1}**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
	1	25.0	25.0	25.0	25.1	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
	10	24.7	24.6	24.7	25.5	24.8	24.7	24.7	24.7	24.7	24.8	24.8	24.7
	100	22.1	21.0	22.2	29.9	23.5	22.2	22.1	22.5	22.7	23.5	23.2	22.2
Melhus	**Present**	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0
	1	35.9	35.9	35.9	36.0	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9
	10	35.1	35.0	35.1	36.0	35.3	35.1	35.1	35.2	35.2	35.3	35.2	35.1
	100	28.2	27.4	28.5	35.8	29.7	28.3	28.3	28.6	28.8	29.5	29.2	28.3
Stange	**Present**	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
	1	14.0	14.0	14.0	14.1	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
	10	14.0	13.9	14.0	14.9	14.2	14.0	14.0	14.0	14.0	14.1	14.1	14.0
	100	13.7	12.9	14.0	22.9	15.5	14.0	13.8	14.1	14.3	15.1	14.8	13.8
Alun shale	**Present**	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0
	1	19.0	19.0	19.0	19.1	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0
	10	18.9	18.8	19.0	19.9	19.1	18.9	18.9	19.0	19.0	19.1	19.0	18.9
	100	18.2	17.4	18.5	27.4	20.0	18.5	18.3	18.6	18.7	19.6	19.2	18.3
Ås	**Present**	27.0	27.0	27.0	27.0	27.0	n.i	27.0	27.0	27.0	27.0	27.0	27.0
	1	27.0	26.9	27.0	27.0	27.0	n.i	26.9	27.0	27.0	27.0	27.0	27.0
	10	26.5	26.5	26.6	27.4	26.7	n.i	26.4	26.6	26.6	26.7	26.7	26.6
	100	22.9	22.1	23.2	30.4	24.4	n.i.	21.8	23.3	23.4	24.2	23.9	23.0
Time	**Present**	9.3	n.i.	n.i.	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3
	1	9.3	n.i.	n.i.	9.4	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3
	10	8.9	n.i.	n.i.	10.1	9.1	8.9	8.9	8.9	9.0	9.1	9.0	8.9
	100	6.0	n.i.	n.i.	15.0	7.5	6.2	6.1	6.5	6.7	7.7	7.3	6.2

>50% Loss

10-50% Loss

10-100% Acc.

>100% Acc.

8.1.4 PEC$_{soil}$ for copper (Cu)

The present concentrations of Cu in soil vary from 11 mg kg^{-1} DW (Ås and Time) to 43 mg kg^{-1} DW in the alum shale area.

The temporal trends of PEC$_{soil}$ are increasing in most of the input scenarios (except for mineral fertilisers, #1) and all regions. The highest accumulation is estimated for the evaluation of organic fertiliser regulation quality class II (#2), 460% increase from 12 - 68 mg kg^{-1} DW after 100 years at Stange. At Stange, the application of pig manure with measured maximum Cu concentration (#4) and sewage sludge with mean Cu concentration from SBB data base (#3), showed an appr. 170% and 110% increases, respectively. Evaluation of organic fertilisers regulation quality class II (#2) showed an increase higher than 400% at Time and Ås. Application of mineral fertilisers together with atmospheric input (#1) gives decreasing concentrations of Cu at all regions, and particularly at Time.

Table 8.1.4-1. PEC$_{soil}$ (mg kg^{-1} DW) for Cu.

Cu	**mg kg^{-1}**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	14	14	14	14	14	14	14	14	14	14	14	14
	1	14	14	14	15	14	14	14	14	14	14	14	14
	10	14	14	14	19	15	14	14	14	14	15	15	14
	100	12	11	12	62	25	16	15	13	18	19	20	17
Melhus	**Present**	20	20	20	20	20	20	20	20	20	20	20	20
	1	20	20	20	20	20	20	20	20	20	20	20	20
	10	20	19	20	25	21	20	20	20	20	20	20	20
	100	16	15	16	64	28	23	20	17	22	23	24	21
Stange	**Present**	12	12	12	12	12	12	12	12	12	12	12	12
	1	12	12	12	13	12	12	12	12	12	12	12	12
	10	12	12	12	18	13	14	13	12	13	13	13	12
	100	11	11	11	68	25	33	22	12	17	18	19	16
Alun shale	**Present**	43	43	43	43	43	43	43	43	43	43	43	43
	1	43	43	43	44	43	43	43	43	43	43	43	43
	10	42	42	42	48	44	45	44	43	43	43	43	43
	100	38	38	38	95	52	60	49	39	44	45	46	43
Ås	**Present**	11	11	11	11	11	11	11	11	11	11	11	11
	1	11	11	11	12	11	11	11	11	11	11	11	11
	10	11	11	11	16	12	11	11	11	11	12	12	11
	100	9	9	10	57	22	9	9	10	16	16	18	14
Time	**Present**	11	11	11	11	11	11	11	11	11	11	11	11
	1	11	11	11	12	11	11	11	11	11	11	11	11
	10	10	10	10	18	12	11	11	10	11	11	11	11
	100	5	5	5	59	19	14	10	6	12	13	14	11

>50% Loss
10-50% Loss
10-100% Acc.
>100% Acc.

8.1.5 PEC$_{soil}$ for mercury (Hg)

Present Hg concentrations in soil vary from 0.025 mg kg^{-1} DW in Målselv to 0.069 mg kg^{-1} DW in Time.

The estimated worst-case atmospheric contribution alone is sufficient to cause accumulation of Hg at all regions, and up to 59% increase from 0.025- to 0.040 mg kg^{-1} DW after 100 years at Målselv. Evaluation of fertiliser regulation quality class II (#2), and addition of other input sources, particularly - sewage sludge (#3), digestate of food waste (#8) and fish sludge (#6), causes increase of Hg concentrations. For evaluation of regulation quality class II in Målselv the concentration reaches 0.29 mg kg^{-1} DW after 100 years causing over 1000% increase. In the other regions, the increase was in the range of 540% (Time) to 970% (Stange).

It should be noted though, that evaporation of Hg from soil is not included in the model. The issue cannot be resolved by model simulation because we lack the right input data. Moreover, there is a potential risk for wildlife and humans if highly toxic mercury really accumulates in the organisms.

Table 8.1.5-1. PEC$_{soil}$ (mg kg^{-1} DW) for Hg.

Hg	**mg kg^{-1}**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.025	0.025	0.025	0.025	0.025	n.i.	n.i.	0.025	0.025	0.025	0.025	n.i.
	1	0.025	0.025	0.025	0.028	0.025	n.i.	n.i.	0.025	0.025	0.026	0.025	n.i.
	10	0.026	0.025	0.026	0.052	0.029	n.i.	n.i.	0.027	0.028	0.034	0.027	n.i.
	100	0.040	0.025	0.040	0.291	0.065	n.i.	n.i.	0.043	0.052	0.111	0.045	n.i.
Melhus	**Present**	0.033	0.033	0.033	0.033	0.033	n.i.	n.i.	0.033	0.033	0.033	0.033	n.i.
	1	0.033	0.033	0.033	0.036	0.033	n.i.	n.i.	0.033	0.033	0.034	0.033	n.i.
	10	0.034	0.033	0.034	0.059	0.037	n.i.	n.i.	0.035	0.036	0.041	0.035	n.i.
	100	0.047	0.032	0.047	0.293	0.071	n.i.	n.i.	0.050	0.058	0.116	0.051	n.i.
Stange	**Present**	0.030	0.030	0.030	0.030	0.030	n.i.	n.i.	0.030	0.030	0.030	0.030	n.i.
	1	0.030	0.030	0.030	0.033	0.030	n.i.	n.i.	0.030	0.030	0.031	0.030	n.i.
	10	0.031	0.030	0.031	0.059	0.034	n.i.	n.i.	0.032	0.033	0.038	0.032	n.i.
	100	0.044	0.030	0.044	0.320	0.072	n.i.	n.i.	0.047	0.055	0.111	0.048	n.i.
Alun shale	**Present**	0.038	0.038	0.038	0.038	0.038	n.i.	n.i.	0.038	0.038	0.038	0.038	n.i.
	1	0.038	0.038	0.038	0.041	0.038	n.i.	n.i.	0.038	0.038	0.039	0.038	n.i.
	10	0.039	0.038	0.039	0.067	0.042	n.i.	n.i.	0.040	0.041	0.046	0.040	n.i.
	100	0.051	0.038	0.052	0.328	0.079	n.i.	n.i.	0.055	0.063	0.119	0.056	n.i.
Ås	**Present**	0.040	0.040	0.040	0.040	0.040	n.i.	n.i.	0.040	0.040	0.040	0.040	n.i.
	1	0.040	0.040	0.040	0.043	0.040	n.i.	n.i.	0.040	0.040	0.041	0.040	n.i.
	10	0.041	0.040	0.041	0.065	0.044	n.i.	n.i.	0.042	0.042	0.048	0.042	n.i.
	100	0.053	0.039	0.053	0.287	0.076	n.i.	n.i.	0.056	0.064	0.119	0.057	n.i.
Time	**Present**	0.069	n.i	n.i	0.069	0.069	n.i.	n.i.	0.069	0.069	0.069	0.069	n.i.
	1	0.069	n.i	n.i	0.073	0.070	n.i.	n.i.	0.069	0.069	0.070	0.069	n.i.
	10	0.071	n.i	n.i	0.108	0.074	n.i.	n.i.	0.071	0.073	0.081	0.071	n.i.
	100	0.086	n.i	n.i	0.444	0.122	n.i.	n.i.	0.091	0.103	0.187	0.093	n.i.

>50% Loss
10-50% Loss
10-100% Acc.
>100% Acc.

8.1.6 PEC$_{soil}$ for nickel (Ni)

The present concentration of Ni is lowest at Time with 3.6 mg kg^{-1} DW, and highest at the alum shale region (51 mg kg^{-1} DW). In the other regions, concentrations vary from 12 mg kg^{-1} DW in Stange to 23 mg kg^{-1} DW in Melhus.

The PEC$_{soil}$ is decreasing in all regions and with all input scenarios.

Table 8.1.6-1. $\mathrm{PEC_{soil}}$ (mg $\mathrm{kg^{-1}}$ DW) for Ni.

Ni	**mg $\mathrm{kg^{-1}}$**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00
	1	12.86	12.85	12.86	12.90	12.87	12.86	12.86	12.86	12.86	12.86	12.86	12.86
	10	11.63	11.56	11.63	12.03	11.73	11.66	11.64	11.65	11.70	11.65	11.69	11.66
	100	4.44	4.03	4.46	6.95	5.10	4.64	4.51	4.57	4.92	4.60	4.86	4.62
Melhus	**Present**	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00
	1	22.69	22.68	22.69	22.73	22.70	22.69	22.69	22.69	22.69	22.69	22.69	22.69
	10	20.04	19.98	20.05	20.44	20.15	20.10	20.06	20.07	20.12	20.07	20.11	20.08
	100	6.01	5.66	6.06	8.30	6.64	6.31	6.12	6.13	6.45	6.16	6.39	6.18
Stange	**Present**	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
	1	11.94	11.93	11.94	11.99	11.95	11.95	11.94	11.94	11.95	11.94	11.95	11.94
	10	11.40	11.35	11.41	11.87	11.53	11.47	11.42	11.42	11.48	11.43	11.47	11.43
	100	7.31	6.87	7.40	10.95	8.31	7.83	7.48	7.48	7.90	7.51	7.83	7.54
Alun shale	**Present**	51.00	51.00	51.00	51.00	51.00	51.00	51.00	51.00	51.00	51.00	51.00	51.00
	1	50.72	50.71	50.72	50.77	50.73	50.72	50.72	50.72	50.73	50.72	50.72	50.72
	10	48.25	48.19	48.26	48.71	48.38	48.31	48.27	48.27	48.32	48.27	48.31	48.28
	100	29.41	28.96	29.49	33.04	30.40	29.93	29.57	29.57	29.99	29.60	29.92	29.63
Ås	**Present**	14.00	14.00	14.00	14.00	14.00	n.i	n.i	14.00	14.00	14.00	14.00	14.00
	1	13.85	13.85	13.86	13.89	13.87	n.i	n.i	13.86	13.86	13.86	13.86	13.86
	10	12.61	12.56	12.62	13.00	12.72	n.i	n.i	12.63	12.69	12.64	12.68	12.64
	100	5.10	4.73	5.15	7.58	5.78	n.i	n.i	5.23	5.57	5.26	5.51	5.28
Time	**Present**	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60
	1	3.46	3.45	3.45	3.52	3.48	3.47	3.46	3.46	3.47	3.47	3.47	3.47
	10	2.44	2.36	2.36	2.95	2.58	2.51	2.47	2.48	2.55	2.48	2.53	2.49
	100	0.30	0.05	0.05	1.75	0.68	0.50	0.38	0.39	0.59	0.40	0.55	0.42

>50% Loss

10-50% Loss

10-100% Acc.

>100% Acc.

8.1.7 $\mathrm{PEC_{soil}}$ for lead (Pb)

The present concentrations of Pb vary from 6.0 mg $\mathrm{kg^{-1}}$ DW in Målselv to 23 mg $\mathrm{kg^{-1}}$ DW in Time.

Atmospheric contribution alone is sufficient to cause increasing concentrations of Pb at all regions, except for Time and amounting to a 24% increase after 100 years at Målselv. Highest accumulation, over 100% in Målselv and Stange, was estimated for evaluation of the MLs quality class II (#2). The other input scenarios have a moderate effect on the accumulation rate. All input scenarios showed increased soil concentration in Målselv, Melhus, Stange and alum shale. Application of horse manure (#9) and sewage sludge (#3) showed also increase in Time and Ås.

Table 8.1.7-1. PEC$_{soil}$ (mg kg^{-1} DW) for Pb.

Pb	**mg kg^{-1}**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
	1	6.01	6.00	6.02	6.08	6.03	6.02	6.02	6.02	6.02	6.02	6.04	6.02
	10	6.15	5.98	6.15	6.83	6.27	6.15	6.15	6.16	6.20	6.23	6.40	6.16
	100	7.46	5.81	7.48	14.14	8.63	7.52	7.52	7.62	8.01	8.24	9.91	7.56
Melhus	**Present**	9.60	9.60	9.60	9.60	9.60	9.60	9.60	9.60	9.60	9.60	9.60	9.60
	1	9.61	9.60	9.61	9.68	9.63	9.61	9.61	9.62	9.62	9.62	9.64	9.61
	10	9.73	9.57	9.74	10.41	9.86	9.75	9.75	9.75	9.79	9.81	9.98	9.74
	100	10.91	9.29	10.96	17.54	12.12	11.03	11.03	11.09	11.46	11.69	13.33	11.01
Stange	**Present**	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10
	1	8.11	8.10	8.12	8.19	8.13	8.12	8.12	8.12	8.12	8.12	8.14	8.12
	10	8.25	8.09	8.25	9.00	8.38	8.26	8.26	8.26	8.30	8.32	8.48	8.26
	100	9.56	8.01	9.60	16.99	10.87	9.65	9.65	9.71	10.08	10.30	11.89	9.65
Alun shale	**Present**	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
	1	20.01	20.00	20.01	20.09	20.03	20.01	20.01	20.01	20.02	20.02	20.04	20.01
	10	20.13	19.97	20.13	20.88	20.26	20.14	20.14	20.14	20.18	20.20	20.36	20.14
	100	21.27	19.72	21.31	28.71	22.59	21.37	21.37	21.42	21.80	22.02	23.60	21.37
Ås	**Present**	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
	1	16.01	16.00	16.01	16.08	16.02	16.00	16.00	16.01	16.02	16.02	16.03	16.01
	10	16.11	15.96	16.12	16.75	16.23	15.95	15.95	16.13	16.16	16.19	16.35	16.12
	100	17.10	15.57	17.15	23.43	18.23	15.53	15.53	17.25	17.62	17.84	19.41	17.20
Time	**Present**	23.00	n.i	n.i	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00
	1	22.99	n.i	n.i	23.09	23.01	23.00	23.00	23.00	23.00	23.01	23.03	23.00
	10	22.95	n.i	n.i	23.93	23.12	22.96	22.96	22.97	23.03	23.06	23.31	22.96
	100	22.49	n.i	n.i	31.79	24.13	22.65	22.65	22.73	23.28	23.60	25.92	22.66

>50% Loss

10-50% Loss

10-100% Acc.

>100% Acc.

8.1.8 PEC$_{soil}$ for zinc (Zn)

The present concentrations of Zn vary from 36 mg kg^{-1} DW in Time to 110 mg kg^{-1} DW in the alum shale region.

Several of the fertilising scenarios causes temporal increase in PEC$_{soil}$ in most of the regions. The highest increase is estimated for manure (#4 and #5), followed by evaluation of the ML quality class II (#2), sewage sludge (#3) and digestate (#8). At Stange, high input of manure (#4) increases PEC$_{soil}$ from 110- to 215 mg kg^{-1} DW (400%) in 100 years, the addition of evaluation of ML to 107 mg kg^{-1} DW (#2) or 72 mg kg^{-1} DW (#3), the addition of digestate from food waste (#8) to 82 mg kg^{-1} DW in 100 years. With input from mineral fertilisers together with atmospheric contribution (#1), Zn concentrations show a decreasing temporal trend in all regions, and no other fertiliser leads to lower concentrations of Zn.

Table 8.1.8-1. PEC$_{soil}$ (mg kg^{-1} DW) for Zn.

Zn	**mg kg^{-1}**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	46	46	46	46	46	46	46	46	46	46	46	46
	1	46	46	46	46	46	46	46	46	46	46	46	46
	10	44	44	44	51	47	46	45	47	47	49	45	47
	100	30	28	30	84	57	43	41	51	54	71	41	55
Melhus	**Present**	55	55	55	55	55	55	55	55	55	55	55	55
	1	55	55	55	55	55	55	55	55	55	55	55	55
	10	53	53	53	60	57	56	56	56	56	58	55	56
	100	40	39	41	97	68	63	59	62	65	83	51	67
Stange	**Present**	43	43	43	43	43	43	43	43	43	43	43	43
	1	43	43	43	44	43	45	44	43	43	43	43	43
	10	42	42	43	50	46	62	50	45	45	47	44	45
	100	38	37	39	107	72	215	111	60	64	82	49	65
Alun shale	**Present**	110	110	110	110	110	110	110	110	110	110	110	110
	1	110	110	110	111	110	112	111	110	110	110	110	110
	10	108	108	108	116	112	127	116	111	111	113	109	111
	100	93	92	94	162	127	270	166	115	119	137	104	120
Ås	**Present**	81	81	81	81	81	n.i	n.i	81	81	81	81	81
	1	81	81	81	81	81	n.i	n.i	81	81	81	81	81
	10	79	78	79	85	82	n.i	n.i	81	81	83	80	82
	100	60	59	61	115	87	n.i	n.i	81	85	102	71	86
Time	**Present**	36	n.i	n.i	36	36	36	36	36	36	36	36	36
	1	35	n.i	n.i	36	36	36	36	36	36	36	36	36
	10	31	n.i	n.i	40	36	35	34	35	35	38	33	35
	100	9	n.i	n.i	59	34	30	27	28	32	47	19	33

>50% Loss
10-50% Loss
10-100% Acc.
>100% Acc.

8.2 Modelling environmental concentrations in surface water ($PEC_{surface\ water}$) and sediment ($PEC_{sediment}$)

8.2.1 Transport of PTEs with drainage water

In the calculation of PEC_{soil} described in section 8.1, it is assumed that excess precipitation infiltrates the soil and leaves the upper 20 cm of the soil profile containing Cd that has been leached from the soil. This is a simplified model of the very complex interaction between water and soil, where some of the water, especially during heavy rainfall, may be transported along the surface as runoff, and some of the water may bypass the upper soil layer as macropore flow through cracks or tunnels made by animals. These processes will tend to reduce the interaction of water with the soil and, thereby, affect the leaching of PTEs. Here, the simplified assumption is that all precipitation excess interacts fully with the soil resulting in a PTE concentration that is in equilibrium with the soil. This is a conservative approach regarding effect in aquatic risk assessment.

After penetration of the upper soil profile, excess precipitation may be transported via lateral flow or drainage pipes to surface water or may reach the groundwater. Here, the assumption is made that all precipitation excess reaches a surface-water recipient. This is a worst-case scenario that is also conservative regarding aquatic risk assessment.

8.2.2 Predicted concentrations of PTEs in surface water.

The predicted concentration of PTEs in surface water has been calculated for a scenario in which the drainage water reaches a small water course with constant dilution ratio, in accordance with the recommendation for local exposure estimation in TGD (ECB, 2003). The calculation involves removal from aqueous medium by adsorption to suspended matter.

The concentration in local recipient water is calculated using the following equation:

$$PEC_{sw} = PEC_{regional} + \left(\frac{C_{effluent}}{(1+Kp_{susp,mix} \times SUSP_{water,mix} \times 10^{-6})\ x\ DILUTION}\right) \quad \text{(Eq. 9)}$$

Where:

PEC_{sw}	concentration of PTEs in surface water (µg L^{-1})
$PEC_{regional}$	concentration of PTEs in dilution water (µg L^{-1})
$C_{effluent}$	concentration of PTEs in effluent water (drainage + runoff), (µg L^{-1})
$Kp_{susp,\ mix}$	solids-water partitioning coefficient of suspended matter after mixing L kg^{-1}
$SUSP_{water,\ mix}$	concentration of suspended matter in the river after mixing (mg kg^{-1})
DILUTION	dilution factor (default = 10)

A dilution factor of 10, which is the recommended default dilution for local PEC calculation in (ECB, 2003; ECHA, 2016), is used for calculation of PEC_{SW}.

For background concentration of PTEs, the annual mean value obtained from major rivers in the regions where the case sites are located is used, as shown in Table 8.2.2-1 (NIVA 2019).

Table 8.2.2-1. Concentrations of PTEs in regional rivers (mean values of four samples in 2018) used as $C_{regional}$ for calculation of PEC_{SW} (NIVA 2019).

Region	**Målselv**	**Melhus**	**Stange**	**Alum shale**	**Ås**	**Time**
River	Målselva	Nidelva	Glomma	Glomma	Glomma	Orreelva
PTE	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}
As	0.04	0.09	0.16	0.16	0.16	0.27
Cd	0.03	0.02	0.10	0.10	0.10	0.10
Cr	0.18	0.17	0.22	0.22	0.22	0.14
Cu	0.65	0.65	01.39	1.39	1.39	1.53
Hg	0.001	0.001	0.001	0.001	0.001	0.001
Ni	0.47	0.69	0.71	0.71	0.71	1.0
Pb	0.06	0.02	0.20	0.20	0.20	0.16
Zn	0.51	0.48	3.82	3.82	3.82	2.50

A default value of 15 mg L^{-1} is used as $SUSP_{water}$, in the recipient, as recommended in the TGD (ECB, 2003; ECHA, 2016). To this, the suspended material carried with the runoff-water is added to calculate the $SUSP_{water, mix}$, in the receiving water after mixing with the drainage and runoff water.

Kp_{susp} for the suspended matter in the receiving water has been adopted Allison & Allison (2005), as shown in Table 8.2.2.-2. The $Kp_{susp, mix}$ in the recipient after mixing with the runoff water has been calculated from the Kp_{sup} and the soil/water Kd, taking the ratio of suspended water from the recipient and runoff water after mixing into account.

Table 8.2.2.-2. Partition coefficients for suspended material and sediment.

	Kp_{susp}	**Ref**	**Kp_{sed}**	**Ref**
	kg L^{-1}		kg L^{-1}	
As	10 000	Allison & Allison (2005)	4 786	REACH Dossier-As (2021)
Cd	50 119	Allison & Allison (2005)	3 981	Allison & Allison (2005)
Cr	15 849^{1}	Allison & Allison (2005)	31 623^{2}	Allison & Allison (2005)
Cu	50 119	Allison & Allison (2005)	15 849	Allison & Allison (2005)
Hg	199 526	Allison & Allison (2005)	79 433	Allison & Allison (2005)
Ni	39 811	Allison & Allison (2005)	10 000	Allison & Allison (2005)
Pb	398 107	Allison & Allison (2005)	125 893	Allison & Allison (2005)
Zn	125 893	Allison & Allison (2005)	63 096	Allison & Allison (2005)

^{1}Cr(VI), ^{2}Cr(III)

The concentrations of PTEs in surface water, calculated as described in Eq. 9 are shown in the following paragraphs 8.2.2.1 to 8.2.2.8. Since the concentrations are calculated from measured regional concentration in soil, the present PEC_{sw} is compared to measured concentrations in small watercourses in those regions where such data are available. Most of the data are from a national programme for soil and water monitoring in agriculture dominated catchments in Norway (JOVA) (Table 8.2.2.-3), which included analysis of metals in the years 1996-1998 (Bechmann and Ludvigsen, 1998). Additional data have been extracted from the Vannmiljø database of the Norwegian Environment Agency. https://vannmiljo.miljodirektoratet.no/).

Table 8.2.2.-3. Watercourses included in the national programme for soil and water monitoring in agriculture dominated catchments in Norway (JOVA) from which data on PTE concentrations are available (Bechmann and Ludvigsen, 1998).

Region	Watercourse	Catchment (ha)	Agriculture
Melhus	Hotrankanalen	2000	58%
Stange	Kolstadbekken	209	39%
Ås	Skuterudbekken	449	61%
Time	Timebekken	114	85%

8.2.2.1 Arsenic (As)

Table 8.2.2.1-1. PEC$_{SW}$ for As in surface water recipients (µg As L^{-1}). n.i.=not included scenario in this region.

As	**µg L^{-1}**	Only atmospheric contribution	Only mineral fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.23	0.23	0.23	0.23	n.i.	0.23	0.23	0.23	0.23	n.i.	0.23	0.23
	1	0.23	0.23	0.23	0.23	n.i.	0.23	0.23	0.23	0.23	n.i.	0.23	0.23
	10	0.22	0.22	0.22	0.24	n.i.	0.23	0.23	0.23	0.22	n.i.	0.23	0.23
	100	0.20	0.19	0.20	0.35	n.i.	0.21	0.21	0.21	0.20	n.i.	0.21	0.21
Melhus	**Present**	0.40	0.40	0.40	0.40	n.i.	0.40	0.40	0.40	0.40	n.i.	0.40	0.40
	1	0.40	0.40	0.40	0.40	n.i.	0.40	0.40	0.40	0.40	n.i.	0.40	0.40
	10	0.39	0.39	0.39	0.40	n.i.	0.39	0.39	0.39	0.39	n.i.	0.39	0.39
	100	0.33	0.32	0.33	0.45	n.i.	0.34	0.34	0.34	0.33	n.i.	0.34	0.33
Stange	**Present**	0.28	0.28	0.28	0.28	n.i.	0.28	0.28	0.28	0.28	n.i.	0.28	0.28
	1	0.28	0.28	0.28	0.28	n.i.	0.28	0.28	0.28	0.28	n.i.	0.28	0.28
	10	0.28	0.28	0.28	0.29	n.i.	0.28	0.28	0.28	0.28	n.i.	0.28	0.28
	100	0.27	0.27	0.28	0.43	n.i.	0.28	0.28	0.28	0.27	n.i.	0.28	0.28
Alun shale	**Present**	1.76	1.76	1.76	1.76	n.i.	1.76	1.76	1.76	1.76	n.i.	1.76	1.76
	1	1.76	1.76	1.76	1.76	n.i.	1.76	1.76	1.76	1.76	n.i.	1.76	1.76
	10	1.75	1.75	1.75	1.76	n.i.	1.75	1.75	1.75	1.75	n.i.	1.75	1.75
	100	1.60	1.59	1.60	1.75	n.i.	1.61	1.61	1.61	1.60	n.i.	1.61	1.60
Ås	**Present**	0.44	0.44	0.44	0.44	n.i.	n.i.	n.i.	0.44	0.44	n.i.	0.44	0.44
	1	0.44	0.44	0.44	0.44	n.i.	n.i.	n.i.	0.44	0.44	n.i.	0.44	0.44
	10	0.43	0.43	0.43	0.45	n.i.	n.i.	n.i.	0.44	0.43	n.i.	0.44	0.44
	100	0.39	0.38	0.39	0.51	n.i.	n.i.	n.i.	0.40	0.39	n.i.	0.40	0.40
Time	**Present**	0.49	n.i.	n.i.	0.49	n.i.	0.49	0.49	0.49	0.49	n.i.	0.49	0.49
	1	0.49	n.i.	n.i.	0.50	n.i.	0.49	0.49	0.49	0.49	n.i.	0.49	0.49
	10	0.48	n.i.	n.i.	0.50	n.i.	0.48	0.48	0.48	0.48	n.i.	0.48	0.48
	100	0.38	n.i.	n.i.	0.54	n.i.	0.40	0.40	0.40	0.39	n.i.	0.40	0.39

The present PECsw of As varies from 0.23 µg L-1 in Målselv to 1.76 µg L-1 in the alum shale region. The concentrations decrease with time in most regions and scenarios. However, the ML quality class II scenario (#2), results in increasing concentrations in all regions except in the alum shale area. The highest increase after 100 years (54%), is predicted in Stange. There are no measured concentrations available from representative watercourses.

8.2.2.2 Cadmium (Cd)

Table 8.2.2.2-1. PEC_{SW} for Cd in surface water recipients (µg Cd L^{-1}). n.i.=not included scenario in this region.

Cd	**µg L^{-1}**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
	1	0.040	0.040	0.040	0.041	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
	10	0.037	0.037	0.037	0.045	0.040	0.037	0.037	0.038	0.039	0.039	0.038	0.037
	100	0.017	0.018	0.022	0.066	0.035	0.021	0.020	0.028	0.029	0.032	0.029	0.021
Melhus	**Present**	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
	1	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
	10	0.022	0.023	0.023	0.027	0.024	0.023	0.023	0.023	0.023	0.023	0.023	0.023
	100	0.013	0.017	0.019	0.043	0.026	0.016	0.015	0.018	0.019	0.021	0.019	0.015
Stange	**Present**	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041
	1	0.041	0.041	0.041	0.042	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041
	10	0.040	0.042	0.042	0.047	0.044	0.042	0.041	0.041	0.041	0.041	0.041	0.040
	100	0.033	0.048	0.051	0.087	0.062	0.050	0.040	0.040	0.041	0.043	0.041	0.036
Alun shale	**Present**	0.211	0.211	0.211	0.211	0.211	0.211	0.211	0.211	0.211	0.211	0.211	0.211
	1	0.210	0.210	0.210	0.210	0.210	0.210	0.210	0.210	0.210	0.210	0.210	0.210
	10	0.202	0.204	0.205	0.209	0.206	0.204	0.203	0.203	0.203	0.204	0.203	0.203
	100	0.143	0.158	0.161	0.197	0.172	0.160	0.150	0.151	0.151	0.154	0.151	0.146
Ås	**Present**	0.066	0.066	0.066	0.066	0.066	n.i.	n.i.	0.066	0.066	0.066	0.066	0.066
	1	0.065	0.065	0.065	0.066	0.065	n.i.	n.i.	0.065	0.065	0.065	0.065	0.065
	10	0.061	0.062	0.063	0.067	0.064	n.i.	n.i.	0.062	0.062	0.063	0.062	0.062
	100	0.036	0.042	0.044	0.073	0.053	n.i.	n.i.	0.042	0.043	0.045	0.043	0.038
Time	**Present**	0.104	n.i.	n.i.	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104
	1	0.099	n.i.	n.i.	0.100	0.100	0.099	0.099	0.100	0.100	0.100	0.100	0.099
	10	0.067	n.i.	n.i.	0.076	0.070	0.068	0.068	0.069	0.069	0.070	0.069	0.068
	100	0.012	n.i.	n.i.	0.036	0.020	0.016	0.015	0.018	0.019	0.021	0.019	0.015

The present PEC_{sw} of Cd varies from 0.02 µg L^{-1} in Melhus to 0.21 µg L^{-1} in the alum shale region. Measured concentrations in Hotrankanalen (Melhus) 1996-1998, were below the limit of detection (LOD=0.05 µg L^{-1}), except for one sample in 1996 with 0.1 µg L^{-1}. In Skuterudbekken Cd concentrations varied from LOD to 0.1 µg L^{-1}. Later, in 2017, nine samples from Skuterudbekken showed 0.014 - 0.039 µg Cd L^{-1} (one extreme value of 200 µg L^{-1} excluded). In Timebekken (Time) six of ten samples analysed in 1996-98 showed <0.05 µg Cd L^{-1}, and the highest concentration was 0.16 µg L^{-1}.

Measured concentrations are also available from two watercourses in the alum shale area in 2010. Three samples from Fura showed 0.051 - 0.21 µg Cd L^{-1}. In Vingergjessa the concentrations were 0.10 - 0.22 µg L^{-1}. (https://vannmiljo.miljodirektoratet.no/).

The predicted present concentrations appear to be in reasonable accordance with measured concentrations in representative watercourses.

In Stange, input of Cd from mineral P fertilisers only (#0b), is sufficient to cause 27% increase in PEC_{sw} in 100 years. For evaluation of ML quality class (#2), PEC_{sw} reaches 0.09 µg Cd L^{-1} which corresponds to 100% increase in 100 years. Evaluation of ML also causes increasing PEC_{sw} in Målselv, Melhus, and Ås.

8.2.2.3 Chromium (Cr)

Table 8.2.2.3-1. PEC_{SW} for Cr in surface water recipients (µg Cr L^{-1}). n.i.=not included scenario in this region.

Cr	**µg L^{-1}**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56
	1	2.55	2.55	2.55	2.56	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55
	10	2.53	2.52	2.53	2.61	2.54	2.53	2.53	2.53	2.53	2.54	2.54	2.53
	100	2.28	2.18	2.29	3.03	2.41	2.29	2.28	2.32	2.33	2.41	2.38	2.29
Melhus	**Present**	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50
	1	3.49	3.49	3.49	3.50	3.49	3.49	3.49	3.49	3.49	3.49	3.49	3.49
	10	3.42	3.41	3.42	3.50	3.43	3.42	3.42	3.42	3.42	3.43	3.43	3.42
	100	2.78	2.70	2.81	3.48	2.92	2.79	2.79	2.81	2.83	2.90	2.87	2.79
Stange	**Present**	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55
	1	1.55	1.54	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55
	10	1.54	1.54	1.55	1.63	1.56	1.55	1.54	1.55	1.55	1.56	1.55	1.54
	100	1.52	1.44	1.55	2.39	1.69	1.55	1.53	1.55	1.57	1.65	1.62	1.53
Alun shale	**Present**	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02
	1	2.02	2.02	2.02	2.03	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02
	10	2.01	2.00	2.01	2.10	2.03	2.01	2.01	2.02	2.02	2.03	2.02	2.01
	100	1.94	1.87	1.98	2.81	2.12	1.97	1.95	1.98	1.99	2.07	2.04	1.95
Ås	**Present**	2.71	2.71	2.71	2.71	2.71	n.i.	2.71	2.71	2.71	2.71	2.71	2.71
	1	2.71	2.71	2.71	2.72	2.71	n.i.	2.71	2.71	2.71	2.71	2.71	2.71
	10	2.67	2.66	2.67	2.75	2.69	n.i.	2.66	2.68	2.68	2.68	2.68	2.67
	100	2.33	2.26	2.36	3.03	2.48	n.i.	2.23	2.37	2.38	2.45	2.43	2.35
Time	**Present**	1.01	n.i.	n.i.	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01
	1	1.00	n.i.	n.i.	1.02	1.01	1.00	1.00	1.01	1.01	1.01	1.01	1.00
	10	0.97	n.i.	n.i.	1.08	0.99	0.97	0.97	0.97	0.98	0.99	0.98	0.97
	100	0.70	n.i.	n.i.	1.54	0.84	0.72	0.71	0.75	0.77	0.86	0.82	0.72

The present PEC_{sw} of Cr varies from 1.0 µg L^{-1} in Time to 3.5 µg L^{-1} in Melhus. Measured concentrations of Cr in JOVA monitoring programme were less than the LOD (1 µg L^{-1}) in most samples in Hotrankanalen (Melhus), Kolstadbekken (Stange) and Timebekken. In Skuterudbekken (Ås), maximum concentration of 12 µg L^{-1} was found in May 1996 and later that year, two samples showed respective 1.9 and 3.6 µg L^{-1}. During the following two years, all samples showed below the LOD concentration of 1 µg L^{-1}. 17 samples taken in Skuterudbekken in 2017-2020 contained from 0.14 - 0.50 µg Cr L^{-1}. Compared to these measured concentrations of Cr, the predicted present PEC_{sw} appear to be rather high.

Temporal increase of Cr concentrations was obtained with evaluation of ML quality class II (#2) in Målselv, Stange, alum shale and Time. The highest increase after 100 years is 54% (Stange). In Stange, increasing concentrations occur also with several other scenarios including mineral fertilisers, manure and digestate food waste.

8.2.2.4 Copper (Cu)

Table 8.2.2.4-1. PEC$_{SW}$ for Cu in surface water recipients (µg Cu L^{-1}). n.i. = not included scenario in this region.

Cu	**µg L^{-1}**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	1	1.5	1.5	1.5	1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	10	1.5	1.5	1.5	1.8	1.6	1.5	1.5	1.5	1.6	1.6	1.6	1.5
	100	1.4	1.4	1.4	4.5	2.2	1.7	1.6	1.5	1.8	1.8	1.9	1.7
Melhus	**Present**	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
	1	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
	10	1.8	1.7	1.8	2.1	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
	100	1.5	1.5	1.5	4.2	2.2	2.0	1.8	1.6	1.9	1.9	2.0	1.8
Stange	**Present**	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
	1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
	10	2.1	2.1	2.1	2.5	2.2	2.2	2.2	2.1	2.1	2.1	2.2	2.1
	100	2.0	2.0	2.0	5.4	2.9	3.3	2.7	2.1	2.4	2.5	2.5	2.3
Alun shale	**Present**	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
	1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
	10	3.9	3.9	3.9	4.3	4.0	4.1	4.0	3.9	4.0	4.0	4.0	4.0
	100	3.7	3.6	3.7	7.0	4.5	5.0	4.3	3.7	4.0	4.1	4.2	4.0
Ås	**Present**	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	10	1.9	1.9	1.9	2.2	2.0	1.9	1.9	2.0	2.0	2.0	2.0	2.0
	100	1.9	1.9	1.9	4.3	2.5	1.9	1.9	1.9	2.2	2.2	2.3	2.1
Time	**Present**	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
	1	2.3	2.3	2.3	2.4	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
	10	2.2	2.2	2.2	2.8	2.4	2.3	2.3	2.3	2.3	2.3	2.3	2.3
	100	1.9	1.9	1.9	5.7	2.9	2.5	2.2	2.0	2.4	2.4	2.5	2.3

The calculated present concentrations of Cu vary from 1.5 µg L^{-1} at Målselv to 4.0 µg L^{-1} at the alum shale area. Measured concentrations of Cu in the JOVA monitoring programme 1996-98 were 2.0 - 5.2 µg L^{-1} in Hotrankanalen (Melhus). During 1996-97 at Kolstadbekken (Stange), eight samples showed 1.2 - 3.2 µg L^{-1}, while two samples from 1998 contained 6.1 and 29 µg L^{-1}. It was noted that those two samples with high concentrations could be a result of low water flow. In Timebekken, Cu concentrations were 1.2 - 7.9 µg L^{-1}, and in Skuterudbekken (Ås) <1.0 – 8.8 µg L^{-1}. Later measurements in Skuterudbekken during 2017-2020, showed 1.0 - 4.4 µg L^{-1}, with a median value of 1.3 µg L^{-1} (n=19). The predicted present concentrations appear to be in reasonable accordance with measured concentrations in representative watercourses.

A temporal increase in PEC$_{sw}$ was found in all regions at scenarios with manure, fish sludge and digestate food waste. Sewage sludge (#3) also caused increasing concentrations in all regions. At Stange, PEC$_{sw}$ increased 157% from 2.1 to 5.4 µg L^{-1} in 100 years for evaluation of the organic fertiliser regulation quality class II (#2). The same scenario at Målselv gave 200% increase from 1.5 to 4.5 µg L^{-1}.

8.2.2.5 Mercury (Hg)

Table 8.2.2.5-1 PEC_{SW} for Hg in surface water recipients (µg Hg L^{-1}). n.i. = not included scenario at this region.

Hg	**µg L^{-1}**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.0011	0.0011	0.0011	0.0011	0.0011	n.i.	n.i.	0.0011	0.0011	0.0011	0.0011	n.i.
	1	0.0011	0.0011	0.0011	0.0011	0.0011	n.i.	n.i.	0.0011	0.0011	0.0011	0.0011	n.i.
	10	0.0011	0.0011	0.0011	0.0011	0.0011	n.i.	n.i.	0.0011	0.0011	0.0011	0.0011	n.i.
	100	0.0011	0.0011	0.0011	0.0018	0.0012	n.i.	n.i.	0.0011	0.0011	0.0013	0.0011	n.i.
Melhus	**Present**	0.0011	0.0011	0.0011	0.0011	0.0011	n.i.	n.i.	0.0011	0.0011	0.0011	0.0011	n.i.
	1	0.0011	0.0011	0.0011	0.0011	0.0011	n.i.	n.i.	0.0011	0.0011	0.0011	0.0011	n.i.
	10	0.0011	0.0011	0.0011	0.0012	0.0011	n.i.	n.i.	0.0011	0.0011	0.0011	0.0011	n.i.
	100	0.0011	0.0011	0.0011	0.0018	0.0012	n.i.	n.i.	0.0011	0.0011	0.0013	0.0011	n.i.
Stange	**Present**	0.0011	0.0011	0.0011	0.0011	0.0011	n.i.	n.i.	0.0011	0.0011	0.0011	0.0011	n.i.
	1	0.0011	0.0011	0.0011	0.0011	0.0011	n.i.	n.i.	0.0011	0.0011	0.0011	0.0011	n.i.
	10	0.0011	0.0011	0.0011	0.0012	0.0011	n.i.	n.i.	0.0011	0.0011	0.0011	0.0011	n.i.
	100	0.0011	0.0011	0.0011	0.0019	0.0012	n.i.	n.i.	0.0011	0.0012	0.0013	0.0011	n.i.
Alum shale	**Present**	0.0011	0.0011	0.0011	0.0011	0.0011	n.i.	n.i.	0.0011	0.0011	0.0011	0.0011	n.i.
	1	0.0011	0.0011	0.0011	0.0011	0.0011	n.i.	n.i.	0.0011	0.0011	0.0011	0.0011	n.i.
	10	0.0011	0.0011	0.0011	0.0012	0.0011	n.i.	n.i.	0.0011	0.0011	0.0011	0.0011	n.i.
	100	0.0011	0.0011	0.0011	0.0019	0.0012	n.i.	n.i.	0.0012	0.0012	0.0013	0.0012	n.i.
Ås	**Present**	0.0011	0.0011	0.0011	0.0011	0.0011	n.i.	n.i.	0.0011	0.0011	0.0011	0.0011	n.i.
	1	0.0011	0.0011	0.0011	0.0011	0.0011	n.i.	n.i.	0.0011	0.0011	0.0011	0.0011	n.i.
	10	0.0011	0.0011	0.0011	0.0012	0.0011	n.i.	n.i.	0.0011	0.0011	0.0011	0.0011	n.i.
	100	0.0011	0.0011	0.0011	0.0017	0.0012	n.i.	n.i.	0.0011	0.0012	0.0013	0.0011	n.i.
Time	**Present**	0.0012	n.i	n.i	0.0012	0.0012	n.i.	n.i.	0.0012	0.0012	0.0012	0.0012	n.i.
	1	0.0012	n.i	n.i	0.0012	0.0012	n.i.	n.i.	0.0012	0.0012	0.0012	0.0012	n.i.
	10	0.0012	n.i	n.i	0.0013	0.0012	n.i.	n.i.	0.0012	0.0012	0.0012	0.0012	n.i.
	100	0.0012	n.i	n.i	0.0022	0.0013	n.i.	n.i.	0.0012	0.0013	0.0015	0.0012	n.i.

The calculated present concentration of Hg is lowest at Time, 0.4 ng L^{-1}. At the other regions, present PEC_{sw} is 1.1 ng L^{-1}. There are few data on Hg concentrations in small Norwegian water courses that are influenced by agricultural runoff, but in Skuterudbekken (Ås), eleven samples were taken for Hg analysis in 2017-20. The concentrations varied between 2 - 4 ng L^{-1}, with a mean value of 2.6 ng L^{-1}. Samples from two watercourses at the alum shale area (2010) showed higher concentrations: Vingergjessa <5 (LOD) – 8 ng L^{-1} and Mura <5 – 11 ng L^{-1}. The calculated PEC_{sw} for the alum shale area is a factor of 10 lower than the highest measured values and similar to PEC_{sw} in Målselv, Melhus, Stange and Ås. This is because of the PEC_{soil} in these regions are also similar.

The atmospheric contribution alone (#0a) is sufficient to cause a small temporal increase in Hg concentrations in all regions. With additional contributions from fertilisers, higher rates of increase are found. Evaluation of quality class II organic fertiliser regulation (#2), Hg concentrations increase from 1.1- to 2.0 ng L^{-1} in the alum shale area in 100 years. (82 %).

8.2.2.6 Nickel (Ni)

Table 8.2.2.6-1. PEC$_{SW}$ for Ni in surface water recipients (µg Ni L^{-1}). n.i. = not included scenario in this region.

Ni	**µg L^{-1}**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8
	1	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7
	10	6.1	6.1	6.1	6.3	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1
	100	2.6	2.4	2.6	3.8	2.9	2.7	2.7	2.7	2.8	2.7	2.8	2.7
Melhus	**Present**	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1
	1	8.9	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
	10	8.0	8.0	8.1	8.1	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
	100	2.8	2.9	3.7	3.7	3.1	3.0	2.9	2.9	3.0	2.9	3.0	2.9
Stange	**Present**	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3
	1	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3
	10	5.1	5.1	5.1	5.3	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
	100	3.5	3.3	3.5	4.9	3.9	3.7	3.6	3.6	3.7	3.6	3.7	3.6
Alun shale	**Present**	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3
	1	20.1	20.1	20.1	20.2	20.2	20.2	20.2	20.2	20.2	20.2	20.2	20.2
	10	19.2	19.2	19.2	19.4	19.3	19.2	19.2	19.2	19.2	19.2	19.2	19.2
	100	12.0	11.8	12.0	13.4	12.4	12.2	12.0	12.0	12.2	12.1	12.2	12.1
Ås	**Present**	6.0	6.0	6.0	6.0	6.0	n.i	n.i	6.0	6.0	6.0	6.0	6.0
	1	5.9	5.9	5.9	5.9	5.9	n.i	n.i	5.9	5.9	5.9	5.9	5.9
	10	5.5	5.4	5.5	5.6	5.5	n.i	n.i	5.5	5.5	5.5	5.5	5.5
	100	2.6	2.5	2.6	3.6	2.9	n.i	n.i	2.7	2.8	2.7	2.8	2.7
Time	**Present**	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
	1	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
	10	2.1	2.1	2.1	2.3	2.2	2.1	2.1	2.1	2.1	2.1	2.1	2.1
	100	1.1	1.0	1.0	1.8	1.3	1.2	1.2	1.2	1.3	1.2	1.2	1.2

The present PEC$_{sw}$ for Ni is lowest at Time (2.6 µg L^{-1}) and highest at the alum shale area (20.3 µg L^{-1}). In the other regions, PECsw are between 5.3 and 9.1 µg L^{-1}. Measured concentrations in representative watercourses sampled during 1996-98 were <1 – 3.5 µg L^{-1} in Hotrakanalen (Melhus), 1.8 – 5.0 µg L^{-1} in Kolstadbekken (Stange), <1 – 2 µg L^{-1} Timebekken and <1 – 9.2 µg L^{-1} in Skuterudbekken (Ås). More recent data from Skuterudbekken during 2017-2020 show concentrations from 1.1 - 2.4 µg L^{-1} with median value 1.4 µg L^{-1} (n=17). Measured concentrations of Ni from water courses in the alum shale area in 2010 show 4.5-11 µg L^{-1} in Fura and 7.8-12 µg L^{-1} in Vingergjessa. These measured concentrations confirm the concentration differences between the regions as shown by the calculated PEC$_{sw}$ (i.e. Ni concentrations being lowest at Time and highest in the alum area). However, the calculated present PECs are generally higher than the measured concentrations.

The soil/water distribution factor for Ni, used in the calculation of PECsw is influenced only by pH, but possible effects of different sources of Ni on the mobility are not accounted for. Thus, the same Kd value has been used in Stange and the alum shale area. However, it has been shown by sequential extraction of soil developed on alum shale minerals that Ni was strongly associated with the soil components and less mobile than Zn and Cd (Narwal et al. 2008). The rather low Kd for Ni (163) which is intermediate between Cd and Zn may therefore not be representative for the soil in the alum shale area. A higher Kd value implies less mobility and lower PECsw.

The temporal trends in PECsw for Ni are decreasing in all regions and scenarios.

8.2.2.7 Lead (Pb)

Table 8.2.2.7-1. PEC_{SW} for Pb in surface water recipients (µg Pb L^{-1}). n.i. = not included scenario in this region.

Pb	**µg L^{-1}**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
	1	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
	10	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
	100	0.08	0.08	0.08	0.10	0.09	0.08	0.08	0.08	0.08	0.09	0.09	0.08
Melhus	**Present**	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	1	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	10	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	100	0.04	0.04	0.04	0.06	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.04
Stange	**Present**	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
	1	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
	10	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
	100	0.22	0.22	0.22	0.24	0.22	0.22	0.22	0.22	0.22	0.22	0.23	0.22
Alun shale	**Present**	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
	1	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
	10	0.24	0.24	0.24	0.25	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
	100	0.25	0.24	0.25	0.26	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Ås	**Present**	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
	1	0.23	0.23	0.23	0.24	0.24	0.23	0.23	0.23	0.23	0.24	0.24	0.23
	10	0.24	0.23	0.24	0.24	0.24	0.23	0.23	0.24	0.24	0.24	0.24	0.24
	100	0.24	0.23	0.24	0.25	0.24	0.23	0.23	0.24	0.24	0.24	0.24	0.24
Time	**Present**	0.23	n.i	n.i	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
	1	0.23	n.i	n.i	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
	10	0.23	n.i	n.i	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
	100	0.23	n.i	n.i	0.26	0.23	0.23	0.23	0.23	0.23	0.23	0.24	0.23

The calculated present PEC_{sw} for Pb varies from 0.04 µg L^{-1} at Melhus to 0.24 µg L^{-1} in the alum shale area. The concentrations measured in the JOVA survey during 1996-98 were mostly under the LOD (1µg Pb L^{-1}) in Hotrankanalen (Melhus), Timebekken and Kolstadbekken (Stange). In Skuterudbekken (Ås), three samples taken in 1996 showed 3.3 – 5.6 µg L^{-1}, while all samples in the following years were <1 µg L^{-1}. Although the LOD of the analyses is high, the data from small watercourses in arable areas, generally support the calculated low PEC_{sw} of Pb.

The temporal trend of PEC_{sw} indicates that atmospheric contribution alone is sufficient to cause a small increase of Pb at all regions (except for Time). With additional contribution of Pb from fertilisers, the PEC_{sw} increases further, but remains below 0.3 µg L^{-1} after 100 years in all scenarios. The highest relative increase is found at Melhus, where the evaluation of organic fertiliser regulation quality class II (#2) causes an increase in PEC_{sw} from 0.039-0.055 µg L^{-1} in 100 years (41 %).

8.2.2.8 *Zinc (Zn)*

Table 8.2.2.8-1. PEC_{SW} for Zn in surface water recipients (μg Zn L^{-1}). n.i. = not included scenario in this region.

Zn	**μg L^{-1}**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
	1	5.1	5.1	5.1	5.2	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
	10	4.9	4.9	4.9	5.6	5.2	5.1	5.1	5.2	5.2	5.4	5.0	5.2
	100	3.5	3.4	3.6	8.9	6.2	4.9	4.6	5.6	6.0	7.6	4.6	6.1
Melhus	**Present**	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
	1	3.0	3.0	3.0	3.1	3.0	3.0	3.0	3.0	3.0	3.1	3.0	3.0
	10	3.0	2.9	3.0	3.3	3.1	3.1	3.1	3.1	3.1	3.2	3.0	3.1
	100	2.3	2.3	2.4	5.0	3.6	3.4	3.2	3.3	3.5	4.3	2.9	3.6
Stange	**Present**	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1
	1	6.1	6.1	6.1	6.1	6.1	6.2	6.2	6.1	6.1	6.1	6.1	6.1
	10	6.1	6.1	6.1	6.5	6.3	7.1	6.5	6.2	6.2	6.3	6.1	6.2
	100	5.8	5.8	5.9	9.5	7.7	15.3	9.7	7.0	7.2	8.2	6.4	7.3
Alun shale	**Present**	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7
	1	9.7	9.7	9.7	9.7	9.7	9.8	9.7	9.7	9.7	9.7	9.7	9.7
	10	9.6	9.6	9.6	10.0	9.8	10.6	10.0	9.7	9.7	9.8	9.7	9.7
	100	8.8	8.7	8.8	12.5	10.6	18.2	12.7	10.0	10.2	11.1	9.4	10.2
Ås	**Present**	7.9	7.9	7.9	7.9	7.9	n.i	n.i	7.9	7.9	7.9	7.9	7.9
	1	7.9	7.9	7.9	7.9	7.9	n.i	n.i	7.9	7.9	7.9	7.9	7.9
	10	7.8	7.8	7.8	8.1	8.0	n.i	n.i	7.9	7.9	8.0	7.9	7.9
	100	6.9	6.8	6.9	9.6	8.2	n.i	n.i	7.9	8.1	9.0	7.4	8.2
Time	**Present**	5.5	n.i	n.i	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
	1	5.4	n.i	n.i	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
	10	5.1	n.i	n.i	5.8	5.4	5.4	5.3	5.4	5.4	5.7	5.2	5.4
	100	3.3	n.i	n.i	7.4	5.3	5.0	4.7	4.9	5.1	6.4	4.1	5.2

The calculated present PEC_{sw} of Zn is lowest at Melhus (3.0 μg L^{-1}) and highest at the alum shale area (9.7 μg L^{-1}). Measured concentrations in Hotrankanalen (Melhus) during 1996-98 were 2.9 -13.7 μg L^{-1}. In Kolstadbekken (Stange), the range of concentration was 1.4 – 9.9 μg L^{-1}, in Timebekken 2.7 – 32 μg L^{-1}, and in Skuterudbekken (Ås) 2.2 – 45 μg L^{-1}. More recent data from Skuterudbekken show lower concentrations of Zn. In 2017-2020, the concentrations were 0.88 – 5.9 μg with a median of 1.7 μg L^{-1} (n=19).

Several of the fertilisation scenarios causes increasing PECsw in most regions. With application of manure (#4), PEC_{sw} increases from 6.1 μg L^{-1} to 16 μg L^{-1} in 100 years (160 %) at Stange.

8.2.3 Predicted concentrations of PTE in sediment

The concentration of Cd in the sediment of a recipient surface water can be calculated from the PEC_{SW}, using the solid-water partition coefficient of sediments, Kp_{sed} as:

$PEC_{sed} = Kp_{sed} \times PEC_{sw}$ (Eq. 10)

For As the Kp_{sed} has been derived from the REACH dossier-As (2021), while for the other PTEs the Kp_{sed} have been adopted from Allison & Allison (2005). (See Table 8.2.2-2)

The calculated PEC for surface water sediments is shown in Tables 8.2.3-1 – 8.2.3-8.

There are few available data on concentrations of PTEs in representative watercourses in Norway.

The FOREGS Geochemical Baseline Programme (FGBP) organised sampling of soil, stream water and stream water sediments to provide high quality environmental geochemical baseline data for Europe in 1997-1998 (Salminen et al. 1998). From a grid net with 160 km x 160 km cells, five points in each cell was randomly selected and the nearest small drainage basin of <100 km^2 was selected for sampling. Stream sediment (<0.15 mm) was collected to reflect the mean geogenic composition of a catchment basin. In Norway, the number of sampling sites was 58. The sediment samples were analysed for several metals, except for Cd and Hg. The Norwegian dataset has been used for comparison of the calculated PEC$_{sed}$ of PTEs in the Norwegian focus regions. The FOREGS geochemical database is available at http://weppi.gtk.fi/publ/foregsatlas/ForegsData.php.

Additional data from Norway are available from Lake Årungen (a lake in the Ås region). The catchment area of Lake Årungen is 52 km^2, of which 53% is agricultural land. Zambon (2010) sampled 122 sediment cores for analysis of metals. The data for concentration of PTEs in the upper 2.5 cm of the sediment has been used for comparison with the calculated PEC$_{soil}$ in the present assessment.

8.2.3.1 Arsenic (As)

The predicted present concentration of As in sediment is highest at the alum shale region (8.5 mg kg^{-1}). In the other regions, the range is from 1.1 mg kg^{-1} at Målselv to 2.4 mg kg^{-1} at Time.

Measured As concentration in sediments in the FOREGS database is reported as the LOD which was 2.5 mg kg^{-1} in 54 of the 58 sites that were sampled. The maximum concentration was 19 mg kg^{-1}. In Lake Årungen, the range was 1.9 - 11 mg kg^{-1}, and median 6.4 mg kg^{-1}. Compared to these measured concentrations, the predicted sediment concentrations appear reasonable.

The temporal trends of PTEs in sediment are identical to those for PEC$_{sw}$ and are not further discussed in this section.

Table 8.2.3.1-1. PEC_{sed} for As, (mg kg^{-1}) n.i. = not included scenario in this region.

AS	**mg kg^{-1}**	Only atmopheric contribution	Only mineral fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	1.09	1.09	1.09	1.09	n.i.	1.09	1.09	1.09	1.09	n.i.	1.09	1.09
	1	1.09	1.09	1.09	1.09	n.i.	1.09	1.09	1.09	1.09	n.i.	1.09	1.09
	10	1.07	1.07	1.07	1.15	n.i.	1.08	1.08	1.08	1.07	n.i.	1.08	1.08
	100	0.97	0.92	0.97	1.66	n.i.	1.00	1.00	1.02	0.97	n.i.	1.02	1.01
Melhus	**Present**	1.90	1.90	1.90	1.90	n.i.	1.90	1.90	1.90	1.90	n.i.	1.90	1.90
	1	1.90	1.90	1.90	1.91	n.i.	1.90	1.90	1.90	1.90	n.i.	1.90	1.90
	10	1.86	1.86	1.87	1.93	n.i.	1.87	1.87	1.87	1.87	n.i.	1.87	1.87
	100	1.57	1.53	1.58	2.15	n.i.	1.62	1.62	1.61	1.57	n.i.	1.61	1.60
Stange	**Present**	1.33	1.33	1.33	1.33	n.i.	1.33	1.33	1.33	1.33	n.i.	1.33	1.33
	1	1.33	1.33	1.33	1.34	n.i.	1.33	1.33	1.33	1.33	n.i.	1.33	1.33
	10	1.33	1.32	1.33	1.40	n.i.	1.33	1.33	1.33	1.33	n.i.	1.33	1.33
	100	1.31	1.28	1.33	2.05	n.i.	1.36	1.36	1.36	1.31	n.i.	1.36	1.35
Alum shale	**Present**	8.45	8.45	8.45	8.45	n.i.	8.45	8.45	8.45	8.45	n.i.	8.45	8.45
	1	8.44	8.44	8.44	8.44	n.i.	8.44	8.44	8.44	8.44	n.i.	8.44	8.44
	10	8.36	8.36	8.36	8.44	n.i.	8.37	8.37	8.36	8.36	n.i.	8.37	8.36
	100	7.64	7.61	7.65	8.37	n.i.	7.69	7.69	7.68	7.64	n.i.	7.69	7.68
Ås	**Present**	2.10	2.10	2.10	2.10	n.i.	n.i.	n.i.	2.10	2.10	n.i.	2.10	2.10
	1	2.10	2.10	2.10	2.11	n.i.	n.i.	n.i.	2.10	2.10	n.i.	2.10	2.10
	10	2.08	2.07	2.08	2.14	n.i.	n.i.	n.i.	2.08	2.08	n.i.	2.08	2.08
	100	1.87	1.84	1.88	2.45	n.i.	n.i.	n.i.	1.91	1.88	n.i.	1.92	1.91
Time	**Present**	2.37	n.i.	n.i.	2.37	n.i.	2.37	2.37	2.37	2.37	n.i.	2.37	2.37
	1	2.36	n.i.	n.i.	2.37	n.i.	2.36	2.36	2.36	2.36	n.i.	2.36	2.36
	10	2.29	n.i.	n.i.	2.40	n.i.	2.30	2.30	2.30	2.29	n.i.	2.30	2.30
	100	1.84	n.i.	n.i.	2.58	n.i.	1.90	1.90	1.89	1.84	n.i.	1.90	1.88

8.2.3.2 Cadmium (Cd)

The present PEC_{sed} of Cd varies from 0.23 mg kg^{-1} at Melhus to 2 mg kg^{-1} at the alum shale region.

Data on sediments Cd are not included in the FOREGS database. The study in Lake Årungen showed Cd concentrations in the range 0.15 - 1.5 mg kg-1, with medium 0.5 mg kg-1. These measured concentrations support the calculated PECsed of Cd.

Table 8.2.3.2-1. PEC$_{sed}$ for Cd (mg kg^{-1}) n.i. = not included scenario in this region.

Cd	**mg kg^{-1}**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
	1	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
	10	0.34	0.35	0.35	0.42	0.37	0.35	0.35	0.36	0.36	0.37	0.36	0.35
	100	0.16	0.17	0.21	0.62	0.33	0.20	0.19	0.26	0.28	0.31	0.27	0.20
Melhus	**Present**	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
	1	0.22	0.22	0.22	0.23	0.23	0.22	0.22	0.22	0.22	0.22	0.22	0.22
	10	0.21	0.22	0.22	0.25	0.23	0.21	0.21	0.22	0.22	0.22	0.22	0.21
	100	0.12	0.16	0.18	0.40	0.25	0.15	0.14	0.17	0.18	0.20	0.18	0.14
Stange	**Present**	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
	1	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
	10	0.38	0.40	0.40	0.44	0.41	0.40	0.39	0.39	0.39	0.39	0.39	0.38
	100	0.31	0.45	0.48	0.82	0.58	0.47	0.37	0.38	0.39	0.41	0.39	0.34
Alun shale	**Present**	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99
	1	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98
	10	1.91	1.93	1.93	1.97	1.94	1.93	1.92	1.92	1.92	1.92	1.92	1.91
	100	1.35	1.49	1.52	1.86	1.62	1.51	1.41	1.42	1.43	1.45	1.43	1.38
Ås	**Present**	0.62	0.62	0.62	0.62	0.62	n.i.	n.i.	0.62	0.62	0.62	0.62	0.62
	1	0.61	0.62	0.62	0.62	0.62	n.i.	n.i.	0.62	0.62	0.62	0.62	0.62
	10	0.58	0.59	0.59	0.63	0.60	n.i.	n.i.	0.59	0.59	0.59	0.59	0.58
	100	0.34	0.39	0.42	0.68	0.50	n.i.	n.i.	0.40	0.41	0.43	0.41	0.36
Time	**Present**	0.98	n.i.	n.i.	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
	1	0.94	n.i.	n.i.	0.95	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
	10	0.63	n.i.	n.i.	0.72	0.66	0.64	0.64	0.65	0.65	0.66	0.65	0.64
	100	0.12	n.i.	n.i.	0.34	0.19	0.15	0.14	0.17	0.18	0.20	0.18	0.14

8.2.3.3 Chromium (Cr)

The present PEC$_{sed}$ for Cr varies from 32 mg kg^{-1} in Time to 111 mg kg^{-1} in Melhus.

Measured Cr concentration in sediments in the FOREGS database range from 4 to 290 mg kg^{-1}, with median 19 mg kg^{-1}. In Lake Årungen the range was 33 -120 mg kg^{-1}, and median 100 mg kg^{-1}. The calculated PEC$_{sed}$ for the Norwegian regions are within the range expected, based on the measured concentrations.

Table 8.2.3.3-1. PEC$_{sed}$ for Cr (mg kg^{-1}) n.i.=not included scenario in this region.

Cr	**mg kg^{-1}**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	81	81	81	81	81	81	81	81	81	81	81	81
	1	81	81	81	81	81	81	81	81	81	81	81	81
	10	80	80	80	82	80	80	80	80	80	80	80	80
	100	72	69	72	96	76	72	72	73	74	76	75	72
Melhus	**Present**	111	111	111	111	111	111	111	111	111	111	111	111
	1	110	110	110	111	110	110	110	110	110	110	110	110
	10	108	108	108	111	109	108	108	108	108	109	108	108
	100	88	85	89	110	92	88	88	89	89	92	91	88
Stange	**Present**	49	49	49	49	49	49	49	49	49	49	49	49
	1	49	49	49	49	49	49	49	49	49	49	49	49
	10	49	49	49	52	49	49	49	49	49	49	49	49
	100	48	46	49	75	54	49	48	49	50	52	51	48
Alun shale	**Present**	64	64	64	64	64	64	64	64	64	64	64	64
	1	64	64	64	64	64	64	64	64	64	64	64	64
	10	64	63	64	66	64	64	64	64	64	64	64	64
	100	61	59	62	89	67	62	62	63	63	66	65	62
Ås	**Present**	86	86	86	86	86	n.i.	86	86	86	86	86	86
	1	86	86	86	86	86	n.i.	86	86	86	86	86	86
	10	84	84	85	87	85	n.i.	84	85	85	85	85	85
	100	74	72	75	96	78	n.i.	71	75	75	78	77	74
Time	**Present**	32	n.i.	n.i.	32	32	32	32	32	32	32	32	32
	1	32	n.i.	n.i.	32	32	32	32	32	32	32	32	32
	10	31	n.i.	n.i.	34	31	31	31	31	31	31	31	31
	100	22	n.i.	n.i.	49	27	23	22	24	24	27	26	23

8.2.3.4 Copper (Cu)

The present PEC$_{sed}$ for Cu varies from 24 mg kg^{-1} at Målselv to 63 mg kg^{-1} at the alum shale region.

Measured Cu concentration in sediments at the FOREGS database range from 2 - 32 mg kg^{-1}, with median 12 mg kg^{-1}. In Lake Årungen, the range was 9.1 - 63 mg kg^{-1}, with medium 33 mg kg^{-1}. The calculated PEC$_{sed}$ for the Norwegian regions are within the expected range, based on the measured concentrations.

Table 8.2.3.4-1. PEC_{sed} for Cu (mg kg^{-1}) n.i. = not included scenario in this region.

Cu	**mg kg^{-1}**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	24	24	24	24	24	24	24	24	24	24	24	24
	1	24	24	24	25	24	24	24	24	24	24	24	24
	10	24	24	24	29	24	24	24	25	25	25	25	24
	100	22	22	22	71	23	27	25	29	28	29	30	27
Melhus	**Present**	28	28	28	28	28	28	28	28	28	28	28	28
	1	28	28	28	29	28	28	28	28	28	28	28	28
	10	28	28	28	33	28	28	28	28	28	28	29	28
	100	24	24	25	67	25	31	28	31	30	31	32	29
Stange	**Present**	33	33	33	33	33	33	33	33	33	33	33	33
	1	33	33	33	34	33	34	33	33	33	33	33	33
	10	33	33	33	39	33	35	34	34	34	34	34	34
	100	32	32	32	86	33	53	43	39	38	39	40	37
Alun shale	**Present**	63	63	63	63	63	63	63	63	63	63	63	63
	1	63	63	63	63	63	63	63	63	63	63	63	63
	10	62	62	62	68	62	64	63	63	63	63	63	63
	100	58	58	58	112	59	79	69	65	64	65	66	63
Ås	**Present**	31	31	31	31	31	31	31	31	31	31	31	31
	1	31	31	31	31	31	31	31	31	31	31	31	31
	10	31	31	31	35	31	31	31	31	31	31	32	31
	100	30	30	30	68	31	30	30	35	35	35	36	34
Time	**Present**	36	36	36	36	36	36	36	36	36	36	36	36
	1	36	36	36	37	36	37	36	37	36	37	37	36
	10	36	35	36	44	36	37	36	37	37	37	37	36
	100	30	29	30	90	31	39	35	39	38	39	40	36

8.2.3.5 Mercury (Hg)

The present PEC_{sed} for Hg varies from 0.085 mg kg^{-1} at Målselv to 0.094 mg kg^{-1} at Time.

Data on Hg in sediments are not included in the FOREGS database. In Lake Årungen, the range was 0.02 – 0.27 mg kg^{-1}, and median 0.10 mg kg^{-1}. The calculated PEC_{sed} for the Norwegian regions are within the range found in Lake Årungen, and very close to the median concentration of Hg in the lake.

Table 8.2.3.5-1. PEC$_{sed}$ for Hg (mg kg^{-1}) n.i. = not included scenario in this region.

Hg	**mg kg^{-1}**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.085	0.085	0.085	0.085	0.085	n.i.	n.i.	0.085	0.085	0.085	0.085	n.i.
	1	0.085	0.085	0.085	0.086	0.085	n.i.	n.i.	0.085	0.085	0.085	0.085	n.i.
	10	0.085	0.085	0.085	0.091	0.086	n.i.	n.i.	0.085	0.086	0.087	0.085	n.i.
	100	0.088	0.085	0.088	0.144	0.094	n.i.	n.i.	0.089	0.091	0.104	0.089	n.i.
Melhus	**Present**	0.086	0.086	0.086	0.086	0.086	n.i.	n.i.	0.086	0.086	0.086	0.086	n.i.
	1	0.086	0.086	0.086	0.087	0.086	n.i.	n.i.	0.086	0.086	0.086	0.086	n.i.
	10	0.086	0.086	0.086	0.092	0.087	n.i.	n.i.	0.087	0.087	0.088	0.087	n.i.
	100	0.089	0.086	0.089	0.139	0.094	n.i.	n.i.	0.090	0.091	0.103	0.090	n.i.
Stange	**Present**	0.086	0.086	0.086	0.086	0.086	n.i.	n.i.	0.086	0.086	0.086	0.086	n.i.
	1	0.086	0.086	0.086	0.087	0.086	n.i.	n.i.	0.086	0.086	0.086	0.086	n.i.
	10	0.086	0.086	0.086	0.092	0.087	n.i.	n.i.	0.086	0.087	0.088	0.086	n.i.
	100	0.089	0.086	0.089	0.150	0.095	n.i.	n.i.	0.090	0.092	0.104	0.090	n.i.
Alun shale	**Present**	0.088	0.088	0.088	0.088	0.088	n.i.	n.i.	0.088	0.088	0.088	0.088	n.i.
	1	0.088	0.088	0.088	0.088	0.088	n.i.	n.i.	0.088	0.088	0.088	0.088	n.i.
	10	0.088	0.088	0.088	0.094	0.089	n.i.	n.i.	0.088	0.088	0.090	0.088	n.i.
	100	0.091	0.088	0.091	0.152	0.097	n.i.	n.i.	0.091	0.093	0.106	0.092	n.i.
Ås	**Present**	0.088	0.088	0.088	0.088	0.088	n.i.	n.i.	0.088	0.088	0.088	0.088	n.i.
	1	0.088	0.088	0.088	0.088	0.088	n.i.	n.i.	0.088	0.088	0.088	0.088	n.i.
	10	0.088	0.088	0.088	0.093	0.088	n.i.	n.i.	0.088	0.088	0.089	0.088	n.i.
	100	0.090	0.087	0.090	0.138	0.095	n.i.	n.i.	0.091	0.092	0.104	0.091	n.i.
Time	**Present**	0.094	n.i.	n.i.	0.094	0.094	n.i.	n.i.	0.094	0.094	0.094	0.094	n.i.
	1	0.094	n.i.	n.i.	0.095	0.094	n.i.	n.i.	0.094	0.094	0.094	0.094	n.i.
	10	0.094	n.i.	n.i.	0.102	0.095	n.i.	n.i.	0.094	0.095	0.097	0.094	n.i.
	100	0.097	n.i.	n.i.	0.173	0.105	n.i.	n.i.	0.099	0.101	0.119	0.099	n.i.

8.2.3.6 Nickel (Ni)

The present PEC$_{sed}$ for Ni is highest at the alum shale region (203 mg kg^{-1}). In the other regions the present concentrations vary from 26 mg kg^{-1} at Time to 91 mg kg^{-1} at Melhus.

Measured Ni concentration in sediments in the FOREGS database range from 3 to 69 mg kg^{-1}, with median 13 mg kg^{-1}. In Lake Årungen the range was 18 – 72 mg kg^{-1}, and median 57 mg kg^{-1}. Compared to these measured data, the predicted concentration at the alum shale area is high, which can be explained by the geological conditions. For the other regions the PEC$_{sed}$ are in the same range as the measured concentrations.

Table 8.2.3.6-1. PEC$_{sed}$, for Ni (mg kg^{-1}) n.i. = not included scenario in this region.

Ni	**mg kg^{-1}**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	68	68	68	68	68	68	68	68	68	68	68	68
	1	67	67	67	67	67	67	67	67	67	67	67	67
	10	61	61	61	63	61	61	61	61	61	61	61	61
	100	26	24	26	38	29	27	27	27	28	27	28	27
Melhus	**Present**	91	91	91	91	91	91	91	91	91	91	91	91
	1	90	89	90	90	90	90	90	90	90	90	90	90
	10	80	80	80	81	80	80	80	80	80	80	80	80
	100	29	28	29	37	31	30	29	29	30	29	30	29
Stange	**Present**	53	53	53	53	53	53	53	53	53	53	53	53
	1	53	53	53	53	53	53	53	53	53	53	53	53
	10	51	51	51	53	51	51	51	51	51	51	51	51
	100	35	33	35	49	39	37	36	36	37	36	37	36
Alun shale	**Present**	203	203	203	203	203	203	203	203	203	203	203	203
	1	201	201	201	202	202	202	202	202	202	202	202	202
	10	192	192	192	194	193	192	192	192	192	192	192	192
	100	120	118	120	134	124	122	120	120	122	121	122	121
Ås	**Present**	60	60	60	60	60	n.i	n.i	60	60	60	60	60
	1	59	59	59	59	59	n.i	n.i	59	59	59	59	59
	10	55	54	55	56	55	n.i	n.i	55	55	55	55	55
	100	26	25	26	36	29	n.i	n.i	27	28	27	28	27
Time	**Present**	26	26	26	26	26	26	26	26	26	26	26	26
	1	26	26	26	26	26	26	26	26	26	26	26	26
	10	21	21	21	23	22	21	21	21	21	21	21	21
	100	11	10	10	18	13	12	12	12	13	12	12	12

8.2.3.7 Lead (Pb)

The present PEC$_{sed}$ for Pb varies from 5 mg kg^{-1} at Melhus to 31 mg kg^{-1} at the alum shale region.

Measured Pb concentration in sediments in the FOREGS database range from 1.5 to 60 mg kg^{-1}, with median 9.0 mg kg^{-1}. In Lake Årungen the range was 11 – 36 mg kg^{-1}, and median 28 mg kg^{-1}. The calculated PEC$_{sed}$ for the Norwegian regions are within the range expected, based on the measured concentrations.

Table 8.2.3.7-1. PEC_{sed} for Pb (mg kg^{-1}) n.i.=not included scenario in this region.

Pb	**mg kg^{-1}**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	9.85	9.85	9.85	9.85	9.85	9.85	9.85	9.85	9.85	9.85	9.85	9.85
	1	9.86	9.85	9.86	9.88	9.86	9.86	9.86	9.86	9.86	9.86	9.87	9.86
	10	9.91	9.84	9.91	10.17	9.95	9.91	9.91	9.91	9.93	9.94	10.00	9.91
	100	10.41	9.78	10.42	12.97	10.86	10.43	10.43	10.47	10.62	10.71	11.35	10.45
Melhus	**Present**	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95
	1	4.95	4.95	4.95	4.97	4.95	4.95	4.95	4.95	4.95	4.95	4.96	4.95
	10	4.98	4.94	4.98	5.15	5.01	4.98	4.98	4.98	4.99	5.00	5.04	4.98
	100	5.28	4.87	5.29	6.95	5.58	5.31	5.31	5.32	5.42	5.47	5.89	5.30
Stange	**Present**	27.40	27.40	27.40	27.40	27.40	27.40	27.40	27.40	27.40	27.40	27.40	27.40
	1	27.41	27.40	27.41	27.43	27.41	27.41	27.41	27.41	27.41	27.41	27.41	27.41
	10	27.44	27.40	27.45	27.65	27.48	27.45	27.45	27.45	27.46	27.46	27.51	27.45
	100	27.80	27.38	27.82	29.85	28.17	27.83	27.83	27.85	27.95	28.01	28.44	27.83
Alun shale	**Present**	30.67	30.67	30.67	30.67	30.67	30.67	30.67	30.67	30.67	30.67	30.67	30.67
	1	30.68	30.67	30.68	30.70	30.68	30.68	30.68	30.68	30.68	30.68	30.68	30.68
	10	30.71	30.67	30.71	30.91	30.75	30.71	30.71	30.71	30.72	30.73	30.77	30.71
	100	31.02	30.60	31.03	33.07	31.38	31.05	31.05	31.06	31.17	31.23	31.66	31.05
Ås	**Present**	29.58	29.58	29.58	29.58	29.58	29.58	29.58	29.58	29.58	29.58	29.58	29.58
	1	29.58	29.58	29.58	29.60	29.59	29.58	29.58	29.58	29.58	29.59	29.59	29.58
	10	29.61	29.57	29.61	29.79	29.64	29.57	29.57	29.62	29.63	29.63	29.68	29.61
	100	29.88	29.46	29.90	31.62	30.19	29.45	29.45	29.92	30.03	30.09	30.52	29.91
Time	**Present**	28.85	n.i	n.i	28.85	28.85	28.85	28.85	28.85	28.85	28.85	28.85	28.85
	1	28.85	n.i	n.i	28.89	28.86	28.85	28.85	28.85	28.85	28.85	28.86	28.85
	10	28.83	n.i	n.i	29.20	28.90	28.84	28.84	28.84	28.86	28.88	28.97	28.84
	100	28.66	n.i	n.i	32.18	29.28	28.72	28.72	28.75	28.96	29.08	29.96	28.72

8.2.3.8 Zinc (Zn)

The present PEC_{sed} for Zn varies from 192 mg kg^{-1} in Melhus to 611 mg kg^{-1} at the alum shale region.

Measured sediment Zn concentration in the FOREGS database range from 7 - 171 mg kg^{-1}, with median 37 mg kg^{-1}. In Lake Årungen, the range was 46 – 260 mg kg^{-1}, and median 210 mg kg^{-1}. The calculated present concentration of Zn in the alum shale region is high in comparison with the measured data, which can be explained by the geological conditions. However, also in the other regions the concentrations are higher than the maximum values in the datasets from FOREGS and Lake Årungen. This indicates that the Kp_{sed} used to calculate PEC_{sed} from the PEC_{sw} tends to overestimate the concentration of Zn in sediments.

Table 8.2.3.8-1. PEC$_{sed}$ for Zn (mg kg^{-1}) n.i. = not included scenario in this region.

Zn	**mg kg^{-1}**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	323	323	323	323	323	323	323	323	323	323	323	323
	1	321	321	321	326	323	322	322	323	323	325	322	323
	10	310	309	310	352	331	321	319	326	329	342	318	330
	100	223	212	224	563	390	307	293	353	376	482	290	382
Melhus	**Present**	192	192	192	192	192	192	192	192	192	192	192	192
	1	191	191	191	193	192	192	192	192	192	192	191	192
	10	186	186	187	206	196	194	193	194	195	201	190	195
	100	148	143	150	314	230	216	205	211	222	274	180	225
Stange	**Present**	386	386	386	386	386	386	386	386	386	386	386	386
	1	385	385	386	388	387	392	388	386	386	387	386	386
	10	384	383	384	409	396	449	411	392	393	400	388	394
	100	368	365	372	600	484	964	614	442	456	517	406	460
Alun shale	**Present**	611	611	611	611	611	611	611	611	611	611	611	611
	1	610	610	610	613	612	617	613	611	611	612	611	611
	10	605	605	605	630	617	670	632	613	614	621	609	615
	100	554	551	558	786	670	1150	800	628	642	703	592	646
Ås	**Present**	500	500	500	500	500	n.i	n.i	500	500	500	500	500
	1	499	499	499	501	500	n.i	n.i	500	500	501	499	500
	10	492	492	492	512	502	n.i	n.i	500	501	507	496	502
	100	433	429	435	609	520	n.i	n.i	500	511	566	467	515
Time	**Present**	346	n.i	n.i	346	346	346	346	346	346	346	346	346
	1	343	n.i	n.i	348	346	345	345	345	345	347	344	345
	10	320	n.i	n.i	368	344	340	337	339	342	357	330	343
	100	207	n.i	n.i	467	334	314	296	306	324	406	258	329

8.3 Modelling concentrations in crops, vegetables, fruits and mushroom

Uptake from soil into plants was calculated using constant transfer factors TF. The choices made for selection of TFs in this assessment were discussed and argued for in section 6.2.2. PTE concentrations in crops, vegetables and mushrooms are estimated based on the selected TFs and for agricultural crops related to predicted PTE soil concentration for 1, 10 and 100 years in agricultural soil (Table 8.1.1-1 – 8.1.8-1), and for vegetables related to MLs in engineered soil and growing media (Table 3.1.1-2 and Table 3.1.2-1).

8.3.1 Estimation of plant concentration over time – agricultural crops

Table 6.2.1-1 shows the transfer factors in dry weight and the dry matter content in plants used for the calculations. The TFs vary for each PTE, and with each plant. This is also due to the different dry matter contents of the plants. Fresh weight TFs are calculated from dry weight TFs by multiplying with the fraction of dry matter in the plant material. Values for the dry weight content of the crops were taken from the Norwegian food composition database (NFSA, 2020) and differ largely (e.g. 85% for cereals and 11% in carrot: Table 6.2.2-1). Subsequently, the transfer factors based on dry weight and fresh weight differ only slightly for barley and wheat because DW (of the harvested product, here the grains) is 85%. For grass, the difference is factor 5 (DW is 20%), for carrots, it is factor 9 (DW is 11%) and for lettuce it is factor 18 (DW is 5.4%).

Highest predicted uptake (based on dry weight TFs) in cereals is for Zn, Cu and Cd; in grass for Zn, Cd, Cu; for potatoes in Cd, Cu, Zn; in carrots for Cu, Cd, Zn (Table 6.2.2-1). Lowest uptake into cereals is for Cr and Pb; into grass for Cr, Hg and Pb; in potato for Hg, As, Cr, Pb; in carrots for Cr, As, Ni.

Based on fresh weight, the same condition applies, i.e., highest TFs are seen for Zn, followed by Cu, but the uptake into potatoes and grass is now much lower than cereals, due to the higher DW content of the latter.

Predicted plant concentration are directly proportional to the predicted concentrations in soil, because in the model, TF values are constant, independent of the soil concentrations. Hence, predicted concentrations in plants follow the same trends as those predicted for the soil over time in the different scenarios (Tables 8.3.1.1-1 to 8.3.1.8-1). All calculated PEC_{plants} over time (present, 10 and 100 years) are presented in Appendix AVII (Table AVII-1 – Table AVII-32), and in the following section, the scenarios with highest increase over time were extracted and are presented (Tables 8.3.1.1-1 - 8.3.1.8-1).

Human exposure of PTEs via food is evaluated based on fresh weight PTE concentrations in consumables. Thus, the crop concentrations are presented for FW. Barley and wheat were included in the study by Novotna et al. (2015), but not oat. In general, there are limited TFs available for oat and the results are therefore not included in the following data presentation. The TFs for barley and wheat were rather similar, and the highest difference was seen for Cd (TF DW 0.17 and 0.11 for wheat and barley, respectively). In our calculations, wheat TF has been used for all cereals.

Similarly, for PEC_{soil}, evaluation of quality class II (applied 2000 kg DW ha^{-1} yr^{-1} and MLs) Norwegian organic fertiliser regulation, produced the highest increase in PEC_{plants} (#2) for all PTEs and scenarios, except for Zn and a high application of pig manure (Stange and alum shale) and cattle manure (Melhus) with measured maximum Zn value (#4) (see Table 8.3.1.8-1).

8.3.1.1 PEC agricultural crops As

Arsenic concentration in soil and crops are predicted to decline for most scenarios.

Highest estimated As concentrations are in crops cultivated on alum shale at the present soil concentrations of 332, 12, 14 and 108 µg kg^{-1} FW for cereals, carrot, potato and grass, respectively. However, these concentrations are predicted to decrease over time. Next highest predicted concentrations are estimated at Ås after 100 years, appr. 5 times lower.

Evaluation of suggested As ML for organic fertiliser quality class II, cause increase in soil (Table 8.1.1-1) and crops (Table AVII-1-4) at all regions, except alum shale. Highest increase is predicted at Stange (127% increase), and PECs after 100 years are 55.2, 2.2, 2.4 and 18.0 µg kg^{-1} FW for cereals, carrot, potato and grass, respectively.

At Stange, a slight increase is predicted for application of fish sludge (#6) and all other manures - cattle and pig (#4, 5), horse (#9) and poultry (#10) (appr. 5-6 % increase over 100 years). For fish sludge, the prediction is based on measured mean value (1.7 mg kg^{-1} DW, maximum measured value in our data set is 3.2 mg kg^{-1} DW) of samples from aquaculture. Fish sludge from marine aquaculture is expected to have a higher As concentration and thus, not unlikely increasing spreading of As-rich fertiliser products. For fertiliser schemes, application of cattle/pig manure (#4 and 5), poultry (#10), all analyses, except one poultry sample, were below LOQ 0.8 mg kg^{-1} DW (data from Daugstad et al., 2012, n=7 to n=14). After an evaluation of the data set, an upper bound approach was chosen as a worse-case scenario where the analyses were below LOQ (i.e., value = LOD). Thus, these are uncertain dataset.

Most plant take up As as arsenate. Due to structural similarity between As and phosphate it is found that addition of phosphate can increase solubility of As (Peryea, 1991), causing movement of As soil to groundwater, or increasing its availability for plant uptake (Cao et al., 2003; Creger and Peryea, 1994; Peryea and Kammereck, 1997; Wang et al., 2002; Zhao et al., 2009).

Table 8.3.1.1-1. PEC$_{plants}$ of As presented as µg kg^{-1} FW at present and predicted concentrations after 100 years for selected scenarios.

As	Sc.#		Målselv	Melhus	Stange	Alum shale	Ås	Time
Cereals		Present	35.4	66.3	24.3	332	59.7	44.2
	#2	100 yr	**57.8**	**77.3**	**55.2**	328	**75.0**	**53.0**
	#6	100 yr			**27.0**			
Carrot		Present	1.4	2.6	1.0	13.2	2.4	1.8
	#2	100 yr	**2.3**	**3.1**	**2.2**	13.1	**3.0**	**2.1**
Potato		Present	1.5	2.9	1.1	14.4	2.6	1.9
	#2	100 yr	**2.5**	**3.4**	**2.4**	14.3	**3.3**	**2.3**
Grass		Present	11.5	21.6	7.9	108	19.4	14.4
	#2	100 yr	**18.8**	**25.2**	**18.0**	107	**24.4**	**17.3**

8.3.1.2 PEC agricultural crops Cd

Fresh weight-based TFs for Cd vary from 0.007 (carrot) to 0.1445 (wheat). This 20-fold difference is mostly caused by the difference in dry weight. Another reason for the low TF of Cd in carrots may be the differences in the origin of the value. TF-values for cereals (0.11 - 0.17 g g^{-1} DW), grass (0.3 g g^{-1} DW) and potato (0.23 g g^{-1} DW) were chosen from Novotna et al. (2015), the TF of carrot is taken from US EPA 1996 and is somewhat lower (0.064 g g^{-1} DW).

The predicted concentrations of Cd in wheat vary from 11.8 (Målselv) to 121 (alum shale) µg kg^{-1} (Table 8.3.1.2-1.). Increases in the predicted concentrations are – as for soil – mainly seen with scenario #2 (evaluation of organic fertiliser regulation quality class II) in Målselv, Melhus, and Stange. Some increase is also seen for scenarios #1, 3 and 4 (only Melhus, Stange). The calculated concentration for Cd in cereals (wheat) after 100 years of scenario #2 is 46.6 µg kg^{-1} FW, which is still lower than the predicted concentration for cereals grown on alum shale, 113 µg kg^{-1} FW (see also Table AVII-5).

With similar trend (Målselv as lowest and alum shale, Stange, as highest) and following the order of FW based TFs, predicted Cd concentrations for potato, grass and carrot were in the range of 5.7 - 58 µg kg^{-1} FW, 3.8 µg kg^{-1} FW – 38.6 µg kg^{-1} FW, and 0.6 – 6 µg kg^{-1} FW, respectively.

Concentrations in crops have the same temporal trend as those in soil, and as shown in section 8.1, Table 8.1.2-1, most trends are declining, for all regions and scenarios #5 to #10, and mostly at Målselv and Time. Concentrations predicted for crops grown on alum, which are currently the highest of all regions, will decline for all scenarios and all crops to < 100 µg kg^{-1}.

Most of the cattle manure samples, pig (#4, 5) and poultry (#10) were below LOD. Since LOQ was used as a result (upper-bound LOQ), these scenarios also indicated to be a relevant source of Cd, however, there is some level uncertainty on the data. Only scenario #4 for Stange leads to an increase of predicted concentrations in crops.

In the reference Legind and Trapp (2010), a higher value for the TF of Cd in carrots (0.25 g g^{-1} DW) was reported, and this value was also used in the previous risk assessment of Cd (VKM 2019). A closer look at the distribution of the underlying measurements shows that the value 0.25 g g^{-1} DW is median of 109 values with a 5%-tile at 0.059 and a 95% at 1.8 g g^{-1} DW, and 0.064 g g^{-1} DW is the geometric mean of 25 values which range from 0.002 to 1.188 g g^{-1} DW. Both values are thus within the range of underlying data. For reasons outlined in chapter 6.2.2, mostly point 1 Comprehensiveness, the US EPA value was preferred because that source covers more metals, crops and vegetables (in addition to the TF-values of carrots, TF-values for mercury were taken from this source). However, Legind and Trapp (2010) found that "the US EPA model ... tends to underestimate the concentration of Cd in roots".

If the TF of 0.25 g g^{-1} DW is used for carrots instead of 0.064 g g^{-1}, the calculated concentrations in carrot are factor 3.9 higher, but still lower than those in cereals, grass or potato.

Table 8.3.1.2-1. PEC_{plants} of Cd presented as µg kg^{-1} FW at present and predicted concentrations after 100 years for selected scenarios. **In bold: increase over 100 years.**

Cd	**Scenario #**		**Målselv**	**Melhus**	**Stange**	**Alum shale**	**Ås**	**Time**
Cereals		Present	11.8	14.5	18.8	121	30.3	27.5
	#2	100 yr	**20.1**	**26.9**	**46.6**	113	**34.1**	7.6
	#0b		4.9	9.8	**23.1**	89.8	17.4	n.i.
	#1		6.1	11.2	**24.8**	91.5	18.8	n.i.
Carrot[1]		Present	0.6	0.7	0.9	5.9	1.5	1.3
	#2	100 yr	**1.0**	**1.3**	**2.3**	5.5	**1.7**	0.4
	#0b		0.24	0.48	1.13	4.4	0.85	n.i.
	#1		0.30	0.55	1.21	4.5	0.91	n.i
Carrot[2]		Present	2.3	2.7	3.5	23.4	5.9	5.1
	#2	100 years	**3.9**	**5.1**	**9.0**	23.4	**6.6**	1.6
	#0b		0.8	2.0	4.3	17.2	3.1	n.i.
	#1							
Potato		Present	5.7	7.0	9.0	58	14.6	13.2
	#2	100 yr	**9.7**	**12.9**	**22.5**	55	**16.4**	3.7
	#0b		2.3	4.7	11.1	43.3	8.4	n.i.
	#1		2.9	5.4	11.9	44.1	9.0	n.i.
Grass		Present	3.8	4.6	6.0	39	9.7	8.7
	#2	100 yr	**6.4**	**8.6**	**14.8**	36	**10.9**	2.4
	#0b		1.6	3.1	7.4	28.6	5.5	n.i.
	#1		1.9	3.6	7.9	29.1	6.0	n.i.

[1]TF from US EPA (1996); [2]Legind and Trapp (2010)

8.3.1.3 PEC agricultural crops Cr

Chromium concentrations in soil and crops are predicted to decline for all scenarios, and all regions, except for Stange and except for application of maximum loading of organic fertilisers quality class II (scenario #2). This scenario leads to an increase at all regions (only Melhus remains constant), highest increase is seen for Stange (63% over 100 years). For Stange, and only for this region, addition of sewage sludge with measured mean Cr concentration (#3), mineral P fertilisers (#1), fish sludge (#6), digestates (#7,8) and horse manure (#9) cause also an increase of Cr in crops with time, but only a very minor (≤ 11%) increase (Table 8.3.1.3-1, for soil see Table 8.1.3-1).

Highest Cr concentrations are predicted for cereals (Melhus: 91.8 µg kg^{-1} FW, declining trend), lowest for carrot (Time: 5.1 µg kg^{-1} FW; increasing trend for scenario #2, other scenarios declining).

Cr is not known to be essential for plants but have no specific mechanisms for uptake in plants. However, as discussed in a review by Sharma et al. (2020), specific carriers for other essential ions help uptake of Cr; e.g. Cr(VI) due to structural similarity via the same carriers and transporters as for sulfate and phosphate. In the plants, Cr(VI) is transformed to Cr(III) which has the tendency to bind to cell wall, and thus has low translocation from roots to aboveground plant tissues. Higher accumulation of Cr in roots, compared to many metals might be due to this transformation and binding, but also accumulation in vacuoles in root cells which is a common protective mechanism. Uptake of Cr decreases with increasing organic matter and pH (Raptis et al., 2018).

Table 8.3.1.3-1. PEC_{plants} of Cr(tot) presented as µg kg^{-1} FW at present and predicted concentrations after 100 years. Bold: increasing trend. Only scenario #2 shows an increasing trend for most regions.

Cr	Sc.#		Målselv	Melhus	Stange	Alum shale	Ås	Time
Cereals	#2	Present	63.8	91.8	35.7	48	68.9	23.7
	#2	100 yr	**76.3**	91.3	**58.3**	**70**	**77.5**	**38.1**
Carrot	#2	Present	13.8	19.8	7.7	10	14.9	5.1
	#2	100 yr	**16.5**	19.7	**12.6**	**15**	**16.7**	**8.2**
Potato	#2	Present	30.0	43.2	16.8	23	32.4	11.2
	#2	100 yr	**35.9**	42.9	**27.4**	**33**	**36.5**	**18.0**
Grass	#2	Present	40.0	57.6	22.4	30	43.2	14.9
	#2	100 yr	**47.9**	57.3	**36.6**	**44**	**48.6**	**23.9**

8.3.1.4 PEC agricultural crops Cu

TF values for Cu were taken from Novotna et al. (2015). This source does not provide a TF for carrot, and mean value of three other TFs – barley (0.15 g g^{-1} DW), grass (0.19 g g^{-1}) and potato (0.24 g g^{-1}) was taken for carrot (0.20 g g^{-1} DW, rounded) (Table 6.2.1-1). Current levels of Cu in soil are low, from 11 to 20 mg kg-1 DW, except for the alum shale with 43 mg kg^{-1} DW. This results in the following present concentrations in crops: wheat 1309 – 2380 µg kg^{-1} FW, carrot 242 – 946 µg kg^{-1} FW, potato 634 - 2477 µg kg^{-1} FW, and gras 418 – 1634 µg kg^{-1} FW. The highest concentrations are always from the alum shale region.

Copper is widely used, and concentrations in soil and crops are predicted to increase in all regions and all scenarios, except mineral fertiliser (#1), and fish sludge (#6) (for details, see Table 8.1.4-1). The highest increase is found for evaluation of organic fertiliser regulation quality class II (#2), which shows an increase of Cu in soil and crops of up to 463% (Stange). Significant increase of Cu over 100 years is also predicted for application of sewage sludge (#3) (114%, Stange) and pig manure (maximum measured concentration) (#4) (173%, Stange). The calculated concentrations in crops increase proportionally to those in soil, with maximum concentrations of Cu in cereals or wheat after 100 years > 8000 µg kg^{-1} FW (Stange) and > 11000 µg kg^{-1} FW for alum shale (Table 8.3.1.4-1). Predicted future concentrations for cereals in 100 years with other scenarios are throughout >1000 µg kg^{-1} (except for Time).

Predicted maximum concentrations in carrots with scenario #2 after 100 years range between 1200- and 1500 µg kg^{-1} FW, except for alum shale (2082 µg kg^{-1} FW). Predicted future concentrations in carrots with scenario #3 and #9 (Compost horse manure) are lower (between 300 and 720 µg kg^{-1} FW). Predicted fresh-weight concentrations of crop types of grass and potatoes lie between those of carrots and cereals, and also have the maximum concentrations in 100 years and with scenario #2 (Table 8.3.1.4-1). The steep increase of the predicted concentrations of Cu in many regions and for most scenarios may be a reason for concern.

Table 8.3.1.4-1. PEC$_{plants}$ of Cu presented as µg kg^{-1} FW at present and predicted soil concentrations after 100 years for selected scenarios.

Cu	**Scenario #**		**Målselv**	**Melhus**	**Stange**	**Alum shale**	**Ås**	**Time**
Cereals	#2	Present	1666	2380	1428	5117	1309	1309
	#2	100 yr	**7337**	**7592**	**8043**	**11261**	**6735**	**7039**
	#4		**1962**	**2765**	**3900**	**7117**	n.i.	**1612**
	#9		**2428**	**2861**	**2289**	**5506**	**2086**	**1720**
Carrot	#2	Present	308	440	264	946	242	242
	#2	100 yr	**1356**	**1403**	**1487**	**2082**	**1245**	**1301**
	#4		**363**	**511**	**721**	**1316**	n.i.	**298**
	#9		**449**	**529**	**423**	**1018**	**386**	**318**
Potato	#2	Present	806	1152	691	2477	633	633
	#2	100 yr	**3551**	**3675**	**3893**	**5451**	**3260**	**3407**
	#4		**950**	**1338**	**1888**	**3445**	n.i.	**780**
	#9		1175	1385	1108	2665	1010	833
Grass	#2	Present	532	760	456	1634	418	418
	#2	100 yr	**2343**	**2424**	**2568**	**3596**	**2150**	**2247**
	#4		**626**	**883**	**1245**	**2273**	n.i.	**515**
	#9		**775**	**914**	**731**	**1758**	**666**	**549**

n.i.: fertiliser scheme not included in this region.

8.3.1.5 PEC agricultural crops Hg

Present concentrations of mercury (Hg) in cereals range from 1.8 to 5 µg kg^{-1} FW, in carrots from 0.04 to 0.1 µg kg^{-1} FW, in potato from 0.01 to 0.03 µg kg^{-1} FW, and in grass from 0.04 to 0.11 µg kg^{-1} FW. The highest concentrations are predicted for Time (Table 8.3.1.5-1). As outlined in section 8.1, atmospheric deposition of Hg is sufficient to lead to a predicted increase of Hg in soil (and thus also in crops) in all scenarios. However, mercury is a volatile metal, and non-consideration of volatilisation in the model calculations may be a reason for over-prediction. Disregarding volatilization of Hg, an increase of Hg concentrations in crops over time was predicted for all scenarios (all fertiliser schemes and all regions) (mineral P fertilisers not included at Time and cattle and pig manure not included in Ås). Such a broad impact is due to the estimated high contribution from atmospheric contribution. A second

reason is that the upper-bound LOD has been used for the calculation of Hg input to soil for manure samples where the analytical result was < LOD. The highest increase (more than a 10-fold increase, Melhus in 100 years) is predicted for evaluation of organic fertiliser regulation quality class II (#2). Also, application of digestate based on food waste (#8) leads to a high increase of Hg in 100 years.
Predicted Hg concentrations in cereals from Time in 100 years with scenario #2 was around 32 µg kg^{-1} FW, while for all other regions, it was in the range of 21-24 µg kg^{-1} FW (Table 8.3.1.5-1). Predicted concentrations in carrot and grass were around 0.7 µg kg^{-1} FW in Time and for all other regions, it is in the range of 0.45 to 0.50 µg kg^{-1} FW. For potato the predicted Hg concentration was in the range of 0.14 and up to 0.21 µg kg^{-1} FW, where Time was highest.

Future experimental studies might reduce the high uncertainty of the predicted Hg concentrations.

Table 8.3.1.5-1. PEC$_{plants}$ of Hg presented as µg kg^{-1} FW at present and predicted concentrations after 100 years for selected scenarios.

Hg	**Scenario #**		**Målselv**	**Melhus**	**Stange**	**Alum shale**	**Ås**	**Time**
Cereals		Present	1.82	2.4	2.2	2.8	2.9	5.0
	#2	100 yr	**21.15**	**21.3**	**23.3**	**23.8**	**20.9**	**32.2**
	#8		**8.1**	**8.5**	**8.5**	**8.6**	**8.65**	**13.6**
Carrot		Present	0.04	0.05	0.046	0.06	0.06	0.11
	#2	100 yr	**0.45**	**0.45**	**0.49**	**0.51**	**0.44**	**0.68**
	#8		**0.17**	**0.18**	**0.17**	**0.18**	**0.18**	**0.29**
Potato		Present	0.012	0.016	0.014	0.018	0.019	0.033
	#2	100 yr	**0.14**	**0.14**	**0.15**	**0.16**	**0.14**	**0.21**
	#8		**0.05**	**0.06**	**0.05**	**0.06**	**0.06**	**0.09**
Grass		Present	0.04	0.05	0.05	0.06	0.06	0.11
	#2	100 yr	**0.47**	**0.47**	**0.51**	**0.53**	**0.46**	**0.71**
	#8		**0.18**	**0.19**	**0.18**	**0.19**	**0.19**	**0.30**

8.3.1.6 PEC agricultural crops Ni

The application of mineral or organic fertiliser did not lead to an increase of predicted Ni concentrations in crops, for none of the regions and none of the scenarios. The highest input of Ni is via scenario #2, but even in this scenario predicted concentrations fall between 7% and 64% (chapter 8.1.6).
Present concentrations in cereals (wheat) were calculated to between 24.5 (Time) to 347 (alum shale) µg kg^{-1} FW, and fall within 100 years, scenario #2, to 12 (Time) to 225 (alum shale) µg kg^{-1} FW. Fresh weight based; Ni has the highest TF for grass. This is reflected in the calculated concentrations, being the highest of all the crops. Initial concentrations in

grass reach up to 510 μg kg^{-1} FW (alum shale) but fall to 330 μg kg^{-1} FW even with scenario #2. All other crops have lower Ni fresh-weight concentrations (Table 8.3.1.6-1).

Table 8.3.1.6-1. PEC$_{plants}$ of Ni presented as μg kg^{-1} FW at present and predicted concentration after 100 years.

Ni	Scenario #		Målselv	Melhus	Stange	Alum shale	Ås	Time
Cereals		Present	88.4	156.4	81.6	346.8	95.2	24.5
	#2	100 yr	47.3	56.5	74.4	224.7	51.5	11.9
Carrot		Present	11.4	20.2	10.6	44.9	12.3	3.2
	#2	100 yr	6.1	7.3	9.6	29.1	6.7	1.5
Potato		Present	62.4	110.4	57.6	244.8	67.2	17.3
	#2	100 yr	33.4	39.9	52.6	158.6	36.4	8.4
Grass		Present	130.0	230.0	120.0	510.0	140.0	36.0
	#2	100 yr	69.5	83.0	109.5	330.4	75.8	17.5

8.3.1.7 PEC agricultural crops Pb

Present concentrations of Pb in soil show a wide variation among regions, from 6 mg kg^{-1} DW in Målselv (Stange 8.1 mg kg^{-1}, Melhus 9.6 mg kg^{-1}) to 23 mg kg^{-1} DW in Time (Ås 16 mg kg^{-1}, alum shale 20 mg kg^{-1}), as shown in Table 8.1.7-1. Due to high predicted atmospheric deposition, Pb increases in all regions with low current soil concentration for all scenarios #1 to #10, that is Målselv, Stange and Melhus. In the regions with high present soil concentrations, an increase is seen only for some scenarios, namely #2 (evaluation of fertiliser regulation MLs class II) and #9 (horse manure). Furthermore, increasing concentrations are predicted for the alum shale region with #3 and #8, and for Ås with #3, #7 and #8. The concentrations in crops follow proportional to those in soil. Lead has low transfer factors into plants, thus, predicted concentrations in crops for present time are throughout < 100 μg kg^{-1} FW, though, cereals in Time are close (97.8 μg kg^{-1} FW). After 100 years of application of scenario #2, concentrations above 100 μg kg^{-1} are reached for cereals grown in the alum shale region and in Time (Table 8.3.1.7-1) Time has at present values close to 100 μg kg^{-1} also with scenario #3 (not shown). Generally, highest contribution to increasing crop concentrations was predicted for evaluation of organic fertiliser regulation quality class II (scenario #2). Concentrations in cereals after 100 years were predicted to around 60-75 μg kg^{-1} FW in Målselv, Melhus and Stange, close to but below 100 μg kg^{-1} FW in Ås and around 122-135 μg kg^{-1} FW in alum shale and Time (Table 8.3.1.7-1). Corresponding concentrations for potato and grass were in the range from around 30 μg kg^{-1} FW up to 60-63 μg kg^{-1} FW, and for carrot the concentration was predicted around 17-20 μg kg^{-1} FW up to 39 μg kg^{-1} FW.

Table 8.3.1.7-1. PEC_{plants} of Pb presented as µg kg^{-1} FW at present and predicted concentration after 100 years with scenario #2.

Pb	Scenario #		Målselv	Melhus	Stange	Alum shale	Ås	Time
Cereals		Present	25.5	40.8	34.4	85.0	68.0	97.8
	#2	100 yr	**60.1**	**74.5**	**72.2**	**122.0**	**99.6**	**135.1**
Carrot		Present	7.3	11.6	9.8	24.2	19.4	27.8
	#2	100 yr	**17.1**	**21.2**	**20.6**	**34.7**	**28.4**	**38.5**
Potato		Present	11.5	18.4	15.6	38.4	30.7	44.2
	#2	100 yr	**27.1**	**33.7**	**32.6**	**55.1**	**45.0**	**61.0**
Grass		Present	12.0	19.2	16.2	40.0	32.0	46.0
	#2	100 yr	**28.3**	**35.1**	**34.0**	**57.4**	**46.9**	**63.6**

8.3.1.8 PEC agricultural crops Zn

Zn has the highest present concentration in soil of all studied PTEs (chapter 8.1). Moreover, Zn also has the highest (cereals) or among the highest TF-values. Subsequently, Zn has the highest concentration in crops of all studied PTEs. Present concentrations are in the mg kg^{-1}-range (Table 8.3.1.8-1), and range for cereals from 9 mg kg^{-1} FW (Time) to 29 mg kg^{-1} FW (alum shale). Also all other considered crops, except carrots, have predicted present concentrations > 1 mg kg^{-1} FW. Zn is widely used (chapter 1.3.9) and is thus present in a range of sources, and the input to soil is high for most scenarios. Consequently, the predicted Zn concentration in soil and crops increase in all fertiliser scenarios, except #1 mineral P fertilisers. Zn concentration predicted after 100 years in cereals for evaluation of organic fertiliser regulation quality class II (#2), digestate only with food waste as substrate (#8) and cow and pig manure (#5) were in the range of 15,6-42.7 mg kg^{-1} FW, 12.5-36.2 mg kg^{-1} FW and 7.0-43,8 mg kg^{-1} FW, respectively (Table 8.3.1.8-1). The highest concentrations in cereals were predicted for 100 years of scenario #4 in Stange and the alum shale region and reach 56.6 (Stange) and 71.2 mg kg^{-1} FW. Contrary, in Time, evaluation of organic fertiliser regulation quality class II (#2) and digestate with only food waste (#8) as substrate showed predicted increase in crops over time.

Predicted concentration in potato and grass for scenarios #2, 5 and 8 range from 1.3 to 8.3 mg kg^{-1} FW. Predicted concentrations in carrots were around 10 times lower, in the range of 0.13-0.80 mg kg^{-1} FW (Table 8.3.1.8-1).

Table 8.3.1.8-1. PEC_{plants} of Zn in crops presented as µg kg^{-1} FW at present and predicted concentrations after 100 years for selected scenarios; n.i.: not investigated.

Zn	**Scenario #**		**Målselv**	**Melhus**	**Stange**	**Alum shale**	**Ås**	**Time**
Cereals		Present	12121	14493	11331	28985	21344	9486
	#4	100 yr		**16660**	**56621**	**71180**		
	#2	100 yr	**22145**	**25490**	**28150**	**42709**	**30318**	**15590**
	#8	100 yr	**18769**	**21866**	**21626**	**36186**	**26783**	**12505**
	#5	100 yr	**10895**	**15672**	**29200**	**43760**	**n.i.**	**6997**
Carrot		Present	223	266	208	532	392	174
	#4	100 yr		**306**	**1040**	**1307**		
	#2	100 yr	**407**	**468**	**517**	**784**	**557**	**286**
	#8	100 yr	**345**	**402**	**397**	**665**	**492**	**230**
	#5	100 yr	**200**	**288**	**536**	**804**	**n.i.**	**129**
Potato		Present	2098	2508	1961	5016	3694	1642
	#4	100 yr		**2883**	**9799**	**12318**		
	#2	100 yr	**3832**	**4411**	**4871**	**7391**	**5247**	**2698**
	#8	100 yr	**3248**	**3784**	**3742**	**6262**	**4635**	**2164**
	#5	100 yr	**1885**	**2712**	**5053**	**7573**	**n.i.**	**1211**
Grass		Present	2300	2750	2150	5500	4050	1800
	#4	100 yr		**3161**	**10744**	**13507**		
	#2	100 yr	**4202**	**4837**	**5342**	**8104**	**5753**	**2958**
	#8	100 yr	**3561**	**4149**	**4104**	**6866**	**5082**	**2373**
	#5	100 yr	**2067**	**2974**	**5541**	**8304**	**n.i.**	**1328**

8.3.2 Home gardening and urban farming - estimated plant concentrations in vegetables and garden

Urban farming is trendy, and several scenarios were calculated for the uptake and fate of PTEs in order to evaluate the ML in engineered soil and different growing media. In all these calculations, no leaching was assumed, and the harvested amount was set to half of that in ordinary agriculture (averaged for the regions).

Off season (autumn and spring precipitation and flooding) loss of PTEs via runoff and leaching is assumed to be much less than in agricultural fields (compare section 8.3.2). Thus, to simply the prediction, no removal via leaching and runoff was included in the predictions. Although this is a realistic scenario for cultivation of plants in greenhouses, indoors and under roofs, excluding leaching for cultivation in engineered soil applied in kitchen gardens and market gardens might give an overestimation in soil and crop concentrations over time. Mixed growing media has higher content of OM and higher water holding capacity than field agricultural soil, while mineral engineered soils normally have similar OM content as agricultural topsoil.

Thus, loss from the substrate is rather small, compared to the loss for the previous calculations of soil in the six regions (chapter 8.1 and 8.3.1). It is thus no surprise that the general trend of substrate concentrations is stable, or slightly upwards in most calculations. The vegetables included in the evaluation is lettuce, garden fruits, carrot and potato. The dry weight content of lettuce, 5.4%, was taken from US EPA 1996, and the predicted PTE concentration in vegetables is based on selected TF-values and chosen as in the previous chapter from Novotna et al. (2015) (Cr, Cu), US EPA (1996) (As, Cd, Hg, Ni, Zn), and Legind and Trapp (2010) (Pb in vegetables) (Table 6.2.2-2).

The selection of scenarios was a request from NFSA. The main aim for including these scenarios is to evaluate and compare the MLs for the Norwegian regulations for engineered soil, organic fertilisers and organic growing media (quality class 0 and 2) and EU regulation, CE-labelled organic growing media (Table 3.1.2-1) by comparing predicted PTE concentrations in vegetables and garden fruits cultivated in growing media and engineered soil with maximum limit values. An overview of the chosen scenarios; engineered soils used in private garden growing for home consume (Scenario A), engineered soils used in market garden growing vegetables sold on the local marked (Scenario B) and mixed organic growing media used for establishing beds in gardens, used in pots and containers and hobby greenhouses (Scenario C) is found in section 3.1.1.

8.3.2.1 Evaluation of MLs for engineered soil for private garden growing for home consume of vegetables and garden fruits (Scenario A)

The scenario cultivation of vegetables and garden fruits in engineered soil (MLs for engineered soil in Norwegian regulation, Table 3.1.1-2) with annual application of organic fertilisers with ML quality class II, was used to exemplify a home garden situation and for private consumption. Estimated PTE concentrations in the selected vegetables and fruits are shown in Tables 8.3.2.1-1 to 8.3.2.1-8. Loss from leaching or runoff was not taken into consideration, and the only loss is through plant uptake and harvest. The harvest was set to half of that in professional agriculture, hence, loss is small and does not balance the input with organic fertiliser.

Table 8.3.2.1-1 shows the calculated concentrations of As in µg kg^{-1} FW in vegetables and garden fruits grown in engineered soil with As present at 8 mg kg^{-1} DW (ML engineered soil, Table 3.1.1-2), and with annual addition of 2000 kg DW ha^{-1} (200 g m^{-2}) organic fertilisers (Table 3.1.1-2) that contain 16 mg kg^{-1} DW As, according to ML quality class II. Four calculations were made, for potato, leafy vegetables, root vegetables and garden fruits. The calculated concentrations in the soil of all four crops increases rather similar, but quite slowly, to 8.66 - 8.67 mg kg^{-1} DW in soil after 50 years (Table 8.3.2.1-1). The highest concentrations are calculated for leafy vegetables, in this case lettuce, with 15.6 µg kg^{-1} FW at present to 16.8 µg kg^{-1} FW in 50 years. Lettuce is known to have high transfer due to close contact to soil and thus also transfer of particulate PTEs (Kulhanek et al. 2005). Potato and carrot have concentrations between 7 and 9 µg kg^{-1} FW, while tomato have the lowest predicted concentrations, around 1 µg kg^{-1} FW (Table 8.3.2.1-1).

Table 8.3.2.1-1. PEC for As in vegetables and garden fruits (µg kg^{-1} FW) grown in engineered soil (ML for engineered soil As 8 mg kg^{-1} DW) and annual added organic fertilisers with ML quality class II (ML As 16 mg kg^{-1} DW).

		Grown plants			
Year		**Potato**	**Leafy vegetables Lettuce**	**Root vegetables Carrot**	**Garden fruits**
Present	Engineered soil w/annual added organic fertilisers (mg kg^{-1} DW)	8.0	8.0	8.0	8.0
1		8.0	8.0	8.0	8.0
10		8.1	8.1	8.1	8.1
50		8.7	8.7	8.7	8.7
Present	$\text{PEC}_{\text{plants}}$ (µg kg^{-1} FW)	7.7	15.6	7.0	0.94
1		7.7	15.6	7.1	0.95
10		7.8	15.8	7.2	0.96
50		8.3	16.8	7.6	1.02

Table 8.3.2.1-2 shows the calculated concentrations of Cd (µg kg^{-1} FW) in vegetables and garden fruits grown in engineered soil with Cd present at 1 mg kg^{-1} DW (ML for engineered soil, Table 3.1.1-2), and with annual addition of 2000 kg DW ha^{-1} (200g m^{-2}) organic fertilisers that contain 2 mg kg^{-1} DW Cd according to ML quality class II. Concentrations of Cd in soil increase to 1.08 mg kg^{-1} DW after 50 years. Highest transfer is predicted for potato from 69.6 at present to 73.8 µg kg^{-1} FW after 50 years of fertiliser addition. Predicted concentration in lettuce, garden fruits and carrot at present and after 50 years of fertiliser addition were from 19.7 µg kg^{-1} FW to 21.2 µg kg^{-1} FW, around 5 to 6 µg kg^{-1} FW and about 7 to 7.6 µg kg^{-1} FW, all slightly increasing with time.

Table 8.3.2.1-2. PEC for Cd in vegetables and garden fruits (µg kg^{-1} FW) grown in engineered soil (ML for engineered soil Cd 1 mg kg^{-1} DW) and annual added organic fertilisers with ML quality class II (ML Cd 2 mg kg^{-1} DW).

		Grown plants			
Year		**Potato**	**Leafy vegetables Lettuce**	**Root vegetables Carrot**	**Garden fruits**
Present	Engineered soil w/annual added organic fertilisers (mg kg^{-1} DW)	1.00	1.00	1.00	1.00
1		1.00	1.00	1.00	1.00
10		1.02	1.02	1.02	1.02
50		1.08	1.08	1.08	1.08
Present	$\text{PEC}_{\text{plants}}$ (µg kg^{-1} FW)	69.6	19.7	7.0	5.3
1		69.8	19.7	7.1	5.3
10		70.5	20.0	7.2	5.4
50		73.8	21.2	7.6	5.7

Table 8.3.2.1-3 shows the calculated concentrations of total Cr (µg kg^{-1} FW) in vegetables and garden fruits grown in engineered soil with Cr present at 100 mg kg^{-1} DW (ML for engineered soil, Table 3.1.1-2), and with annual addition of 2000 kg DW ha^{-1} (200 g m^{-2}) organic fertilisers that contain 100 mg kg^{-1} DW Cr according to ML quality class II. Concentrations of Cr(tot) in soil increase from 100 mg kg^{-1} DW at present to 104.1 mg kg^{-1} DW in 50 years due to the annual application of organic fertiliser. Calculated concentrations in potatoes, carrots and lettuce cultivated in this scenario over 50 years, increase in the range of 120-125 µg kg^{-1} FW, 55-57 µg kg^{-1} FW, and 44-45.5 µg kg^{-1} FW, respectively.

Table 8.3.2.1-3. PEC for Cr(tot) in vegetables and garden fruits (µg kg^{-1} FW) grown in engineered soil (ML for engineered soil Cr 100 mg kg^{-1} DW) and annual added organic fertilisers with ML quality class II (ML Cr 100 mg kg^{-1} DW); n.i. is not included due to lack of TF.

		Grown plants			
Year		**Potato**	**Leafy vegetables Lettuce**	**Root vegetables Carrot**	**Garden fruits**
Present	Engineered soil w/annual added organic fertilisers (mg kg^{-1} DW)	100	100	100	100
1		100	100	100	n.i.
10		101	101	101	n.i.
50		104	104	104	n.i.
Present	PEC$_{plants}$ (µg kg^{-1} FW)	120	43.7	55.0	n.i.
1		120	43.8	55.1	n.i.
10		121	44.1	55.5	n.i.
50		125	45.5	57.3	n.i.

Table 8.3.2.1-4 shows the calculated concentrations of Cu in soil, vegetables and garden fruits, same scenario as before. TF-values were only available for potato and root vegetables. The concentration in soil shows a significant increase over time, from 100 mg kg^{-1} DW to 125 mg kg^{-1} DW in 50 years, because ML class II allows 650 mg kg^{-1} DW Cu, while for engineered soils ML for engineered soil is 100 mg kg^{-1} (initial value). Calculated concentrations in root vegetables (carrots) increase from 2200 µg kg^{-1} FW to 2767 57 µg kg^{-1} FW after 50 years, for potato from 5760 µg kg^{-1} FW at present to 7203 µg kg^{-1} FW after 50 years, and from 2376 to 3006 µg kg^{-1} FW for leafy vegetables.

Table 8.3.2.1-4. PEC for Cu in vegetables and garden fruits (µg kg^{-1} FW) grown in engineered soil ML quality class II (ML for engineered soil Cu 100 mg kg^{-1} DW) and annual added organic fertilisers with ML quality class II (ML Cu 650 mg kg^{-1} DW); n.i. is not included due to lack of TF.

		Grown plants			
Year		**Potato**	**Leafy vegetables Lettuce**	**Root vegetables Carrot**	**Garden fruits**
Present	Engineered soil w/annual added organic fertilisers (mg kg^{-1} DW)	100	100	100	100
1		101	101	101	n.i.
10		105	105	105	n.i.
50		125	127	126	n.i.
Present	PEC$_{plants}$ (µg kg^{-1} FW)	5760	2376	2200	n.i.
1		5818	2401	2223	n.i.
10		6051	2502	2314	n.i.
50		7203	3006	2767	n.i.

Table 8.3.2.1-5 shows the calculated concentrations of Hg in soil, vegetables and garden fruits, same scenario as before. The predicted concentrations in soil show only a minor increase after 50 years, from 1 mg kg^{-1} DW to 1.1 mg kg^{-1} DW. Calculated concentrations in vegetables and fruits thus also remain almost constant and range from 0.49 µg kg^{-1} FW (lettuce) to 1.73 µg kg^{-1} FW (carrots).

Table 8.3.2.1-5. PEC for Hg in vegetables and garden fruits (µg kg^{-1} FW) grown in engineered soil (ML for engineered soil, Hg 1 mg kg^{-1} DW) and annual added organic fertilisers with ML quality class II (ML Hg 3 mg kg^{-1} DW).

		Grown plants			
Year		**Potato**	**Leafy vegetables Lettuce**	**Root vegetables Carrot**	**Garden fruits**
Present	Engineered soil w/annual added organic fertilisers (mg kg^{-1} DW)	1.00	1.00	1.00	1.00
1		1.00	1.00	1.00	1.00
10		1.02	1.02	1.02	1.02
50		1.12	1.12	1.12	1.12
Present	PEC$_{plants}$ (µg kg^{-1} FW)	0.48	0.43	1.54	0.59
1		0.48	0.43	1.55	0.59
10		0.49	0.44	1.58	0.60
50		0.54	0.49	1.73	0.66

Table 8.3.2.1-6 shows the calculated concentrations of Ni in soil, vegetables and garden fruits, same scenario as before. As before for Hg, the predicted concentrations of Ni in soil

show only a very minor increase after 50 years, from 50 mg kg^{-1} DW to 52 mg kg^{-1} DW. Calculated concentrations in vegetables and fruits thus also remain almost constant and range from 18 µg kg^{-1} FW (garden fruits) to 90 µg kg^{-1} FW (lettuce), and for potato up to 250 µg kg^{-1} FW.

Table 8.3.2.1-6. PEC for Ni in vegetables and garden fruits (µg kg^{-1} FW) grown in engineered soil (ML for engineered soil, Ni 50 mg kg^{-1} DW) and annual added organic fertilisers with ML quality class II (ML Ni 50 mg kg^{-1} DW).

		Grown plants			
Year		**Potato**	**Leafy vegetables Lettuce**	**Root vegetables Carrot**	**Garden fruits**
Present	Engineered soil w/annual added organic fertilisers (mg kg^{-1} DW)	50.0	50.0	50.0	50.0
1		50.1	50.1	50.1	50.1
10		50.4	50.4	50.4	50.4
50		52.0	52.1	52.1	52.1
Present	PEC_{plants} (µg kg^{-1} FW)	240	86.4	44.0	17.7
1		240	86.5	44.1	17.7
10		242	87.1	44.4	17.8
50		250	90.0	45.8	18.4

Table 8.3.2.1-7 shows the calculated concentrations of Pb in soil, vegetables and garden fruits, same scenario as before. Initial concentration in soil with ML for engineered soil is 60 mg Pb kg^{-1} DW which increase to 63 mg kg^{-1} DW. Lettuce shows higher calculated concentrations of lead, up to 153 µg kg^{-1} FW after 50 years, and potato and carrot up to 122 and 77 µg kg^{-1} FW after 50 years, respectively.

Table 8.3.2.1-7. PEC for Pb in vegetables and garden fruits (µg kg^{-1} FW) grown in engineered soil (ML for engineered soil, Pb 60 mg kg^{-1} DW) and annual added organic fertilisers with ML quality class II (ML Pb 80 mg kg^{-1} DW). n.i. is not included due to lack of TF.

		Grown plants			
Year		**Potato**	**Leafy vegetables Lettuce**	**Root vegetables Carrot**	**Garden fruits**
Present	Engineered soil w/annual added organic fertilisers (mg kg^{-1} DW)	60.0	60.0	60.0	60.0
1		60.1	60.1	60.1	n.i.
10		60.7	60.6	60.7	n.i.
50		63.3	63.0	63.3	n.i.
Present	PEC$_{plants}$ (µg kg^{-1} FW)	115	146	72.6	n.i.
1		115	146	72.8	n.i.
10		116	147	73.4	n.i.
50		122	153	76.6	n.i.

Table 8.3.2.1-8 shows the calculated concentrations of Zn in soil, vegetables and garden fruits, same scenario as before. The ML for engineered soils is 150 mg Zn kg^{-1} DW, while the quality target class II for organic fertiliser is at 800 mg kg^{-1} DW (Table 3.1.1-2). Hence, concentrations are increasing upon addition of such organic fertiliser, from 150 mg Zn kg^{-1} at present to 183 mg kg^{-1} DW after 50 years. Lettuce shows again the best uptake, reaching 2734 µg kg^{-1} FW after 50 years. Potato (8252 µg kg^{-1} FW after 50 years), carrots (981 µg kg^{-1} FW after 50 years) and tomatoes (551 µg kg^{-1} FW after 50 years) have less but still high predicted uptake of Zn, when grown under this scenario.

Table 8.3.2.1-8. PEC for Zn in vegetables and garden fruits (µg kg^{-1} FW) grown in engineered soil (ML for engineered soil, Zn 150 mg kg^{-1} DW) and annual added organic fertilisers with ML quality class II (ML Zn 800 mg kg^{-1} DW); n.i. is not included due to lack of TF.

		Grown plants			
Year		**Potato**	**Leafy vegetables Lettuce**	**Root vegetables Carrot**	**Garden fruits**
Present	Engineered soil w/annual added organic fertilisers (mg kg^{-1} DW)	150	150	150	150
1		151	151	151	151
10		157	157	157	157
50		183	183	183	183
Present	PEC$_{plants}$ (µg kg^{-1} FW)	6840	2025	726	407
1		6897	2043	732	411
10		7124	2114	758	425
50		8252	2469	885	497

8.3.2.2 Evaluation of MLs for engineered soil for urban farming of vegetables and garden fruits and sold on the local market (Scenario B)

This scenario was chosen by NFSA to evaluate vegetables cultivated in engineered soil, e.g. re-establishing agricultural cultivation in urban farming and locally sold products. The following simulations and estimation of PTE concentrations in vegetables and garden fruits were made with the same annual input of PTEs through organic fertiliser with concentrations at the ML class II, but the initial concentration in soil was according to MLs quality class 0.

As before, loss from leaching or runoff was not taken into consideration, and the only loss is through plant uptake and harvest. Concentrations in soil and, also in vegetables and fruits increase with time, but less than in the previous scenario with ML for engineered soil. Table 8.3.2.2-1 shows the predicted concentrations for As, which increases 27% over the considered time span of 100 years. Highest concentration is predicted for lettuce, from 9.7 to 12.3 µg kg^{-1} FW.

Table 8.3.2.2-1 PEC for As in vegetables and garden fruits, presented as µg kg^{-1} FW, grown in engineered soil (ML quality class 0, As 5 mg kg^{-1} DW) and annual added organic fertilisers with ML quality class II (ML As 16 mg kg^{-1} DW).

		Grown plants			
Year		**Potato**	**Leafy vegetables**	**Root vegetables**	**Garden fruits**
Present	Engineered soil w/annual added organic fertilisers (mg kg^{-1} DW)	5.0	5.0	5.0	5.0
1		5.0	5.0	5.0	5.0
10		5.1	5.1	5.1	5.1
100		6.3	6.3	6.3	6.3
Present	PEC_{plants} (µg kg^{-1} FW)	4.8	9.7	4.4	0.59
1		4.8	9.7	4.4	0.59
10		4.9	10.0	4.5	0.61
100		6.1	12.3	5.6	0.75

Table 8.3.2.2-2 shows the predicted concentrations for Cd. Cd concentrations increase 42% over the considered time span of 100 years. Highest concentration is predicted for potato, from 28 to 38 µg kg^{-1} FW.

Table 8.3.2.2-2 PEC for Cd in vegetables and garden fruits, presented as µg kg^{-1} FW, grown in engineered soil (ML quality class 0, Cd 0.4 mg kg^{-1} DW) and annual added organic fertilisers with ML quality class II (ML Cd 2 mg kg^{-1} DW).

		Grown plants			
Year		**Potato**	**Leafy vegetables**	**Root vegetables**	**Garden fruits**
Present	Engineered soil w/annual added organic fertilisers (mg kg^{-1} DW)	0.40	0.40	0.40	0.40
1		0.40	0.40	0.40	0.40
10		0.42	0.42	0.42	0.42
100		0.57	0.56	0.56	0.56
Present	PEC_{plants} (µg kg^{-1} FW)	27.8	7.9	2.8	2.1
1		27.9	7.9	2.8	2.1
10		28.9	8.2	2.9	2.2
100		38.0	11.1	4.0	3.0

Table 8.3.2.2-3 shows the predicted concentrations for Cr(tot). Only potato and root vegetables could be simulated due to a lack of TF-values for the other plants. Concentrations increase 17% over 100 years. Highest concentrations were predicted for potatoes, 60 to 70 µg kg^{-1} FW.

Table 8.3.2.2-3. PEC for Cr in vegetables and garden fruits, presented as µg kg^{-1} FW, grown in engineered soil (ML Cr 50 mg kg^{-1} DW) and annual added organic fertilisers with ML quality class II (ML quality class 0, Cr 100 mg kg^{-1} DW); n.i. = not included due to lack of TF.

		Grown plants			
Year		**Potato**	**Leafy vegetables**	**Root vegetables**	**Garden fruits**
Present	Engineered soil w/annual added organic fertilisers (mg kg^{-1} DW)	50.0	50.0	50.0	50.0
1		50.1	50.1	50.1	n.i.
10		50.8	50.8	50.8	n.i.
100		58.3	58.3	58.3	n.i.
Present	PEC$_{plants}$ (µg kg^{-1} FW)	60.0	21.9	27.5	n.i.
1		60.1	21.9	27.5	n.i.
10		61.0	22.2	28.0	n.i.
100		70.0	25.5	32.1	n.i.

Table 8.3.2.2-4 shows the predicted concentrations for Cu. Only potato and root vegetables could be simulated due to a lack of TF-values for the other plants. Predicted concentrations in soils and vegetables increase more than 100% in 100 years. Highest concentrations were predicted for potato, maximum after 100 years is 5843 µg kg^{-1} FW.

Table 8.3.2.2-4 PEC for Cu in vegetables and garden fruits, presented as µg kg^{-1} FW, grown in engineered soil (ML Cu 50 mg kg^{-1} DW) and annual added organic fertilisers with ML quality class II (ML quality class 0, Cu 650 mg kg^{-1} DW); n.i. = not included due to lack of TF.

		Grown plants			
Year		**Potato**	**Leafy vegetables**	**Root vegetables**	**Garden fruits**
Present	Engineered soil w/annual added organic fertilisers (mg kg^{-1} DW)	50.0	50.0	50.0	50.0
1		50.5	50.5	50.5	n.i.
10		55.2	55.4	55.3	n.i.
100		101	103	102	n.i.
Present	PEC$_{plants}$ (µg kg^{-1} FW)	2880	1188	1100	n.i.
1		2910	1201	1112	n.i.
10		3181	1315	1217	n.i.
100		5843	2457	2253	n.i.

Table 8.3.2.2-5 shows the predicted concentrations for Hg. Predicted concentrations in soils and vegetables increase by 125% in 100 years. Highest concentrations were predicted for root vegetables, maximum after 100 years is 0.7 µg kg^{-1} FW.

Table 8.3.2.2-5 PEC for Hg in vegetables and garden fruits, presented as µg kg^{-1} FW, grown in engineered soil (ML quality class 0, Hg 0.2 mg kg^{-1} DW) and annual added organic fertilisers with ML quality class II (ML Hg 3 mg kg^{-1} DW).

		Grown plants			
Year		**Potato**	**Leafy vegetables**	**Root vegetables**	**Garden fruits**
Present	Engineered soil w/annual added organic fertilisers (mg kg^{-1} DW)	0.20	0.20	0.20	0.20
1		0.20	0.20	0.20	0.20
10		0.22	0.22	0.22	0.22
100		0.45	0.45	0.45	0.45
Present	PEC$_{plants}$ (µg kg^{-1} FW)	0.10	0.09	0.31	0.12
1		0.10	0.09	0.31	0.12
10		0.11	0.10	0.35	0.13
100		0.22	0.19	0.69	0.27

Table 8.3.2.2-6 shows the predicted concentrations for Ni. Predicted concentrations in soils and vegetables increase by 21% in 100 years. Highest concentrations were predicted for potatoes, maximum after 100 years is 116 µg kg^{-1} FW.

Table 8.3.2.2-6 PEC for Ni in vegetables and garden fruits, presented as µg kg^{-1} FW, grown in engineered soil (ML quality class 0, Ni 20 mg kg^{-1} DW) and annual added organic fertilisers with ML quality class II (ML Ni 50 mg kg^{-1} DW); n.i. = not included due to lack of TF.

		Grown plants			
Year		**Potato**	**Leafy vegetables**	**Root vegetables**	**Garden fruits**
Present	Engineered soil w/annual added organic fertilisers (mg kg^{-1} DW)	20.0	20.0	20.0	20.0
1		20.0	20.0	20.0	20.0
10		20.4	20.4	20.4	20.4
100		24.1	24.2	24.1	24.2
Present	PEC$_{plants}$ (µg kg^{-1} FW)	96.0	34.6	17.60	7.08
1		96.2	34.6	17.64	7.09
10		98.0	35.3	17.97	7.23
100		116	41.7	21.25	8.55

Table 8.3.2.2-7 shows the predicted concentrations for Pb. Simulations were only possible for lettuce, potatoes and carrots, due to a lack of TF-values for garden fruits. Concentrations in soil, vegetables and fruits increased about 17% in 100 years. Highest concentrations were predicted for lettuce (leafy vegetables), maximum after 100 years is 112 µg kg^{-1} FW.

Table 8.3.2.2-7 PEC for Pb in vegetables and garden fruits, presented as µg kg^{-1} FW, grown in engineered soil (ML Pb 40 mg kg^{-1} DW) and annual added organic fertilisers with ML quality class II (ML quality class 0, Pb 80 mg kg^{-1} DW); n.i.= not included due to lack of TF.

		Grown plants			
Year		**Potato**	**Leafy vegetables**	**Root vegetables**	**Garden fruits**
Present	Engineered soil w/annual added organic fertilisers (mg kg^{-1} DW)	40.0	40.0	40.0	40.0
1		40.1	40.1	40.1	n.i.
10		40.7	40.6	40.7	n.i.
100		46.6	46.2	46.6	n.i.
Present	PEC$_{plants}$ (µg kg^{-1} FW)	76.8	97.2	48.4	n.i.
1		76.9	97.4	48.5	n.i.
10		78.1	98.7	49.2	n.i.
100		89.5	112	56	n.i.

Table 8.3.2.2-8 shows the predicted concentrations for Zn. Concentrations in soil, vegetables and fruits increase by 44% in 100 years. Highest concentrations were predicted for potatoes, maximum after 100 years is 9645 µg kg^{-1} FW.

Table 8.3.2.2-8 PEC for Zn in vegetables and garden fruits, presented as µg kg^{-1} FW, grown in engineered soil (ML quality class 0, Zn 150 mg kg^{-1} DW) and annual added organic fertilisers with ML quality class II (ML Zn 800 mg kg^{-1} DW).

		Grown plants			
Year		**Potato**	**Leafy vegetables**	**Root vegetables**	**Garden fruits**
Present	Engineered soil w/annual added organic fertilisers (mg kg^{-1} DW)	150	150	150	150
1		151	151	151	151
10		157	157	157	157
100		216	216	216	216
Present	PEC$_{plants}$ (µg kg^{-1} FW)	6840	2025	726	407
1		6868	2034	729	409
10		7124	2114	758	425
100		9645	2911	1044	587

8.3.2.3 Cultivation of vegetables and fruits in organic growing media (C) in private gardens

The following simulations refer to a scenario where organic growing media are used to establish small beds, or in container, in hobby greenhouses and private consumption. It is assumed that no further addition of PTEs occurs, except at the initial stage.

Three different initial concentrations are simulated, namely: growing media with i) MLs of organic fertilisers ML quality class 0 (Scenario C1), ii) MLs of organic fertilisers ML quality class II (both Norwegian regulation) (Scenario C2), and iii) ML EC regulation (chapter 3.1.1, Table 3.1.1-2) (Scenario C3).

The simulated concentrations for soil (mg kg^{-1} DW), fruits and vegetables (µg kg^{-1} FW) are shown in Tables 8.3.2.3-1 - 8.3.2.3-3, respectively. Common to all scenarios is that loss of PTEs from the growing media is only by phytoextraction, which is very low. Thus, concentrations are practically constant over time (less than 1% decline over 50 years for all considered PTE). Thus, only initial concentrations (the highest) are shown in the tables below.

Table 8.3.2.3-1 shows the calculated PEC for the selected PTEs in vegetables and garden fruits, presented as µg kg^{-1} FW, grown in organic growing media ML quality class 0. The results equal those given for the previous scenario B (engineered soil ML class 0), present time, presented in chapter 8.3.2.2, and are thus not further discussed here.

Table 8.3.2.3-1 PEC for the selected PTEs in vegetables and garden fruits, presented as µg kg^{-1} FW, grown in organic growing media ML quality class 0 (Norwegian regulation) (Scenario C1), concentration of PTE in growing media given as mg kg^{-1} DW; n.i. = not included due to lack of TF.

	Growing media	**Potato**	**Leafy vegetables**	**Root vegetables**	**Garden fruits**
As	5.0	4.8	9.7	4.4	0.6
Cd	0.40	27.8	7.9	2.8	2.1
Cr	50.0	60	21.9	27.5	n.i.
Cu	50.0	2880	1188	1100	n.i.
Hg	0.20	0.10	0.09	0.31	0.12
Ni	20.0	96.0	34.6	17.6	7.1
Pb	40.0	76.8	97	48.4	n.i.
Zn	150	6840	2025	726	407

Table 8.3.2.3-2 shows the calculated PEC for the selected PTEs in vegetables and garden fruits, presented as µg kg^{-1} FW, grown in organic growing media ML quality class II. Highest concentrations in vegetables and fruits are predicted for Cu and Zn in potato (max. 37440 and 36480 µg kg^{-1} FW in potatoes, respectively) and leafy vegetables (max. 15444 and 10800 µg kg^{-1} FW, respectively) and Cu in root vegetables (14300 µg kg^{-1} FW).

Table 8.3.2.3-2 PEC for the selected PTEs in vegetables and garden fruits, presented as µg kg^{-1} FW, grown in organic growing media ML quality class II (Norwegian regulation) (Scenario C2); concentration of PTE in growing media given as mg kg^{-1} DW; n.i. = not included due to lack of TF.

	Growing media	Potato	Leafy vegetables	Root vegetables	Garden fruits
As	16.0	15.4	31.1	14.1	1.9
Cd	2.0	139	39.3	14.1	10.6
Cr	100	120	44	55	n.i.
Cu	650	37440	15444	14300	n.i.
Hg	3.0	1.4	1.3	4.6	1.8
Ni	50	240	86.4	44.0	17.7
Pb	80	154	194	96.8	n.i.
Zn	800	36480	10800	3872	2171

Table 8.3.2.3-3 shows the calculated PEC for the selected PTEs in vegetables and garden fruits, presented as µg kg^{-1} FW, grown in organic growing media ML CE-marked products (EU regulation) (Scenario C3). Highest concentrations in vegetables and fruits are predicted for Cu (max. 11520 µg kg^{-1} FW in potatoes) and Zn (max. 22800 µg kg^{-1} FW in potatoes).

For As, Cd, Hg and Pb no increased exposure is desirable. Highest predicted concentrations of As were in leafy vegetables (77.8 µg kg^{-1} FW), of Cd in potato (104 µg kg^{-1} FW), of Hg in root vegetables (1.5 µg kg^{-1} FW) and of Pb in leafy vegetables (296 µg kg^{-1} FW), respectively. PTE concentrations in the growth medium and thus also predicted concentrations in vegetables and fruits are in between those of the two previous simulations.

Table 8.3.2.3-3 PEC for the selected PTEs in vegetables and garden fruits, presented as µg kg^{-1} FW, grown in organic growing media ML CE-marked products (EU regulation) (Scenario C3).

	Growing media	Potato	Leafy vegetables	Root vegetables	Garden fruits
As	40.0	38.4	77.8	35.2	4.7
Cd	1.5	104	29.5	10.6	8.0
Cr(VI)	2.0	2.4	0.9	1.1	n.i.
Cu	200	11520	4752	4400	n.i.
Hg	1.00	0.48	0.43	1.54	0.59
Ni	50.0	240	86.4	44.0	17.7
Pb	120	230	296	145	n.i.
Zn	500	22800	6750	2420	1357

8.3.3 Evaluation of concentrations and PEC in cultivated mushrooms

For people often eating mushrooms, cultivated mushrooms might be an important part of the diet, and exposure of PTEs through cultivated mushroom might be an extra PTE exposure source. We have little information about expected PTE concentration in relevant substrates based on recycled resources and for the present estimations, MLs for organic fertilisers quality class 0 and 2 and CE-labelled growing media (same as for urban farming and home growing vegetables) were chosen. For selection of TFs for calculating $PEC_{mushroom}$ for Cd, Cu and Zn (Koutrotisios et al., 2020) and for Hg (Falandysz and Gucia, 2008), see section 6.2.1.

Relevant literature showing measured concentrations of selected PTEs in edible mushroom and corresponding substrate concentration is shown in Table 8.3.3-2. Since TFs for estimating predicted concentrations of PTEs in mushroom with relevance for the present assessment were not available, measured values from two studies cultivating oyster mushroom on agro-industrial wastes is presented (Table 8.3.3-1). These values, in fresh weight, are used for evaluating cultivated mushroom as an additional PTE source for mushroom enthusiasts.

$PEC_{mushroom}$ for Cd, Cu, Hg and Zn (selected those showing bioaccumulation, see section 6.2.1), TFs from different papers are applied (Cd, Cu and Zn from Koutrotsios et al., 2020, and Hg from Falandysz and Gucia, 2008). Predicted concentration in mushrooms cultivated on substrates containing PTEs with MLs for Norwegian regulation of organic fertilisers quality class 0 and 2, and MLs for CE-labelled growing media is shown in Table 8.3.3-1.

Compared to reported measured values in the literature (Table 8.3.3-2), the predicted values were very high. According to literature, TFs for instance Cd tend to decrease with concentration in substrate, indicating regulatory mechanisms (Favero et al., 1990; Seyfferth et al., 2016; Koutrotsios et al., 2020) and there is no clear linearity in concentration in substrates and mushroom. Thus, the predicted values probably overestimate the values expected to find by comparing measure values from literature. However, the high bioaccumulation factors reported for Cd, Cu, Hg and Zn (Sakellari et al., 2019; Koutrotsios et al., 2020; Kojta et al., 2012; Chojnacka et al., 2013) give reason to call for more knowledge of transfer of these elements to cultivated mushroom, and if people with high intake of cultivated mushroom have an additional exposure source for these PTEs.

Table 8.3.3-1. Estimated concentrations in mushrooms ($PEC_{mushroom}$), given as mg kg^{-1} DW, based on selected TFs for Cd, Cu, Hg and Zn (Table 6.2.2-3) and MLs for Norwegian organic fertilisers quality class 0 and II (Table 3.1.1-2) and CE-labelled growth medium (EU regulation (Table 3.1.2-1).

		Cd	Cu	Hg	Zn
Quality class 0	ML	0.4	50	0.2	150
	$PEC_{mushroom}$	2.1	280	3.2	1155
Quality class II	ML	2	650	3	800
	$PEC_{mushroom}$	10.4	3640	48	6160

		Cd	**Cu**	**Hg**	**Zn**
CE-labled	ML	1.5	200	1	500
	PEC$_{\text{mushroom}}$	7.8	1120	16	3850

Table 8.3.3-2. Measured concentrations of PTEs in edible mushrooms from different papers. In the literature the concentration in most papers were given as mg kg^{-1} DW and based a general assumption of 10% DW (Kalać, 2019; Siwulski et al, 2017; Mleczek et al., 2018), values are also presented as mg kg^{-1} FW.

	Measured conc. in mushroom		**Measured conc. in substrate**	**Ref.**
	mg kg^{-1} DW^{-1}	**mg kg^{-1} FW^{-1}**	**mg kg^{-1} DW^{-1}**	
Cd	0.30-0.62	0.03-0.062	0.09-0.23	2
Cd	1.1-**4.9**	0.11-0.49	0.36-**2.3**	3
Cd	0.28-0.31; 0.31-0.48	0.028-0.031; 0.031-0.048	0.05-0.09; 0.07-0.18	1
Cd	0.58; 0.68	0.058; 0.068	0.56; 0.55	4
Crtot	0.10-0.80	0.01.0-0.08	0.92-2.6	3
Crtotal	0.15-0.29; 0.20-0.26	0.015-0.029; 0.02-0.026	9.8-16; 15-58	1
Crtotal	21.0; 19.0	2.1; 1.9	18.3; 16.6	4
Cu	15.86-39.05	1.59-3.91	5.67-27.28	2
Cu	100-200	10-20	0.95-5.7	3
Cu	7.4-53; 20-35	0.74-5.3; 2.0-3.5	1.7-9.9; 5.2-9.0	1
Cu	72.8; 26.3	7.28; 2.63		
Hg	0.57; 0.95	0.057; 0.095	0.57; 0.95	4
Hg	2.7- 7.0	<LOD, 0.27-0.7		6
Ni	<0.01, 0.15-0.43	<LOD, 0.015-0.043	0.74-2.1	3
Ni	0.19-0.41; 0.33-1.7	0.019-0.041; 0.033-0.017		1
Ni	0.28-0.69	0.028-0.069	3.46-93.95	2
Pb	1.9-8.5	0.19-0.85	6.8-16	3
Pb	0.01-0.15; 0.43-0.51	0.001-0.15; 0.043-0.051	0.66-1.2; 11-41	1
Pb	3.08; 2.15	0.308; 0.215	5.2; 4.3	4
Zn	75.83; 96.56	7.58; 9.66		5
Zn	73.38-118.26	7.34-11.83	1.76-75.03	2
Zn	74-190	7.4-19.0	06.07.1946	3
Zn	56-125; 74-107	5.6-12.5; 7.4-10.7	18-21; 26-47	1
Zn	92; 66	9.2; 6.6	29.3; 22.6	4

[1] Sakellari et al., 2019, *P.ostreatus*; [2]Koutrotsios et al., 2020. *P. ostreatus;* [3]Gucia et al., 2012 (collected, wilde), Parasol Mushroom, Macrolepiota procera, Champigong family; [4]Siwulski et al., 2019, *Pleurotus eryngi*j; [5]Alonso et al., 2003 (collected, wild, 28 species collected from soil incl. *Agaricus bisporus* and *Pleorotus ostreatus*); [6]Falandysz et al., 2007; Falandysz and Gucia, 2008.

8.3.4 Comparison with earlier risk assessments

VKM has previous performed environmental and health risk assessment related to the potential hazardous compounds in fertilisers and soil improvers; Risk assessment of contaminants in sewage sludge applied on Norwegian soil (VKM, 2009), Zn and Cu in pig and poultry production – fate and effects in the food chain and the environment (VKM, 2014b), and Risk assessment of cadmium in mineral fertilisers - fate and effects in the food chain and the environment in Norway (VKM, 2019).

There were some differences between the present and the Cd risk assessment from 2019. In 2019, another approach for selection of TF was used, resulting to different TFs. The applied dry weight content in crop in the Cd risk assessment were the same as used in risk assessment about sewage sludge (VKM, 2009), while in the present assessment, we have used realistic numbers from nutrition tables (NFSA, Norwegian Food Composition Database 2020). In addition, in 2019 the present agricultural concentration in soil in Hedmark and alum shale was presented differently, showing the highest impact on the difference between these risk assessments (see comparison parameters 2019 and 2022 in Table 8.3.4-1). In 2019 all alum shale soil data originated from Stange (Joner, personal communication and unpublished data), in this study additional data is used from Hamar, Ås, Løten, Østre Toten and Ringsaker (Esser 1996; HIAS personal communication): The data foundation has those increased from 32 sample sites to 71 sites, which still is low but better than what used in 2019.

The applied distribution coefficient, Kd, for Cu was in the medium range, with lowest value in Time (805 L kg^{-1}) and for the other regions in the range of 915 L kg^{-1} (Målselv) and 1079 L kg^{-1} (alum shale). In the Cu and Zn report published by VKM (2014b), Kd used in Time was much lower (448 L kg^{-1}), while the Kd in Melhus was comparable with Kd used in the present assessment. In the previous risk assessment, a higher application of manure (70 kg P ha^{-1} yr^{-1}) as a realistic worst case was included. This might indicate that the estimate for applied manure is not a worst-case scenario in all regions.

Transfer to crops, determined by the selected TFs, is highest for cereals (based on FW basis which human exposure is based on), however, based on DW the highest estimated transfer is to potato and carrot. In the risk assessment from 2014, the TFs for cereals is higher than the present assessment (0.26 versus 0.15 based on DW), while for TFs for potato were opposite (0.09 and 0.24).

With the lower present Cd concentration in alum shale soil, the risk concentration ratio (RCR) no longer indicates a risk for secondary poisoning in terrestrial food chains. For aquatic organisms the risk characterisation ratio (RCR) is also reduced, but remains above 1, which indicates a risk for adverse effects.

Table 8.3.4-1. Comparison of predicted concentration of Cd in selected crops, presented as µg kg^{-1} FW from risk assessment from Cd (2019) and current assessment, together with used Cd concentration in soil, in Hedmark region.

	TF	**DW%**	**TF**	**DW%**
	2019[1]		**2022[2]**	
Present soil mg/kg DW				
Stange	0.4 (Whole region)		0.13	
Alum shale	1.7		0.84	
Plants				
Carrot Root vegetables	0.25	30	0.064	11
Potato	0.27	30	0.29	24
Cereals	0.165	85	0.11	85
Grass	0.36	20	0.23	20
Leafy vegetables	0.364	30	0.364	54

[1]TFs and DW% content used in risk assessment of Cd in mineral P fertilisers (VKM 2019 Table 7.2-1.). [2]TFs and DW% content used in the present risk assessment.

8.3.5 Comparison with measured data of PTE in fields

To verify estimates for the concentrations in crops and vegetables, measured data from Norway and elsewhere were collected and compared to the estimated PEC$_{\text{plants}}$. Few measured data are available, but several studies from the 1990s were very useful, particularly for the alum shale area. It can be argued that concentrations in soil change only slowly, thus, these data can still be used. However, aerial deposition has declined in the last decades (e.g., lead, Legind et al. 2011). When aerial deposition is of relevance for concentrations in crops, the comparison to old data needs to be done with care.

Concentrations of PTE in plant material typically show large variations, even for samples taken from the same crop and at the same site. This is due to the many processes and parameters that affect concentrations of chemicals in plants, including - fluctuating concentrations in soils, soil properties (pH, SOM, clay content), deposition from air, meteorological factors, and plant properties, such as water content, biomass, growth rate, transpiration and rooting depths (Trapp 2015). For example, the TF values of Cd from soil to wheat of 175 samples reported by Novotna et al. (2015) ranged from 0.02 to 2.33 kg kg^{-1} DW (factor 112), with a median of 0.17 and a mean of 0.24 kg kg^{-1} DW. Individual samples may thus be far off the predicted or expected concentration in plant. Table 8.3.5-1 compares the predicted concentrations of PTE in Norwegian crops with those measured in various studies, mostly from Norway, and if those were not available then from other countries, preferably Sweden or Denmark.

The first part of the Table shows the comparison from measured to predicted concentrations for cereals, and the few available for grass. For cereals, measured values for all PTEs except Hg were available for wheat, barley and oat. For grass, only measured values for Cd were found. There is only a small difference between the concentrations measured in the various cereals (W = wheat, B = barley, O = oats), the PECs are within the reported range (often LOD), and there is generally a good agreement between predicted and measured concentrations in grains. For As, the PEC overlaps with the data from Denmark. For Cd, the PEC is in good agreement and the higher concentrations in alum are well reflected by the estimation. For Cu, concentrations are well predicted, including the alum shale region. For Ni, there is a tendency to underestimate the data reported for Norwegian grains, while those for wheat and barley in Sweden (wheat grains mean 0.15 mg kg^{-1} FW, barley 0.06 mg kg^{-1} FW, Hamner et al. 2013) are within the predicted range. Predicted concentrations of Pb in grains are mostly within the measured concentration range, those of Zn below but close to the measured range.

The second part of the Table 8.3.5-1 shows the comparison measured to predicted concentrations for potatoes and carrots. For As, no Norwegian data could be retrieved, but measured data from Denmark is in agreement with the PEC_{plants} for potato, which are lower than those of carrot. For Cd, a lot of measured data in potatoes and carrots were available. Predicted Cd concentration in potato is overestimated compared to the measured Norwegian values, but in good agreement with data reported from Denmark. For carrots, the PEC is underestimated both for alum shale and the other regions. This indicates that the TF-value for carrots (0.064 kg kg^{-1} DW), originating from the US EPA (1996) soil screening guidance, is too low. Interestingly, this has been reported earlier by Legind and Trapp (2010). Using their transfer factor for carrots (0.25 kg kg^{-1} DW) would result in PEC carrots within the range of reported values (calculated 2.3-5.9 µg kg^{-1} FW, measured 2.1 – 68 µg kg^{-1} FW). The authors write that "The US EPA model tends to underestimate the concentration of Cd in carrot and lettuce, and Pb in carrot." (Legind and Trapp 2010). For Cu, the predicted and measured concentrations in potato and carrot are in good agreement, even though PEC carrot for the alum shale is slightly overestimated. For Ni, a lot of data from Norway, as well as, from Denmark is available, and the agreement between measured and predicted concentrations is appropriate for potato, while for carrot on no-alum shale concentrations are underestimated. However, reported measured data also show a wide range. For lead, PEC_{plants} tend to be overestimated, thus, the finding of Legind and Trapp (2010) (underprediction of carrot with the US EPA TF) cannot be confirmed. Concentrations of Zn in vegetables are the highest of all PTE. The prediction is close, but for carrots, it is below the measured range.

The studies of Mellum et al. (1998) and Singh et al. (1995) focus specifically on the difference between alum shale and other areas ("moraine"). Interestingly, the measured concentrations of PTE in vegetables or crops grown in the alum shale do not differ significantly as expected from the typically higher concentrations of PTE in these soils. One reason may be that the clay and organic carbon contents in these soils are above mean (Schovsbo et al., 2018), and thus the adsorption to soils may be higher than in moraine soils. Another reason is that PTE stemming from geogenic sources (i.e., from weathering of rocks and minerals) are less bioavailable than freshly added PTE as salts or within easily degradable organic matter (manure), and thus transfer into plants is reduced.

Overall, the comparison of estimated and measured concentrations in crops is satisfactory, despite a few obvious deviations. To predict the concentrations in crops correctly requires that concentrations in soil are representative for the investigated areas, and that the transfer factors chosen for the crops are representative for the crops grown in the areas. Given the mentioned large variations, both in soil and crop concentrations, and the many influencing parameters, processes and factors, a successful prediction of PTE concentrations require sufficient expertise.

Table 8.3.5-1. Measured and predicted concentration (PEC) in **A)** cereals and grass and **B)** potato and carrot for As, Cd, Cu, Ni, Pb and Zn, given as mg kg^{-1} FW or µg kg^{-1} FW. Measured values of crops cultivated on alum shale and not alum shale soil is shown. A) data for potato and carrot, and B) data for cereals and grass. If insufficient data from Norway were found, international data are shown instead (mostly Denmark). PEC: predicted for present soil concentration in all regions.

A) Cereals & Grass		**Cereals (grain)**		**Grass**	
		Not alum shale	**Alum shale**	**Not alum shale**	**Alum shale**
As µg kg^{-1} FW	Measured International	9-85[5]			
	PEC present	35-66	33	12-22	11
Cd µg kg^{-1} FW	Measured Norway	W: 20-55[1]; B: 10-12[1] O: 9-68[1]	26-238[9]		
	PEC present	12-30	121	4-10	39
Cu mg kg^{-1} FW	Measured Norway	2.7-3.9[4]	0.51-6.0[9]; 3.4-4.8[4]		
	PEC present	1.66-2.38	5.1	0.42-0.76	1.63
Ni mg kg^{-1} FW	Measured international	W: 0.15[3]; B: 0.06[3]; O: 1.0[3]			
	Measured Norway	0.65-1.18[4]	0.56-1.1[4]; 0.00-9.4 (mean 0.43)[9]		
	PEC present	0.025-0.156	0.35	0.036-0.23	0.51
Pb µg kg^{-1} FW	Measured Norway	6-9 (W), 14-19 (B), 17-58 (O)[1]	17-179[9]		
	PEC present	25-98	85	12-46	40
Zn mg kg^{-1} FW	Measured Norway	23.3-40.6[4]; 26.4-32.3[1]	8.2-13.7[9] 31.3-36.7[4]		
	PEC present	9.5-21.3	29	1.8-4.1	5.5

B) Vegetables		**Potato**		**Carrot**	
		not alum	**alum**	**not alum**	**alum**
As µg kg^{-1} FW	Measured International	<1.1-1.8[7]; <1-10[8]		7-63[8]	
	Measured Norway	nd	nd	nd	nd
	PEC present	1-3	14	1-3	13
Cd µg kg^{-1} FW	Measured Norway	0.72[2]	19[6]; 32[6]; 65[6]; 12-67[9]		95[6]
	Measured International	12-33[7]; 0.8-37.6[8]		2.1-62.8[8]	

B) Vegetables		**Potato**		**Carrot**	
		not alum	**alum**	**not alum**	**alum**
	PEC present	5.7-14.6	58	0.6-1.5 US EPA; 2.3-5.9 (Legind & Trapp)	6.0
Cu mg kg^{-1} FW	Measured Norway		0.79-1.44[9]; 1.3-2.9[6]	0.34-0.47[4]	0.27-0.34[4]; 0.45[6]
	PEC present	0.6-1.2	2.5-5.4	0.24-0.44	0.95-2.1
Ni mg kg^{-1} FW	Measured Norway	0.07-0.12[4]	0.05-0.58[9]	0.03-0.16[4]; 0.35[6]	0.08-0.19[4]
	Measured International	0.013-0.035[7];0.004-0.365, median 0.017[8]		0.013-0.145[8]	
	PEC present	0.017-0.11	0.24	0.003-0.02	0.045
Pb µg kg^{-1} FW	Measured Norway	n.d.[6]	5-19[9]; 3.2; 7.2; <LOD[6]	n.d.[6]	2.8[6]
	Measured International	< 1.2-2.7[7]; <0.8-7.2[8]		0.5-34[8]	
	PEC present	11.5-44.2	38.4	7.3-27.8	24.2
Zn mg kg^{-1} FW	Measured Norway		2.3-3.9[9]	2.2-3.7[4]	1.8-2.2[4]
	PEC present	1.6-3.7	5.0	0.17-0.39	0.53

[1] div ref. NIBIO data for cereals; [2] Bærug and Singh (1990); [3] Hamner et al. (2013); [4] Singh et al. (1995); [5] Dansk Fødevarestyrelsen 2011: Uorganisk arsen i cerealier; [6] Salbu et al. (2013); [7] Dansk Fødevarestyrelsen and Danmarks Fødevareforskning 2005. CKL project: Sporelemente i kartofler. [8] Danish Food and Veterinary Administration. Food monitoring, 1998-2003; [9] Mellum et al. (1998). W = wheat, b = barley, o = oat.

8.4 Exposure of farm animals

For herbivorous domestic animals on pasture, such as cattle, sheep, goat and horse, their whole ration may be comprised of pasture plants. However, dairy cattle and goat usually receive grain-based feed (compound feed), also when at pasture, ranging from 0 to about 1/3 of total DW intake. According to Norwegian legislation, cattle must be kept outside for at least 8 weeks per year, and sheep and goats at least 16 weeks per year. Sheep, goat, and horse usually graze rough grass, but cattle may often graze on fertilised areas.

Animals at pasture usually ingest some soil. Soil intake may depend on the pasture quality and the mineral needs of the animals. The intake of soil is supposed to constitute up to some percentages (5 %) of the DW ration.

Table 8.4-1. Intake of farm animals (dry weight (DW)) related to body weight and their relatively intake of compound feed, roughage and soil.

Animal species and age group	Percent DW intake related to body weight	Grazing animals			Fed animals		
		Ratio of total intake (DW)			Ratio of total intake (DW)		
		Compound feed	Roughage	Soil	Compound feed	Roughage	Soil
Cattle							
Calves	3.0	0.10	0.85	0.05	0.25	0.75	0
Young heifers	2.7	0.10	0.85	0.05	0.25	0.75	0
Dry cattle	1.7	0.10	0.85	0.05	0.15	0.85	0
High-lactation cattle	4.0	0.50	0.45	0.05	0.5	0.50	0
Sheep							
Early weaned lambs	5.0	0	0.95	0.05	0.25	0.75	0
Finishing lambs	4.0	0	0.95	0.05	0.25	0.75	0
Adult sheep, maintenance	2.0	0	0.95	0.05	0.25	0.75	0
Adult sheep with twins	4.0	0	0.95	0.05	0.25	0.75	0
Goats							
Kids	3.5	0.10	0.85	0.05	0.25	0.75	0
Adult goats, maintenance	2.0	0.10	0.85	0.05	0.25	0.75	0
Adult lactating goats	6.0	0.50	0.45	0.05	0.50	0.50	0
Horses							
Adult maintenance	1.5	0.25	0.70	0.05	0.30	0.70	0
Mares in lactation	3.0	0.25	0.70	0.05	0.30	0.70	0
Pigs							
Piglets	10.0				1.00	0	0
Growing pigs	4.0				1.00	0	0
Adult pigs, maintenance	1.2				1.00	0	0
Lactating sow	3.2				1.00	0	0
Poultry					1.00		
Growing chickens	10.0				1.00	0	0
Laying hens	6.0				1.00	0	0
Broiler parents	6.0				1.00	0	0
Turkey	6.0				1.00	0	0

Because the levels of potentially toxic elements are generally higher in soil than in grazing and fodder plants, intake of soil when grazing will give a significant contribution to the total intake. Consequently, the total exposure of elements is generally somewhat higher in periods of grazing than for fed animals.

Omnivorous animals, such as poultry and pigs, may ingest grass and other vegetables when outside. They may also ingest considerable amounts of soil and soil organisms, such as earthworms.

For herbivorous domestic animals, such as cattle, sheep, goat, and horse receiving feedstuff, forage constitutes the main part of the ration. In addition, compound feed (grain-based feed) or in some cases, potatoes etc, are fed (up to about 50 % of the DW ration; see Table 8.4-1.).

Small grains, oil seeds, an array of pulses, and some maizes are common ingredients in pig feed and are usually grown on fertilised soil. The main ingredients in poultry feeds are small grains, pulses, and maize. The normal amounts of dietary intake relative to the body weight of different livestock species at different physiological stages are shown in Table 8.4-1. The table also shows the common composition of diets for grazing and fed animals. These data are adapted to Norwegian conditions. EFSA has recently published a report on animal dietary exposure with overview of current approaches used at EFSA (EFSA, 2019). The Norwegian figures agree with those used by EFSA.

Predicted intake of potentially toxic elements in ruminants and horses via grazing or feeding at present and after up to 100 years with use of the various organic fertilising regimes in the various regions are calculated. If pigs and poultry are given a diet correspondingly grown at fertilised soil, they will be similarly exposed to the elements. However, most pigs and poultry are fed commercial compound feed, and these species are not included in this assessment.

The results of estimated concentrations in plants and, in feed and forage are expressed by DW.

8.4.1 Animal exposure of arsenic (As)

In all regions, the background As levels in animal diets from pasture and feeding are below a maximum tolerable level. By most fertilisation schemes, a further decline in these levels is estimated. The exception is Stange, where an increase at 130 % by fertilisation scheme #2 (organic fertiliser quality class II with maximum PTE levels) and marginal increases at 3-6 % by fertilisation schemes #4, 5, 6, 9 and 10 after 100 years are expected. Thus, also fish sludge (#6) gives a marginal increase. None of the increments imply health risk for the farm animals.

8.4.2 Animal exposure of cadmium (Cd)

By most fertilisations and regions, Cd levels in animal diet are estimated to decline or are averagely at steady state after 100 years. Thus, there are only a few fertilising schemes where an increment of Cd is expected. For fertilisation schemes #2 (organic fertiliser quality class II with maximum PTE levels), there will be an increase at Stange, Ås, Melhus and Målselv regions. At Stange, this increment of Cd in total diets for grazing and fed animals will be about 160%, and respective 15-, 90- and 70% at Ås, Melhus and Målselv. Furthermore, for fertilisation scheme #3 (averagely contaminated sewage sludge) an increment at ca 70 % is estimated in Stange and 10% in Melhus. In Stange, fertilisation schemes #0b, #1, #4 and #8 are expected to increase dietary Cd between 10 - 40%.

In the alum shale area, no significant change in Cd for fertilisation scheme #2 is estimated.

For all other fertilisations, an either decline or no change in Cd is expected. In the alum shale area, a decline is particularly possible as the basic Cd level is relatively high. In fact, the highest Cd levels in animal diet will be found in the alum shale area, where the background levels are much higher than any increase due to organic fertilisers. The total dietary Cd level for grazing animals in this area is about 0.22 mg kg^{-1}, whereas the highest increase by fertilisation #2 in Stange at 160% means dietary levels up to levels still below 0.1 mg kg^{-1} after 100 years. Thus, the maximum Cd levels in animal diet will anyway be below 1 mg kg^{-1} diet DW, the upper limit set by WHO.

8.4.3 Animal exposure of chromium (Cr)

In all regions, the background Cr levels in animal diets from pasture and feeding are far below a maximum tolerable level. By most fertilisation schemes, a further decline in these levels is estimated. The exception is scheme #2 which implies an increase in most regions, with up to 60-70% at Stange and Time, and somewhat lower increases at the alum shale area, Ås and Målselv, and steady state in Melhus. A certain, but less increase is also estimated at Stange by fertiliser schemes #3, 8 and 9. The increases imply no health risk for farm animals as the Cr is the trivalent form.

8.4.4 Animal exposure of copper (Cu)

For Cu, scenario #2 (organic fertiliser quality class II with maximum PTE levels) implies a sharp increase in most regions during 100 years. At Stange, Ås, Time, Melhus and Målselv, the estimated Cu in animal diet will increase between 220 and 450%. This results in total dietary levels of about 15 mg kg^{-1} for grazing animals at Stange; and between 11 and 15 mg kg^{-1} at Ås, Time, Melhus and Målselv. For fertiliser scheme #3 (sewage sludge with mean Cu) at Stange, Ås, Time and Målselv, the estimated 100 years increase will be between 70 and 110%, and at Melhus 40%. In the alum shale area, the estimated increment by #2 is 120%, up to about 22 mg kg^{-1}, and by #3 an increment of 22% up to 12 mg kg^{-1} in total diet for grazing animals is estimated.

Furthermore, using manure from pigs with maximum Cu, the estimated increase of Cu after 100 years is 170% at Stange, 40% at the alum shale area, 120% at Time, and about 60% at Melhus and Målselv. Because of the relative high Cu background levels at the alum shale area, this increase will elevate the dietary concentration for grazing animals in this area to about 14 mg kg^{-1}. For other regions, the corresponding dietary concentrations will be safely lower. By using manure from cattle in various regions, only marginal increase of Cu is expected.

For the rest of the scenarios estimated, increments of Cu are lower than those discussed above, steady state or reduced.

By use of organic fertiliser quality class II with maximum PTE levels (#2), after 100 years at Stange and the alum shale area in particular, the soils are expected to contain elevated Cu levels, that is considered harmful for grazing sheep. For other farm animals, these levels imply no health risk. Manure fertiliser (#4) from pigs at the alum shale area may also increase the Cu to levels at risk for sheep.

The levels of Cu in animal diets by use of manure and various other organic fertilisers for up to 100 years will (except the scenarios creating health risk to sheep), not adversely exceed the animals´ requirement for Cu. Thus, occurrence of levels that potentially could create microbial resistance in animal guts and environment against Cu and possible co-resistance against antimicrobial drugs, is not likely.

8.4.5 Animal exposure of mercury (Hg)

In all selected geographical regions, the current Hg levels in feed and pasture plants including soil, and thus the animal diet, are below a suggested critical level of concern for health of studied animals. By organic fertiliser quality class II with maximum PTE levels (#2), a dramatic increase of Hg is estimated in all regions. After 100 years, the expected increase is about 10 times at Stange, alum shale area, Melhus and Målselv, and slightly less (6 times) at Ås and Time. The levels in animal pasture diet will rise to about 0.03 or maximum 0.04 mg kg^{-1} at the various regions. By fertiliser schemes #3 and 8, lower increases are estimated: 1-4 times during 100 years in various regions. Despite the increments, the dietary levels will still be below levels considered to be critical for animal health.

8.4.6 Animal exposure of nickel (Ni)

The background levels of Ni are far below a critical level for animal health concern, and a decline by all scenarios is estimated.

8.4.7 Animal exposure of lead (Pb)

In all selected geographical regions, the current Pb levels in feed and pasture plants including soil, and thus animal diet, are below a suggested critical level of concern for animal health and also below a level of concern for consumers of animal products.

By organic fertiliser quality class II with maximum PTE levels (#2), an increase of Pb is estimated at all regions - about doubling the levels at Stange, Melhus and Målselv after 100 years and somewhat less increase in the other regions. Further, some other fertilisation schemes (#3, 9) seem to increase Pb to a marginal degree above the atmospheric deposition. The levels in animal pasture diet will rise to between 1 and 2 mg kg^{-1} at the various regions, which is below a level of animal health concern.

8.4.8 Animal exposure of zinc (Zn)

Background levels of Zn are below animal health concern.

For Zn, fertiliser #2 (organic fertiliser quality class II with maximum PTE levels) implies increase at all regions during 100 years. At Stange, alum shale area, Ås, Time, Melhus and Målselv, the respective estimated increments are 160, 50, 50, 20, 80 and 90%.

Furthermore, #4 at Stange and the alum shale area (pig manure), implies estimated increase of 430 and 160%, respectively, which means that the diet of grazing animals at Stange and the alum shale area will contain up to respective 70 and 85 mg Zn kg^{-1}, which are still below levels for animal health concern.

Fertiliser schemes #3 (averagely contaminated sewage sludge), #5 (averagely contaminated pig manure) and #8 (digestate food) at Stange will increase Zn by 70, 170 and 100%, respectively. Use of pig manure instead of cattle manure also at other regions will increase the Zn level in soil and thus, in animal diets from these soils, but resulting in lower levels than at Stange and the alum shale area. For all other scenarios estimated, a marginal Zn increment, steady state or decline are expected.

The levels of Zn in animal diets by use of manure and various other organic fertilisers for up to 100 years will not adversely exceed the animals´ requirement for Zn. Thus, occurrence of Zn levels that potentially could create microbial resistance in animal guts and environment against Zn and possibly co-resistance against antimicrobial drugs is not very likely.

8.5 Exposure assessment humans

The significance of use of fertilisers on human exposure to PTE has been assessed by evaluating the potential change in plant concentrations and comparing the contribution of these plants to previously estimated total dietary intake of each element. This simplified approach has been considered as appropriate to evaluate the significance of an altered dietary intake of each element following the use of fertilisers.

8.5.1 Arsenic (As)

In general, the As concentration in agricultural crops (wheat, carrots and potatoes) will have a time-dependent decrease in most of the scenarios (Table 8.3.1.1-1 and Tables AVII-1 to -3). In a 10-year perspective, the estimated concentrations will remain at a similar level or decrease, while in a 100-year perspective, the concentrations will decrease. In fertiliser scenario 2, As concentration will increase in crops grown at Målselv, Melhus and Stange.

The use of engineered soil in home gardening will lead to a small increase in As concentrations in lettuce, carrot, tomato and potato in a 50-year perspective (Table 8.3.2.1-1), while the use of engineered soil in urban farming and market gardens will increase As concentrations in potato, leaf vegetables, root vegetables and garden fruits in a 100-year perspective (8.3.2.2-1).

The As concentration in vegetables (potato, lettuce and carrot) and garden fruits grown in growing media depends on the As concentration in the growing media (Tables 8.3.2.3-1; 8.3.2.3-2 and 8.3.2.3-3). The concentration in crops increase with increasing concentrations in the growing media.

8.5.2 Cadmium (Cd)

The modelling indicates an increase in Cd concentration in wheat, potatoes and carrot, when applying fertiliser scenario 2 at Målselv, Melhus and Stange locations in a 10- and 100-year perspective (Table 8.3.12-3 and Tables AVII-5 to –7). In all other scenarios (fertiliser, location and time), a decrease or no change in Cd content in wheat, potatoes and carrots (Table 8.3.12-3 and Tables AVII-5 to –7) is shown.

The use of engineered soil in home gardening will lead to a small increase in Cd concentrations in lettuce, carrot, tomato and potato in a 50-year perspective (Table 8.3.2.1-2), while the use of engineered soil in urban farming and market gardens will increase the Cd concentrations in potato, leaf vegetables, root vegetables and garden fruits in a 100-year perspective (8.3.2.2-2).

Cadmium concentration in vegetables (potato, lettuce and carrot) and garden fruits grown in growing media depends on the Cd concentration in the growing media (Tables 8.3.2.3-1; 8.3.2.3-2 and 8.3.2.3-3). The concentration in crops increase with increasing concentration in growing media. Similar for mushrooms grown on growing media (Table 8.3.3.-1), the Cd concentration in mushroom increase with increasing Cd concentration in the growing media.

8.5.3 Chromium (Cr)

The modelling indicates an increase in Cr content in wheat, potatoes and carrot at Målselv, Stange, alum shale, Ås and Time, when evaluating organic fertiliser regulation quality class II (#2), but not in Melhus (no change). The modelling also indicates a small increase at Stange following scenario #3, sewage sludge containing the current medium Cr concentration. For other locations and other fertilising schemes, the models indicate a decrease or no change (see Table 8.3.1.3-1 and Table AVII-9 - Table AVII-12).

The use of engineered soil in home gardening or urban farming and market gardens may lead to a very small increase in potato, carrot (and lettuce) in a 50-year perspective, while the use of engineered soil in urban farming and market gardens may increase Cr concentrations in potato, leafy vegetables, root vegetables and garden fruits in a 100 year perspective (Tables 8.3.2.1-3 and 8.3.2.2-3). The modelled changes are, however, very small (generally <10).

8.5.4 Copper (Cu)

Evaluating quality class II organic fertiliser regulation for Cu leads to a considerable increase of in Cu levels in the modelled crop plants at all locations except Time (see Table 8.3.1.4-1 and Table AVII-13 – AVII-16). The increase is up to 3-4-fold in Målselv and Melhus, but due to the high Cu concentrations currently at Stange, the modelled concentrations after 100 years application are still highest at Stange where the increase is about 2-fold. Even the use of sewage sludge containing current mean Cu concentrations (scenario 3), will increase the Cu concentrations in crop plants in these locations. For the other scenarios, the changes from the present Cu concentrations are small. Even at scenario 4, the current practice of pig/cattle manure with maximum concentrations is expected to result in increasing Cu concentrations in wheat, potatoes and carrots at Målselv, Melhus and both Stange scenarios (Table AVII-13 – AVII-16). At Ås and Time, the model also predicts an increase in Cu concentrations in crop plants, also for scenarios 5-10. But, from a lower starting point than the other locations and the modelled increase of up to 50% in a 100-year perspective is still not exceeding present predicted levels at the other locations. However, still at the end of the period, the predicted concentrations are well below the current concentrations of Cu in normal crop land (Table 8.3.1.4-1).

8.5.5 Mercury (Hg)

For agricultural crops, mercury concentration will increase in wheat, carrots and potatoes at all locations, depending on time (Table 8.3.1.5-1 and Tables AVII-17- to –19.). In a 100-year perspective, the estimated concentrations will increase in crops where all fertiliser scenarios were applied (numbers 2-4, 6-9 and 11-12). The largest increases are seen for evaluation of organic fertiliser regulation quality class II (#2) and digestate based on food waste (#8). In these scenarious, mercury concentrations are expected to increase in crops in a 10-year perspective.

The use of engineered soil in home gardening will lead to an increase in mercury concentrations in lettuce, tomato, carrot and potato in a 10- and 50-year perspective (Table 8.3.2.1-5), while the use of engineered soil in urban gardening and market gardens will increase mercury concentrations in potato, leafy vegetables, root vegetables and garden fruits in a 10- and 100-year perspective (Table 8.3.2.2-5).

Mercury concentration in vegetables (potato, lettuce, carrot and tomato) grown in growing media will depend on mercury concentration in the growing media (Tables 8.3.2.3-1; 8.3.2.3-2 and 8.3.2.3-3). The concentration in crops increase with increasing concentrations in the growing media.

8.5.6 Nickel (Ni)

The Ni concentrations in crop plants are predicted to decrease at all locations in all fertiliser application schemes (Table 8.3.1.6-1).

8.5.7 Lead (Pb)

Lead concentration will increase in agricultural crops (wheat, carrots and potatoes) at all locations, depending on time (Table 8.3.1.6-1 and Tables AVII-25 to -27). In a 100-year perspective, the estimated concentrations will increase in crops where all fertiliser scenarios are applied (numbers 2-10). The largest increases are seen for MLs and maximum allowed application of organic fertiliser according to quality class II. In a 10-year perspective, the estimated Pb concentrations in crops are estimated to increase, when applying fertiliser scenario number 2.

The use of engineered soil in home gardening will lead to an increase in Pb concentrations in lettuce, carrot and potato in a 10- and 50-year perspective (Table 8.3.2.1-7), while the use of engineered soil in urban farming and market gardens will increase Pb concentrations in potato, leaf vegetables and root vegetables in a 10- and 100-year perspective (8.3.2.2-7).

Lead concentration in vegetables (potato, lettuce and carrot) grown in growing media will depend on the Pb concentration in the growing media (Tables 8.3.2.3-1; 8.3.2.3-2 and 8.3.2.3-3). The concentration in crops increase with increasing concentrations in the growing media.

8.5.8 Zinc (Zn)

The concentration of Zn in crop plants are expected to increase considerably in all scenarios, except scenario 1. The models indicate an increase of up to 3 times the current concentration, depending on location and fertiliser scheme (Table 8.3.1.8).

9 Risk characterisation

The risk of adverse effects on organisms in the terrestrial and aquatic compartments of the environment, including sediments, have been assessed from measured or predicted environmental concentrations (PEC) of PTEs in soil, surface water and sediment and the predicted no effect concentrations (PNEC) in the same media. From these two parameters a risk characterisation ratio (RCR) has been calculated as $RCR = PEC/PNEC$. $RCR<1$ indicates no risk, while $RCR>1$ indicates a risk. In the assessment the risk has been further categorised as follows:

$RCR<1$	No risk
$1\leq RCR<2$	Low risk
$\leq 2RCR<5$	Significant risk
$RCR\geq 5$	High risk

9.1 Risk characterisation for terrestrial organisms

9.1.1 Direct exposure of terrestrial organisms

9.1.1.1 Arsenic (As)

For As in soil and all scenarios, except for evaluation of organic fertiliser regulation quality class II (#2), show declining As concentrations over the modelled 100 year period, indicating a decline in risk for soil-dwelling organisms relative to the present state.

RCR was calculated with a PNEC$_{add}$ approach for As. In essence, the added risk assessment approach assumes that species are fully adapted to the natural background concentration and therefore that only the anthropogenic added fraction should be regulated or controlled.

Risk characterization ratios (RCR) for As are <1 for all scenarios and regions indicating no risk to soil organisms.

Table 9.1.1.1-1 Risk Characterization Ratio (RCR) for direct exposure of terrestrial organisms to arsenic (As) in soil.

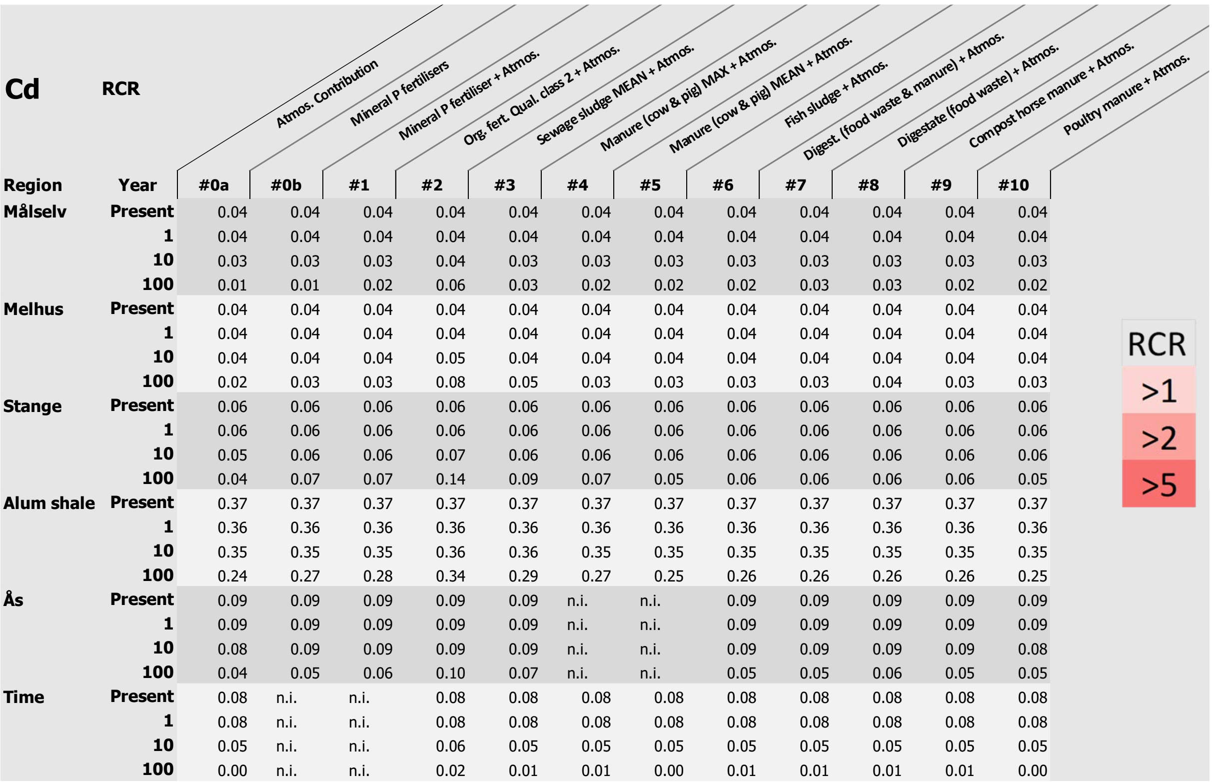
As	**RCR**	Only atmopheric contribution	Only mineral fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.36	0.36	0.36	0.36	n.i.	0.36	0.36	0.36	0.36	n.i.	0.36	0.36
	1	0.36	0.35	0.36	0.36	n.i.	0.36	0.36	0.36	0.36	n.i.	0.36	0.36
	10	0.35	0.35	0.35	0.38	n.i.	0.35	0.35	0.35	0.35	n.i.	0.35	0.35
	100	0.31	0.29	0.31	0.58	n.i.	0.32	0.32	0.33	0.31	n.i.	0.33	0.32
Melhus	**Present**	0.51	0.51	0.51	0.51	n.i.	0.51	0.51	0.51	0.51	n.i.	0.51	0.51
	1	0.51	0.51	0.51	0.51	n.i.	0.51	0.51	0.51	0.51	n.i.	0.51	0.51
	10	0.50	0.49	0.50	0.52	n.i.	0.50	0.50	0.50	0.50	n.i.	0.50	0.50
	100	0.39	0.38	0.40	0.59	n.i.	0.41	0.41	0.41	0.39	n.i.	0.41	0.41
Stange	**Present**	0.28	0.28	0.28	0.28	n.i.	0.28	0.28	0.28	0.28	n.i.	0.28	0.28
	1	0.27	0.27	0.27	0.28	n.i.	0.28	0.28	0.28	0.27	n.i.	0.28	0.28
	10	0.27	0.27	0.27	0.31	n.i.	0.28	0.28	0.28	0.27	n.i.	0.28	0.28
	100	0.27	0.25	0.27	0.62	n.i.	0.29	0.29	0.29	0.27	n.i.	0.29	0.28
Alum shale	**Present**	0.84	0.84	0.84	0.84	n.i.	0.84	0.84	0.84	0.84	n.i.	0.84	0.84
	1	0.84	0.84	0.84	0.84	n.i.	0.84	0.84	0.84	0.84	n.i.	0.84	0.84
	10	0.83	0.83	0.83	0.84	n.i.	0.83	0.83	0.83	0.83	n.i.	0.83	0.83
	100	0.75	0.75	0.75	0.83	n.i.	0.76	0.76	0.75	0.75	n.i.	0.76	0.75
Ås	**Present**	0.47	0.47	0.47	0.47	n.i.	n.i.	n.i.	0.47	0.47	n.i.	0.47	0.47
	1	0.46	0.46	0.46	0.47	n.i.	n.i.	n.i.	0.46	0.46	n.i.	0.46	0.46
	10	0.46	0.46	0.46	0.48	n.i.	n.i.	n.i.	0.46	0.46	n.i.	0.46	0.46
	100	0.39	0.37	0.39	0.59	n.i.	n.i.	n.i.	0.40	0.39	n.i.	0.40	0.40
Time	**Present**	0.41	n.i.	n.i.	0.41	n.i.	0.41	0.41	0.41	0.41	n.i.	0.41	0.41
	1	0.41	n.i.	n.i.	0.41	n.i.	0.41	0.41	0.41	0.41	n.i.	0.41	0.41
	10	0.38	n.i.	n.i.	0.42	n.i.	0.38	0.38	0.38	0.38	n.i.	0.38	0.38
	100	0.21	n.i.	n.i.	0.49	n.i.	0.23	0.23	0.23	0.21	n.i.	0.23	0.22

RCR
>1
>2
>5

9.1.1.2 Cadmium (Cd)

Cadmium shows accumulation in soil for scenario #0b, #1 and #4 in Stange, for scenario #2 in Målselv, Melhus, Stange and Ås, and for scenario #3 in Melhus and Stange. None of the scenarios result in RCR >1 and thus, Cd does not pose a risk to soil organisms.

Table 9.1.1.2-1. Risk Characterization Ratio (RCR) for direct exposure of terrestrial organisms to cadmium (Cd) in soil.



Cd	**RCR**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	1	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	10	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	100	0.01	0.01	0.02	0.06	0.03	0.02	0.02	0.02	0.03	0.03	0.02	0.02
Melhus	**Present**	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	1	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	10	0.04	0.04	0.04	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	100	0.02	0.03	0.03	0.08	0.05	0.03	0.03	0.03	0.03	0.04	0.03	0.03
Stange	**Present**	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	1	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	10	0.05	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	100	0.04	0.07	0.07	0.14	0.09	0.07	0.05	0.06	0.06	0.06	0.06	0.05
Alum shale	**Present**	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
	1	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
	10	0.35	0.35	0.35	0.36	0.36	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	100	0.24	0.27	0.28	0.34	0.29	0.27	0.25	0.26	0.26	0.26	0.26	0.25
Ås	**Present**	0.09	0.09	0.09	0.09	0.09	n.i.	n.i.	0.09	0.09	0.09	0.09	0.09
	1	0.09	0.09	0.09	0.09	0.09	n.i.	n.i.	0.09	0.09	0.09	0.09	0.09
	10	0.08	0.09	0.09	0.09	0.09	n.i.	n.i.	0.09	0.09	0.09	0.09	0.08
	100	0.04	0.05	0.06	0.10	0.07	n.i.	n.i.	0.05	0.05	0.06	0.05	0.05
Time	**Present**	0.08	n.i.	n.i.	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
	1	0.08	n.i.	n.i.	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
	10	0.05	n.i.	n.i.	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	100	0.00	n.i.	n.i.	0.02	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.00

RCR
>1
>2
>5

9.1.1.3 Chromium (Cr)

Chromium shows accumulation in soil for scenario #2 in Målselv, Stange, alum shale, Ås and Time, and for scenario #3 at Stange and alum shale. Chromium further shows moderate accumulation at Stange for scenarios #6, #7, #8 and #9, and in alum shale for scenarios #8 and #9.

RCR was calculated with a $PNEC_{add}$ approach for Cr. RCR>1 is found only in scenario#2 after 100 years in all regions (due to accumulation), and the highest RCR was calculated to 1.33 at Stange, indicating a low risk to soil organisms.

Table 9.1.1.3-1. Risk Characterization Ratio (RCR) for direct exposure of terrestrial organisms to chromium (Cr) in soil.

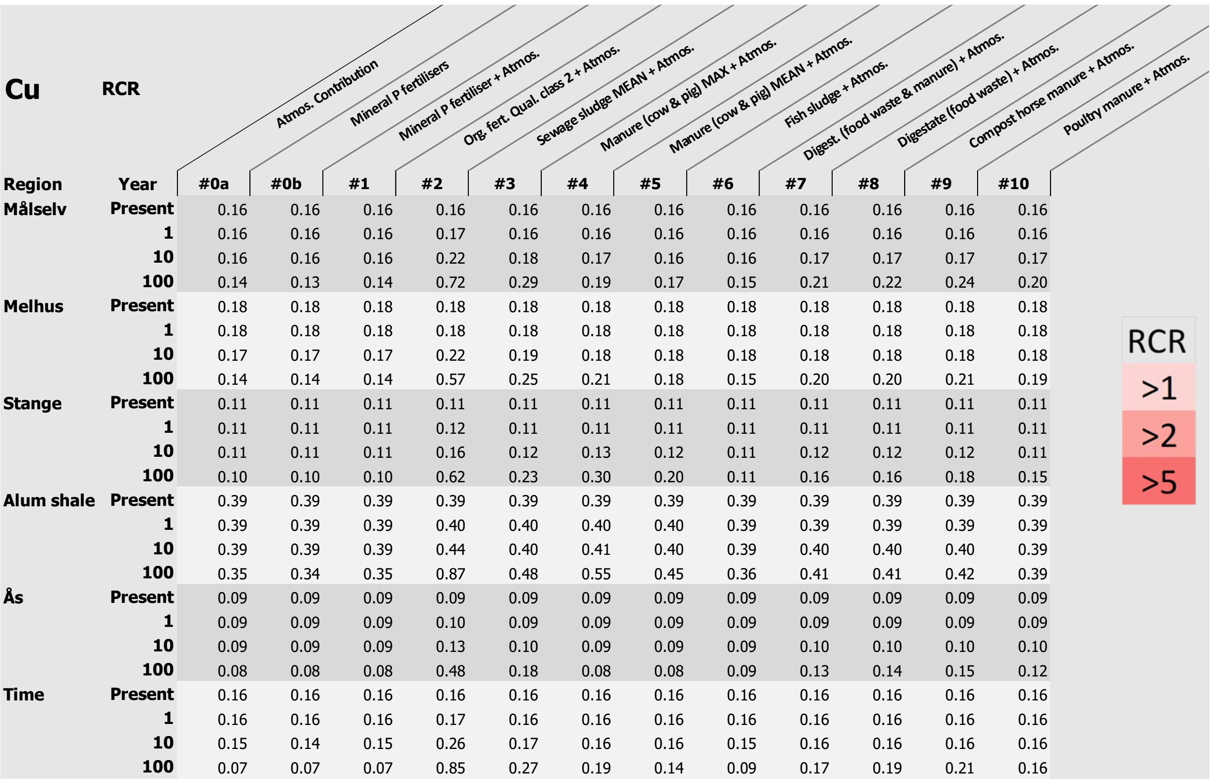
Cr	**RCR**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89
	1	0.89	0.88	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89
	10	0.88	0.87	0.88	0.91	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
	100	0.78	0.75	0.79	**1.06**	0.83	0.79	0.78	0.80	0.80	0.83	0.82	0.79
Melhus	**Present**	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
	1	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
	10	0.90	0.89	0.90	0.92	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
	100	0.72	0.70	0.73	0.91	0.76	0.72	0.72	0.73	0.73	0.75	0.75	0.72
Stange	**Present**	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81
	1	0.81	0.81	0.81	0.82	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81
	10	0.81	0.81	0.81	0.87	0.82	0.81	0.81	0.81	0.82	0.82	0.82	0.81
	100	0.80	0.75	0.82	**1.33**	0.90	0.81	0.80	0.82	0.83	0.88	0.86	0.80
Alum shale	**Present**	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
	1	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
	10	0.85	0.85	0.85	0.90	0.86	0.85	0.85	0.85	0.85	0.86	0.86	0.85
	100	0.82	0.78	0.83	**1.23**	0.90	0.83	0.82	0.84	0.84	0.88	0.87	0.82
Ås	**Present**	0.89	0.89	0.89	0.89	0.89	n.i.	0.89	0.89	0.89	0.89	0.89	0.89
	1	0.89	0.89	0.89	0.90	0.89	n.i.	0.89	0.89	0.89	0.89	0.89	0.89
	10	0.88	0.88	0.88	0.91	0.88	n.i.	0.88	0.88	0.88	0.88	0.88	0.88
	100	0.76	0.73	0.77	**1.01**	0.81	n.i.	0.72	0.77	0.78	0.80	0.79	0.76
Time	**Present**	0.74	n.i.	n.i.	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
	1	0.74	n.i.	n.i.	0.75	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
	10	0.71	n.i.	n.i.	0.80	0.73	0.71	0.71	0.71	0.72	0.73	0.72	0.71
	100	0.48	n.i.	n.i.	**1.20**	0.60	0.50	0.49	0.52	0.54	0.61	0.58	0.50

RCR
>1
>2
>5

9.1.1.4 Copper (Cu)

For Cu, all scenarios #2 - #10 show accumulation of Cu across regions. The calculated $PNEC_{soil}$ varies between regions depending on their mean soil characteristics, from 70 mg kg^{-1} at Time to 119 mg kg^{-1} at Ås. None of the scenarios result in RCR >1 and thus, Cu does not pose a risk to soil organisms.

Table 9.1.1.4-1. Risk Characterization Ratio (RCR) for direct exposure of terrestrial organisms to copper (Cu) in soil.



Cu	**RCR**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
	1	0.16	0.16	0.16	0.17	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
	10	0.16	0.16	0.16	0.22	0.18	0.17	0.16	0.16	0.17	0.17	0.17	0.17
	100	0.14	0.13	0.14	0.72	0.29	0.19	0.17	0.15	0.21	0.22	0.24	0.20
Melhus	**Present**	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
	1	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
	10	0.17	0.17	0.17	0.22	0.19	0.18	0.18	0.18	0.18	0.18	0.18	0.18
	100	0.14	0.14	0.14	0.57	0.25	0.21	0.18	0.15	0.20	0.20	0.21	0.19
Stange	**Present**	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
	1	0.11	0.11	0.11	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
	10	0.11	0.11	0.11	0.16	0.12	0.13	0.12	0.11	0.12	0.12	0.12	0.11
	100	0.10	0.10	0.10	0.62	0.23	0.30	0.20	0.11	0.16	0.16	0.18	0.15
Alum shale	**Present**	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
	1	0.39	0.39	0.39	0.40	0.40	0.40	0.40	0.39	0.39	0.39	0.39	0.39
	10	0.39	0.39	0.39	0.44	0.40	0.41	0.40	0.39	0.40	0.40	0.40	0.39
	100	0.35	0.34	0.35	0.87	0.48	0.55	0.45	0.36	0.41	0.41	0.42	0.39
Ås	**Present**	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
	1	0.09	0.09	0.09	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
	10	0.09	0.09	0.09	0.13	0.10	0.09	0.09	0.09	0.10	0.10	0.10	0.10
	100	0.08	0.08	0.08	0.48	0.18	0.08	0.08	0.09	0.13	0.14	0.15	0.12
Time	**Present**	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
	1	0.16	0.16	0.16	0.17	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
	10	0.15	0.14	0.15	0.26	0.17	0.16	0.16	0.15	0.16	0.16	0.16	0.16
	100	0.07	0.07	0.07	0.85	0.27	0.19	0.14	0.09	0.17	0.19	0.21	0.16

RCR
>1
>2
>5

9.1.1.5 Mercury (Hg)

Accumulation of Hg occurs in most scenarios and regions and is most prominent for evaluation of organic fertiliser regulation quality class II (#2). RCR at present ranges from 0.06 at Målselv and 0.18 at Time. After 100 years with scenario #2, RCR approaches 1 in all regions and even exceeds 1 at Time (RCR 1.1), indicating a possible risk of adverse effects on soil organisms.

Table 9.1.1.5-1. Risk Characterization Ratio (RCR) for direct exposure of terrestrial organisms to mercury (Hg) in soil.

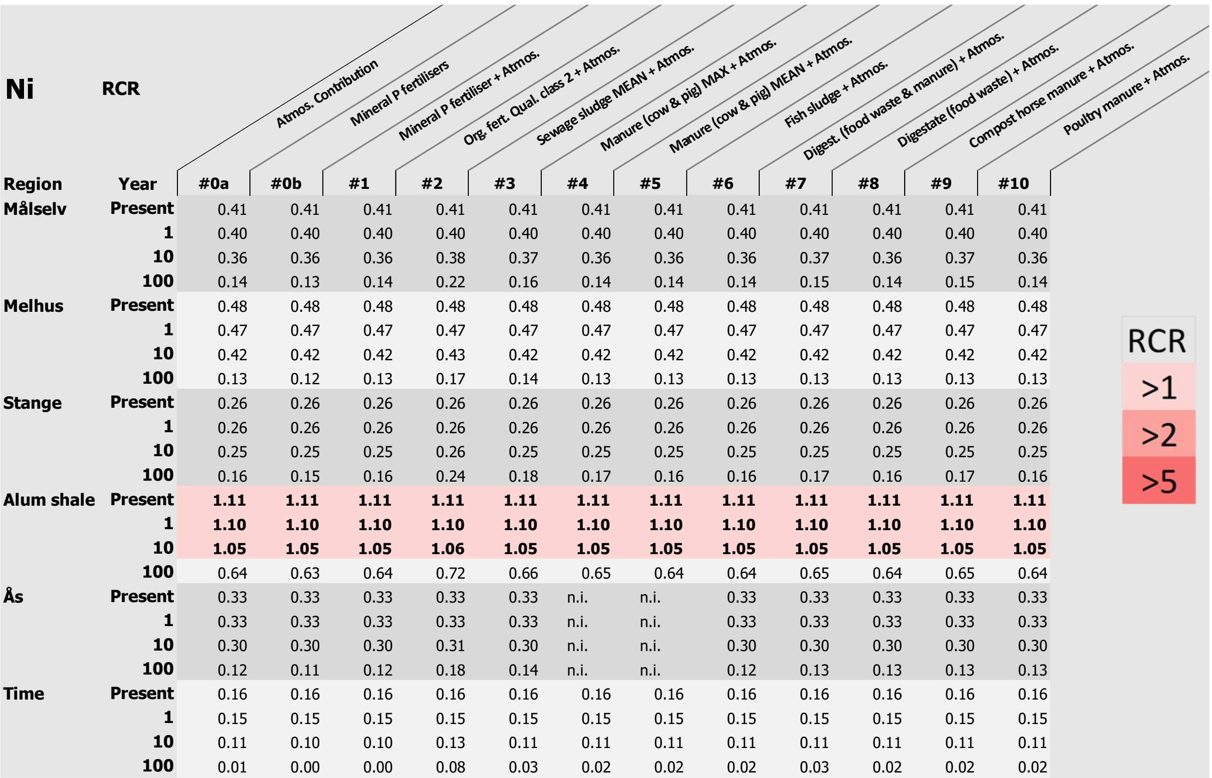
Hg	**RCR**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.06	0.06	0.06	0.06	0.06	n.i.	n.i.	0.06	0.06	0.06	0.06	n.i.
	1	0.06	0.06	0.06	0.07	0.07	n.i.	n.i.	0.06	0.06	0.07	0.06	n.i.
	10	0.07	0.06	0.07	0.13	0.07	n.i.	n.i.	0.07	0.07	0.09	0.07	n.i.
	100	0.10	0.06	0.10	0.75	0.17	n.i.	n.i.	0.11	0.13	0.28	0.11	n.i.
Melhus	**Present**	0.08	0.08	0.08	0.08	0.08	n.i.	n.i.	0.08	0.08	0.08	0.08	n.i.
	1	0.08	0.08	0.08	0.09	0.09	n.i.	n.i.	0.09	0.09	0.09	0.09	n.i.
	10	0.09	0.08	0.09	0.15	0.09	n.i.	n.i.	0.09	0.09	0.11	0.09	n.i.
	100	0.12	0.08	0.12	0.75	0.18	n.i.	n.i.	0.13	0.15	0.30	0.13	n.i.
Stange	**Present**	0.08	0.08	0.08	0.08	0.08	n.i.	n.i.	0.08	0.08	0.08	0.08	n.i.
	1	0.08	0.08	0.08	0.08	0.08	n.i.	n.i.	0.08	0.08	0.08	0.08	n.i.
	10	0.08	0.08	0.08	0.15	0.09	n.i.	n.i.	0.08	0.08	0.10	0.08	n.i.
	100	0.11	0.08	0.11	0.82	0.18	n.i.	n.i.	0.12	0.14	0.28	0.12	n.i.
Alum shale	**Present**	0.10	0.10	0.10	0.10	0.10	n.i.	n.i.	0.10	0.10	0.10	0.10	n.i.
	1	0.10	0.10	0.10	0.10	0.10	n.i.	n.i.	0.10	0.10	0.10	0.10	n.i.
	10	0.10	0.10	0.10	0.17	0.11	n.i.	n.i.	0.10	0.10	0.12	0.10	n.i.
	100	0.13	0.10	0.13	0.84	0.20	n.i.	n.i.	0.14	0.16	0.30	0.14	n.i.
Ås	**Present**	0.10	0.10	0.10	0.10	0.10	n.i.	n.i.	0.10	0.10	0.10	0.10	n.i.
	1	0.10	0.10	0.10	0.11	0.10	n.i.	n.i.	0.10	0.10	0.10	0.10	n.i.
	10	0.11	0.10	0.11	0.17	0.11	n.i.	n.i.	0.11	0.11	0.12	0.11	n.i.
	100	0.13	0.10	0.14	0.74	0.20	n.i.	n.i.	0.14	0.16	0.31	0.15	n.i.
Time	**Present**	0.18	n.i.	n.i.	0.18	0.18	n.i.	n.i.	0.18	0.18	0.18	0.18	n.i.
	1	0.18	n.i.	n.i.	0.19	0.18	n.i.	n.i.	0.18	0.18	0.18	0.18	n.i.
	10	0.18	n.i.	n.i.	0.28	0.19	n.i.	n.i.	0.18	0.19	0.21	0.18	n.i.
	100	0.22	n.i.	n.i.	**1.14**	0.31	n.i.	n.i.	0.23	0.26	0.48	0.24	n.i.

RCR
>1
>2
>5

9.1.1.6 Nickel (Ni)

Nickel soil concentrations show a decline over time in all scenarios. Calculated RCR values are low; except for the alum shale region, where the background concentration is high due to the geochemical composition of the shale. However, Ni in soils developed on alum shale minerals have been shown to be strongly associated with the soil components and the biovailability is considered to be low. (Narwal et al. 2008). Therefore, the RCR slightly above 1 in the alum shale area should probably not be interpreted as a risk of adverse effects.

Table 9.1.1.6-1. Risk Characterization Ratio (RCR) for direct exposure of terrestrial organisms to nickel (Ni) in soil.



Ni	**RCR**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
	1	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	10	0.36	0.36	0.36	0.38	0.37	0.36	0.36	0.36	0.37	0.36	0.37	0.36
	100	0.14	0.13	0.14	0.22	0.16	0.14	0.14	0.14	0.15	0.14	0.15	0.14
Melhus	**Present**	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
	1	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
	10	0.42	0.42	0.42	0.43	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
	100	0.13	0.12	0.13	0.17	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Stange	**Present**	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
	1	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
	10	0.25	0.25	0.25	0.26	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
	100	0.16	0.15	0.16	0.24	0.18	0.17	0.16	0.16	0.17	0.16	0.17	0.16
Alum shale	**Present**	**1.11**	**1.11**	**1.11**	**1.11**	**1.11**	**1.11**	**1.11**	**1.11**	**1.11**	**1.11**	**1.11**	**1.11**
	1	**1.10**	**1.10**	**1.10**	**1.10**	**1.10**	**1.10**	**1.10**	**1.10**	**1.10**	**1.10**	**1.10**	**1.10**
	10	**1.05**	**1.05**	**1.05**	**1.06**	**1.05**	**1.05**	**1.05**	**1.05**	**1.05**	**1.05**	**1.05**	**1.05**
	100	0.64	0.63	0.64	0.72	0.66	0.65	0.64	0.64	0.65	0.64	0.65	0.64
Ås	**Present**	0.33	0.33	0.33	0.33	0.33	n.i.	n.i.	0.33	0.33	0.33	0.33	0.33
	1	0.33	0.33	0.33	0.33	0.33	n.i.	n.i.	0.33	0.33	0.33	0.33	0.33
	10	0.30	0.30	0.30	0.31	0.30	n.i.	n.i.	0.30	0.30	0.30	0.30	0.30
	100	0.12	0.11	0.12	0.18	0.14	n.i.	n.i.	0.12	0.13	0.13	0.13	0.13
Time	**Present**	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
	1	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
	10	0.11	0.10	0.10	0.13	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
	100	0.01	0.00	0.00	0.08	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.02

RCR
>1
>2
>5

9.1.1.7 Lead (Pb)

For lead, present RCRs are <<1 in all regions. There is a slight increase in most regions and scenarios, but the highest RCR is still only 0.17 after 100 years (alum shale with #2, evaluating MLs quality class organic fertiliser), indicating no risk.

Table 9.1.1.7-1. Risk Characterization Ratio (RCR) for direct exposure of terrestrial organisms to lead (Pb).

Pb	**RCR**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	1	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	10	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	100	0.04	0.04	0.05	0.09	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.05
Melhus	**Present**	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	1	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	10	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	100	0.07	0.06	0.07	0.11	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.07
Stange	**Present**	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	1	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	10	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	100	0.06	0.05	0.06	0.10	0.07	0.06	0.06	0.06	0.06	0.06	0.07	0.06
Alum shale	**Present**	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
	1	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
	10	0.12	0.12	0.12	0.13	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
	100	0.13	0.12	0.13	0.17	0.14	0.13	0.13	0.13	0.13	0.13	0.14	0.13
Ås	**Present**	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	1	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	100	0.10	0.09	0.10	0.14	0.11	0.09	0.09	0.10	0.11	0.11	0.12	0.10
Time	**Present**	0.14	n.i.	n.i.	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
	1	0.14	n.i.	n.i.	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
	10	0.14	n.i.	n.i.	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
	100	0.14	n.i.	n.i.	0.19	0.15	0.14	0.14	0.14	0.14	0.14	0.16	0.14

RCR
>1
>2
>5

9.1.1.8 Zinc (Zn)

For Zn, all present RCRs are <1 in all regions. RCR increases to >1 after 100 years at Stange and alum shale with scenario #4, indicating low risk. RCR is also increasing over time with #2, #3, #5, #6, #7, #8 and #10 in most regions (except Time), but remains <1 after 100 years indicating no risk.

Table 9.1.1.8-1. Risk Characterization Ratio (RCR) for direct exposure of terrestrial organisms to zinc (Zn).

Zn	**RCR**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	1	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	10	0.33	0.33	0.33	0.38	0.36	0.35	0.34	0.35	0.36	0.37	0.34	0.36
	100	0.23	0.22	0.23	0.64	0.43	0.33	0.31	0.38	0.41	0.54	0.31	0.42
Melhus	**Present**	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
	1	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
	10	0.26	0.26	0.26	0.30	0.28	0.28	0.27	0.27	0.28	0.29	0.27	0.28
	100	0.20	0.19	0.20	0.48	0.34	0.31	0.29	0.30	0.32	0.41	0.25	0.33
Stange	**Present**	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
	1	0.24	0.24	0.24	0.24	0.24	0.25	0.24	0.24	0.24	0.24	0.24	0.24
	10	0.23	0.23	0.24	0.28	0.26	0.34	0.28	0.25	0.25	0.26	0.24	0.25
	100	0.21	0.20	0.22	0.59	0.40	**1.19**	0.61	0.33	0.35	0.45	0.27	0.36
Alum shale	**Present**	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
	1	0.61	0.61	0.61	0.61	0.61	0.62	0.61	0.61	0.61	0.61	0.61	0.61
	10	0.60	0.60	0.60	0.64	0.62	0.70	0.64	0.61	0.61	0.62	0.60	0.61
	100	0.51	0.51	0.52	0.90	0.70	**1.49**	0.92	0.64	0.66	0.76	0.58	0.66
Ås	**Present**	0.35	0.35	0.35	0.35	0.35	n.i.	n.i.	0.35	0.35	0.35	0.35	0.35
	1	0.35	0.35	0.35	0.35	0.35	n.i.	n.i.	0.35	0.35	0.35	0.35	0.35
	10	0.34	0.34	0.34	0.37	0.35	n.i.	n.i.	0.35	0.35	0.36	0.35	0.35
	100	0.26	0.25	0.26	0.50	0.38	n.i.	n.i.	0.35	0.37	0.44	0.31	0.37
Time	**Present**	0.31	n.i.	n.i.	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
	1	0.31	n.i.	n.i.	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
	10	0.27	n.i.	n.i.	0.35	0.31	0.30	0.30	0.30	0.30	0.33	0.28	0.31
	100	0.08	n.i.	n.i.	0.51	0.29	0.26	0.23	0.25	0.27	0.41	0.17	0.28

RCR
>1
>2
>5

9.1.2 Direct exposure of agricultural plants

For the PTEs assessed in this report, the available toxicity data that are discussed in detail in chapter 7 indicate that plants in general have a sensitivity that is in line with that of soil-dwelling organisms, including microorganisms. The RCRs calculated for terrestrial organisms are therefore representative also for agricultural plants. In a previous risk assessment of Cd by VKM, a specific PNEC for plants was derived (VKM, 2021). The PNEC$_{\text{soil, plants}}$ of 2.8 mg Cd kg^{-1} is higher than the PNEC$_{\text{soil}}$ of 2.3 mg kg^{-1} and much higher than the calculated PEC$_{\text{soil}}$ in all sceanarios and regions, indicating that plants are not at risk.

9.1.3 Secondary poisoning of terrestrial mammals

For elements where secondary poisoning through a terrestrial food-chain are relevant and a PNEC for secondary poisoning could be derived (Cd, Ni, Pb, Section 7.1), risk characterisation ratios (RCR) have been calculated and presented in the tables below (Table 9.1.3-1-1-3).

9.1.3.1 Cadmium (Cd)

The PNEC$_{\text{soil sec.pois}}$ of 0.9 mg kg^{-1} is lower than the PNEC$_{\text{soil}}$ of 2.3 mg kg^{-1}. Hence, the RCR-values are higher for secondary poisoning than for direct effect of Cd on terrestrial organisms. However, in the alum shale area, the present RCR for secondary poisoning is

0.93. The trend is decreasing even in the scenario evaluation of organic fertiliser regulation quality class II (#2), where the RCR is 0.87 after 100 years. In the other case areas, the RCRs are 0.09 - 0.23, and the highest value after 100 years is 0.36 (Stange, #2).

Table 9.1.3.1-1. Risk Characterization Ratio (RCR) for secondary poisoning of Cd through terrestrial food-chains.

Cd	**RCR secpois**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region		**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
	1	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
	10	0.08	0.08	0.08	0.10	0.09	0.08	0.08	0.09	0.09	0.09	0.09	0.08
	100	0.04	0.04	0.05	0.15	0.08	0.05	0.04	0.06	0.06	0.07	0.06	0.05
Melhus	**Present**	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
	1	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
	10	0.10	0.11	0.11	0.13	0.11	0.11	0.10	0.11	0.11	0.11	0.11	0.10
	100	0.05	0.08	0.09	0.21	0.12	0.07	0.07	0.08	0.09	0.10	0.09	0.07
Stange	**Present**	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
	1	0.14	0.14	0.15	0.15	0.15	0.14	0.14	0.14	0.14	0.14	0.14	0.14
	10	0.14	0.15	0.15	0.17	0.16	0.15	0.14	0.14	0.14	0.15	0.14	0.14
	100	0.11	0.18	0.19	0.36	0.24	0.19	0.14	0.14	0.15	0.16	0.14	0.12
Alun shale	**Present**	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
	1	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
	10	0.90	0.90	0.91	0.93	0.91	0.91	0.90	0.90	0.90	0.90	0.90	0.90
	100	0.62	0.69	0.70	0.87	0.75	0.70	0.65	0.65	0.66	0.67	0.66	0.63
Ås	**Present**	0.23	0.23	0.23	0.23	0.23	n.i.	n.i.	0.23	0.23	0.23	0.23	0.23
	1	0.23	0.23	0.23	0.23	0.23	n.i.	n.i.	0.23	0.23	0.23	0.23	0.23
	10	0.22	0.22	0.22	0.24	0.23	n.i.	n.i.	0.22	0.22	0.22	0.22	0.22
	100	0.11	0.13	0.14	0.26	0.18	n.i.	n.i.	0.14	0.14	0.15	0.14	0.12
Time	**Present**	0.21	n.i.	n.i.	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
	1	0.20	n.i.	n.i.	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
	10	0.13	n.i.	n.i.	0.15	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
	100	0.01	n.i.	n.i.	0.06	0.02	0.01	0.01	0.02	0.02	0.02	0.02	0.01

RCR
>1
>2
>5

9.1.3.2 Mercury (Hg)

$PNEC_{soil,\ secpois}$ have been estimated for inorganic Hg and methyl-Hg as described in 7.1.7. Exceedance of $PNEC_{soil,\ secpois}$ are not predicted for inorganic Hg, but for methyl-Hg, a risk is indicated in all regions after 100 years with organic fertilisers quality class II (#2).

Table 9.1.3.2-1 Risk Characterization Ratio (RCR) for secondary poisoning of methyl-Hg through terrestrial food-chains

me-Hg	**RCR secpois soil**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.152	0.152	0.152	0.152	0.152	n.i.	n.i.	0.152	0.152	0.152	0.152	n.i.
	1	0.152	0.151	0.152	0.168	0.154	n.i.	n.i.	0.153	0.153	0.157	0.153	n.i.
	10	0.160	0.151	0.161	0.314	0.176	n.i.	n.i.	0.163	0.168	0.204	0.164	n.i.
	100	0.240	0.149	0.241	**1.765**	0.393	n.i.	n.i.	0.261	0.314	0.673	0.270	n.i.
Melhus	**Present**	0.191	0.191	0.191	0.191	0.191	n.i.	n.i.	0.191	0.191	0.191	0.191	n.i.
	1	0.192	0.191	0.192	0.206	0.193	n.i.	n.i.	0.192	0.192	0.196	0.192	n.i.
	10	0.199	0.190	0.199	0.344	0.213	n.i.	n.i.	0.201	0.206	0.240	0.202	n.i.
	100	0.269	0.184	0.270	**1.695**	0.413	n.i.	n.i.	0.289	0.338	0.673	0.297	n.i.
Stange	**Present**	0.176	0.176	0.176	0.176	0.176	n.i.	n.i.	0.176	0.176	0.176	0.176	n.i.
	1	0.177	0.176	0.177	0.194	0.179	n.i.	n.i.	0.177	0.178	0.181	0.178	n.i.
	10	0.185	0.176	0.185	0.349	0.201	n.i.	n.i.	0.187	0.191	0.224	0.187	n.i.
	100	0.257	0.174	0.258	**1.885**	0.421	n.i.	n.i.	0.276	0.324	0.652	0.284	n.i.
Alum shale	**Present**	0.213	0.213	0.213	0.213	0.213	n.i.	n.i.	0.213	0.213	0.213	0.213	n.i.
	1	0.214	0.213	0.214	0.230	0.216	n.i.	n.i.	0.214	0.215	0.218	0.215	n.i.
	10	0.221	0.213	0.221	0.378	0.237	n.i.	n.i.	0.223	0.228	0.259	0.224	n.i.
	100	0.289	0.211	0.291	**1.844**	0.446	n.i.	n.i.	0.308	0.353	0.667	0.315	n.i.
Ås	**Present**	0.222	0.222	0.222	0.222	0.222	n.i.	n.i.	0.222	0.222	0.222	0.222	n.i.
	1	0.223	0.222	0.223	0.236	0.224	n.i.	n.i.	0.223	0.224	0.227	0.223	n.i.
	10	0.229	0.221	0.229	0.362	0.243	n.i.	n.i.	0.231	0.236	0.267	0.232	n.i.
	100	0.292	0.215	0.293	**1.597**	0.424	n.i.	n.i.	0.310	0.355	0.662	0.317	n.i.
Time	**Present**	0.330	n.i.	n.i.	0.330	0.330	n.i.	n.i.	0.330	0.330	0.330	0.330	n.i.
	1	0.331	n.i.	n.i.	0.349	0.333	n.i.	n.i.	0.331	0.332	0.336	0.331	n.i.
	10	0.338	n.i.	n.i.	0.515	0.356	n.i.	n.i.	0.341	0.347	0.389	0.342	n.i.
	100	0.410	n.i.	n.i.	**2.123**	0.582	n.i.	n.i.	0.434	0.493	0.896	0.444	n.i.

RCR
>1
>2
>5

9.1.3.3 *Nickel (Ni)*

For Ni, the $PNEC_{soil\ sec.pois}$ of 23 mg kg^{-1} is lower than the $PNEC_{soil}$ of 23-48 mg kg^{-1}, and, the RCRs indicate a risk for secondary poisoning at the present Ni concentrations at Melhus and alum shale areas. However, Ni in soils developed on alum shale minerals have been shown to be strongly associated with the soil components and the bioavailability is considered to be low. (Narwal et al. 2008). Therefore, the risk is likely overpredicted in this area.

Table 9.1.3.3-1. Risk Characterization Ratio (RCR) for secondary poisoning of Ni through terrestrial food-chains.

Ni	**RCR secpois**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Sewage sludge MAX + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58
	1	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
	10	0.51	0.51	0.51	0.53	0.52	0.52	0.51	0.52	0.52	0.52	0.52	0.52
	100	0.20	0.18	0.20	0.31	0.23	0.21	0.20	0.20	0.22	0.20	0.21	0.20
Melhus	**Present**	**1.02**	**1.02**	**1.02**	**1.02**	**1.02**	**1.02**	**1.02**	**1.02**	**1.02**	**1.02**	**1.02**	**1.02**
	1	**1.00**	**1.00**	**1.00**	**1.01**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
	10	0.89	0.88	0.89	0.90	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89
	100	0.27	0.25	0.27	0.37	0.29	0.28	0.27	0.27	0.29	0.27	0.28	0.27
Stange	**Present**	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
	1	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
	10	0.50	0.50	0.51	0.53	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
	100	0.32	0.30	0.33	0.48	0.37	0.35	0.33	0.33	0.35	0.33	0.35	0.33
Alun shale	**Present**	**2.26**	**2.26**	**2.26**	**2.26**	**2.26**	**2.26**	**2.26**	**2.26**	**2.26**	**2.26**	**2.26**	**2.26**
	1	**2.24**	**2.24**	**2.24**	**2.25**	**2.24**	**2.24**	**2.24**	**2.24**	**2.24**	**2.24**	**2.24**	**2.24**
	10	**2.13**	**2.13**	**2.14**	**2.16**	**2.14**	**2.14**	**2.14**	**2.14**	**2.14**	**2.14**	**2.14**	**2.14**
	100	**1.30**	**1.28**	**1.30**	**1.46**	**1.35**	**1.32**	**1.31**	**1.31**	**1.33**	**1.31**	**1.32**	**1.31**
Ås	**Present**	0.62	0.62	0.62	0.62	0.62			0.62	0.62	0.62	0.62	0.62
	1	0.61	0.61	0.61	0.61	0.61			0.61	0.61	0.61	0.61	0.61
	10	0.56	0.56	0.56	0.58	0.56			0.56	0.56	0.56	0.56	0.56
	100	0.23	0.21	0.23	0.34	0.26			0.23	0.25	0.23	0.24	0.23
Time	**Present**	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
	1	0.15	0.15	0.15	0.16	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
	10	0.11	0.10	0.10	0.13	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
	100	0.01	0.00	0.00	0.08	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.02

RCR
>1
>2
>5

9.1.3.4 Lead (Pb)

For Pb, the PNEC$_{\text{soil sec.pois.}}$ at 272 mg kg^{-1} is higher than the PNEC$_{\text{soil}}$ of 166 mg kg^{-1}, and all RCRs are <<1, indicating no risk for secondary poisoning of Pb in terrestrial food chains.

Table 9.1.3.4-1. Risk Characterization Ratio (RCR) for secondary poisoning of Pb through terrestrial food-chains.

Pb	**RCR secpois**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	1	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	10	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	100	0.03	0.02	0.03	0.05	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03
Melhus	**Present**	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	1	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	10	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	100	0.04	0.03	0.04	0.06	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.04
Stange	**Present**	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	1	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	10	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	100	0.04	0.03	0.04	0.06	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Alun shale	**Present**	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
	1	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
	10	0.07	0.07	0.07	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
	100	0.08	0.07	0.08	0.11	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.08
Ås	**Present**	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	1	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	10	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	100	0.06	0.06	0.06	0.09	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.06
Time	**Present**	0.08	n.i.	n.i.	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
	1	0.08	n.i.	n.i.	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
	10	0.08	n.i.	n.i.	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.08
	100	0.08	n.i.	m.i.	0.12	0.09	0.08	0.08	0.08	0.09	0.09	0.10	0.08

RCR
>1
>2
>5

9.2 Risk characterisation in aquatic organisms

9.2.1 Surface water

9.2.1.1 Arsenic (As)

All RCRs are <<1, at present and after 100 years, in all regions and indicating no risk.

Table 9.2.1.1-1. Risk Characterization Ratio (RCR) for exposure of organisms in surface water to arsenic (As).

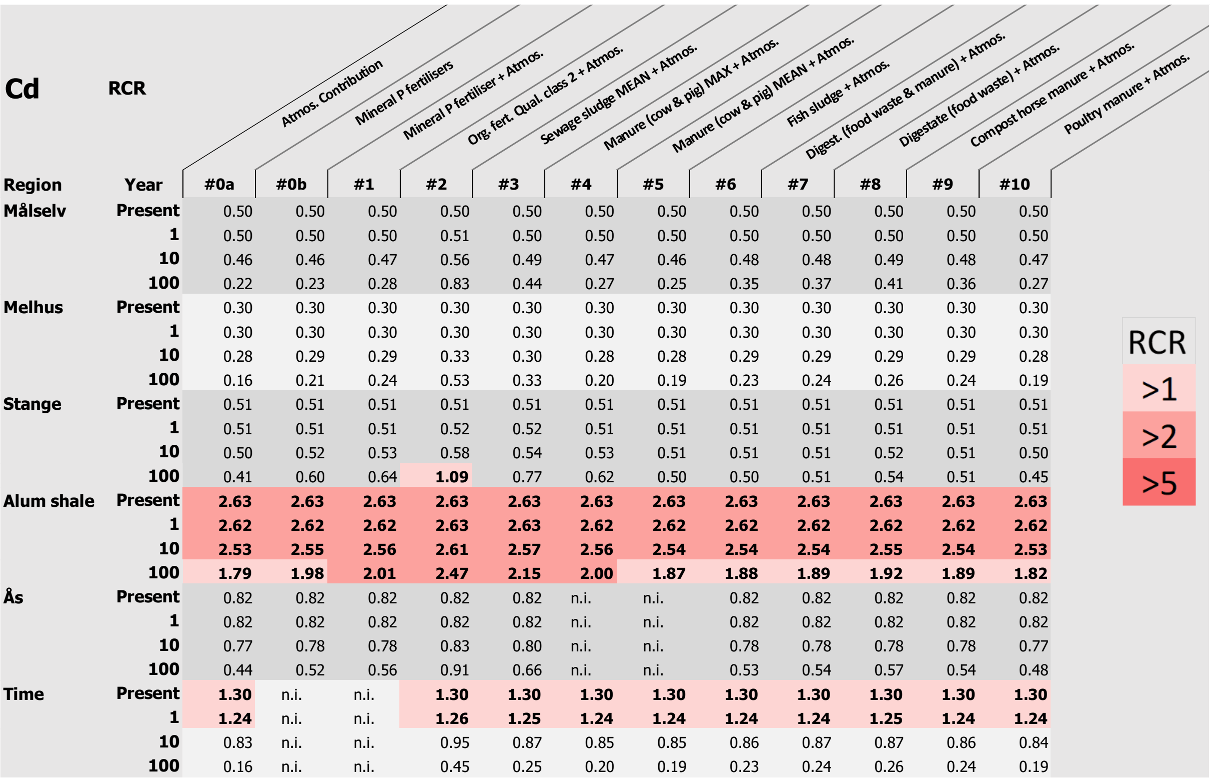
As	**RCR**	Only atmopheric contribution	Only mineral fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.04	0.04	0.04	0.04	n.i.	0.04	0.04	0.04	0.04	n.i.	0.04	0.04
	1	0.04	0.04	0.04	0.04	n.i.	0.04	0.04	0.04	0.04	n.i.	0.04	0.04
	10	0.04	0.04	0.04	0.04	n.i.	0.04	0.04	0.04	0.04	n.i.	0.04	0.04
	100	0.04	0.03	0.04	0.06	n.i.	0.04	0.04	0.04	0.04	n.i.	0.04	0.04
Melhus	**Present**	0.07	0.07	0.07	0.07	n.i.	0.07	0.07	0.07	0.07	n.i.	0.07	0.07
	1	0.07	0.07	0.07	0.07	n.i.	0.07	0.07	0.07	0.07	n.i.	0.07	0.07
	10	0.07	0.07	0.07	0.07	n.i.	0.07	0.07	0.07	0.07	n.i.	0.07	0.07
	100	0.06	0.06	0.06	0.08	n.i.	0.06	0.06	0.06	0.06	n.i.	0.06	0.06
Stange	**Present**	0.05	0.05	0.05	0.05	n.i.	0.05	0.05	0.05	0.05	n.i.	0.05	0.05
	1	0.05	0.05	0.05	0.05	n.i.	0.05	0.05	0.05	0.05	n.i.	0.05	0.05
	10	0.05	0.05	0.05	0.05	n.i.	0.05	0.05	0.05	0.05	n.i.	0.05	0.05
	100	0.05	0.05	0.05	0.08	n.i.	0.05	0.05	0.05	0.05	n.i.	0.05	0.05
Alum shale	**Present**	0.32	0.32	0.32	0.32	n.i.	0.32	0.32	0.32	0.32	n.i.	0.32	0.32
	1	0.31	0.31	0.31	0.32	n.i.	0.31	0.31	0.31	0.31	n.i.	0.31	0.31
	10	0.31	0.31	0.31	0.31	n.i.	0.31	0.31	0.31	0.31	n.i.	0.31	0.31
	100	0.29	0.28	0.29	0.31	n.i.	0.29	0.29	0.29	0.29	n.i.	0.29	0.29
Ås	**Present**	0.08	0.08	0.08	0.08	n.i.	n.i.	n.i.	0.08	0.08	n.i.	0.08	0.08
	1	0.08	0.08	0.08	0.08	n.i.	n.i.	n.i.	0.08	0.08	n.i.	0.08	0.08
	10	0.08	0.08	0.08	0.08	n.i.	n.i.	n.i.	0.08	0.08	n.i.	0.08	0.08
	100	0.07	0.07	0.07	0.09	n.i.	n.i.	n.i.	0.07	0.07	n.i.	0.07	0.07
Time	**Present**	0.09	n.i.	n.i.	0.09	n.i.	0.09	0.09	0.09	0.09	n.i.	0.09	0.09
	1	0.09	n.i.	n.i.	0.09	n.i.	0.09	0.09	0.09	0.09	n.i.	0.09	0.09
	10	0.09	n.i.	n.i.	0.09	n.i.	0.09	0.09	0.09	0.09	n.i.	0.09	0.09
	100	0.07	n.i.	n.i.	0.10	n.i.	0.07	0.07	0.07	0.07	n.i.	0.07	0.07

RCR
>1
>2
>5

9.2.1.2 Cadmium (Cd)

The present RCR is >1 in alum shale (significant risk) and Time (low risk). In alum shale, RCR decreases in all scenarios but remains >1 after 100 years. In Time, RCR decreases to <1 with all scenarios after 10 years. In Stange, RCR increases with scenarios #0b, #1, #2, #3 and #4 but reaches >1 only with #2 after 100 years.

Table 9.2.1.2-1. Risk Characterization Ratio (RCR) for exposure of organisms in surface water to cadmium (Cd).



Cd	RCR	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	1	0.50	0.50	0.50	0.51	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	10	0.46	0.46	0.47	0.56	0.49	0.47	0.46	0.48	0.48	0.49	0.48	0.47
	100	0.22	0.23	0.28	0.83	0.44	0.27	0.25	0.35	0.37	0.41	0.36	0.27
Melhus	**Present**	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
	1	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
	10	0.28	0.29	0.29	0.33	0.30	0.28	0.28	0.29	0.29	0.29	0.29	0.28
	100	0.16	0.21	0.24	0.53	0.33	0.20	0.19	0.23	0.24	0.26	0.24	0.19
Stange	**Present**	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
	1	0.51	0.51	0.51	0.52	0.52	0.51	0.51	0.51	0.51	0.51	0.51	0.51
	10	0.50	0.52	0.53	0.58	0.54	0.53	0.51	0.51	0.51	0.52	0.51	0.50
	100	0.41	0.60	0.64	**1.09**	0.77	0.62	0.50	0.50	0.51	0.54	0.51	0.45
Alum shale	**Present**	**2.63**	**2.63**	**2.63**	**2.63**	**2.63**	**2.63**	**2.63**	**2.63**	**2.63**	**2.63**	**2.63**	**2.63**
	1	**2.62**	**2.62**	**2.62**	**2.63**	**2.63**	**2.62**	**2.62**	**2.62**	**2.62**	**2.62**	**2.62**	**2.62**
	10	**2.53**	**2.55**	**2.56**	**2.61**	**2.57**	**2.56**	**2.54**	**2.54**	**2.54**	**2.55**	**2.54**	**2.53**
	100	**1.79**	**1.98**	**2.01**	**2.47**	**2.15**	**2.00**	**1.87**	**1.88**	**1.89**	**1.92**	**1.89**	**1.82**
Ås	**Present**	0.82	0.82	0.82	0.82	0.82	n.i.	n.i.	0.82	0.82	0.82	0.82	0.82
	1	0.82	0.82	0.82	0.82	0.82	n.i.	n.i.	0.82	0.82	0.82	0.82	0.82
	10	0.77	0.78	0.78	0.83	0.80	n.i.	n.i.	0.78	0.78	0.78	0.78	0.77
	100	0.44	0.52	0.56	0.91	0.66	n.i.	n.i.	0.53	0.54	0.57	0.54	0.48
Time	**Present**	**1.30**	n.i.	n.i.	**1.30**	**1.30**	**1.30**	**1.30**	**1.30**	**1.30**	**1.30**	**1.30**	**1.30**
	1	**1.24**	n.i.	n.i.	**1.26**	**1.25**	**1.24**	**1.24**	**1.24**	**1.24**	**1.25**	**1.24**	**1.24**
	10	0.83	n.i.	n.i.	0.95	0.87	0.85	0.85	0.86	0.87	0.87	0.86	0.84
	100	0.16	n.i.	n.i.	0.45	0.25	0.20	0.19	0.23	0.24	0.26	0.24	0.19

RCR
>1
>2
>5

9.2.1.3 Chromium (Cr)

The current RCR is marginally >1 in Melhus, indicating low risk, but decreases to <1 with all scenarios (no risk), except #2 after 100 years. In the other case areas, RCR remains below 1 but increases slowly in scenario #2 (evaluation of fertiliser regulation).

Table 9.2.1.3-1. Risk Characterization Ratio (RCR) for exposure of organisms in surface water to chromium (Cr).

Cr	**RCR**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
	1	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
	10	0.54	0.53	0.54	0.55	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
	100	0.48	0.46	0.49	0.64	0.51	0.49	0.48	0.49	0.50	0.51	0.51	0.49
Melhus	**Present**	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
	1	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
	10	0.73	0.72	0.73	0.74	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
	100	0.59	0.57	0.60	0.74	0.62	0.59	0.59	0.60	0.60	0.62	0.61	0.59
Stange	**Present**	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
	1	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
	10	0.33	0.33	0.33	0.35	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
	100	0.32	0.31	0.33	0.51	0.36	0.33	0.32	0.33	0.33	0.35	0.34	0.32
Alum shale	**Present**	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
	1	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
	10	0.43	0.43	0.43	0.45	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
	100	0.41	0.40	0.42	0.60	0.45	0.42	0.41	0.42	0.42	0.44	0.43	0.41
Ås	**Present**	0.58	0.58	0.58	0.58	0.58	n.i.	0.58	0.58	0.58	0.58	0.58	0.58
	1	0.57	0.57	0.57	0.58	0.58	n.i.	0.57	0.57	0.58	0.58	0.58	0.57
	10	0.57	0.57	0.57	0.58	0.57	n.i.	0.56	0.57	0.57	0.57	0.57	0.57
	100	0.50	0.48	0.50	0.64	0.53	n.i.	0.47	0.50	0.51	0.52	0.52	0.50
Time	**Present**	0.21	n.i.	n.i.	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
	1	0.21	n.i.	n.i.	0.22	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
	10	0.21	n.i.	n.i.	0.23	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
	100	0.15	n.i.	n.i.	0.33	0.18	0.15	0.15	0.16	0.16	0.18	0.17	0.15

RCR
>1
>2
>5

9.2.1.4 Copper (Cu)

All RCRs are <<1 at present and after 100 years and indicates no risk.

Table 9.2.1.4-1. Risk Characterization Ratio (RCR) for exposure of organisms in surface water to copper (Cu).

Cu	**RCR**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
	1	0.26	0.26	0.26	0.27	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
	10	0.26	0.26	0.26	0.32	0.28	0.27	0.26	0.26	0.27	0.27	0.27	0.27
	100	0.24	0.24	0.24	0.78	0.38	0.29	0.27	0.25	0.31	0.32	0.33	0.30
Melhus	**Present**	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
	1	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
	10	0.13	0.13	0.13	0.15	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
	100	0.11	0.11	0.11	0.31	0.16	0.14	0.13	0.12	0.14	0.14	0.15	0.13
Stange	**Present**	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	1	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	10	0.10	0.10	0.10	0.12	0.10	0.11	0.10	0.10	0.10	0.10	0.10	0.10
	100	0.10	0.10	0.10	0.26	0.14	0.16	0.13	0.10	0.11	0.12	0.12	0.11
Alum shale	**Present**	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
	1	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
	10	0.19	0.19	0.19	0.20	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
	100	0.17	0.17	0.17	0.34	0.22	0.24	0.21	0.18	0.19	0.19	0.20	0.19
Ås	**Present**	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
	1	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
	10	0.09	0.09	0.09	0.11	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09
	100	0.09	0.09	0.09	0.21	0.12	0.09	0.09	0.09	0.10	0.11	0.11	0.10
Time	**Present**	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
	1	0.09	0.09	0.09	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
	10	0.09	0.09	0.09	0.11	0.10	0.10	0.09	0.09	0.09	0.10	0.10	0.09
	100	0.08	0.08	0.08	0.23	0.12	0.10	0.09	0.08	0.10	0.10	0.10	0.09

RCR
>1
>2
>5

9.2.1.5 Mercury (Hg)

All RCRs are at <<1 even after 100 years, indicating no risk, despite increasing exposure concentrations in most scenarios.

For Hg, secondary poisoning in aquatic food-chains is a potential risk even when the $PNEC_{sw}$ is not exceeded. Monitoring of Hg in fish from Norwegian lakes show that concentrations of total Hg in trout and perch frequently exceed the European quality standard for secondary poisoning of MeHg (0.022 mg kg^{-1}) and some also the QS for inorganic Hg (0.4 mg kg^{-1}) even in lakes that are not influenced by point sources of Hg (Lyche et al. 2018; EQS 2005c).

Analysis of fish sampled from streams in an agriculturally dominated watershed in Canada by Donadt et al. (2021), showed Hg concentrations of 0.34 - 1.2 mg kg^{-1}. The measured Hg concentrations in the streams were 0.006 - 0,017 µg L^{-1} which is almost a factor of 10 higher than the predicted Hg concentrations in the Norwegian scenarios.

Table 9.2.1.5-1. Risk Characterization Ratio (RCR) for exposure of organisms in surface water to mercury (Hg).

Hg	**RCR**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.022	0.022	0.022	0.022	0.022	n.i.	n.i.	0.022	0.022	0.022	0.022	n.i.
	1	0.022	0.022	0.022	0.022	0.022	n.i.	n.i.	0.022	0.022	0.022	0.022	n.i.
	10	0.022	0.022	0.022	0.024	0.023	n.i.	n.i.	0.022	0.022	0.023	0.022	n.i.
	100	0.023	0.022	0.023	0.038	0.025	n.i.	n.i.	0.023	0.024	0.027	0.023	n.i.
Melhus	**Present**	0.023	0.023	0.023	0.023	0.023	n.i.	n.i.	0.023	0.023	0.023	0.023	n.i.
	1	0.023	0.023	0.023	0.023	0.023	n.i.	n.i.	0.023	0.023	0.023	0.023	n.i.
	10	0.023	0.023	0.023	0.024	0.023	n.i.	n.i.	0.023	0.023	0.023	0.023	n.i.
	100	0.023	0.023	0.023	0.037	0.025	n.i.	n.i.	0.024	0.024	0.027	0.024	n.i.
Stange	**Present**	0.023	0.023	0.023	0.023	0.023	n.i.	n.i.	0.023	0.023	0.023	0.023	n.i.
	1	0.023	0.023	0.023	0.023	0.023	n.i.	n.i.	0.023	0.023	0.023	0.023	n.i.
	10	0.023	0.023	0.023	0.024	0.023	n.i.	n.i.	0.023	0.023	0.023	0.023	n.i.
	100	0.023	0.023	0.023	0.039	0.025	n.i.	n.i.	0.024	0.024	0.027	0.024	n.i.
Alum shale	**Present**	0.023	0.023	0.023	0.023	0.023	n.i.	n.i.	0.023	0.023	0.023	0.023	n.i.
	1	0.023	0.023	0.023	0.023	0.023	n.i.	n.i.	0.023	0.023	0.023	0.023	n.i.
	10	0.023	0.023	0.023	0.025	0.023	n.i.	n.i.	0.023	0.023	0.023	0.023	n.i.
	100	0.024	0.023	0.024	0.040	0.025	n.i.	n.i.	0.024	0.024	0.028	0.024	n.i.
Ås	**Present**	0.023	0.023	0.023	0.023	0.023	n.i.	n.i.	0.023	0.023	0.023	0.023	n.i.
	1	0.023	0.023	0.023	0.023	0.023	n.i.	n.i.	0.023	0.023	0.023	0.023	n.i.
	10	0.023	0.023	0.023	0.024	0.023	n.i.	n.i.	0.023	0.023	0.023	0.023	n.i.
	100	0.024	0.023	0.024	0.036	0.025	n.i.	n.i.	0.024	0.024	0.027	0.024	n.i.
Time	**Present**	0.025	n.i.	n.i.	0.025	0.025	n.i.	n.i.	0.025	0.025	0.025	0.025	n.i.
	1	0.025	n.i.	n.i.	0.025	0.025	n.i.	n.i.	0.025	0.025	0.025	0.025	n.i.
	10	0.025	n.i.	n.i.	0.027	0.025	n.i.	n.i.	0.025	0.025	0.025	0.025	n.i.
	100	0.026	n.i.	n.i.	0.045	0.028	n.i.	n.i.	0.026	0.027	0.031	0.026	n.i.

RCR
>1
>2
>5

9.2.1.6 Nickel (Ni)

The present RCR are >1 in Målselv, Melhus and alum shale, but RCRs decrease to <1 in all scenarios, except in alum shale after 10 or 100 years. As commented in 8.2.2.6, the predicted concentrations of Ni are generally high compared to measured concentrations indicating possible overestimation in the model, especially in the alum shale area where the geogenic Ni may be less mobile.

Table 9.2.1.6-1. Risk Characterization Ratio (RCR) for exposure of organisms in surface water to nickel (Ni).

Ni	**RCR**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**
	1	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**
	10	**1.5**	**1.5**	**1.5**	**1.6**	**1.5**	**1.5**	**1.5**	**1.5**	**1.5**	**1.5**	**1.5**	**1.5**
	100	0.7	0.6	0.7	1.0	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Melhus	**Present**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**
	1	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**
	10	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	100	0.3	0.3	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Stange	**Present**	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	10	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	100	0.3	0.3	0.3	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Alum shale	**Present**	**1.8**	**1.8**	**1.8**	**1.8**	**1.8**	**1.8**	**1.8**	**1.8**	**1.8**	**1.8**	**1.8**	**1.8**
	1	**1.8**	**1.8**	**1.8**	**1.8**	**1.8**	**1.8**	**1.8**	**1.8**	**1.8**	**1.8**	**1.8**	**1.8**
	10	**1.7**	**1.7**	**1.7**	**1.8**	**1.8**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**
	100	**1.1**	**1.1**	**1.1**	**1.2**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**
Ås	**Present**	0.5	0.5	0.5	0.5	0.5	n.i.	n.i.	0.5	0.5	0.5	0.5	0.5
	1	0.5	0.5	0.5	0.5	0.5	n.i.	n.i.	0.5	0.5	0.5	0.5	0.5
	10	0.5	0.5	0.5	0.5	0.5	n.i.	n.i.	0.5	0.5	0.5	0.5	0.5
	100	0.2	0.2	0.2	0.3	0.3	n.i.	n.i.	0.2	0.3	0.2	0.3	0.2
Time	**Present**	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	10	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	100	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

RCR
>1
>2
>5

9.2.1.7 Lead (Pb)

All RCRs are <<1 at the present assessment and after 100 years, indicating no risk.

Table 9.2.1.7-1. Risk Characterization Ratio (RCR) for exposure of organisms in surface water to lead (Pb).

Pb	**RCR**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026
	1	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026
	10	0.026	0.026	0.026	0.027	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026
	100	0.028	0.026	0.028	0.034	0.029	0.028	0.028	0.028	0.028	0.028	0.030	0.028
Melhus	**Present**	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
	1	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
	10	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
	100	0.007	0.006	0.007	0.009	0.007	0.007	0.007	0.007	0.007	0.007	0.008	0.007
Stange	**Present**	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
	1	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
	10	0.025	0.025	0.025	0.026	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
	100	0.026	0.025	0.026	0.028	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026
Alum shale	**Present**	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
	1	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
	10	0.028	0.028	0.028	0.029	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
	100	0.029	0.028	0.029	0.031	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029
Ås	**Present**	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027
	1	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027
	10	0.027	0.027	0.027	0.028	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027
	100	0.028	0.027	0.028	0.029	0.028	0.027	0.027	0.028	0.028	0.028	0.028	0.028
Time	**Present**	0.015	n.i.	n.i.	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
	1	0.015	n.i.	n.i.	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
	10	0.014	n.i.	n.i.	0.015	0.015	0.014	0.014	0.014	0.015	0.015	0.015	0.014
	100	0.014	n.i.	n.i.	0.016	0.015	0.014	0.014	0.014	0.015	0.015	0.015	0.014

RCR
>1
>2
>5

9.2.1.8 Zinc (Zn)

All current RCRs are <1 and remains so after 100 years, indicating no risk

Table 9.2.1.8-1. Risk Characterization Ratio (RCR) for exposure of organisms in surface water to zinc (Zn).

Zn	**RCR**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
	1	0.42	0.42	0.42	0.43	0.42	0.42	0.42	0.42	0.42	0.43	0.42	0.42
	10	0.41	0.40	0.41	0.46	0.43	0.42	0.42	0.43	0.43	0.45	0.42	0.43
	100	0.29	0.28	0.29	0.74	0.51	0.40	0.38	0.46	0.49	0.63	0.38	0.50
Melhus	**Present**	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
	1	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
	10	0.18	0.18	0.18	0.20	0.19	0.19	0.19	0.19	0.19	0.20	0.19	0.19
	100	0.15	0.14	0.15	0.31	0.23	0.21	0.20	0.21	0.22	0.27	0.18	0.22
Stange	**Present**	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
	1	0.25	0.25	0.25	0.25	0.25	0.26	0.25	0.25	0.25	0.25	0.25	0.25
	10	0.25	0.25	0.25	0.27	0.26	0.29	0.27	0.26	0.26	0.26	0.25	0.26
	100	0.24	0.24	0.24	0.39	0.32	0.63	0.40	0.29	0.30	0.34	0.27	0.30
Alum shale	**Present**	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	1	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	10	0.40	0.40	0.40	0.41	0.40	0.44	0.41	0.40	0.40	0.41	0.40	0.40
	100	0.36	0.36	0.37	0.51	0.44	0.75	0.52	0.41	0.42	0.46	0.39	0.42
Ås	**Present**	0.33	0.33	0.33	0.33	0.33	n.i.	n.i.	0.33	0.33	0.33	0.33	0.33
	1	0.33	0.33	0.33	0.33	0.33	n.i.	n.i.	0.33	0.33	0.33	0.33	0.33
	10	0.32	0.32	0.32	0.34	0.33	n.i.	n.i.	0.33	0.33	0.33	0.32	0.33
	100	0.28	0.28	0.29	0.40	0.34	n.i.	n.i.	0.33	0.33	0.37	0.31	0.34
Time	**Present**	0.13	n.i.	n.i.	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
	1	0.13	n.i.	n.i.	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
	10	0.12	n.i.	n.i.	0.14	0.13	0.13	0.12	0.13	0.13	0.13	0.12	0.13
	100	0.08	n.i.	n.i.	0.17	0.12	0.12	0.11	0.11	0.12	0.15	0.10	0.12

RCR
>1
>2
>5

9.2.2 Sediment-dwelling (benthic) organisms

9.2.2.1 Arsenic (As)

All RCRs are <1, indicating no risk.

Table 9.2.2.1-1. Risk Characterization Ratio (RCR) for exposure of sediment-dwelling organisms to arsenic (As).

As	**RCR**	Only atmospheric contribution	Only mineral fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.040	0.040	0.040	0.040	n.i.	0.040	0.040	0.040	0.040	n.i.	0.040	0.040
	1	0.040	0.040	0.040	0.041	n.i.	0.040	0.040	0.040	0.040	n.i.	0.040	0.040
	10	0.040	0.040	0.040	0.043	n.i.	0.040	0.040	0.040	0.040	n.i.	0.040	0.040
	100	0.036	0.034	0.036	0.061	n.i.	0.037	0.037	0.038	0.036	n.i.	0.038	0.037
Melhus	**Present**	0.070	0.070	0.070	0.070	n.i.	0.070	0.070	0.070	0.070	n.i.	0.070	0.070
	1	0.070	0.070	0.070	0.071	n.i.	0.070	0.070	0.070	0.070	n.i.	0.070	0.070
	10	0.069	0.069	0.069	0.071	n.i.	0.069	0.069	0.069	0.069	n.i.	0.069	0.069
	100	0.058	0.057	0.058	0.080	n.i.	0.060	0.060	0.060	0.058	n.i.	0.060	0.059
Stange	**Present**	0.049	0.049	0.049	0.049	n.i.	0.049	0.049	0.049	0.049	n.i.	0.049	0.049
	1	0.049	0.049	0.049	0.050	n.i.	0.049	0.049	0.049	0.049	n.i.	0.049	0.049
	10	0.049	0.049	0.049	0.052	n.i.	0.049	0.049	0.049	0.049	n.i.	0.049	0.049
	100	0.049	0.047	0.049	0.076	n.i.	0.051	0.051	0.050	0.049	n.i.	0.050	0.050
Alum shale	**Present**	0.313	0.313	0.313	0.313	n.i.	0.313	0.313	0.313	0.313	n.i.	0.313	0.313
	1	0.312	0.312	0.312	0.313	n.i.	0.312	0.312	0.312	0.312	n.i.	0.312	0.312
	10	0.310	0.310	0.310	0.313	n.i.	0.310	0.310	0.310	0.310	n.i.	0.310	0.310
	100	0.283	0.282	0.283	0.310	n.i.	0.285	0.285	0.285	0.283	n.i.	0.285	0.284
Ås	**Present**	0.078	0.078	0.078	0.078	n.i.	n.i.	n.i.	0.078	0.078	n.i.	0.078	0.078
	1	0.078	0.078	0.078	0.078	n.i.	n.i.	n.i.	0.078	0.078	n.i.	0.078	0.078
	10	0.077	0.077	0.077	0.079	n.i.	n.i.	n.i.	0.077	0.077	n.i.	0.077	0.077
	100	0.069	0.068	0.070	0.091	n.i.	n.i.	n.i.	0.071	0.070	n.i.	0.071	0.071
Time	**Present**	0.088	n.i.	n.i.	0.088	n.i.	0.088	0.088	0.088	0.088	n.i.	0.088	0.088
	1	0.087	n.i.	n.i.	0.088	n.i.	0.087	0.087	0.087	0.087	n.i.	0.087	0.087
	10	0.085	n.i.	n.i.	0.089	n.i.	0.085	0.085	0.085	0.085	n.i.	0.085	0.085
	100	0.068	n.i.	n.i.	0.096	n.i.	0.070	0.070	0.070	0.068	n.i.	0.070	0.070

RCR
>1
>2
>5

9.2.2.2 Cadmium (Cd)

All RCRs are <1, indicating low risk.

Table 9.2.2.2-1. Risk Characterization Ratio (RCR) for exposure of sediment-dwelling organisms to cadmium (Cd).

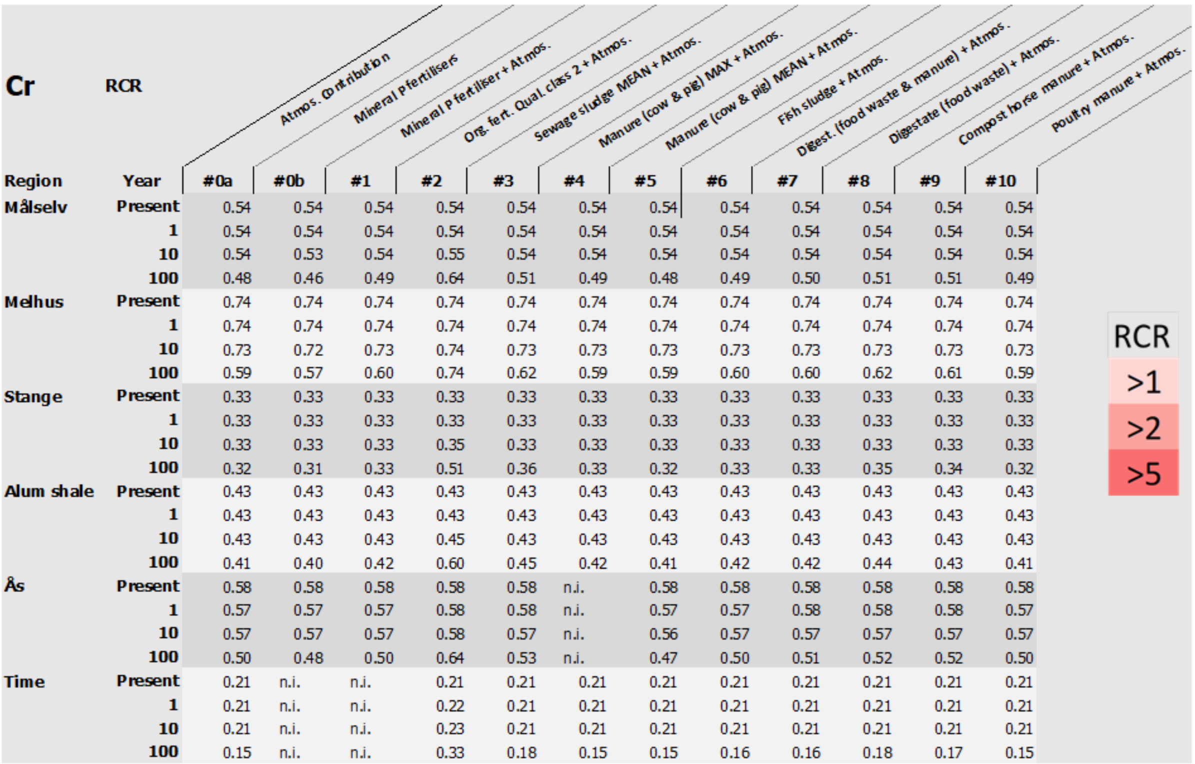
Cd	**RCR**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
	1	0.16	0.16	0.16	0.17	0.17	0.16	0.16	0.16	0.16	0.16	0.16	0.16
	10	0.15	0.15	0.15	0.18	0.16	0.15	0.15	0.16	0.16	0.16	0.16	0.15
	100	0.07	0.08	0.09	0.27	0.15	0.09	0.08	0.12	0.12	0.13	0.12	0.09
Melhus	**Present**	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	1	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	10	0.09	0.09	0.09	0.11	0.10	0.09	0.09	0.09	0.09	0.10	0.09	0.09
	100	0.05	0.07	0.08	0.17	0.11	0.07	0.06	0.08	0.08	0.09	0.08	0.06
Stange	**Present**	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
	1	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
	10	0.16	0.17	0.17	0.19	0.18	0.17	0.17	0.17	0.17	0.17	0.17	0.17
	100	0.13	0.20	0.21	0.36	0.25	0.20	0.16	0.17	0.17	0.18	0.17	0.15
Alum shale	**Present**	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
	1	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
	10	0.83	0.84	0.84	0.86	0.84	0.84	0.83	0.83	0.83	0.84	0.83	0.83
	100	0.59	0.65	0.66	0.81	0.70	0.66	0.61	0.62	0.62	0.63	0.62	0.60
Ås	**Present**	0.27	0.27	0.27	0.27	0.27	n.i.	n.i.	0.27	0.27	0.27	0.27	0.27
	1	0.27	0.27	0.27	0.27	0.27	n.i.	n.i.	0.27	0.27	0.27	0.27	0.27
	10	0.25	0.26	0.26	0.27	0.26	n.i.	n.i.	0.26	0.26	0.26	0.26	0.25
	100	0.15	0.17	0.18	0.30	0.22	n.i.	n.i.	0.17	0.18	0.19	0.18	0.16
Time	**Present**	0.43	n.i.	n.i.	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
	1	0.41	n.i.	n.i.	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
	10	0.27	n.i.	n.i.	0.31	0.29	0.28	0.28	0.28	0.28	0.29	0.28	0.28
	100	0.05	n.i.	n.i.	0.15	0.08	0.07	0.06	0.08	0.08	0.08	0.08	0.06

RCR
>1
>2
>5

9.2.2.3 *Chromium (Cr)*

All present RCRs are <1 indicating no risk and are decreasing in most scenarios except with scenario #2 (organic fertilisers quality class II).

Table 9.2.2.3-1. Risk Characterization Ratio (RCR) for exposure of sediment-dwelling organisms to chromium (Cr).



Cr	RCR	Atmos. contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
	1	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
	10	0.54	0.53	0.54	0.55	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
	100	0.48	0.46	0.49	0.64	0.51	0.49	0.48	0.49	0.50	0.51	0.51	0.49
Melhus	**Present**	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
	1	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
	10	0.73	0.72	0.73	0.74	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
	100	0.59	0.57	0.60	0.74	0.62	0.59	0.59	0.60	0.60	0.62	0.61	0.59
Stange	**Present**	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
	1	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
	10	0.33	0.33	0.33	0.35	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
	100	0.32	0.31	0.33	0.51	0.36	0.33	0.32	0.33	0.33	0.35	0.34	0.32
Alum shale	**Present**	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
	1	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
	10	0.43	0.43	0.43	0.45	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
	100	0.41	0.40	0.42	0.60	0.45	0.42	0.41	0.42	0.42	0.44	0.43	0.41
Ås	**Present**	0.58	0.58	0.58	0.58	0.58	n.i.	0.58	0.58	0.58	0.58	0.58	0.58
	1	0.57	0.57	0.57	0.58	0.58	n.i.	0.57	0.57	0.58	0.58	0.58	0.57
	10	0.57	0.57	0.57	0.58	0.57	n.i.	0.56	0.57	0.57	0.57	0.57	0.57
	100	0.50	0.48	0.50	0.64	0.53	n.i.	0.47	0.50	0.51	0.52	0.52	0.50
Time	**Present**	0.21	n.i.	n.i.	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
	1	0.21	n.i.	n.i.	0.22	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
	10	0.21	n.i.	n.i.	0.23	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
	100	0.15	n.i.	n.i.	0.33	0.18	0.15	0.15	0.16	0.16	0.18	0.17	0.15

RCR
>1
>2
>5

9.2.2.4 *Copper (Cu)*

The present RCR is <1 in all regions, indicating no risk. In several scenarios, RCR values are increasing but still remain <1, except for in the alum shale area and Time after 100 years.

Table 9.2.2.4-1. Risk Characterization Ratio (RCR) for exposure of sediment-dwelling organisms to copper (Cu).

Cu	**RCR**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
	1	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
	10	0.27	0.27	0.27	0.34	0.28	0.28	0.28	0.28	0.28	0.28	0.29	0.28
	100	0.25	0.25	0.25	0.82	0.26	0.31	0.28	0.33	0.33	0.33	0.35	0.31
Melhus	**Present**	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	1	0.32	0.32	0.32	0.33	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	10	0.32	0.32	0.32	0.37	0.32	0.33	0.32	0.33	0.33	0.33	0.33	0.32
	100	0.28	0.28	0.28	0.77	0.29	0.36	0.33	0.35	0.34	0.35	0.37	0.33
Stange	**Present**	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
	1	0.38	0.38	0.38	0.39	0.38	0.39	0.38	0.38	0.38	0.38	0.38	0.38
	10	0.38	0.38	0.38	0.45	0.38	0.41	0.40	0.39	0.39	0.39	0.39	0.39
	100	0.37	0.37	0.37	0.99	0.38	0.61	0.49	0.45	0.44	0.45	0.46	0.43
Alum shale	**Present**	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
	1	0.72	0.72	0.72	0.73	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
	10	0.72	0.71	0.72	0.78	0.72	0.74	0.73	0.72	0.72	0.72	0.72	0.72
	100	0.67	0.66	0.67	**1.28**	0.68	0.90	0.79	0.74	0.73	0.74	0.76	0.72
Ås	**Present**	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
	1	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
	10	0.35	0.35	0.36	0.40	0.36	0.35	0.35	0.36	0.36	0.36	0.36	0.36
	100	0.34	0.34	0.34	0.78	0.35	0.34	0.34	0.41	0.40	0.41	0.42	0.39
Time	**Present**	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
	1	0.42	0.42	0.42	0.43	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
	10	0.41	0.41	0.41	0.51	0.41	0.42	0.42	0.42	0.42	0.42	0.43	0.42
	100	0.34	0.34	0.35	**1.03**	0.36	0.45	0.41	0.44	0.43	0.44	0.46	0.42

RCR
>1
>2
>5

9.2.2.5 *Mercury (Hg)*

All RCRs are <<1, indicating no risk.

Table 9.2.2.5-1. Risk Characterization Ratio (RCR) for exposure of sediment-dwelling organisms to mercury (Hg).

Hg	**RCR**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.009	0.009	0.009	0.009	0.009	n.i.	n.i.	0.009	0.009	0.009	0.009	n.i.
	1	0.009	0.009	0.009	0.009	0.009	n.i.	n.i.	0.009	0.009	0.009	0.009	n.i.
	10	0.009	0.009	0.009	0.010	0.009	n.i.	n.i.	0.009	0.009	0.009	0.009	n.i.
	100	0.009	0.009	0.009	0.016	0.010	n.i.	n.i.	0.010	0.010	0.011	0.010	n.i.
Melhus	**Present**	0.009	0.009	0.009	0.009	0.009	n.i.	n.i.	0.009	0.009	0.009	0.009	n.i.
	1	0.009	0.009	0.009	0.009	0.009	n.i.	n.i.	0.009	0.009	0.009	0.009	n.i.
	10	0.009	0.009	0.009	0.010	0.009	n.i.	n.i.	0.009	0.009	0.009	0.009	n.i.
	100	0.010	0.009	0.010	0.015	0.010	n.i.	n.i.	0.010	0.010	0.011	0.010	n.i.
Stange	**Present**	0.009	0.009	0.009	0.009	0.009	n.i.	n.i.	0.009	0.009	0.009	0.009	n.i.
	1	0.009	0.009	0.009	0.009	0.009	n.i.	n.i.	0.009	0.009	0.009	0.009	n.i.
	10	0.009	0.009	0.009	0.010	0.009	n.i.	n.i.	0.009	0.009	0.009	0.009	n.i.
	100	0.010	0.009	0.010	0.016	0.010	n.i.	n.i.	0.010	0.010	0.011	0.010	n.i.
Alum shale	**Present**	0.009	0.009	0.009	0.009	0.009	n.i.	n.i.	0.009	0.009	0.009	0.009	n.i.
	1	0.009	0.009	0.009	0.010	0.009	n.i.	n.i.	0.009	0.009	0.009	0.009	n.i.
	10	0.009	0.009	0.009	0.010	0.010	n.i.	n.i.	0.009	0.009	0.010	0.009	n.i.
	100	0.010	0.009	0.010	0.016	0.010	n.i.	n.i.	0.010	0.010	0.011	0.010	n.i.
Ås	**Present**	0.009	0.009	0.009	0.009	0.009	n.i.	n.i.	0.009	0.009	0.009	0.009	n.i.
	1	0.009	0.009	0.009	0.009	0.009	n.i.	n.i.	0.009	0.009	0.009	0.009	n.i.
	10	0.009	0.009	0.009	0.010	0.009	n.i.	n.i.	0.009	0.009	0.010	0.009	n.i.
	100	0.010	0.009	0.010	0.015	0.010	n.i.	n.i.	0.010	0.010	0.011	0.010	n.i.
Time	**Present**	0.010	n.i.	n.i.	0.010	0.010	n.i.	n.i.	0.010	0.010	0.010	0.010	n.i.
	1	0.010	n.i.	n.i.	0.010	0.010	n.i.	n.i.	0.010	0.010	0.010	0.010	n.i.
	10	0.010	n.i.	n.i.	0.011	0.010	n.i.	n.i.	0.010	0.010	0.010	0.010	n.i.
	100	0.010	n.i.	n.i.	0.019	0.011	n.i.	n.i.	0.011	0.011	0.013	0.011	n.i.

RCR
>1
>2
>5

9.2.2.6 *Nickel (Ni)*

The present RCR is <1 in all case areas, except for the alum shale area, where a potential risk is indicated. Even if the concentration of Ni is generally decreasing in all scenarios and regions, the RCR remains >1, indicating a low risk in the alum shale area after 100 years.

Table 9.2.2.6-1. Risk Characterization Ratio (RCR) for exposure of sediment-dwelling organisms to nickel (Ni).

Ni	**RCR**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
	1	0.61	0.61	0.61	0.62	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
	10	0.56	0.56	0.56	0.58	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56
	100	0.24	0.22	0.24	0.35	0.27	0.25	0.24	0.25	0.26	0.25	0.26	0.25
Melhus	**Present**	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83
	1	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
	10	0.73	0.73	0.73	0.75	0.74	0.73	0.73	0.73	0.74	0.73	0.74	0.73
	100	0.26	0.25	0.27	0.34	0.28	0.27	0.27	0.27	0.28	0.27	0.28	0.27
Stange	**Present**	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
	1	0.48	0.48	0.48	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
	10	0.47	0.46	0.47	0.48	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
	100	0.32	0.31	0.33	0.45	0.36	0.34	0.33	0.33	0.34	0.33	0.34	0.33
Alum shale	**Present**	**1.86**	**1.86**	**1.86**	**1.86**	**1.86**	**1.86**	**1.86**	**1.86**	**1.86**	**1.86**	**1.86**	**1.86**
	1	**1.85**	**1.85**	**1.85**	**1.85**	**1.85**	**1.85**	**1.85**	**1.85**	**1.85**	**1.85**	**1.85**	**1.85**
	10	**1.76**	**1.76**	**1.76**	**1.78**	**1.77**	**1.76**	**1.76**	**1.76**	**1.76**	**1.76**	**1.76**	**1.76**
	100	**1.10**	**1.08**	**1.10**	**1.23**	**1.13**	**1.12**	**1.10**	**1.10**	**1.12**	**1.11**	**1.12**	**1.11**
Ås	**Present**	0.55	0.55	0.55	0.55	0.55	n.i.	n.i.	0.55	0.55	0.55	0.55	0.55
	1	0.54	0.54	0.54	0.54	0.54	n.i.	n.i.	0.54	0.54	0.54	0.54	0.54
	10	0.50	0.50	0.50	0.51	0.50	n.i.	n.i.	0.50	0.50	0.50	0.50	0.50
	100	0.24	0.23	0.24	0.33	0.26	n.i.	n.i.	0.25	0.26	0.25	0.26	0.25
Time	**Present**	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
	1	0.23	0.23	0.23	0.24	0.24	0.24	0.23	0.23	0.24	0.24	0.24	0.24
	10	0.19	0.19	0.19	0.21	0.20	0.20	0.19	0.19	0.20	0.19	0.20	0.19
	100	0.10	0.09	0.09	0.16	0.12	0.11	0.11	0.11	0.12	0.11	0.11	0.11

RCR
>1
>2
>5

9.2.2.7 *Lead (Pb)*

All RCRs are <<1, indicating no effect in any of scenarios and case areas.

Table 9.2.2.7-1. Risk Characterization Ratio (RCR) for exposure of sediment-dwelling organisms to lead (Pb).

Pb	**RCR**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	1	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	10	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	100	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.06
Melhus	**Present**	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	1	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	10	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	100	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Stange	**Present**	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
	1	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
	10	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
	100	0.16	0.16	0.16	0.17	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Alum shale	**Present**	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
	1	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
	10	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
	100	0.18	0.18	0.18	0.19	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Ås	**Present**	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
	1	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
	10	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
	100	0.17	0.17	0.17	0.18	0.17	0.17	0.17	0.17	0.17	0.17	0.18	0.17
Time	**Present**	0.17	n.i.	n.i.	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
	1	0.17	n.i.	n.i.	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
	10	0.17	n.i.	n.i.	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
	100	0.16	n.i.	m.i.	0.18	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17

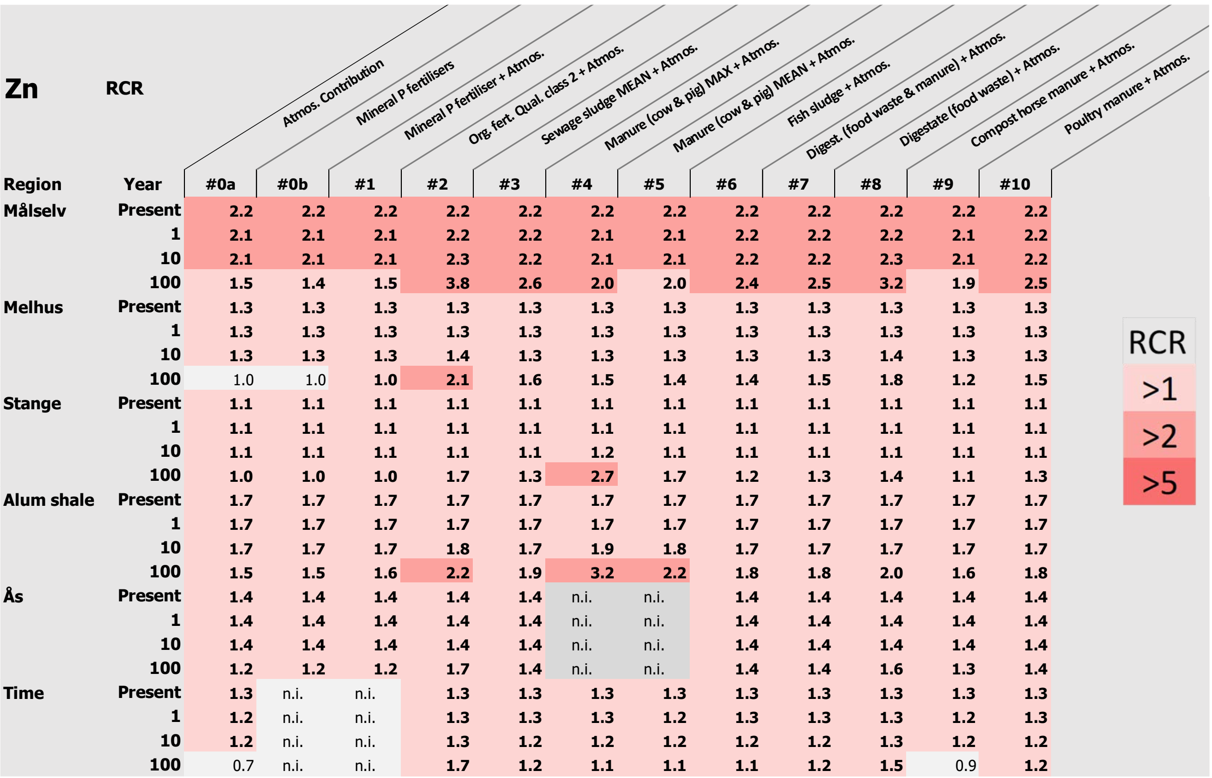
RCR
>1
>2
>5

9.2.2.8 Zinc (Zn)

Current RCRs are between 1.1 (Stange) and 2.2 (Målselv) indicating a risk at the predicted concentrations in sediment. The different input scenarios show either decreasing or increasing concentrations (See section 8.1.8), but the changes in RCR are relatively small, with the highest value of 3.8 in Målselv, scenario #2 (organic fertiliser regulation) and the lowest of 0.7 at Time, scenario #0b (atmospheric contribution) after 100 years.

It should be noted that the PNEC$_{sed}$ is based on toxic effects found in oxygenated sediments, where the availability of Zn is highest. In less oxygenated sediments with higher concentrations of acid volatile sulphides, the availability and toxicity of Zn is lower. The PNEC$_{sed}$ used in the risk assessment is therefore conservative, and verification of a predicted risk requires analysis of the local conditions. Furthermore, a comparison of the predicted concentrations of Zn compared with measured concentrations in sediments indicate that the model tends to overestimate the PEC$_{sed}$ for Zn (See section 8.2.3.8).

Table 9.2.2.8-1. Risk Characterization Ratio (RCR) for exposure of sediment-dwelling organisms to zinc (Zn).



Zn	**RCR**	Atmos. Contribution	Mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. fert. Qual. class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digestate (food waste) + Atmos.	Compost horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
	1	2.1	2.1	2.1	2.2	2.2	2.1	2.1	2.2	2.2	2.2	2.1	2.2
	10	2.1	2.1	2.1	2.3	2.2	2.1	2.1	2.2	2.2	2.3	2.1	2.2
	100	1.5	1.4	1.5	3.8	2.6	2.0	2.0	2.4	2.5	3.2	1.9	2.5
Melhus	**Present**	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
	1	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
	10	1.3	1.3	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.3
	100	1.0	1.0	1.0	2.1	1.6	1.5	1.4	1.4	1.5	1.8	1.2	1.5
Stange	**Present**	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
	1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
	10	1.1	1.1	1.1	1.1	1.1	1.2	1.1	1.1	1.1	1.1	1.1	1.1
	100	1.0	1.0	1.0	1.7	1.3	2.7	1.7	1.2	1.3	1.4	1.1	1.3
Alum shale	**Present**	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
	1	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
	10	1.7	1.7	1.7	1.8	1.7	1.9	1.8	1.7	1.7	1.7	1.7	1.7
	100	1.5	1.5	1.6	2.2	1.9	3.2	2.2	1.8	1.8	2.0	1.6	1.8
Ås	**Present**	1.4	1.4	1.4	1.4	1.4	n.i.	n.i.	1.4	1.4	1.4	1.4	1.4
	1	1.4	1.4	1.4	1.4	1.4	n.i.	n.i.	1.4	1.4	1.4	1.4	1.4
	10	1.4	1.4	1.4	1.4	1.4	n.i.	n.i.	1.4	1.4	1.4	1.4	1.4
	100	1.2	1.2	1.2	1.7	1.4	n.i.	n.i.	1.4	1.4	1.6	1.3	1.4
Time	**Present**	1.3	n.i.	n.i.	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
	1	1.2	n.i.	n.i.	1.3	1.3	1.3	1.2	1.3	1.3	1.3	1.2	1.3
	10	1.2	n.i.	n.i.	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.2	1.2
	100	0.7	n.i.	n.i.	1.7	1.2	1.1	1.1	1.1	1.2	1.5	0.9	1.2

RCR
>1
>2
>5

9.3 Risk characterisation of farm animals

9.3.1 Risk characterisation of arsenic in animals

The background level of As is far below a level considered as maximum tolerable. In most scenarios (region x fertilisation scheme), the estimated temporal development of As in animal diets via grazing and feeding imply reduced levels. The exception is Stange, where an increase at 130% by fertilisation scheme #2 and marginal increases at 3-6% by fertilisation schemes #4, 5, 6, 9 and 10 after 100 years are expected. The maximum increase at Stange will result in dietary As levels for grazing animals at about 0.2 mg kg^{-1}. This increase implies no health risk for the farm animals. Maximal tolerable levels of As are somewhat unclear, but NRC (2005) indicates 30 mg kg^{-1} diet for domestic animals. NRC (2005) also refers to an EU directive (2002) that, without giving scientific basis, set the maximum As contents in products intended for animal feed at 2 mg kg^{-1} feed, with the exception of meals made from grass etc (4 mg kg-1) and feedstuffs obtained from fish and other marine animals (10 mg kg^{-1}).

Thus, fish sludge as fertiliser (#6) is expected to result in marginal increase of As in animal diets. Use of other marine products such as residues from the fish industry and sea weeds as fertilisers would probably far more increase the levels of As in animal diets.

9.3.2 Risk characterisation of cadmium in animals

In all selected geographical regions, including the alum shale area, the current Cd levels in feed and pasture plants including soil, and thus the animal diet, are far below a critical level of concern for animal health and below a level of concern for consumers of animal products. The upper limit set by WHO is 1 mg kg^{-1} diet. Because Cd is a potential toxic element without essential qualities, it is a goal to keep Cd levels as low as possible.

Using most of the organic fertilisers, Cd concentrations in animal diets are estimated to decline, and thus, imply reduced risk of Cd concentrations of concern in animal products, as well as the less-likely risk for adverse health effects in animals. However, there are some exceptions. An increase of Cd will be due to the use of fertiliser #2 (organic fertiliser quality class II with maximum PTE levels), for which the greatest increase after 100 years is estimated at Stange (160%), but also at Melhus (90%) and Målselv (70%). After 100 years of using #2, Cd level is still below 0.1 mg kg^{-1} in total diet for grazing animals at Stange and somewhat lower for fed animals. Lower levels are shown for Melhus and Målselv. In comparison, the background Cd level in the alum shale area implies about 0.22 mg kg^{-1} in total diet for grazing animals. The lower estimated increment of Cd by use of fertilising schemes #0b, 1, 3, 4, and 8 at Stange and #3 at Melhus is at even lower animal health risk.

Thus, most scenarios imply reduced risk of Cd concentrations of concern in animal products, as well as the less-likely risk for adverse health effects in animals. The exceptions where increased Cd is estimated, the estimated levels are still below 1 mg kg^{-1} animal diet. Anyway, ensuring that the liver and kidneys of older animals do not enter the human food chain remains a measure to decrease the risk of human exposure to Cd via foods of animal origin.

Exposure of animals to Cd levels through drinking water is usually far below that from their feed and pasture plants and is not expected to contribute significantly to their total exposure.

9.3.3 Risk characterisation of chromium in animals

At all regions, the background Cr levels in animal diets from pasture and feeding are far below a maximum tolerable level. By most fertilisation schemes a further decline in these levels is estimated. The exception is scheme #2, which implies an increase in most regions, with up to 60-70% at Stange and Time and somewhat lower increases at the alum shale area, Ås and Målselv, and steady state at Melhus. A certain, but, less increase is also estimated at Stange by fertiliser schemes #3, 8 and 9. The increases imply no health risk for farm animals as Cr is considered to be the trivalent form.

For soluble forms of Cr(III), the suggested maximum tolerable level is 500 mg kg^{-1} for poultry and 100 mg kg^{-1} for mammalian species (NRC, 2005). Any increase in Cr concentration in edible tissue, except for kidney, should not represent a human health concern (NRC, 2005).

9.3.4 Risk characterisation of copper (Cu) in animals

By use of organic fertiliser quality class II with maximum PTE levels (#2), after 100 years at Stange and the alum shale area in particular, the soils are expected to contain elevated Cu levels, considered harmful for grazing sheep (maximum tolerable dietary levels 15 mg kg^{-1}). For other farm animals, these levels imply no risk. However, the combination farm animals and use of sewage sludge may not be a common situation.

Also pig manure (#4) in the alum shale area with elevated background Cu, may increase Cu to levels at risk for grazing sheep. No other scenarios (fertilisations x areas) are estimated to reach harmful levels of Cu for sheep within 100 years.

Because Cu levels are mainly within the animals' nutritional requirement, the potential risk that the available Cu could create microbial resistance problems in animal guts and environment against Cu and possible co-resistance against antimicrobial drugs, is considered low.

9.3.5 Risk characterisation of lead (Pb) in animals

At all selected geographical regions, the current Pb levels in feed and pasture plants including soil, and thus the animal diet, are below a suggested critical level of concern for animal health and below a level of concern for consumers of animal products. The legislation on Pb by EU Commission which also include the Norwegian legislation has set maximum limit of 30 mg Pb kg^{-1} in grass etc and 10 mg kg^{-1} in other feedstuffs. Based on available data these limits seem to protect animal health.

By use of organic fertiliser quality class II with maximum PTE levels (#2), an increase of Pb is estimated at all regions - about double levels at Stange, Melhus and Målselv after 100 years and somewhat less at the other regions. Some other fertilisation schemes (#3 and 9) seem to increase Pb somewhat above an atmospheric deposition. The levels in animal pasture diet will rise to between 1 and 2 mg kg^{-1} in the various regions, which is below a level of animal health concern.

Because Pb is a toxic element without essential qualities and accumulates in animal organs and is transferred into milk, any increase is undesirable.

9.3.6 Risk characterisation of mercury (Hg) in animals

At all selected geographical regions, the current Hg levels in feed and pasture plants including soil, and thus the animal diet, are below a suggested critical level of concern for health of studied animals. Chronic consumption of diets containing soluble forms of inorganic Hg at 0.2 mg kg^{-1} is tolerated by poultry, pigs as well as rodents (NRC, 2005). Studies on ruminants are lacking. Chronic consumption of methylmercury at 1 mg kg^{-1} diet is tolerated by poultry, and a dietary level of 2 mg kg^{-1} has been established by NRC as safe for pigs and ruminants.

By use of organic fertiliser quality class II with maximum PTE levels (#2), a dramatic increase of Hg is estimated at all regions. After 100 years, the expected increase is about 10 times at Stange, alum shale area, Melhus and Målselv, and somewhat less at Ås and Time (6 times increase). The levels in animal pasture diet will rise to about 0.03 or maximum 0.04 mg kg^{-1} at the various regions. By fertiliser schemes #3 and 8 lower increases (1-4 times) are estimated after 100 years in the various regions. The dietary levels will still be below levels considered to be critical for animal health.

Because Hg is a toxic element without essential qualities and accumulates in animal products for human consumption such as meat and eggs, there is a goal to keep its level as low as possible.

9.3.7 Risk characterisation of nickel (Ni) in animals

The background levels of Ni are far below a critical level for animal health concern, and a decline by all scenarios is estimated. Thus, the conclusion is that there is no risk for adverse health effects in animals exposed to Ni.

9.3.8 Risk characterisation of zinc (Zn) in animals

The background levels of Zn are below animal health concern.

Use of organic fertiliser quality class II with maximum PTE levels (#2) implies somewhat increase of Zn at all regions. However, the most powerful increase of Zn is by use of pig manure (#4) at Stange (430%) and alum shale area (160%). After 100 years of fertiliser scheme #4, the diet of grazing animals at Stange and alum shale area is estimated to contain up to respective 70 and 85 mg Zn kg^{-1}, which are still below levels for animal health concern. Other fertiliser schemes (#3, 5 and 8) at Stange will also increase Zn, but less dramatically. Use of pig manure instead of cattle manure, also at other regions will increase Zn level in soil and thus in animal diets from these soils but resulting in lower levels than at Stange and the alum shale area.

Thus, all scenarios (fertilisations x areas) in a 100-year perspective are estimated far below MTL levels of Zn for farm animals and will not reach harmful levels.

Use of Zn in animal feed above physiological requirement may potentially induce bacterial resistance problems, but this situation is not very likely under the assessed conditions. Thus, the risk that the available Zn could create microbial resistance problems in animal guts and environment against Zn and possible co-resistance against antimicrobial drugs, is considered low.

9.4 Risk characterisation for humans

9.4.1 Arsenic (As)

EFSA have established a $BMDL_{01}$ range of 0.3 – 8.0 µg kg^{-1} BW per day for inorganic As based on an increased risk of cancers of the lung, skin and bladder, and skin lesions (EFSA, 2009). The mean exposure to inorganic As in the European population are 0.07 – 0.61 µg kg^{-1} BW per day for infants, toddlers and other children, 0.04 – 0.21 µg kg^{-1} BW per day for adolescents, and 0.03 – 0.15 µg kg^{-1} BW per day for adults (EFSA, 2021). The dietary exposures to inorganic As are below the ranges for the $BMDL_{01}$ values for adolescents and adults. However, for infants, toddlers and other children some of the estimated exposures are close to or within the ranges of the $BMDL_{01}$ values. Any increase in the dietary exposure is not desirable.

Grain and grain-based products are one of the largest contributors to the total As exposure in the general European population, while vegetables and vegetable products are main contributors in some countries (EFSA 2021).

In general, the As concentration in wheat, carrots and potatoes will decrease in most of the scenarios, depending on time (chapter 8.3 and 8.5). In a 10-year perspective, the estimated concentrations remain at a similar level or decrease, while in a 100-year perspective the concentrations decrease. A reduction in the concentration of As in wheat, carrots and potatoes is likely to reduce the As exposure in the Norwegian population.

At some locations (Målselv, Melhus, Stange and Ås), the evaluation of organic fertiliser regulation (#2) is expected to lead to an increase in As concentration in wheat, carrots and potatoes in a 100-year perspective (chapter 8.3 and 8.5). Consumption of these crops will lead to an increase in the dietary exposure to As. As the dietary exposure is high, any increase in dietary exposure is not desirable.

The use of engineered soil in home gardening will lead to a small increase in the As concentrations in lettuce, carrot, tomato and potato in 50-year perspective, while the use of engineered soil in urban farming and market gardens will increase the As concentrations in potato, leaf vegetables, root vegetables and garden fruits in a 100-year perspective (chapter 8.3 and 8.5). The use of growing media will lead to an increase in As concentration in potato, leaf vegetables, root vegetables and garden fruits (chapter 8.3 and 8.5). An increase in As concentration in home grown vegetables and vegetables and fruit from urban farming is likely to increase As exposure in persons eating such crops. As the dietary exposure is high, any increase in dietary exposure is not desirable.

9.4.2 Cadmium (Cd)

The TWI for Cd is based on an increased risk of reduced kidney function in adults following long-term dietary exposure and was set at 2.5 µg Cd kg^{-1} BW per week (EFSA, 2009). VKM have earlier assessed the exposure to Cd in the Norwegian population and concluded that exposure of the Norwegian adult population to Cd is comparable to the exposure of adult European population (VKM, 2015). In 2012, EFSA estimated the dietary Cd exposure in the European population (EFSA, 2012). For adolescents, adults, elderly and very elderly, the mean middle bound exposures ranged from 1.63 to 2.20 µg kg^{-1} BW per week. Infants, toddlers, and other children had mean middle bound exposures of 2.74 to 3.96 µg Cd kg^{-1} BW per week. The mean middle bound lifetime dietary exposure to Cd was calculated to be 2.04 µg Cd kg^{-1} BW per week. The dietary exposure to Cd is, in general high, and for infants, toddlers and other children, the mean middle bound exposures exceed the TWI. Any increase in dietary exposure to Cd is not desirable. A mean exposure close to or above TWI dictates that the exposure should be reduced.

In Europe, foods that contribute most to the dietary Cd exposure across all age groups are potatoes, bread and rolls, fine bakery wares, chocolate products, leafy vegetables, and water molluscs (EFSA, 2012).

In general, the Cd concentration in wheat, carrots and potatoes will remain the same or decrease in most of the scenarios (chapter 8.3 and 8.5). A reduction in the concentration of Cd in wheat, carrots and potatoes is likely to reduce Cd exposure in the Norwegian population.

At some locations (Målselv, Melhus, Stange and Ås) organic fertiliser regulation quality class II (#2) is expected to lead to an increase in Cd concentration in agricultural wheat, carrots and potatoes in a 10- and 100-year perspective (chapter 8.3 and 8.5). Consumption of these crops will lead to an increase in dietary exposure to Cd. The increased exposure could be higher in parts of the population consuming large quantities of locally produced food grown at locations where Cd concentrations in crops are expected to increase. As the dietary exposure is high, any increase in dietary exposure is not desirable.

The use of engineered soil in home gardening will lead to a small increase in Cd concentrations in lettuce, carrot, tomato and potato in a 50-year perspective, while the use of engineered soil in urban farming and market gardens will increase Cd concentrations in potato, leaf vegetables, root vegetables and garden fruits in a 100-year perspective (chapter 8.3 and 8.5). The use of growing media will lead to an increase in Cd concentration in potato, lettuce, carrot and mushroom (chapter 8.3 and 8.5). An increase in Cd concentration in home grown vegetables and vegetables and fruit from urban farming is likely to increase Cd exposure in persons eating such crops. As the dietary exposure is high, any increase in dietary exposure is not desirable.

9.4.3 Chromium (Cr)

EFSA established TDI for Cr(III) at 300 µg kg^{-1} BW per day and estimated mean (0.6-5.9 µg kg^{-1} BW per day and high (95 percentile intakes of 1.1 – 9.0 µg kg^{-1} BW perday), well below the TDI. It was also estimated that the food group "bread and rolls" contributed with approximately 4-20% of total intake and vegetables and vegetable products contributed with median values of 4-8% of total dietary intake of Cr(III). Most scenarios indicate no change or decrease in Cr concentrations in crop plants, but organic fertiliser regulation quality class II was estimated to cause an increase of up to 20% of Cr in crop plants, except for Stange where an increase of 58% was estimated. Considering the limited increase in concentrations and the very large safety margin between estimated exposure and TDI, VKM considers that the estimated increase of Cr exposure from food due to the use of fertilisers is of no concern.

The estimated increase of Cr in plants after use of engineered soil in home gardening or urban farming are small (<10%). Considering the limited increase in Cr concentrations and the large margin between TDI and current dietary intake, VKM considers that the use of engineered soil or urban farming is of no concern.

9.4.4 Copper (Cu)

EUs Scientific Committee for Food safety established a tolerable upper intake level for Cu at 1 mg/day for 1-3 year-olds, increasing to 5 mg day^{-1} for adults (SCF 2003). EFSA (2015) concluded that there were insufficient data to establish mean requirements or population reference intakes (PRI) for Cu. EFSA therefore, defined adequate intakes for different age and population groups (sex, lactating etc) based on the current Cu intakes given that there is no evidence of Cu deficiencies in the European population (EFSA 2015). The adequate intakes proposed range from 0.4 mg kg^{-1} BW per day for 7-11 month-olds increasing with age to 1.6 mg day^{-1} for adult men and 1.3 mg day^{-1} for adult females (EFSA 2015).

EFSA estimated dietary intake of Cu for different age groups, with mean estimates ranging between 0.34 and 0.50 mg day^{-1} in infants, between 0.57 and 0.94 mg day^{-1} in 1-3 year-old children, between 0.82 and 1.44 mg day^{-1} in 3-10 year-old children, between 0.98 and 1.92 mg day^{-1} in 10-18 year-olds and between 1.15 and 2.07 mg day^{-1} for adults. Grain and grain-based products were the main contributors to the dietary intake, contributing with 7-44% of the total intake while starchy roots or tubers and products s thereof and vegetables and vegetable products each contributed with 1-12% of the total intake (EFSA 2015).

The scenarios indicate that Cu may increase considerably in crop plants and particularly for scenario 2, but also scenarios 4 and 9 is expected to lead to significant increases in Cu concentrations (Table 8.3.1.4-1). The estimated increases in grain and grain products following scenario 2 may lead to a dietary exposure exceeding the upper safe intake level proposed by SCF (SCF 2003) and is of concern. The increases following scenarios 4 and 9 are less and will probably not lead to an intake exceeding the upper safe intake level.

The scenarios for urban farming, home cultivation and the use of growing media are predicted to increase the Cu concentrations in food plants, but from a lower starting concentration than agricultural farming (Tables 8.3.1.4-4, 8.3.2.1-4 and 8.3.2.2-4). VKM considers that the predicted Cu concentrations in food plants from these scenarios are well below the current Cu concentrations in traditional farming and not of concern.

Despite the high predicted concentrations of Cu in farmed mushroom, a normal ingestion of cultivated mushroom is not predicted to cause any increased exposure of concern due to the low intake. However, for the high consumers, (P95 is 75 g day^{-1}), the predicted increase in Cu concentration may lead to a substantial increase in Cu intake.

9.4.5 Mercury (Hg)

Fish and other seafood is the major contributor of dietary exposure to mercury in the European population (EFSA, 2012). Other food contributes little to the dietary exposure to mercury.

The mercury concentration will increase in agricultural crops (wheat, carrots and potatoes) at all locations, depending on time and type of fertiliser (chapter 8.3 and 8.5). An increase in mercury concentration in wheat, carrots and potatoes is likely to increase the mercury exposure in the Norwegian population, but the contribution will be small compared to the contribution from the consumption of fish and other seafood.

The use of engineered soil in home gardening and urban farming, and the use of growth media, will lead to an increase in mercury concentrations in vegetables and garden fruits (chapter 8.3 and 8.5). An increase in mercury concentration in home grown- and crops from urban farming is likely to increase mercury exposure in persons eating such vegetables. The contribution to total dietary mercury exposure will be small compared to contribution from the consumption of fish and other seafood.

9.4.6 Nickel (Ni)

EFSA established a TDI of 13 µg kg mg day^{-1} BW per day for Ni (EFSA 2012). They also concluded that the estimated high intake (95 percentile) exceeded the TDI for toddlers and other children, as well as infants in some surveys and according to EFSA, this may raise a health concern (EFSA 2012). All fertiliser schemes applied here, however, lead to a decrease in Ni concentrations in crop plants (Table 8.3.1.6-1), which would be beneficial taking the EFSA risk assessment into consideration.

The use of engineered soil in home gardening and urban farming is predicted to lead to a minor increase in Ni concentrations in vegetables, but his increase is not predicted to be of any health concern.

The Ni concentrations in cultivated mushrooms are predicted to increase and reach high concentrations. Due to low intake of cultivated mushroom, particularly for the youngest age groups with the highest estimated intake of Ni, this is not expected to be of any health concern.

9.4.7 Lead (Pb)

EFSA have established three BMDLs based on developmental neurotoxicity in young children, cardiovascular affects in adults, and nephrotoxic effects in adults. The BMDLs ($BMDL_{01}$) are 0.50 µg -, 0.63 - and 1.50 µg Pb kg^{-1} BW per day (EFSA, 2010), respectively. In the adult European populations, the mean dietary exposure ranges from 0.36 to 1.24 µg Pb kg^{-1} BW per day (EFSA, 2010). In children aged 1 – 3 years, the mean dietary exposure is 1.10 – 3.10 µg Pb kg^{-1} BW per day, while in children aged 4 – 7 years, the mean exposure is 0.80 – 2.61 µg Pb kg^{-1} BW per day (EFSA, 2010). The dietary exposures to Pb exceeded some or all the BMDLs, and an increase in Pb exposures is not desirable.

Cereals, vegetable and tap water are the main contributors to dietary Pb exposure in the European population (EFSA, 2010). Specifically, cereal products, potatoes, cereal grains, and cereal-based mixed dishes are among the foods contributing to the exposure.

Lead concentration will increase in agricultural crops (wheat, carrots, and potatoes) at all locations, depending on time and type of fertiliser (chapter 8.3 and 8.5). An increase in Pb concentration in wheat, carrots and potatoes is likely to increase Pb exposure in the Norwegian population. As the dietary exposure is high, any increase in dietary exposure is not desirable.

The use of engineered soil in home gardening and urban farming, will lead to an increase in Pb concentrations in lettuce, carrot and potato, and the use of growth media will lead to an increase in Pb concentration in potato, lettuce, and carrot (chapter 8.3 and 8.5). An increase in Pb concentration of home-grown vegetables and vegetables from urban farming is likely to increase Pb exposure in persons eating such vegetables. As the dietary exposure is high, any increase in dietary exposure is not desirable.

9.4.8 Zinc (Zn)

The models indicate an increase in Zn concentrations in crop plants of up to 3-fold the current concentrations (Table 8.3.1-6).

The recommended intake levels of Zn are in the range of 5-16 mg day^{-1} depending on age and gender (EFSA 2014c, Nordic Council of Ministers, 2014).

The toxicity of Zn is low. Ingestion of >50 mg Zn day^{-1} has been associated with decreased enzyme activity of Cu-dependent enzymes and more severe signs of deficiencies in Cu metabolism and immune toxicity has been associated with ingestion of >150 mg/day (Nordic Council of Ministers, 2014). No upper intake level was set by neither EFSA nor Nordic Council of Ministers.

The current mean dietary intake of Zn was estimated by EFSA to be in the from 4.6 - 6.2 mg/day in children aged 1 - <3 years, from 5.5 - 9.3 mg day^{-1} in children aged 3 - <10 years, from 6.8 - 14.5 mg day^{-1} in adolescents (10 - < 18 years) and from 8.0 - 14.0 mg day^{-1} in adults. The main food groups contributing to Zn intake were meat and meat products, grains, and grain-based products, milk and dairy products. The grain and grain-based products constituted on mean 15-45% of the total dietary intake, while other crop plants contributed with less than 10% of the total dietary Zn intake (EFSA, 2014).

Considering the low toxicity of Zn and the large margin before any toxic effects of Zn has been observed, VKM consider that it is unlikely that the predicted increase in Zn concentrations in crop plants is likely to be of any concern, independent of fertiliser scheme and scenarios.

The use of engineered soil in home gardening and urban farming is expected to increase the concentrations of Zn in lettuce, carrot and potato (Table 8.3.2.1-8). The current margin between estimated exposure and upper safe limit is, however, large, and the increase is not expected to be of any concern.

The scenarios for cultivation of mushroom indicates an increase in Zn concentration in mushroom (Table 8.3.3-1). Mushroom may therefore be an additional source for dietary Zn for high consumers. However, as discussed in 8.3.3 the predicted concentrations are probably an overestimate. Furthermore, the margin between the estimated dietary intake and upper safe limit is large (EFSA 2015) and the potential increased intake is not likely to be of any health concern.

10 Uncertainties

Risk indicates a possibility of something bad happening. In our context, we base the risk assessment on a quantitative comparison of exposure levels and tolerance thresholds for a range of target receptors, spanning from soil organisms to farm animals and humans, from both current and future predicted levels of PTEs.

Risk estimates are quantitative, but they are associated with significant uncertainty, meaning that they could have been higher or lower depending on the assumptions and input data that the assessment is based on. The model used in this report to predict concentrations of PTEs in soils, surface water, crops and food chain up to 100 years from now is considered state-of-the art, in terms of each of the processes involved, but it is a complex matrix with a lot of input data.

In the selection of current-state soil concentrations of PTEs, current-state soil properties, distribution coefficient (Kd) for PTEs in soil, surface water and sediment, and selection of current-state precipitation rates, variability is evident in time and space within each of the selected Norwegian case areas. When selecting one data point over others, it is not necessarily representative for all fields in the case area, and uncertainty becomes part of the model estimates. In addition, when predicting soil concentrations going 100 years forward, many things might have changed. This chapter summarises the input data and algorithms known to contribute to uncertainty in risk estimates and conclusions.

Further to this, the model processes will never mimic nature completely. Known weaknesses include the potential evaporation of elemental Hg, which would likely affect the results. On a general basis, the relevance of estimated concentrations has been quality assessed where possible. This includes a comparison with measured present-state data in surface waters, where cross-checks between PECsw and measured data indicate that the model provides relevant estimates at least for the present state.

For a subset of the input data, a sensitivity analysis has been done in order to illustrate how variations of each of these input parameters will affect the results' matrix.

10.1 Uncertainty in input data due to inherent variability

Current levels of PTEs fertiliser products vary significantly, and for some products and PTEs (for example As content in some of the modelled fertilisers) there is very little information available. With the exception of #2 (maximum levels allowed for organic fertilisers by law) and #4 (maximum levels found in cow and pig manure), mean values were used for the other fertilisers.

Current levels of PTEs in agricultural soils vary significantly, and in most cases mean concentrations of a limited data set is used as input to the model calculations for each of the case areas. If we, as a worst case, use e.g. the 90-percentiles for PTE content, the results of the modelling would look very different, with more indications of risk, but on the other hand less accumulation.

The use of median input values for present soil concentrations and mean fertiliser content (except for cow and pig manure where also a fertiliser scheme with measured maximum concentrations were included) was preferred based on initial discussions that considered the overall robustness of the model as well as known limitations of the available data (e.g. different sampling techniques and analytical methods, as well as large spatial variations for the PTE data).

Variation in soil properties (pH, organic carbon content, cation binding capacity) and climatic conditions (precipitation, temperature) are key factors in the fate modelling for PTEs, and these parameters are also represented by a mean value for each case area. We expect that the soil properties are representative for the average soil type of each case area, but extremes are not captured in the risk estimates. Other areas than the selected municipalities may have other soils with, especially, another level of organic carbon content. Climatic conditions also show local variations.

Climate change and uncertainty. Annual precipitation values have increased the latter half of the 20th century in all of the regions (6-11%), except for Målselv, intermediary and worst-case prospects indicate that this increase is likely to continue in the 22nd century. Increased fluxes from soil to water can therefore be expected, especially for the most mobile PTEs. The ratios between transport by overland flow and matrix flow are likely to change and this will affect different PTEs in different ways. The increasing intensity of precipitation is likely to result in smaller recurrence periods for high waters in small and large rivers. These events can lead to high peaks in soil to water fluxes, even if they are temporary, and water logging in the period after high water levels. In the summer period, periods without precipitation are likely to become longer. Transport through the macropores and cracks of dry soils, especially those with high clay content, will also result in quick flushing of soil profiles when precipitation does occur. Longer periods with water clogging might influence speciation of elements, e.g. methylation of Hg.

Soil properties are in equilibrium with climatic conditions. Long-term trends in weather patterns can therefore be expected to result in changes in soil properties as well; either gradually or as state-shifts (Hirmas *et al.*, 2018). Evidence of such changes is yet to be established for mineral soils, but state shifts with regard to soil hydraulic properties for more organic soils are already being observed (Robinson *et al.*, 2018). Infiltration and runoff ratios and leaching rates are a function of soil matrix potential and macropore flow. The reliability of the long-term predictions in this report therefore depends on the rate and magnitude of these potential changes.

Potential climate-driven changes in soil properties may influence the partitioning of water between overland and matrix flow, which in turn may influence the water-cycle at larger scales. This is being studied, and if proven, presents a case when climate and soil have mutual feedbacks. It is therefore important that climate predictions are further improved, and that soil is looked at as a dynamically changing medium over time-scales that have potential relevance for climate models themselves.

Variation in soil-pore water partitioning coefficient (Kd) data. The Kd is a key parameter for fate modelling, and there is a vast and variable amount of data available in the literature. However, their relevance to newly added fertilisers in agricultural soil is not known.

Variations in agricultural practice will affect removal by plants. The collected information on agricultural practice in the selected case areas included crop rotation, fertilisation and yields typical for the case area. However, there is a large variation in agricultural practice and yields, and the results from the modelling could be different by different selections of crop rotation, fertilisation and yields. However, model estimates calculate differences in soil concentrations less than 5% due to changes in agricultural practice and was not further addressed.

Estimated environmental tolerance thresholds (PNEC values) for target recipients such as soil organisms or farm animals (and humans) are also a source of uncertainty. For each of the estimated tolerance thresholds, generalisations and extrapolations, have, to some degree, been used to come up with a representative value. Safe levels are estimated based on toxicity data for relevant species and a regulatory international framework. The data sources and selection process are documented and transparent, but even when all available data and algorithms have been reviewed and judged based on quality and relevance to the current assessment, the results are presented as best estimates which are affected by built-in uncertainty in the model assumptions and input data selection.

For most of the PTEs addressed in the current assessment, available data on ecotoxic effects is extensive and sufficient to allow the use of a statistical approach to calculate PNECs for aquatic and terrestrial organisms. The remaining uncertainty in the hazard assessment is therefore considered as low. For As, Hg and Cr the data sets are less extensive, especially for effects on sediment dwelling organisms, and the $PNEC_{sed}$ is derived from the lowest available NOEC or calculated from the $PNEC_{sw}$ using the sediment/water partitioning coefficient. This approach implies a larger uncertainty.

Data gaps (see Chapter 13) add additional uncertainty to the model estimates and conclusions.

10.2 Intrinsic uncertainty of the assessment method

To quantitatively show how changes in input data affect the results, input data variability was modelled by sensitivity analysis. The results reflect the significance of each parameter for the final result and is presented below.

10.2.1 Introduction to the Method

The sensitivity of input data on the results was quantitatively assessed by a Monte Carlo analysis. Using this approach, the input data are not fixed values, but following a pre-defined distribution. Relevant input parameters were selected based on an initial (qualitative) inspection of the various equations involved (Table 10.2-1) - the table content is described and discussed in detail in chapter 10.3.

In the Monte Carlo analysis, the fate model was run repeatedly (e.g., 5000 separate runs) with randomized input values drawn from the pre-defined distribution of each parameter in question. This exercise was done separately for the PTEs Cd, Cu and Zn. The strength of the method is that the input parameters are not varied one by one, but instead selected parameters are varied simultaneously. Hence, the result shows possible variation of output with variation of input and can also serve as an uncertainty analysis.

The calculated 5000 results have a distribution that reflects the varied input variables. Therefore, the outcome is shown as frequency distribution f(x), where f is the output parameter, and x is the vector of distributed input data. Moreover, the output statistics and percentiles will be shown. Finally, a Spearman rank correlation r between input data vector x and predicted variable allows for quantification of the explained variance of the output, due to variance of the input, because the coefficient of determination is ideally r2, and the sum of r2(x1), r2(x2) ... r2(xn) is 1, or 100%. However, as no random generator is completely random, and a high number of random numbers need to be generated, small deviations from this rule have to be accepted. Nonetheless, the major influencing parameters, i.e. those with the highest sensitivity, can easily be identified.

Sensitivity is defined here as S = dy/dx, where y is the predicted variable, and x is the input data, and dy and dx are the changes hereof.

The Monte Carlo simulations were conducted using the commercial software Crystal Ball (Oracle), which runs as an add-in to Excel.

10.2.2 Summary of Cd, Cu and Zn simulations and results

The Monte Carlo analysis used for assessing the sensitivity of input data was performed for scenario No. 2 (evaluation of the regulation of organic fertiliser quality class II), and the case area was Ås, (for surface water, Stange was also included). All simulations were made for t = 10 years, i.e. for 10 years of continuous application, starting with the measured median background concentrations in soil and surface water. This assessment was performed for Cd, Cu and Zn.

For sensitivity and uncertainty analysis, all input parameters were randomly varied in 5000 runs from 50 - 200% of the default value within a uniform distribution. The outcome is displayed as frequency chart, as statistics, percentiles, and in a sensitivity chart. Sensitivity dy/dx was assessed by a rank correlation between input and output data. The explained variance (coefficient of determination) is r^2, and the sum of all r^2 equals 1 (100%), which allows for the quantification of relative sensitivity of selected input parameters in relation to each other, and for that scenario.

Forecast parameters (y) were:

- First run concentration in soil PEC_{soil}, concentration in wheat, total loss from soil, loss by plant uptake, and loss by leaching and runoff, each for Cd, Zn and Cu. Varied input data for the first run were Kd, precipitation, Etot (later omitted), and transfer factors from soil to plant TF for wheat, oats and barley.
- Forecast parameters for the second run were concentration in surface water PEC_{sw} and in sediment PEC_{sed}. Varied input parameters for the second run were the partition coefficient suspension to water Kp_{susp} and sediment to water Kp_{sed}, the total erosion Etot, and for Zn and Cu also the dilution factor.

The most relevant parameters for PEC_{soil} were for all three elements the Kd and the precipitation. E_{tot} did not play any role (it does not affect PECsoil and was therefore omitted). The transfer factors for uptake into plants were generally of low relevance for PEC_{soil} and total loss from soil, except for Zn where some contribution to variance was seen. The predicted range of PEC_{soil} was small, varying from 79 - 106% of the median (identical to the default value) for Cd, from 89 - 103% for Cu, and 93 - 102% for Zn. Overall, the main input data determining the concentration in soil after 10 years is the present (initial) concentration in soil.

The concentration in wheat was mainly dependent on the transfer factor into wheat, and thus the calculated concentrations for all three elements were close to the range 50 - 200% of the default value. A large spread was found for the total loss from soil (g ha^{-1} $years^{-1}$), but it would only affect concentrations in soil and plant after a longer period. In all cases, total loss was mainly due to runoff and leaching, only for Zn, plant uptake was of some relevance.

For PEC_{sw}, the Kp_{susp} and the dilution factor were the main sensitive parameters. For both Zn and Cu, and for both Ås and Stange, dilution explained about 80% of the variance. For Cd, where dilution was not varied, Kp_{susp} was the only influential parameter, while Etot and KP_{sed} had no impact on PEC_{sw} of Cd. In fact, erosion E_{tot} did not play any relevant role, for any of the output variables.

PEC_{sed} depended on PEC_{sw} and Kp_{sed} and thus, was correlated to Kp_{sed}, dilution factor and Kp_{susp} (in a descending order of sensitivity). Hence, the widest range of all forecasted values was seen for PEC_{sed}. For example, the concentration of Cu in sediment at Ås varied from 35 - 198% of the median value, or 40 - 240% of the default value (which in this case is not identical to the median because it also depends on the variation of PEC_{sw}). Details are found in the related chapters.

10.3 Sensitivity assessment (all PTEs)

The sensitivity is defined as Δy/Δx, where y is the output parameter, and x is the input data. **In other words: how much does the result change, when an input parameter changes?** Knowing this helps to select the most relevant input data, and to assess the uncertainty of the outcome. If input data are very uncertain, it does not matter if this parameter is insensitive, and vice versa. Table 10.2-1 was derived from an inspection of the equations (qualitative), and results from the sensitivity analysis done for Cd, Cu and Zn, as well as a separate sensitivity analysis Ni and Hg for the environmental and PTE-specific input data (Appendix VIII). As the results for these five elements were very similar, it was decided not to run the sensitivity simulations for the remaining elements.

Note that the table describes the sensitivity of the risk assessment model. In reality, parameters that are not considered in the equations may also have an impact. The sensitivity of input parameters is relative to each other, and many depends also on the other input parameters, see fourth column, "remarks". In particular, the initial concentrations in soil and surface water ("background") are far more sensitive if the PTE input (input g ha^{-1} year^{-1}) is low, and for short simulation periods (10 years, instead of 100 years). The longer the simulation runs, the more relevant the input per year gets, and similarly the parameters which are closely connected to the fate/loss from soil (Kd and pH). The table shows the sensitivity of chemical input parameters and of environmental input parameters, separately (chemical input first). It shows the impact on soil-, plant-, surface water- (PEC local SW), and sediment concentrations. As all risk characterisation factors are based on these concentrations, the sensitivity also holds for the RCR. As can be seen, rather few input parameters have high sensitivity, a couple of input parameters are medium sensitivity, and some are of no relevance.

Table 10.2-1. Parameter sensitivity (initial qualitative assessment – for quantitative values see individual Monte Carlo output).

Output parameter	Input parameter	Sensitivity	Remark
C_{soil}	Initial background concentration	very high	highest when input is low
	Kd	high	for some PTE only medium;
			higher if input is high; higher for long time (100 years)
	Input g/ha/year	medium	only if high (scheme #2)
	BCF values	low	
	K_{susp}, Kp_{sed}, PEC regiola SW	none	affect only surface water
C_{soil}	pH	high	affects Kd of all PTE except Hg and Cr
	orgC	medium	only for Cd, Cr, Pb
	clay content	low	only Cu
	precipitation	medium	
	infiltrated fraction	low	
	runoff fraction	very low	
	E_{tot} Erosion	very low	
	Dilution	none	
	Susp upstream	none	
Conc. in wheat			
same as Csoil, plus	BCF	high	
PEC local SW	Initial background conc. in soil	high	
	Input g ha^{-1} $year^{-1}$	medium	for high input (scheme #2)
	Kpsusp	medium	
	PEC regional SW	medium	high if input is low
	Kd	medium	
	Kp_{sed}	low	
	BCF	none	
	Dilution factor	high	
	Precipitation	medium	
	Infiltrated fraction	medium	
	pH	medium	(except Hg and Cr: none)
	Susp upstream	medium	
	Fraction runoff	low	
	Etot Erosion	very low	
	orgC (SOM)	low	
	% clay	low	only Cu

Output parameter	Input parameter	Sensitivity	Remark
PEC local sediment	same as PEC local SW, plus	Kp_{sed}	high

11 Answers to the terms of reference

Please keep in mind that while the concentration of elements discussed below are based on quantitative estimates, many of these are associated with significant uncertainty, meaning that they could have been higher or lower depending on the assumptions and input data used. Added to that, the very long time-frame for the model predictions (up to 100 years from now) adds a lot of uncertainty on the relevance of current knowledge regarding e.g. soil properties, climatic conditions and agricultural practice in the future.

11.1 What do we know about the levels of these elements in agricultural soil in Norway today?

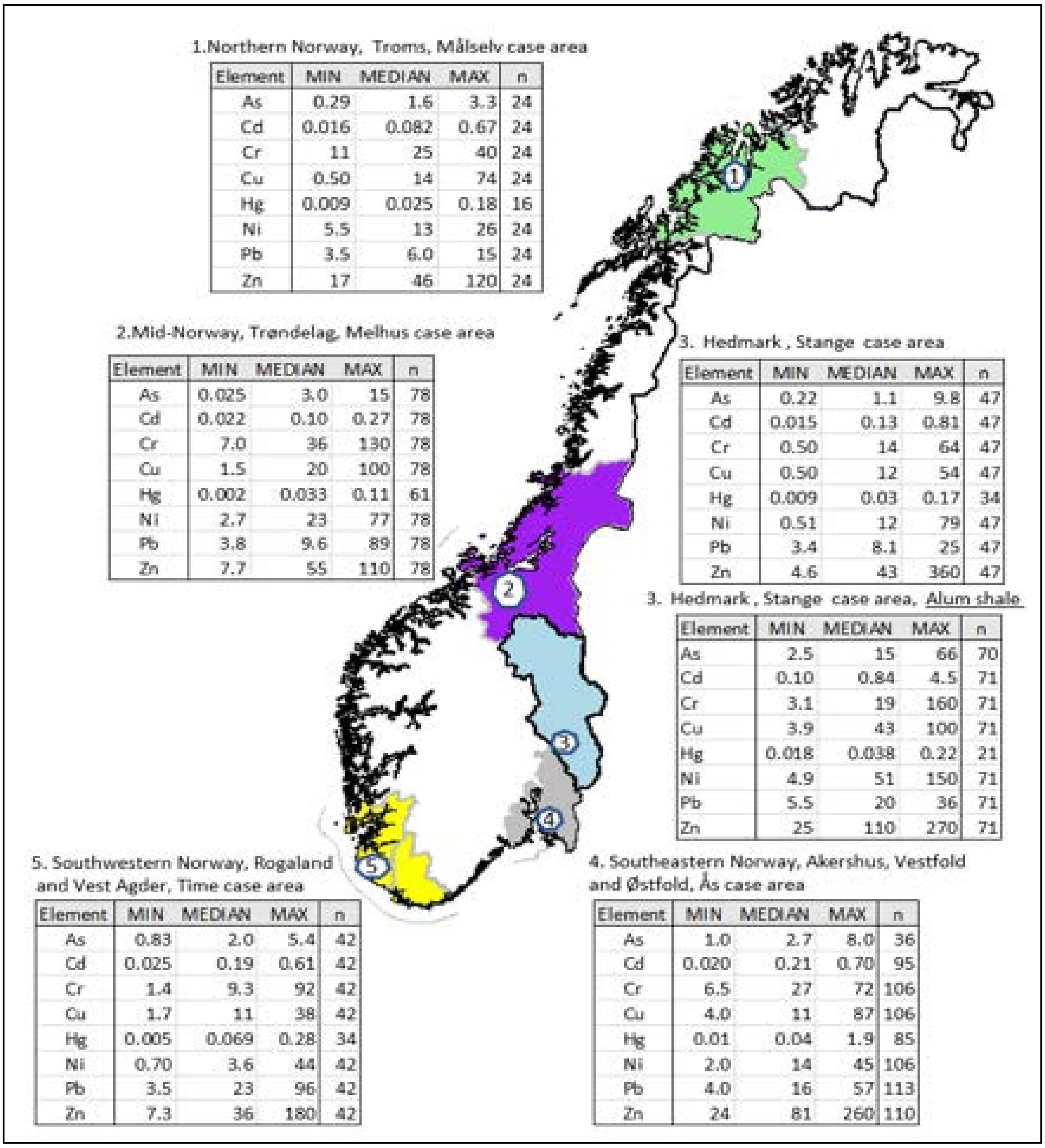
In the present risk assessment, five different municipality case areas covering major agricultural practices in Norway were chosen: 1) Northern Norway, with Målselv municipality as a case area; 2) Trøndelag (Mid-Norway), with Melhus municipality as a case area; 3) Hedmark region, with Stange municipality as a case area (not including samples from alum shale); 4) Southeastern Norway, with Ås municipality as a case area; 5) Southwestern Norway, with Time municipality as a case area. In addition, alum shale was a separate case in Hedmark region.

In general, the data available for Norwegian agricultural soil indicate low geogenic concentrations of all PTEs included in this risk assessment (As, Cd, Cr, Cu, Hg, Ni, Pb and Zn), compared with what is common in southern Europe (Reimann et al. 2014). The median concentrations of As, Cd, Cr, Cu, Hg, Ni, Pb and Zn in European agricultural soil are, respectively, 5.5 mg kg^{-1}, 0.18 mg kg^{-1}, 20 mg kg^{-1}, 14.5 mg kg^{-1}, 0.030 mg kg^{-1}, 14.7 mg kg^{-1}, 15.8 mg kg^{-1} and 45 mg kg^{-1} as determined by an aqua regia extraction (Reimann et al. 2014). In the alum shale area, these eight PTEs have median concentration values that are higher than the European median.

However, looking at the geochemical maps of agricultural and grazing land published in Reimann et al. (2014), clear differences in the distribution of the individual PTEs in soil are apparent. Cr and Ni occur at high levels in the Scandinavian greenstone belts, whereas As, Cd and Ni are prevalent in the area north of Oslo that is underlain by black shales/alum shales (see Chapter 4). Elevated concentrations of Hg are mainly found at the west coast, most likely due to the higher content of organic material in the soil in this area. High deposits of Zn are found in the Oslo Rift (Ramberg et al. 2008), and in known ore districts such as Skorovas in Trøndelag. The naturally high concentrations of Cr in Melhus in Trøndelag, and of Cd and Ni in the alum shale area are considered as environmental healt risks.

The concentration variations of the median PTE background concentrations in the agricultural soil of the different case areas are rather small (Figure 11.1-1). Alum shale soil has the highest median values of all selected PTEs, except for Pb and Hg, which have the highest levels in the Time case area, and for Cr, which has the highest level in the Melhus case area. The highest difference between maximum and minimum values was found for As in the Melhus case area.

The estimates for minimum, median and maximum concentrations in each region are based on very few observations (measured samples) (Figure 11.1-1). In addition, the data regarding sampling techniques and analysis are not harmonised. Since the observed concentrations in soil are important input parameters for the scenario calculations and thereby the outcome of the risk assessment (high sensitivity), uncertainty factors connected to their measurement have a high impact on the overall result uncertainty of the risk assessment (addressed further in question 2 and chapter 13 Data Gaps). To avoid significant and dominating effects of outliers at both ends of the reported PTE concentration ranges, all calculations were based on the median values.



1.Northern Norway, Troms, Målselv case area

Element	MIN	MEDIAN	MAX	n
As	0.29	1.6	3.3	24
Cd	0.016	0.082	0.67	24
Cr	11	25	40	24
Cu	0.50	14	74	24
Hg	0.009	0.025	0.18	16
Ni	5.5	13	26	24
Pb	3.5	6.0	15	24
Zn	17	46	120	24

2.Mid-Norway, Trøndelag, Melhus case area

Element	MIN	MEDIAN	MAX	n
As	0.025	3.0	15	78
Cd	0.022	0.10	0.27	78
Cr	7.0	36	130	78
Cu	1.5	20	100	78
Hg	0.002	0.033	0.11	61
Ni	2.7	23	77	78
Pb	3.8	9.6	89	78
Zn	7.7	55	110	78

3. Hedmark , Stange case area

Element	MIN	MEDIAN	MAX	n
As	0.22	1.1	9.8	47
Cd	0.015	0.13	0.81	47
Cr	0.50	14	64	47
Cu	0.50	12	54	47
Hg	0.009	0.03	0.17	34
Ni	0.51	12	79	47
Pb	3.4	8.1	25	47
Zn	4.6	43	360	47

3. Hedmark , Stange case area, Alum shale

Element	MIN	MEDIAN	MAX	n
As	2.5	15	66	70
Cd	0.10	0.84	4.5	71
Cr	3.1	19	160	71
Cu	3.9	43	100	71
Hg	0.018	0.038	0.22	21
Ni	4.9	51	150	71
Pb	5.5	20	36	71
Zn	25	110	270	71

5. Southwestern Norway, Rogaland and Vest Agder, Time case area

Element	MIN	MEDIAN	MAX	n
As	0.83	2.0	5.4	42
Cd	0.025	0.19	0.61	42
Cr	1.4	9.3	92	42
Cu	1.7	11	38	42
Hg	0.005	0.069	0.28	34
Ni	0.70	3.6	44	42
Pb	3.5	23	96	42
Zn	7.3	36	180	42

4. Southeastern Norway, Akershus, Vestfold and Østfold, Ås case area

Element	MIN	MEDIAN	MAX	n
As	1.0	2.7	8.0	36
Cd	0.020	0.21	0.70	95
Cr	6.5	27	72	106
Cu	4.0	11	87	106
Hg	0.01	0.04	1.9	85
Ni	2.0	14	45	106
Pb	4.0	16	57	113
Zn	24	81	260	110

Figure 11.1-1. Overview of (background) concentrations of PTEs in agricultural soil in the regions included in this risk assessment. All values given for the minimum (MIN), median (MEDIAN) and maximum (MAX) concentrations in each region are given in mg kg^{-1}. The number of observations (n) is also given. The case area's location is indicated by the number 1-5 in the map.

11.2 Describe the fate (mobility) of these elements within and in close proximity to agricultural soil after the application of fertiliser products containing these elements to agricultural land and transfer to the affected organisms in table A

An overview of fate processes and influencing factors

Potential toxic elements (PTEs) in soil undergo several processes which depend on their chemical and physical properties as well as environmental conditions, which collectively determine their fate, i.e. adsorption, leaching, run-off, erosion, plant uptake, evaporation, and if present as organo-elements, also by biotic and abiotic transformation. Most of these transport processes (i.e., excluding evaporation and biotransformation) are accounted for in the mathematical model predicting future concentrations of PTEs in Norwegian soils. The predicted increase, or decrease, depends on the ratio of input to loss. For example, if the annual input exceeds the annual loss, an increase of PTEs in soil will occur. Thus, the input depends on the selected scenario and is by deposition from air, and with fertiliser or soil amendment. The loss is proportional to the amount of PTE present in soil where the loss increases with increasing concentration. Thus, it may well happen that with the same amount of input, the concentration on one site/in one region increases, while it decreases in another region. This is often seen for the Stange area versus the alum shale area, both situated at Hedmark. In the latter, all PTE concentrations except Cr, Hg and Pb, are naturally higher, but both were calculated with the same input scenarios. And while for Stange, concentrations in soil often increase, depending on PTE and chosen scenario, those at the alum shale area sometimes decrease for the same PTE and input scenario until losses (declining with declining concentrations in soil) balance the input (constant over time) to reach a steady state. The same principle holds for the other sites, thus, **present concentrations in soil is a main factor in determining if the modelling results in accumulation or decline of PTEs in soils**.

Leaching and run-off and the importance of Kd and soil parameters

Leaching and run-off were found to be the most relevant fate processes for all investigated PTEs (Table 10.2-1). Loss via leaching and run-off was typically one order of magnitude higher than removal via plant harvesting except for Hg for which plant removal is more relevant (Table 6.1.4-1).

Leaching and run-off of PTEs depend highly on their sorption properties to soil as expressed by the distribution coefficient, Kd, (Table 10.2-1) which is the concentration ratio between soil matrix and soil pore water. For most PTEs, sorption is highly influenced by the soil properties, most of all pH, but also organic matter (OM) content. Cation exchange capacity and clay content are other parameters that are known to influence the Kd.

A high Kd value indicates high binding to the soil and therefore, less loss by leaching with water. A high Kd is generally associated with low transfer to plants. An exception from this rule may occur for essential elements (Cu, Zn and Ni), where uptake (and exclusion) is enzymatically controlled (McLaughlin 2011) (section 5.1.1 and 6.2.1).

Due to the lack of empirical Kd values from studies of Norwegian soil, Kd values were predicted from empirical regressions presented in the literature. The exceptions are Hg and Cr, for which no regressions could be found, and fixed Kd-values are, therefore, used (described in section 5.1.1). In all regressions, pH is included as a predictor variable. Moreover, OM is included in the regressions for Cd and Pb, while percent (%) clay is included for Cu. Soil properties and calculated Kd-values for each region are summarised in Table 8.1-1. The highest Kd-values in soil for Norwegian pH range (in average 5.7 - 6.2) were determined for Cr, Hg and Pb, and the lowest for Ni, Cd and Zn (Figure 11.2-1).

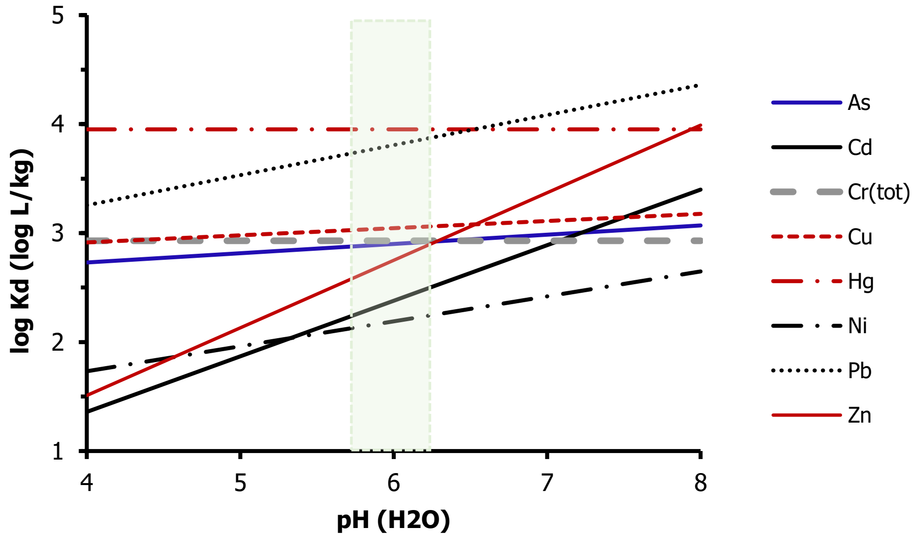


Figure 11.2-1. Correlation of soil pH and log Kd based on selected Kd regressions and default Kd-values (Table 5.1.1.1-1). The median pH range in Norwegian soil is indicated as shaded area.

Comparing Kds from the case regions, Time and Målselv with lowest mean pH (pH < 5.8) and low OM (4.1-5.6 %), have, in general, lower Kd-values (Table 8.1-1) and therefore, somewhat higher mobility and removal of PTEs from soil than the other case areas. For Cu, for which clay content and pH influence Kd, Ås (22% clay) has the highest Kd (1079 L^{-1} kg^{-1}) and Time (8% clay) has the lowest (762 L^{-1} kg^{-1}). The differences for the other regions were relatively small.

Precipitation in case area Time is highest (1542 mm yr^{-1}), around 600-630 mm yr^{-1} higher than case area Ås and Melhus (around 900-950 mm yr^{-1}), and around 900 mm yr^{-1} higher than the case-areas Stange and Målselv (around 600-675 mm yr^{-1}). Annual precipitation values have increased during the last half of the 20th century in all of the regions. Except in Målselv, the increase has been substantial at levels between 6 - 11%. The outlook according to the IPCC's intermediary and worst-case Representation Concentration Pathways indicate that this increase is likely to continue in the 22nd century. However, this has not been accounted for in the model used to predict PTE concentrations in the 100 year's perspective. Erosion is of low significance for the change in PTE concentration in soil because it removes top soil, but does not affect concentration in the remaining soil profile when soil is well-mixed. However, the effect of soil transfer to water by erosion is accounted for in the prediction of PTE concentrations in surface water and sediments.

Ageing effect on fate and risk of PTEs

Ageing processes tend to render PTEs less mobile (i.e. Kd-values will increase). Even if there is an annual input of PTEs, this is small compared with the concentrations already present in soil, and the calculation of loss from soil by leaching should account for ageing. This has been done by selecting Kd-values from field studies in contaminated (aged) soils rather than spiking experiments as explained in 6.1.1.2. This approach causes less loss to surface water and higher tendency of accumulation of PTEs in soil.

Ageing processes also tend to reduce the bioavailability of PTEs for uptake by soil dwelling organisms. For most of the PTEs this has been accounted for in the calculation of $PNEC_{soil}$ by using an "ageing factor". The appropriate ageing factors have been derived from studies where the toxicity observed in freshly spiked soils is compared to the toxicity in aged soils. Sufficient data for establishment of ageing factors is available for Cd, Cu, Ni, Pb and Zn. For As and Cr, no ageing factors have been established and the risk assessment for terrestrial organisms has been based on the "added approach", where the present concentrations are considered as background concentrations and only the risk caused by predicted future increased concentrations of these elements in soil assessment.

Transfer to surface water

The fate model is based on the presumption that all water leaving the soil through leaching and runoff contains dissolved PTEs in accordance with the Kd. The concentration of PTEs in a receiving surface watercourse is dependent on the background concentration in the recipient water, dilution rate, and adsorption/desorption to suspended material in the runoff and recipient waters. This process is described by the partitioning coefficient Kp_{susp}.

The concentration of dissolved PTEs in surface water is therefore not proportional to the concentration in soil, but the temporal trends (increasing or decreasing concentrations over time) are always the same in soil and surface water. The concentration of PTEs in the sediment phase is calculated from the concentration in surface water using a partition coefficient Kp_{sed}. The concentration in sediment is therefore proportional to that in water phase.

Water cycle including precipitation, infiltration, surface runoff, drainage leaching, evaporation and plant uptake is illustrated in Figure 11.2-2.

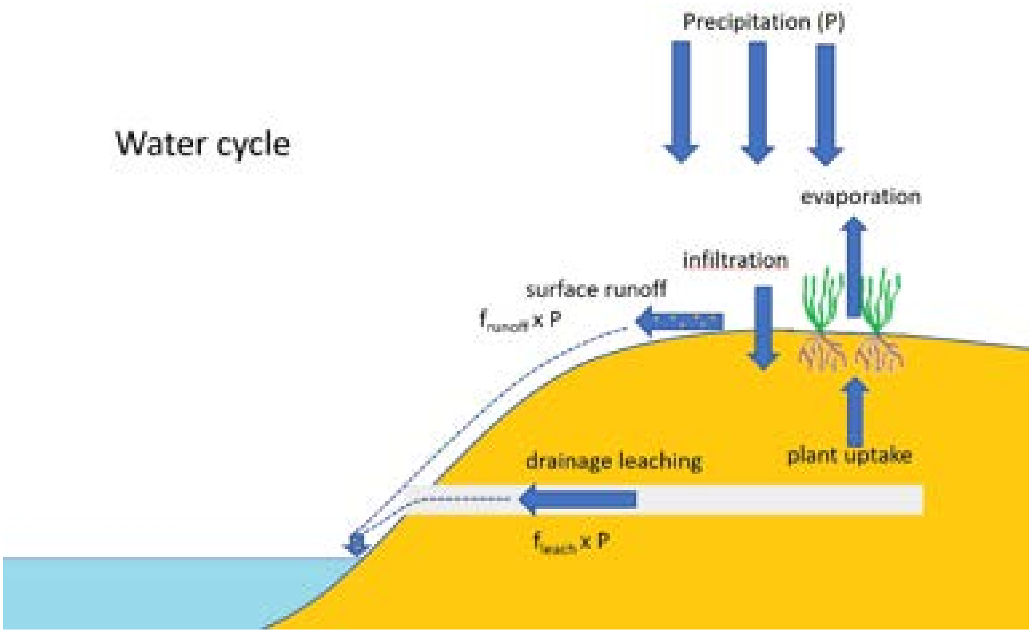


Figure 11.2-2. Illustration of water cycle.

Transfer to crops – removal from soil and transfer to animals and humans

Transfer of PTEs to plants differs among plant species. Choice of transfer factors (TF) for the plants included in the assessment, i.e. for cereals, grass, potato, carrot, leafy vegetables (lettuce) and garden fruits (e.g. strawberry, plum, apple), were based on the criteria described in section 6.2.

For most PTEs (except Hg) transfer and removal of PTEs via crops are of low relevance for the mass balance and change in soil over time, but it has a high relevance for the exposure of animals and humans (Table 10.2-1). The highest TF (based on dry weight, DW) were found for the elements Zn, Cd and Cu, the lowest for Pb and Cr (total Cr), As and Ni are in between. Zn and Cu are essential elements for plants, which explains their high uptake. Comparison of predicted PTE concentrations in plants related to the different scenarios, and further comparison to measure concentrations is discussed below.

Evaluated fertiliser products and maximum levels (MLs) in regulation for organic fertilisers products

Fertiliser products evaluated in the assessment are mineral P fertilisers, manure from cattle, pig, poultry and horse, fish sludge, sewage sludge, and digestate based on food waste as substrate alone, and food waste and manure in combination as substrate. Mean values of measured PTE concentrations have been used except for in cattle and pig manure where also maximum measured concentrations were included.

In addition to evaluation of application of selected fertiliser products in agricultural crop production, maximum levels (MLs) of PTEs in organic fertilisers products quality class II (section 3.1, Table 3.1.1-1 and Table 3.1.1-2) have been evaluated.

Due to an increasing interest in home growing and locally cultivated vegetables, concentrations of PTEs in root vegetables (e.g. carrots), potatoes, leafy vegetables (e.g. lettuce) and garden fruits (example of strawberry, plum, apple) cultivated in engineered soils, comparing two different sets of MLs, were simulated (described in section 3.1, Tables 3.1.1-2 and Table 3.1.2-1). One scenario (A) was chosen to exemplify private garden (e.g., kitchen gardens) for own consume, the other scenario (B) was urban farming for vegetables sold at local markets. In addition, cultivation in growing media applied in containers, hobby greenhouses, and establishment of small bed, was evaluated for three different MLs. Annual application of organic fertilisers (MLs quality class II) was evaluated for cultivation of vegetables and garden fruits in engineered soils, but not for cultivation in growing media.

Off season (autumn and spring precipitation and flooding) loss of PTEs via runoff and leaching is assumed to be much less than in agricultural fields (compare section 8.3.2). Thus, to simply the prediction, no removal via leaching and runoff was included in the predictions. Although this is a realistic scenario for cultivation of plants in greenhouses, indoors and under roofs, excluding leaching for cultivation in engineered soil applied in kitchen gardens and market gardens might give an overestimation in soil and crop concentrations over time. Mixed growing media has higher content of OM and higher water holding capacity than field agricultural soil, while mineral engineered soils normally have similar OM content as agricultural topsoil.

For mushroom enthusiasts (people who often eat mushroom), cultivated mushrooms might be an important part of the diet, and exposure of PTEs through cultivated mushroom might be an extra PTE source. Estimation of concentration in edible mushroom cultivated on agro-industrial wastes using the same three sets of MLs as evaluated for growing media and selected TFs for Cd, Cu, and Zn (Table 6.2.1-3, see section 6.2.2) was performed.

A short summary of all the scenarios and application rates is presented in Table 11.2-1 (see section 6.1.2.1 for more details). Atmospheric contribution of the selected PTEs were included in each of the evaluated schemes as well as evaluated separately as a source (#0a). Since sewage sludge is applied as a soil improver and has low plant available P, mineral P fertiliser according to common practice for the given crop rotation in the different regions was included in the calculation.

Table 11.2-1. Description of evaluated scenarios.

Scenarios	**Description**	
Agricultural field crop production		
	Input source/kind of regulation	**Application rate and PTE concentration**
#0a	Atmospheric contribution	Based on estimated upper limit of excess of PTE influx over 200 yr^1
#2	Regulation organic fertilisers quality class II	Application rate: maximum allowed amount dry weight, 2000 kg DW ha^{-1} yr^{-1} PTE conc.: max ML quality class II (Table 3.1.1-2)
#1	Mineral P fertilisers	Application rate: based on present practice for the given crops PTE conc.: measured max. and mean conc. in manure
#4 and 5	Manure (cattle & pig) #4 and 5, different PTE conc.: max. and mean measured conc. in manure, respectively	
#3	Sewage sludge	Application rate: max. quality class II, 2000 kg DW ha^{-1} yr^{-1} PTE conc.: measured mean conc.
#9	Horse manure	
#6	Fish sludge	Application rate: Suggested limitation for P, 30 kg P^{-1} ha^{-1} yr^{-1} PTE conc.: measured mean conc.
#7	Digestate (food waste & manure)	
#8	Digestate (food waste)	
#10	Poultry manure	
Home growing and urban farming of vegetables and garden fruits		
Sc. A	Engineered soil exemplified for private garden and home consumption[1]	MLs for engineered soil & Fertilising: Application rate: maximum allowed amount dry weight, 2000 kg DW ha^{-1} yr^{-1} & PTE conc. max ML quality class II
Sc. B	Organic fertiliser quality class II exemplified market garden and growth for sold on the local marked[2]	MLs for organic fertilisers quality class 0 & Fertilising: same as for Scenario A
Sc. C1	Organic growing media used in pots, containers, hobby greenhouses, establishing beds in gardens for home consumption[3]	PTE conc.: max ML quality class 0 (Norwegian regulation organic fertilisers)
Sc. C2		Max ML quality class II (same reg. as Sc.C1)
Sc. C3		Max ML CE-labelled growing media (EU regulation)

[1] Annual fertilisation up to 50 years. Leaching is not included. [2] Annual fertilisation up to 100 years. Leaching is not included. [3] Only MLs for different regulations are evaluated and not application of fertilisers over years were included.

A comparison of input of PTEs to agricultural soil via mineral P fertilisers and via various organic fertiliser products, in addition to atmospheric contribution, is presented in Table 11.2-5, given as g PTEs ha^{-1} yr^{-1}. Estimated minimum and maximum input values of PTEs for all case areas are shown, for more details see section 6.1.3 and Appendix VI.

The evaluation of MLs in organic fertilisers quality class II gave the highest estimated input for all selected PTEs. The exception was Zn, which is highest in the case of high application of pig manure for the selected crop rotations in Stange and for alum shale areas with potato-carrot-wheat-potato-wheat-wheat-wheat. Crop rotations were not accounted for in application of digestates, fish sludge and poultry and horse manure (based on a suggested maximum P application and maximum allowed dry weight added according to quality class 2), and the variation in input values was low.

It was selected to use cattle manure in Time, Melhus and Målselv, and pig manure in Stange in the risk assessments. Due to use of Zn and Cu as supplements in the pig and poultry feeds, and Zn in medical remedies, the concentration of Zn and Cu, is particularly high in pig and poultry manure. Thus, a particularly high variation between regions and case areas was seen for Zn, more than 10 times higher in Stange and alum shale (same input) than for instance in Målselv (4943 g Zn ha^{-1} yr^{-1} versus 456 g Zn ha^{-1} yr^{-1}, respectively).

The second highest PTE input of Cd, Cr, Cu and Ni was seen for application of sewage sludge with average PTE concentrations, while horse manure showed the second highest input of As and Pb. Pig manure applied in Stange and alum shale area gives the second highest input of Zn as mentioned above.

Fate and accumulation of PTEs in the environment and crops

Increase in agricultural soil concentration

Comparison of different input scenarios and increasing PTE trends over years in soil, is illustrated in Figure 11.2-3 (A-E), presented as % over 100 years application.

Predicted increase of PTEs in agricultural soil (PEC$_{soil}$) up to 100 years was highest for evaluation of organic fertiliser quality class II. The only exception was for Zn and high application of pig manure (70 kg P ha^{-1} yr^{-1}) (only modelled at Stange case area) (Figure 11.2-3E). Except for Ni, evaluation of the MLs for the other PTEs caused an increase in PEC$_{soil}$ in the range of 65% for Cr up to 1065% for Hg (Figure 11.2-3B).

To illustrate the influence of use of mean and maximum concentration and application amount, the modelling was performed with replacing maximum measured As in fish sludge (Table 6.1.2.2-1) and application of same high amount as modelled for Cu and Zn in pig manure (70 kg P ha^{-1} yr^{-1} and Stange case area), which gives 11 % (max concentration), 14 and 29% (measured mean and maximum values and high amount), respectively.

Application of sewage sludge according to quality class 2 (2000 kg DW ha^{-1} yr^{-1}) and measured mean PTE concentrations will give increased PEC$_{soil}$ for elements with general concern for humans and farm animals, 44%, 67%, 111% and 160% for Pb, Cd, Cu and Hg, respectively (Figure 11.2-4). For Cr and Zn, elements only with environmental risk, the increase were 11% and 68%, respectively. No data for As was available.

A substantial increase in PEC$_{soil}$ for Hg is seen for all other input sources as well, even atmospheric contribution as separate source, and in all case areas (Figure 11.2-3A). Increase after yearly application of digestate based on food waste alone was estimated to 344%, and digestate from food waste combined with manure, horse manure and fish sludge in the range of 107% - 73% (no Hg data from cattle, pig and poultry) (Figure 11.2-3A). The same pattern is seen for Pb, however, increase due to predicted atmospheric contribution as separate source is high and is the main contribution to the increase for some scenarios. Horse manure is the organic fertiliser with highest contribution to Pb (65% increase). For mineral P fertilisers a substantial increase is predicted for Hg, Cd, a low increase of Pb in regions with low present concentration. However, both for Hg and Pb, the atmospheric contribution account for most of the increase.

It is important to notify the high influence of application rates and PTE concentrations in fertiliser products for the outcome of the modelling. This is exemplified with input of Hg via use of fish sludge, digestates, horse manure and sewage sludge with varying application rates, and with mean and maximum measured Hg concentrations (Table 6.1.3-1). Estimated % increase in soil concentrations over 100 years based on these application rates of Hg (g Hg ha^{-1} yr^{-1}) is shown in Table AVI-5C. For instance, a realistic worst-case application of 70 kg P ha^{-1} yr^{-1} (compared to 30 kg P ha^{-1} yr^{-1}) and use of measured mean Hg concentration, shows an increase over 100 years: 32-41%, 49-83%, and 171-368%, for application of fish sludge, and digestate based on combination of food waste and manure, and only food waste, respectively. Comparing application of sewage sludge based on dry weight (2000 kg DW ha^{-1} yr^{-1}) with application according to P limitation, 30 kg and 70 P ha^{-1} yr^{-1}, (measured mean Hg concentrations), the simulation shows an increase over 100 years: 76, 60 and 107%, respectively. Comparison with same application rates and measured maximum concentrations are also shown in Table AVI-5C).

Increase in surface water and sediment

Estimated concentration in surface water, given as µg L^{-1}, and in sediments, given as mg kg^{-1}, for the PTEs and scenarios of most concern, together with percent increase and case areas, is presented in Table 11.2-2.

Table 11.2-2. Estimated percent (%) increase in surface water and sediment. Only case areas with the highest predicted concentration are presented. Concentrations for selected scenarios in surface water (PEC_{soil}), in µg L^{-1}, and sediment (PEC_{sed}), in mg kg^{-1}. ML QC 2: Evaluation of MLs quality class 2 organic fertiliser regulation.

		% increase 100 yr surface water & sediment	**Conc. 100 yr µg L^{-1} surface water**	**Conc. 100 yr mg kg^{-1} sediment**
As	ML QC 2 (#2)	54% (Stange)	0.43	2.05
Cd	ML QC 2 (#2)	112% (Stange)	0.087	0.82
	Sewage Sludge (#3)	50% (Stange)	0.062	0.58
	Mineral P (#1)	24% (Stange)	0.051	0.48
Cr	ML QC 2 (#2)	54% (Stange)	2.39	75
Cu	ML QC 2 (#2)	158% (Stange)	5.4	86
	Manure max. (#4)	60% (Stange)	3.3	53
Hg	ML QC 2 (#2)	70-84% (all)[1]	0.0017-0.0022	0.14-0.17
	Digestate (#8)	18-27% (all)[1]	0.0013-0.0015	0.10-0.12
Pb	ML QC 2 (#2)	41% (Melhus)	0.24	30
Zn	ML QC 2 (#2)	75% (Målselv)	9.5	600
	Manure max. (#4)	149% (Stange)	15	964
	Digestate (#8)	49% (Målselv)	7.6	482

[1] range covering all case areas.

Concentration and increase of PTEs in crops

Predicted transfer to and concentrations of PTEs in crops and vegetables follow the same trends as in soil. The highest estimated crops concentrations of As, Cd, Cu, Ni and Zn were those cultivated at agricultural soil in alum shale due to naturally high present concentration. However, for most PTEs and scenarios the trend is decreasing. Since human exposure of As, Cd, Hg and Pb is already high and no further increase is desired, these elements are focused. Predicted concentration of these PTEs in crops cultivated in alum shale after application of organic fertilisers according to regulation quality class II (#2) are shown in Table 11.2-3. As discussed in section 8.3.1.2, the selected TF for Cd in carrot (0.064 g g^{-1} DW from US EPA (1996)) underestimated predicted concentration compared to measured Cd concentrations in carrot cultivated in alum shale. The TF 0.25 g g^{-1} DW (Legind and Trapp, 2010), also applied in the risk assessment of Cd MLs in mineral fertilisers (VKM, 2019), has been shown to be more realistic. Predicted carrot concentrations based on both TFs, 6 and 23 µg kg^{-1} FW, respectively, are shown in Table 11.2-3.

Table 11.2-3. Estimated maximum concentrations of As, Cd, Hg and Pb in crops in cereals, carrot, potato, and grass (µg kg^{-1} FW), cultivated in alum shale with maximum allowed application rate and PTE concentration according to organic fertiliser regulation quality class II (#2). Highest concentrations were either at present (As and Cd) or after 100 years (Hg and Pb).

PTE	Cereals	Carrot	Potato	Grass
As (present)[1]	332	13	14	108
Cd (present)[1]	121	6[2] / 23[3]	58	39
Hg (present - 100 yr)	2.8 - 24	0.06 - 0.51	0.018 - 0.16	0.06 - 0.53
Pb (present - 100 yr)	85 - 122	24 - 35	38 - 55	40 - 57

[1]Present soil concentration; [2]TF 0.064 g g^{-1} DW US.EPA (used in this assessment), [3]TF 0.25 g g^{-1} DW Legind and Trapp, 2010 (used in risk assessment regarding Cd in mineral fertiliser, VKM, 2009).

Scenarios with highest estimated PTE concentrations in cereals, and information about case area and percent increase over 100 years are shown in Table 11.2-4. In addition to results of evaluation of regulation quality class II, fertiliser scheme with application of fish sludge (#6) for As, mineral P fertilisers (#1) for Cd, digestate (based on food waste and manure as substrates, #8) for Hg, and pig manure (maximum measured values (#4) for Zn are shown.

Table 11.2-4. Estimated maximum PTE concentrations in cereals (µg kg^{-1} FW) and increase (%) after 100 years for selected scenarios.

		% increase 100 yr	Conc. 100 yr µg kg^{-1} FW
As	#2	17% (Stange)	55
	#4	6 % (Stange)	25
	#6	5% (Stange)	25
Cd	#2	148% (Stange)	47
	#1	32% (Stange)	25
Cu	#2	463% (Stange)	8 043
Hg	#2	543-1065 (all; Time)[1]	21-32[1]
	#8	171-344 (all, Time) [1]	8-14[1]
Pb	#2	38% (Time)	135
Zn	#2	42% (Ås)	30 318
	#4	146% (Alum shale)	71 180
	#4	400% (Stange)	56 621

[1]Range covering all case areas.

These estimated concentrations of PTEs in crops are further used for calculations of human and animal exposure.

Evaluation of MLs for home grown and urban farming vegetables and garden fruits

Engineered soil, Norwegian regulation quality class 0 (Scenario B, exemplified for urban farming), has lower MLs for PTEs, and thus, lower initial concentrations in soil and subsequently higher percent increase over time than engineered soil with PTE concentration according to MLs for engineered soils (Scenario A, exemplified for home growing). Percent increase in scenario B in a 100-year perspective in carrots and potato were for As: 25-27%, Cd: 37-43%, Hg: 111-125%, and Pb: 15-17%.

Comparison of the five sets of MLs (Table 3.1.1-2 and Table 3.1.2-1), one set for each regulation/quality class, show that:

- the quality class II in Norwegian regulation organic fertilisers has the highest MLs for Cd and Hg (scenario C2, organic growing media)
- CE-labelled growing media (scenario C3, EU regulation) has the highest MLs for As and Pb
- MLs for engineered soil (scenario A, exemplifying home growing in engineered soil) has the same or lower MLs than these two sets of MLs
- MLs in quality class 0 for organic growing media (scenario C1) and for engineered soil (scenario B, exemplifying urban farming) are lower or same (only for Zn) as MLs in engineered soil.

In Table 11.2-6, predicted concentrations in carrot and potato cultivated with different scenarios for home growing and urban farming and cultivated in agricultural soil after application of organic fertilisers quality class II in alum shale and the region with highest or next highest concentration after alum shale.

For Pb and Hg, predicted concentrations in carrot and potato at present and after 100 years, cultivated in alum shale after application of organic fertilisers according to ML quality class II were lower compared to carrot and potato cultivated in different scenarios selected for home and urban growing (Table 11.2-6). For instance, for:

Pb: predicted concentrations in carrot cultivated in alum shale at present and in 100 years were 24 - 35 µg kg^{-1} FW compared to 49-77 µg kg^{-1} FW in engineered soils, and 48-145 µg kg^{-1} FW in growing media (all three sets of MLs), where CE-labelled growing media has the highest ML and concentration,

Hg: predicted concentrations in carrot cultivated in alum shale at present and in 100 years were 0.06 – 0.51 µg kg^{-1} FW compared to 0.3 – 1.7 µg kg^{-1} FW in engineered soils, and 0.3 – 4.6 µg kg^{-1} FW in growing media (all three sets of MLs) where Norwegian regulation, quality class II has the highest ML and concentration,

For As and Cd the pattern was different (Table 11.2-6).

As: predicted concentration in carrot in alum shale was highest at present soil concentration (no predicted increase with time), 13 µg kg^{-1} FW, compared to 4 -7.6 µg kg^{-1} FW in engineered soils, and 4 -35 µg kg^{-1} FW in growing media (3 MLs), and CE-labelled growing media has the highest ML and concentration.

Cd: predicted concentrations in carrot in alum shale was highest at present soil concentration (no predicted increase with time) was 6 µg kg^{-1} FW, compared to 3 - 8 µg kg^{-1} FW in engineered soils, and 3-14 µg kg^{-1} FW in growth media (3 MLs), and Norwegian regulation, quality class II has the highest ML and concentration.

Estimation of Cd concentrations in carrot with TF of 0.25 kg kg^{-1} DW (from Legind and Trapp, 2010) instead on the TF of 0.064 kg kg^{-1} DW (US EPA, 1996) gave the following concentrations: at present in agriculture soil 23 µg kg^{-1} FW, 11 - 29 µg kg^{-1} FW in engineered soils in the range, and 11 - 55 µg kg^{-1} FW in growth media (3 MLs). Compared to measured values in carrots cultivated in agricultural soils, the higher TF gave predicted values closer to measured values and therefore may seem to be a better choice (see section 8.3.5).

Comparing predicted concentrations in potato cultivated in agriculture soil, engineered soil, and growth media showed largely the same pattern as predicted for carrot (Table 11.2-6) but not further discussed here.

In home and urban growing scenarios, leaching and runoff from soil was not included as loss process (compare section 8.3.2). This assumption is more realistic for cultivation in growth media applied in pots, containers, greenhouses, and smaller beds, than cultivation in engineered soil in private garden and urban farming where this assumption leads to an overestimation of predicted concentrations, while initial concentrations in growing media are not affected.

While pH and OM are taken in account for in Kd values and environmental fate of PTEs over time (except for Cr(tot) and Hg with fixed Kd), this is not included in prediction of uptake in crops where fixed TFs were selected for all PTEs. As discussed elsewhere (section 5.1.1.1 and 6.2), pH influence solubility and bioavailability for many PTEs. Thus, this simplification also affects predicted plant uptake, which might be of particularly importance for Cd (Figure 11.2-1). Mean pH values in agricultural soil used in the modelling were in the range of 5.7 - 6.2. In general, pH_{H2O} in the interval 5.5-6.5 gives high plant availability for Cd, Cu, Cr, Ni and Zn, and liming the soils is recommended as measure to decrease plant uptake of these heavy metals. This is especially important for cadmium, where the plant uptake can be reduced to tolerable levels in plant products by increased pH. The effects of increased pH may be very high. For Zn may an increase in pH by one unit reduce the solubility to 1/100. For Cr there is hardly any relationship between the concentration in soils and uptake in aboveground plant material, while the root growth may be severely damaged by high Cr concentrations. A real problem for assessment of plant uptake of PTEs from soils receiving organic waste materials, is that there are interactions between the different metals and plant nutrients, e.g. uptake of As(V) is taken up by the same transport system as phosphate due to structural similarities (Marschner 1995) (section 6.2). The same is stated for Cr(VI)

(Sharma et al., 2020). High levels of plant available P in soils may thus decrease uptake of As, Cu, Cr and Zn in plants. It is therefore difficult to predict the effects of using large amounts of P-rich organic waste materials.

Evaluation of MLs for cultivated edible mushrooms

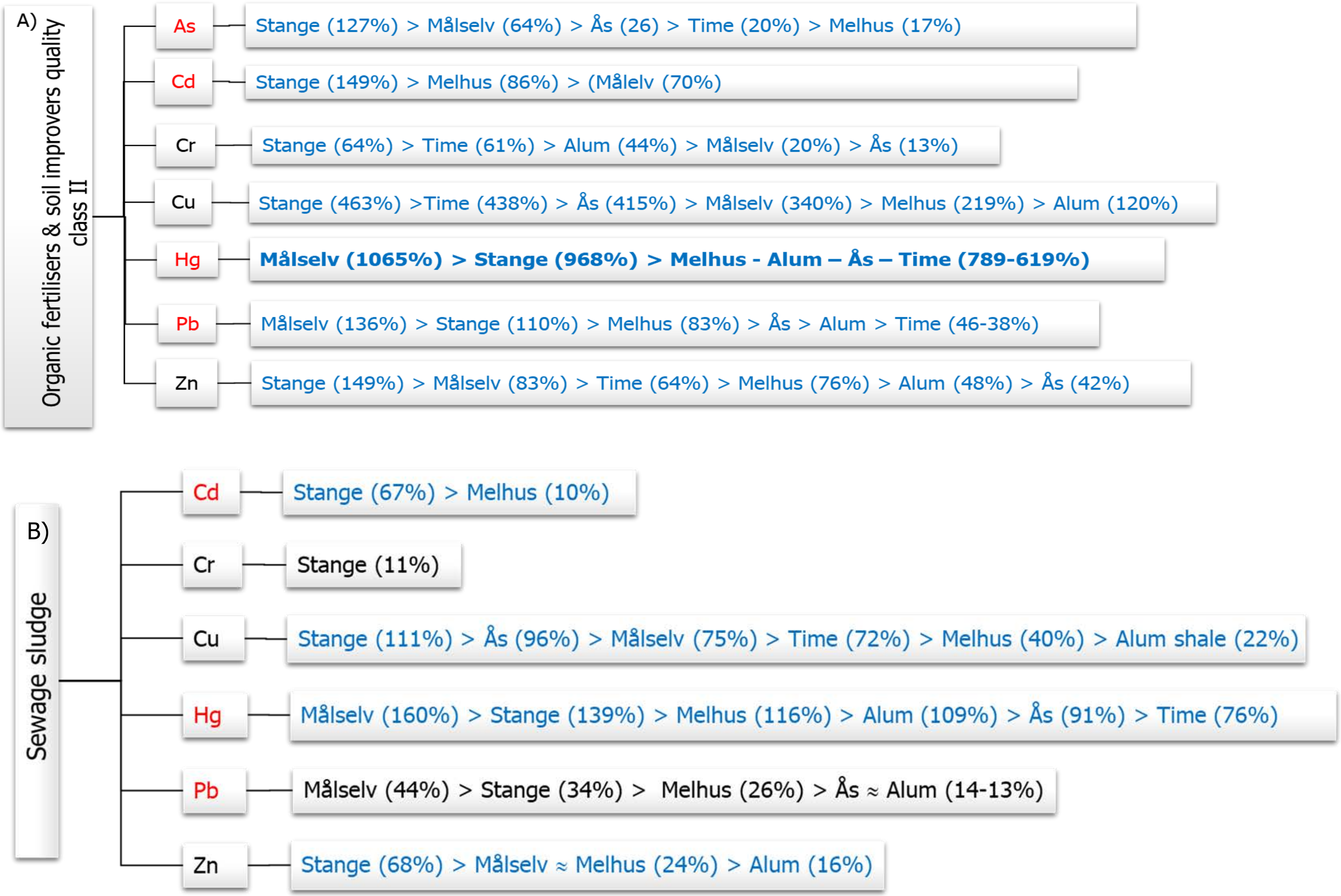
Estimated concentration in edible mushroom cultivated on agro-industrial wastes using the same three set of MLs evaluated for growing media and selected TFs for Cd, Cu, Hg, and Zn (Table 6.2.1-3, see section 6.2.2) was very high compared to measured values in the literature (Table 8.3.3-1 and Table 8.3.3-2). However, the high bioaccumulation factors reported for Cd, Cu, Hg and Zn (see section 8.3.3) give reason to call for more knowledge of transfer of these elements to cultivated mushroom, and if people with high intake of cultivated mushroom have an additional exposure source for these PTEs.

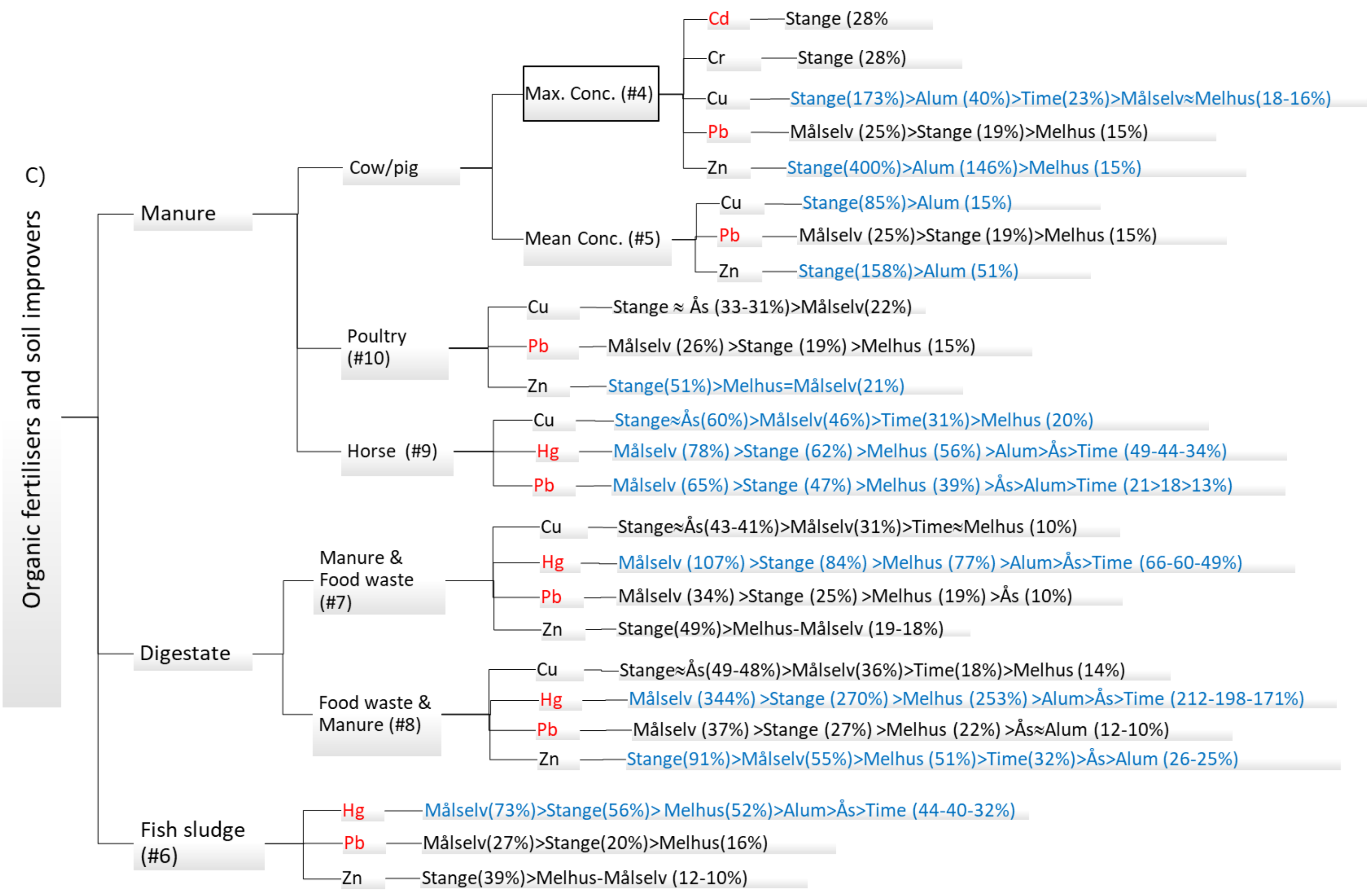
Table 11.2-5. Input of PTEs via selected fertilisers and soil improvers, given as g ha^{-1} yr^{-1}, present as minimum – maximum range for the different case areas. A) Atmospheric contribution is included in the input values, and B) atmospheric contribution is not included. Blue: Upper Bound Limit values were used. FW=Food waste.

	Min. P	**Manure**				**Digestate**		**Fish sludge**	**Sewage sludge**	**Organic fertilisers reg.**
A		Cattle & pig	Cattle & pig	Horse	Poultry	FW + Manure	Food Waste			Quality class II
	Present practice related to nutrient demand			2000 DW ha^{-1} yr^{-1}	30 kg P ha^{-1} yr^{-1}				2000 DW ha^{-1} yr^{-1}	
	#1	Max. #4	Mean #5	Mean #9	Mean #10	Mean #7	Mean #8	Mean #6	Mean #3	MLs #2
	Minimum – maximum range of PTE input in the selected case areas (g ha^{-1} yr^{-1}) with atmospheric contribution									
As	2.6-3.1	3.2-4.1	3.2-4.4	4.8-5.1	3.4-3.7	n.a.	n.a.	4.6-4.9	n.a.	34.6-40.4
Cd	0.77-2.7	0.71-2.5	0.58-1.2	1.4-1.4	0.71-0.74	1.42-1.45	1.71-1.74	1.31-1.34	1.6-4.1	4.4-7.3
Cr	33.2-39.7	32.3-38.6	31.3-33.0	58.2-58.7	33.7-34.1	45.2-45.6	66.8-67.2	40.7-41.1	64.3-79.2	231-273
Cu	13.3-15.6	133-598	82.4-314	235-236	148-149	179-180	199-200	38.6-39.3	343-399	1313-1532
Hg	0.36	n.a.	n.a.	0.48	n.a.	0.65	2.1	0.44	0.96-1.07	6.4-7.4
Ni	17.8-19.7	24.9-34.1	19.9-22.5	33.7-34.6	24.3-25.2	36.2-37.1	23.4-24.3	22.2-23.1	43.6-49.8	118-136
Pb	40.4-41.2	41.4-42.7	41.4-42.7	99.0	42.0	53.1-53.6	58.7-59.2	43.7-44.2	68.0-73.2	200-228
Zn	66.8-99.5	456-4943	392-2076	376	814	783	1284	673	842-1012	1660-1966

	Min. P	**Manure**				**Digestate**		**Fish sludge**	**Sewage sludge**	**Organic fertilisers reg.**
B		Cattle & pig	Cattle & pig	Horse	Poultry	FW + Manure	Food Waste			Quality class II
	Present practice related to nutrient demand			2000 DW ha^{-1} yr^{-1}	30 kg P ha^{-1} yr^{-1}				2000 DW ha^{-1} yr^{-1}	
	#1	Max. #4	Mean #5	Mean #9	Mean #10	Mean #7	Mean #8	Mean #6	Mean #3	MLs #2
	Minimum – maximum range of PTE input in the selected case areas (g ha^{-1} yr^{-1}) without atmospheric contribution									
As	0.19-0.68	1.51-2.77	1.51-2.77	2.42-2.72	1.77-2.08	n.a.	n.a.	2.16-2.47	n.a.	32.2-38.0
Cd	0.43-2.34	0.37-2.20	0.24-0.89	1.05-1.08	0.37-0.40	1.08-1.11	1.37-1.40	0.97-1.00	1.24-3.74	4.04-7.00
Cr	3.20-9.71	2.25-8.61	1.25-2.99	28.2-28.7	3.72-4.14	15.15-15.58	36.8-37.2	10.7-11.1	34.3-49.2	201-243
Cu	1.26-3.56	121-586	70.4-302	223-224	136-137	167-168	187-188	26.6-27.3	331-387	1301-1520
Hg	0.002-0.007	n.a.	n.a.	0.116-0.116	0.0001-0.001	0.2890	1.7000	0.084-0.084	0.601-0.707	6.0-7.0
Ni	0.82-2.69	7.9-17.1	2.85-5.52	16.7-17.6	7.3-8.2	19.2-20.1	6.4-7.3	5.2-6.1	26.6-32.8	100.8-119.4
Pb	0.43-1.20	1.37-2.70	1.37-2.70	58.7-59.2	1.83-2.33	13.14-13.63	18.7-19.2	3.7-4.2	28.0-33.2	160.4-187.6
Zn	6.8-39.5	396-4883	331-2016	316[1]	754[1]	723[1]	1224[1]	613[1]	782-952[2]	1600-1906[2]

[1] only atmospheric contribution and the given fertiliser scheme (#6, 7, 8, 9, 10), same value in all regions. [2] Mineral P was included.


A)
Organic fertilisers & soil improvers quality class II
As
Stange (127%) > Målselv (64%) > Ås (26) > Time (20%) > Melhus (17%)
Cd
Stange (149%) > Melhus (86%) > (Målelv (70%)
Cr
Stange (64%) > Time (61%) > Alum (44%) > Målselv (20%) > Ås (13%)
Cu
Stange (463%) >Time (438%) > Ås (415%) > Målselv (340%) > Melhus (219%) > Alum (120%)
Hg
Målselv (1065%) > Stange (968%) > Melhus - Alum – Ås – Time (789-619%)
Pb
Målselv (136%) > Stange (110%) > Melhus (83%) > Ås > Alum > Time (46-38%)
Zn
Stange (149%) > Målselv (83%) > Time (64%) > Melhus (76%) > Alum (48%) > Ås (42%)
B)
Sewage sludge
Cd
Stange (67%) > Melhus (10%)
Cr
Stange (11%)
Cu
Stange (111%) > Ås (96%) > Målselv (75%) > Time (72%) > Melhus (40%) > Alum shale (22%)
Hg
Målselv (160%) > Stange (139%) > Melhus (116%) > Alum (109%) > Ås (91%) > Time (76%)
Pb
Målselv (44%) > Stange (34%) > Melhus (26%) > Ås ≈ Alum (14-13%)
Zn
Stange (68%) > Målselv ≈ Melhus (24%) > Alum (16%)


C)
Organic fertilisers and soil improvers
Manure
Cow/pig
Max. Conc. (#4)
Cd
Stange (28%
Cr
Stange (28%)
Cu
Stange(173%)>Alum (40%)>Time(23%)>Målselv≈Melhus(18-16%)
Pb
Målselv (25%)>Stange (19%)>Melhus (15%)
Zn
Stange(400%)>Alum (146%)>Melhus (15%)
Mean Conc. (#5)
Cu
Stange(85%)>Alum (15%)
Pb
Målselv (25%)>Stange (19%)>Melhus (15%)
Zn
Stange(158%)>Alum (51%)
Poultry (#10)
Cu
Stange ≈ Ås (33-31%)>Målselv(22%)
Pb
Målselv (26%) >Stange (19%) >Melhus (15%)
Zn
Stange(51%)>Melhus=Målselv(21%)
Horse (#9)
Cu
Stange≈Ås(60%)>Målselv(46%)>Time(31%)>Melhus (20%)
Hg
Målselv (78%) >Stange (62%) >Melhus (56%) >Alum>Ås>Time (49-44-34%)
Pb
Målselv (65%) >Stange (47%) >Melhus (39%) >Ås>Alum>Time (21>18>13%)
Digestate
Manure & Food waste (#7)
Cu
Stange≈Ås(43-41%)>Målselv(31%)>Time≈Melhus (10%)
Hg
Målselv (107%) >Stange (84%) >Melhus (77%) >Alum>Ås>Time (66-60-49%)
Pb
Målselv (34%) >Stange (25%) >Melhus (19%) >Ås (10%)
Zn
Stange(49%)>Melhus-Målselv (19-18%)
Food waste & Manure (#8)
Cu
Stange≈Ås(49-48%)>Målselv(36%)>Time(18%)>Melhus (14%)
Hg
Målselv (344%) >Stange (270%) >Melhus (253%) >Alum>Ås>Time (212-198-171%)
Pb
Målselv (37%) >Stange (27%) >Melhus (22%) >Ås≈Alum (12-10%)
Zn
Stange(91%)>Målselv(55%)>Melhus (51%)>Time(32%)>Ås>Alum (26-25%)
Fish sludge (#6)
Hg
Målselv(73%)>Stange(56%)> Melhus(52%)>Alum>Ås>Time (44-40-32%)
Pb
Målselv(27%)>Stange(20%)>Melhus(16%)
Zn
Stange(39%)>Melhus-Målselv (12-10%)

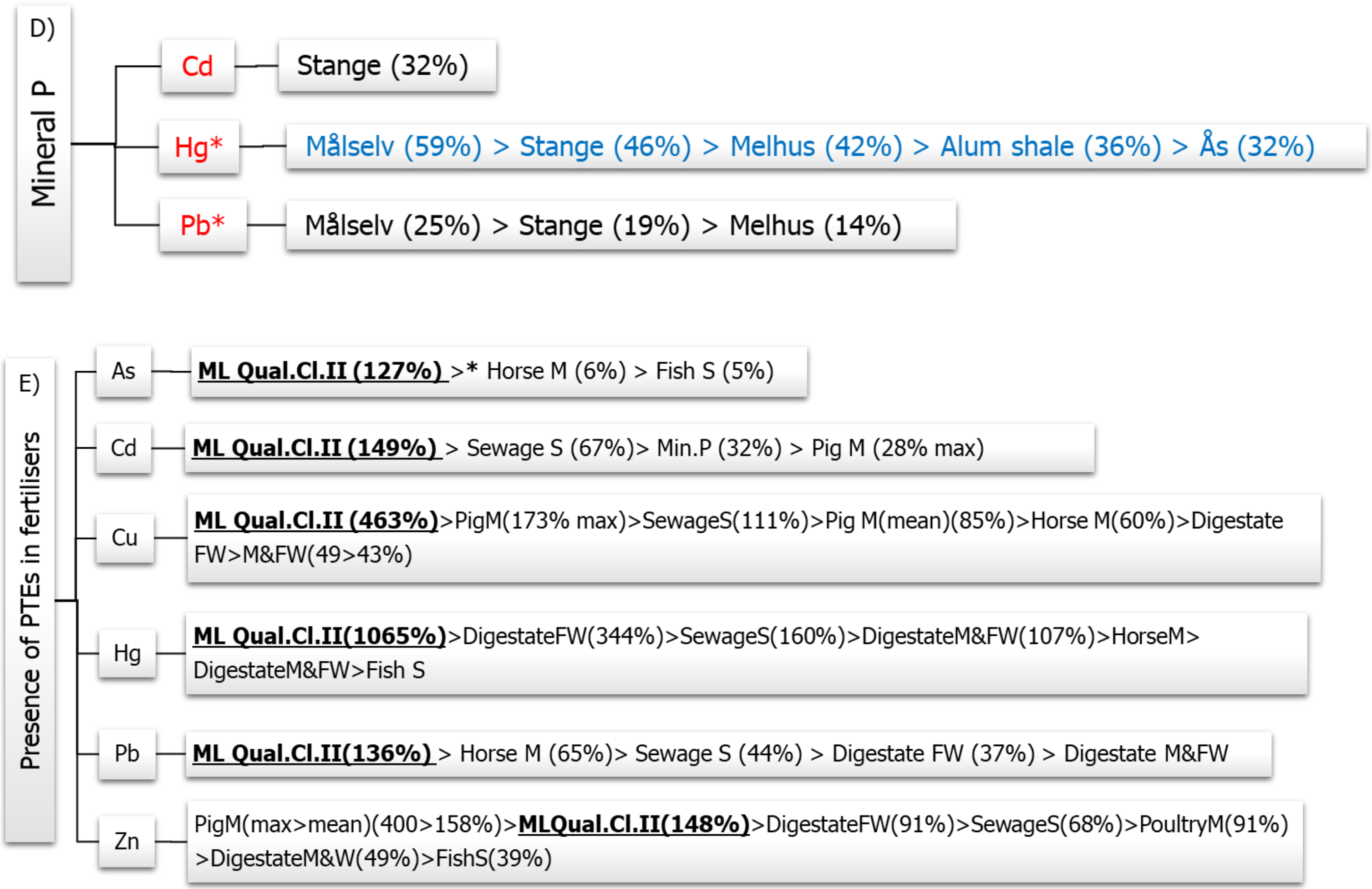


Figure 11.2-4. Estimated accumulation of PTEs in soil over 100 years, given as percent (%) from present soil concentration, after application of (A) fertiliser products according to Norwegian regulation of organic fertilisers, 2000 kg ha^{-1} yr^{-1} and MLs quality class II; (B) sewage sludge,

2000 kg ha^{-1} yr^{-1} and with mean concentrations of PTEs (SSB data); (C) manure (cattle, pig, poultry, horse), fish sludge and digestates (food waste and food waste & manure as substrate); (D) mineral P fertilisers (*Hg and Pb, increase mainly due to atmospheric contribution), and (E) overview of fertiliser products and predicted increase of PTEs (*use of Upper Bound-values for cattle and pig manure gave 6% increase but not included). Only increase > 10% is shown except for As. The PTEs with no further desirable increased exposure to humans and farm animals, As, Cd, Hg and Pb, marked red, and scenarios with estimated increase of PTEs >50% over 100 years, marked blue. Missing analysis: Hg in pig, cattle, poultry manure, and As in digestates and sewage sludge. All fertiliser schemes are included for all regions, except for cattle and pig manure which is rarely applied in Ås (South-east Norway) and mineral P fertilisers for grass production in Time, for which no information was available.

Table 11.2-6. Overview of predicted concentrations of As, Cd, Hg and Pb at present, after 50 and 100 years in parentheses (), given as μg kg^{-1} FW, evaluating five different MLs (Table 3.1.1-2, Table 3.1.2-1), and after application of organic fertilisers according to Norwegian regulation quality class II in alum shale areas and the region with highest or next highest estimated crop concentrations. Measured concentrations is also shown. Recalculate Cd concentrations in carrots with new TF, see footnote, included in parentheses **[]**. (-): lack of data. AS: alum shale.

		Carrot Conc.		Potato Conc.		Carrot Conc.			Potato Conc.		
		Present (50 yr)	100 yr	Present (50 yr)	100 yr	Present (100 yr)		Measured[5]	Present (100 yr)		Measured[5]
						MLs Qu.Cl.II[6]		(Alum shale)	MLs Qu.Cl.II[6]		(Alum shale)
						Alum shale	Not AS	(non-AS)	Alum shale	Not AS	(non-AS)
As	Sc.A	7.0 (7.6)		7.7 (8.3)		13.2 (13.1)	2.6 (3.1)[7]	(-) (7-63)	14.4 (14.3)	2.9 (3.4)[7]	(-) (<1.1-1.8 ; <1-10)
	Sc.B	4.4 (5.0)	5.6	4.8 (5.4)	6.1						
	Sc.C1	4.4		4.8							
	Sc.C2	14.1		15.4							
	Sc.C3	**35.2**		**38.4**							
Cd	Sc.A	[1]7.0 (7.6) [2] **[27.5 (29.4)]**		69.6 (73.8)		[1]5.9 (5.5) [2][23.4 (23.4)]	[1]0.9 (2.3)[3] [2][3.5 (9.0)][3]	(95) (2.1-62.8)	58 (55)	9.0 (22.5)[3]	(19; 32; 65; 12-67) (0.72; 12-33; 0.8-37.6)
	Sc.B	[1]2.8 (3.4) [2]**[11 (13.1)]**	[1]4.0 [2]**[15.2]**	27.8 (33.0)	38.0						
	Sc.C1	[1]2.8 [2]**[11]**		27.8							
	Sc.C2	[1]**14.1** [2]**[55]**		**139**							
	Sc.C3	[1]10.6 [2]**[41.3]**		104							
Hg	Sc.A	1.5 (1.7)		0.48 (0.54)		0.06 (0.51)	0.11 (0.68)[4]	(-) (-)	0.02 (0.16)	0.03 (0.21)[4]	(-) (-)
	Sc.B	0.3 (0.5)	0.7	0.10 (0.16)	0.22						
	Sc.C1	0.31		0.1							
	Sc.C2	**4.62**		**1.44**							
	Sc.C3	1.54		0.48							
Pb	Sc.A	73 (77)		115 (122)		24.2 (34.7)	27.8 (38.5)[4]	(2.8) (0.5-34)	38.4 (55.1)	44.2 (63.6)[4]	(5-19; 3.2; 7.2; <LOD) (<1.2-2.7; <0.8-7.2)
	Sc.B	49 (52)	56	76.6 (83.2)	90						
	Sc.C1	48.4		76.8							
	Sc.C2	96.8		154							
	Sc.C3	**145**		**230**							

[1]TF Cd carrot 0.064 g g^{-1} DW from US EPA (1996); [2]TF Cd carrot 0.25 g g^{-1} DW from Legind and Trapp (2010); [3]Stange, [7]Melhus, [4]Time; [5]See Table 8.3.5-1; [6]Norwegian regulation organic fertilisers Quality Class II.

11.3 What level of these elements in agricultural soils would give the risk of negative effects on the selected affected organisms found in table A

Terrestrial organisms

Terrestrial organisms are exposed directly to the soil and consequently, the level of PTEs that would give as risk of negative effects to these organisms is given by the Predicted No Effect Concentrations ($PNEC_{soil}$), which have been adopted from European Risk Assessment Reports, ECHA Registration dossiers and European Environmental Quality Standards as described in Section 7. The PNECs are based on reported effect concentrations for soil microorganisms, invertebrates and plants. A tentative specific PNEC for effects in plants has been suggested for As and Cd. For PTEs which have potential for bioconcentration in the food chain, and sufficient data is available, a PNEC has also been derived for secondary poisoning ($PNEC_{soil,\ secpois}$).

The $PNEC_{soil}$ for various PTEs are shown in Table 11.3-1. For PNECs that have been calculated by adding a background concentration to a $PNEC_{add}$, or with a model that includes correction for bioavailability based on soil characteristics, site specific PNECs are given as a range for the regions included in the assessment.

Table 11.3-1. Summary of PNEC values for the selected PTEs for terrestrial organisms, given as mg kg^{-1}, for the different target organisms.

PTE	Target organisms	$PNEC_{soil}$
As	Terrestrial organisms, direct effect	$PNEC_{add\ soil}$: 2.9 mg kg^{-1} Site specific: 4.0 - 17.9 mg kg^{-1}
As	Agricultural plants	$PNEC_{soil,\ plants}$: 11 mg kg^{-1}
Cd	Terrestrial organisms, direct effect	$PNEC_{soil}$: 2.3 mg kg^{-1}
Cd	Agricultural plants	$PNEC_{plants}$: 2.8 mg kg^{-1}
Cd	Terrestrial organisms secondary poisoning	$PNEC_{secpois}$: 0.9 mg kg^{-1}
Cr	Terrestrial organisms, direct effect	$PNEC_{add\ soil}$: 3.2 mg kg^{-1} Site specific: 12.5 – 28.2 mg kg^{-1} (Cr III)
Cu	Terrestrial organisms, direct effect	$PNEC_{soil}$: 70 - 112 µg L^{-1} (Site specific)
Hg	Terrestrial organisms, direct effect	$PNEC_{soil}$: 0.39 mg kg^{-1}
Hg	Terrestrial organisms secondary poisoning	$PNEC_{secpois}$; 0.59-0.63 (inorganic Hg), $PNEC_{secpois}$: 0.17-0.21 (methyl-Hg)
Ni	Terrestrial organisms, direct effect	$PNEC_{soil}$: 23 – 46 mg kg^{-1} (Site specific)
Ni	Terrestrial organisms secondary poisoning	22.6 mg kg^{-1}
Pb	Terrestrial organisms, direct effect	$PNEC_{soil}$: 166 mg kg^{-1}
	Terrestrial organisms secondary poisoning	$PNEC_{soil,\ secpois}$: 272 mg kg^{-1}
Zn	Terrestrial organisms, direct effect	$PNEC_{soil}$: 116 – 231 mg kg^{-1} (Site specific)

Aquatic organisms

The model used to calculate exposure concentration for aquatic organisms simulates a scenario where runoff and leaching water from agricultural soil is diluted in an adjacent small watercourse. The final exposure concentration of PTEs in the surface water is dependent on the concentration in the leaching-and runoff water, on the background concentration in the receiving water, as well as on the content of suspended matter in the runoff- and the receiving water. Consequently, the concentration of PTEs in surface water is not directly correlated with the concentrations in the soil. Therefore, the aquatic $PNEC_{sw}$ cannot be converted to a concentration in soil. The same applies to the sediment environment since the PTE concentrations are correlated with the concentration in surface water and not with the soil.

The predicted No Effect Concentrations for PTEs in surface water and sediment are presented in section 7.1.

Farm animals and humans

Farm animals and humans are not mainly directly affected by PTEs concentrations in soil. Effects and risks to farm animals and humans are addressed in following chapters, in the answers to 11.4 and 11.5.

Table 11.3-1: Maximum tolerable levels (MTLs) and upper level (UL) for the various PTEs in animal diets based on NRC (2005).

	Farm animals
As	MTL: 30 mg kg $^{-1}$ diet
Cd	UL: 1 mg kg^{-1} diet (WHO 1992)
Cr	MTL: 100-500 mg kg^{-1} diet (Cr(III))
Cu	MTL: 15-250 mg kg^{-1} diet
Hg	MTL: 0.2-2 mg kg^{-1} diet
Ni	MTL: 100-250 mg kg^{-1} diet
Pb	MTL: 10-30 mg kg^{-1} diet
Zn	MTL: 300-1000 mg kg^{-1} diet

11.4 What do we know about the current and future exposure to these elements for the affected organisms in table A, both when it comes to exposure levels and the sources for the exposure?

The risk of adverse effects on organisms in the terrestrial and aquatic compartments of the environment, including sediments, have been assessed based on measured or predicted environmental concentrations (PEC) of PTEs in soil, surface water, and sediment, as well as the predicted no effect concentrations (PNEC) in the same media. From these two parameters a risk characterisation ratio (RCR) has been calculated as RCR = PEC/PNEC. RCR<1 indicates no risk, while RCR>1 indicates a risk. In the assessment the risk has been further categorised as follows:

- $RCR<1$ No risk
- $1 \le RCR<2$ Low risk
- $2 \le RCR<5$ Significant risk
- $RCR \ge 5$ High risk

11.4.1 Arsenic

Terrestrial organisms

For As the risk assessment for terrestrial organisms is based on a $PNEC_{add}$, i.e. a concentration to which the background concentration shall be added to obtain the $PNEC_{soil}$. Here the present concentrations in the regional soils have been defined as background concentrations, which means that a risk can only occur in scenarios where increasing concentrations are predicted. In the input scenario with organic fertilisers and ML according to quality class II (scenario #2), the concentrations are predicted to increase, but remain below the PNEC after 100 years which indicates no risk. In all other input scenarios, the concentrations of As in soil are predicted to decrease.

Aquatic organisms

The predicted present and future (100 yr.) levels of As in surface water receiving runoff and leachate from agricultural soil are far below the PNEC for aquatic organisms including sediment dwelling organisms in all regions and input scenarios. No risk is indicated.

Farm animals

The background level of As is far below a level considered as maximum tolerable. In most scenarios (region x fertilisation scheme), the estimated temporal development of As in animal diets via grazing and feeding implies reduced levels. The prominent exception is Stange where an increase of 130 % by fertilisation scheme #2 is expected. The maximum increase in Stange will result in dietary As levels for grazing animals at about 0.2 mg kg^{-1}. This increase implies no health risk for the farm animals.

Use of marine products such as residues from the fish industry and sea weeds as fertilisers would probably increase the levels of As in the animal diets far more.

Humans

Grain and grain-based products are one of the largest contributors to the total As exposure in the general European population, while vegetables and vegetable products are main contributors in some countries.

In general, the As concentration in the agricultural crops wheat, carrots and potatoes will decrease in most of the scenarios, depending on time. A reduction in the concentration of As in wheat, carrots and potatoes is likely to reduce the As exposure in the Norwegian population.

At some locations (Målselv, Melhus, Stange and Ås) the use of suggested MLs, organic fertiliser regulation quality class II (#2), will lead to an increase in the As concentration in agricultural wheat, carrots and potatoes in the 100-year perspective. Consumption of these crops will lead to an increase in the dietary exposure to As. As the dietary exposure is high, any increase in dietary exposure is not desirable.

The use of engineered soil in home gardening will lead to a small increase in the As concentrations in lettuce, carrot, tomato and potato in 50-year perspective, while the use of engineered soil in urban farming and market gardens will increase the As concentrations in potato, leaf vegetables, root vegetables and garden fruits in a 100-year perspective. The use of growing media will lead to an increase in the As concentration in potato, leaf vegetables, root vegetables, and garden fruits. An increase in the As concentration in home grown vegetables and vegetables and fruit from urban farming is likely to increase the As exposure in persons eating such crops. As the dietary exposure is high, any increase in dietary exposure is not desirable.

11.4.2 Cadmium

Terrestrial organisms

Elevated concentration of geogenic Cd is found in the alum shale area, but the present concentration in soil is still below the $PNEC_{soil}$, which indicates no risk for adverse effect on terrestrial organisms. In this area the Cd concentration is predicted to decline. In the other regions, the concentrations are far below the $PNEC_{soil}$, and are predicted to remain so in a 100 year perspective even if concentrations are expected to increase with input of organic fertilisers quality class II (scenario #2) in Målselv, Melhus and Stange.

Adverse effects of Cd in terrestrial food-chains by secondary poisoning are predicted to occur at lower concentrations than $PNEC_{soil}$, but the present and predicted future concentrations are not above the $PNEC_{soil,\ secpois}$ in the alum shale area or the other regions, indicating no risk for secondary poisoning. This result is different from a previous risk assessment of Cd in fertilisers by VKM (2018), where a risk for secondary poisoning of Cd in the alum shale area was predicted. The reason for the difference is that a lower present concentration of Cd in alum soil has been used in the calculations in the present assessment.

Aquatic organisms

The predicted present concentration of Cd in surface water are above the $PNEC_{sw}$ in Time and the alum shale area. In the latter area, the risk characterisation ratio (RCR = PEC/PNEC) is 2.6 which indicates a significant risk. Measured concentrations of Cd in watercourses in the alum shale area indicate that the predicted concentrations are reasonable, but data are scarce. In all other regions the concentrations are decreasing in all input scenarios except for the organic fertilisers, ML class II scenario (#2), and are below the $PNEC_{sw}$, indicating no risk. For sediment dwelling organisms no risk is indicated in any region.

Farm animals

In all selected geographical regions, including the alum shale area, the current Cd levels in feed and pasture plants including soil, and thus the animal diet, are far below a critical level of concern for animal health and also below a level of concern for consumers of animal products. By use of most of the organic fertilisers, the Cd concentrations in animal diets are estimated to decline, and thus, imply reduced risk of Cd concentrations of concern in animal products, as well as the less-likely risk for adverse health effects in animals. However, there are some exceptions. In particular, an increase of Cd will be a result of use of organic fertiliser class II with maximum PTEs (#2) but the level will, still after, 100 years be below a level of animal health concern.

Because Cd is a potential toxic element without essential qualities, the goal is to keep its level as low as possible.

Humans

In Europe, the foods contributing the most to the dietary Cd exposure across all age groups are potatoes, bread and rolls, fine bakery wares, chocolate products, leafy vegetables, and water molluscs.

In general, the Cd concentration in wheat, carrots and potatoes will remain the same or decrease in most of the scenarios. A reduction in the concentration of Cd in wheat, carrots and potatoes is likely to reduce the Cd exposure in the Norwegian population.

At some locations (Målselv, Melhus, Stange and Ås) the application of maximum levels (MLs) of Cd in quality class II organic fertiliser regulation for any fertiliser and soil improvers (#2) is expected to lead to an increase in the Cd concentration in agricultural wheat, carrots, and potatoes in a 10- and 100-year perspective. Consumption of these crops will lead to an increase in the dietary exposure to Cd. The increased exposure could be higher in parts of the population consuming large quantities of locally produced food grown at locations where the Cd concentrations in crops are expected to increase. As the dietary exposure is high, any increase in dietary exposure is not desirable.

The use of engineered soil in home gardening will lead to a small increase in the Cd concentrations in lettuce, carrot, tomato, and potato in 50-year perspective, while the use of engineered soil in urban farming and market gardens will increase the Cd concentrations in potato, leaf vegetables, root vegetables and garden fruits in a 100-year perspective. The use of growing media will lead to an increase in the Cd concentration in potato, lettuce, carrot, and mushroom. An increase in the Cd concentration in home grown vegetables and vegetables and fruit from urban farming is likely to increase the Cd exposure in persons eating such crops. As the dietary exposure is high, any increase in dietary exposure is not desirable.

11.4.3 Chromium

Terrestrial organisms

For Cr, the $PNEC_{soil}$ has been calculated from a $PNEC_{add,\ soil}$, to which the present regional concentrations have been added. Therefore, the present concentration cannot be higher than the $PNEC_{soil}$, and only the risk of a future increase in the concentrations can be assessed. Only with the organic fertilisers, ML class II scenario (#2), and the sewage sludge scenario (#3) a temporal increase of Cr is predicted. With the highest PTE input (scenario #2), Cr concentrations are increasing in all regions, while only the Stange region shows an increase with input of sewage sludge with mean concentrations of PTEs (scenario #3). Cr concentrations slightly above $\text{PNEC}_{\text{soil}}$, indicating a low risk of adverse effects, are predicted to occur, but only after 100 years application of organic fertilisers, ML class II (scenario #2) in all regions except Melhus.

Aquatic organisms

The predicted present concentrations of Cr in surface water are below the PNEC_{sw} in all regions except Melhus, where the RCR is 1.03, indicating a low risk of adverse effects. Here the concentrations are decreasing to values lower than PNEC_{sw} with all input scenarios except the organic fertilisers, ML class II (scenario #2). In Målselv, Stange, alum shale and Time the predicted Cr concentrations are increasing with up to 54% after 100 years, but without exceeding the PNEC_{sw}. No risk is indicated for sediment dwelling organisms.

Farm animals

In all regions, the background Cr levels in animal diets from pasture and feeding are far below a maximum tolerable level. By most fertilisation schemes a further decline in these levels is estimated. The prominent exception is organic fertilisers, ML class II (#2), which causes an increase in most regions. The increases imply no health risk for farm animals as the Cr is supposed to be the trivalent, low toxic, form.

Humans

As the current estimated intake of Cr is well below the TDI, the estimated, limited increase of Cr concentration in food plants following the different fertiliser schemes is of no concern for human health.

11.4.4 Copper

Terrestrial organism

Present concentrations of Cu in soil are below the $\mathrm{PNEC_{soil}}$, indicating no risk in all regions. Input scenarios with sewage sludge, manure, and digested food waste (scenarios #2, #3, #4, #5, #7, #8, #9, #10) indicate increasing concentrations in most regions, but PNEC soil is expected not to be exceeded within 100 years, indicating no risk of Cu to soil organisms.

Aquatic organisms

The predicted present concentrations of Cu in surface water are far below the $\mathrm{PNEC_{sw}}$ in all regions. The same scenarios as mentioned for soil for terrestrial organisms, cause increasing concentrations in surface waters in most regions, but $\mathrm{PNEC_{sw}}$ is not exceeded even after 100 years, indicating no risk. Also in sediment, the predicted present concentrations are below the PNEC. The temporal trends are similar as for surface water, and concentrations slightly above $\mathrm{PNEC_{sed}}$ are predicted after 100 years with application of organic fertilisers, ML class II (scenario #2), indicating low risk, in Time and the alum shale area.

Farm animals

By use of worst-case scenario using organic fertiliser class II with maximum PTEs (#2), after 100 years at Stange and the alum shale area in particular, the plants are expected to contain elevated Cu levels, considered harmful for grazing sheep (maximum tolerable dietary levels 15 mg $\mathrm{kg^{-1}}$). For other farm animals, these levels imply no risk.

Moreover, pig manure (#4) in the alum shale area with elevated background Cu, may increase the Cu to levels of risk for grazing sheep.

Humans

The estimated increases in grain and grain products following scenario #2, organic fertilisers quality class II) may lead to a dietary exposure exceeding the upper safe intake level proposed by SCF (SCF 2003) and is of concern. The increases following scenarios #4 and #9 are less and will probably not lead to intakes exceeding the upper safe intake level.

The predicted increase in Cu concentrations in farmed mushroom may also lead to an increase in Cu intake for high consumers.

For all other population groups or scenarios, the modelled Cu concentrations are not of concern.

11.4.5 Mercury

Terrestrial organisms

The present concentrations of Hg in soil are below the $PNEC_{soil}$ in all regions, indicating no risk. The atmospheric contribution alone is sufficient to cause accumulation of Hg in all regions and, consequently increasing concentrations are predicted for all scenarios including atmospheric input. However, organic fertilisers, ML class II and sewage sludge (scenario #2 and #3) and food waste digestate (scenario #7 and #8) cause significantly higher accumulation rates. In scenario #2 the Hg concentration approaches $PNEC_{soil}$ after 100 years, and in Time $PNEC_{soil}$ is exceeded with an RCR of 1.14, indicating a low risk to terrestrial organisms.

A risk for secondary poisoning via a terrestrial food-chain after 100 years application of organic fertilisers, ML class II (#2) is predicted in all regions. This assessment is based on the assumption that Hg is transferred to methyl-Hg in the food-chain.

Aquatic organisms

Predicted present concentrations of Hg in surface water and sediment are far below the $PNEC_{sw}$ and $PNEC_{sed}$ and remains so for 100 years, even though significant increase is predicted for scenarios with input of sewage sludge and organic fertilisers in all regions. Thus, no risk is indicated for the aquatic environment.

Due to lack of reliable water/fish bioconcentration factors, a $PNEC_{secpois}$ for aquatic food-chains has not been established. However, the present exposure to Hg in some Norwegian lakes without known point sources of Hg is high enough to cause accumulation of Hg in fish and concentrations exceeding the European quality standard for secondary poisoning. Thus, all anthropogenic input sources of Hg to the environment should be kept as low as possible.

Farm animals

In all selected geographical regions, the current Hg levels in feed and pasture plants including soil, and thus the animal diet, are below a suggested critical level of concern for health of studied animals.

By worst case fertilisation with organic fertiliser class II with maximum PTEs (#2), a substantial increase of Hg is estimated in all regions. After 100 years the expected increase is about 10 times in Stange, in the alum shale area, in Melhus and Målselv, somewhat less in Ås and Time (6 times increase). By fertiliser schemes #3 and #8 lower increases (1-4 times) are estimated after 100 years in the various regions. However, the dietary levels will be below levels considered to be critical for animal health.

Because Hg is a toxic element without essential qualities and accumulates in animal products for human consumption such as meat and eggs, the goal is to keep its level as low as possible.

Humans:

Fish and other seafood are the major contributors to dietary exposure to Hg in the European population. Other foods contribute little to the dietary Hg exposure.

The Hg concentration will increase in the agricultural crops wheat, carrots and potatoes at all locations, depending on time and type of fertiliser. An increase in the Hg concentration in wheat, carrots and potatoes is likely to increase the Hg exposure in the Norwegian population, but the contribution will be small compared to the contribution from the consumption of fish and other seafood.

The use of engineered soil in home gardening and urban farming, and the use of growing media, will lead to an increase in the Hg concentrations in vegetables, garden fruits and cultivated mushroom. An increase in the Hg concentration in home grown crops and crops from urban farming is likely to increase the Hg exposure in persons eating such vegetables. The contribution to the total dietary Hg exposure will be small compared to the contribution from the consumption of fish and other seafood.

11.4.6 Nickel

Terrestrial organisms

In the alum shale area, the present concentration of Ni in soil is elevated due to a high geogenic contribution and is slightly above the $PNEC_{soil}$, indicating a low risk to terrestrial organisms by direct exposure to soil. For all other regions the concentrations are much lower, and no risk is indicated. The input of Ni in all the scenarios is lower than the predicted loss, and the concentrations are estimated to decrease over time.

A risk is indicated for secondary poisoning at the present Ni concentrations in Melhus (low risk) and alum shale areas (significant risk). However, Ni in soils developed on alum shale minerals have been shown to be strongly associated with the soil components and the bioavailability is considered to be low. (Narwal et al. 2008). Therefore, the risk is likely overpredicted in this area.

Aquatic organisms

The $PNEC_{sw}$ for Ni has been calculated with account for bioavailability based on water quality parameters in the main rivers in each region. The highest predicted present concentration of Ni in surface water is in the alum shale area, where the regional $PNEC_{sw}$ is exceeded (RCR 1.8), indicating a low risk. In spite of much lower present concentration of Ni in Målselv, a similar low risk is predicted here (RCR 1.7), because of a higher bioavailability, due to a low content of DOC, and a relatively high pH in River Målselva. The regional $PNEC_{sw}$ is also marginally exceeded in Melhus. The concentration of Ni is decreasing in all regions but are still above the $PNEC_{sw}$ in all input scenarios in the alum shale area after 100 years. In sediments, the predicted present concentration of Ni exceeds the $PNEC_{sed}$ (RCR 1.9) in the alum shale area, and, although the concentration is decreasing, RCR remains above 1 after 100 years, indicating a low risk to sediment dwelling organisms in this area.

However, a specific study of mobility of elements in soil developed on alum shale have shown that Ni is strongly associated with the soil (Narwal et al. 2005). This implies that the leaching of Ni in the alum shale soil and, hence, the predicted risks to surface water and sediment organisms may be overestimated by the model used.

Farm animals

The background levels of Ni are far below a critical level of animal health concern, and a decline by all scenarios is estimated. Thus, the conclusion is no risk for adverse health effects in the animals from Ni exposure.

Humans

As the models predict a decrease in the Ni concentrations in crop plants, the human intake as a result of the fertiliser schemes is of no concern.

11.4.7 Lead

Terrestrial organisms

The present concentrations of Pb in soil are far below the $PNEC_{soil}$ in all regions. Although Pb is predicted to accumulate in most regions and scenarios, the concentrations remain well below the $PNEC_{soil}$, indicating no risk to terrestrial organisms.

Aquatic organisms

The predicted present concentration of Pb in surface water is far below the $PNEC_{sw}$ in all regions and remains so after 100 years in all input scenarios. The same applies to the sediment compartment, indicating no risk in the aquatic environment.

Farm animals

In all selected geographical regions, the current Pb levels in feed and pasture plants including soil, and thus the animal diet, are below a suggested critical level of concern for animal health and below a level of concern for consumers of animal products.

By worst case fertilisation with organic fertiliser class II with maximum PTEs (#2), an increase of Pb is estimated in all regions - about double levels in Stange, Melhus and Målselv after 100 years, somewhat less in the other regions. Moreover, some of the other fertilisation schemes (#3 and 9) seem to increase Pb somewhat above predicted increase due to atmospheric deposition (estimated worst-case). However, the levels in animal pasture diet will rise to levels well below animal health concern. Even so, because Pb is a toxic element without essential qualities, and accumulates in animal organs and transferred into milk, any increase is undesirable.

Humans

Cereals, vegetable and tap water are the main contributors to dietary Pb exposure in the European population. More specific, cereal products, potatoes, cereal grains, and cereal-based mixed dishes are among the food's contribution to the exposure.

The Pb concentration will increase in the agricultural crops wheat, carrots and potatoes at all locations, depending on time and type of fertiliser. An increase in the Pb concentration in wheat, carrots and potatoes is likely to increase the Pb exposure in the Norwegian population. As the dietary exposure is high, any increase in dietary exposure is not desirable.

The use of engineered soil in home gardening and urban farming, will lead to an increase in the Pb concentrations in lettuce, carrot and potato, and the use of growth media will lead to an increase in the Pb concentration in potato, lettuce, and carrot. An increase in the Pb concentration home grown vegetables and vegetables from urban farming is likely to increase the Pb exposure in persons eating such vegetables. As the dietary exposure is high, any increase in dietary exposure is not desirable.

11.4.8 Zinc

Terrestrial organisms

The present concentrations of Zn in soil are below the $PNEC_{soil}$ in all regions, indicating no risk to terrestrial organisms. Several of the input scenarios, and in particular organic fertilisers, ML class II (#2), sewage sludge (#3) and cattle and pig manure (#4 and #5) will increase concentrations of Zn, which are predicted to exceed $PNEC_{soil}$ after 100 years with application of cattle and pig manure (#4, maximum PTE content) in Stange (RCR 1.2) and the alum shale area (RCR 1.5), indicating a low risk. In the other regions the Zn concentration remains below $PNEC_{soil}$ in all input scenarios, indicating no risk.

Aquatic organisms

The predicted present concentrations of Zn in surface water are below the $PNEC_{sw}$ in all regions and remains so after 100 years in all input scenarios, indicating no risk to aquatic organisms exposed to the water phase.

The $PNEC_{sed}$ for Zn has been calculated from a $PNEC_{add}$ (118 mg kg^{-1}) to which a background concentration must be added. Since background concentrations are not known, those have been calculated from the background concentrations in water of the regional rivers using a partition coefficient (Kp_{sed}) as described in 7.1.9.2. The resulting regional $PNEC_{sed}$ range from 148 mg kg^{-1} in Melhus (River Nidelva) to 359 mg kg^{-1} in Ås, Stange and the alum shale area (River Glomma). The predicted present sediment concentrations are higher than these $PNEC_{sed}$ values in all regions, indicating a low risk in Melhus, Stange, alum shale and Time (RCR 1.1-1.5). In Målselv, the exceedance of the $PNEC_{sed}$ is higher, indicating a significant risk (RCR 2.2). Although the Zn concentrations in sediments are predicted to decrease in some of the scenarios, the risk levels are not much affected. It should be noted that the $PNEC_{sed}$ is based on toxic effects found in oxygenated sediments, where the availability of Zn is highest. In less oxygenated sediments with higher concentrations of acid volatile sulphides the availability and toxicity of Zn is lower. The $PNEC_{sed}$ used in the risk assessment is therefore conservative, and verification of a predicted risk requires analysis of the local conditions. Furthermore, the limited data available on Zn concentrations in sediments from watercourses in agricultural areas indicate that the concentrations calculated by the model may be overestimated.

Farm animals

Background levels of Zn are below animal health concern.

Organic fertiliser class II with maximum PTEs (#2) implies some increase in the concentration of Zn in all regions. The greatest increase of Zn is by use of pig manure (#4) in Stange (430 % increment) and the alum shale area (160 %). However, after 100 years of fertiliser scheme #4, the diet of grazing animals in Stange and the alum shale area is estimated to contain levels that are still below animal health concern. Other fertiliser schemes (#3, 5 and 8) in Stange will also increase Zn, but to a lesser extent. Use of pig manure instead of cattle manure will also in other regions increase the Zn level in soil and thus in animal diets from these soils, but to lower levels than in Stange and the alum shale area.

The increment of Zn by use of pig manure is due to the high supply of Zn in pig diets. Use of Zn in animal feed above physiological requirement may potentially induce bacterial resistance problems, but this situation is not very likely under the assessed conditions. Thus, the risk that the available Zn could create microbial resistance problems in animal guts and environment against Zn and possible co-resistance against antimicrobial drugs, is considered low.

Humans

The predicted Zn concentrations in crop plants are of no concern for humans.

11.5 What do we know about the risk for humans that are high consumers of locally grown vegetables?

The modelled scenarios predicted increased concentration of As, Cd Pb and Hg. Increased concentrations in the crops are expected to increase the exposure in individuals eating such crops. The present dietary exposures to As, Cd and Pb are high, and any increase in exposure levels are undesirable. The exposure to Hg may also increase, but the contribution to the total exposure will be small, as seafood and other seafood are the main contributors. For more details, see the answer given in 11.4.

Risks for humans consuming locally grown vegetables in urban areas have also been studied experimentally. Warming and Hansen (2013) assessed the risk of PTEs or heavy metals ingestion due to urban gardening in Copenhagen. Uptake of heavy metals by vegetables grown in urban soils and intake via direct soil ingestion of As, Cd, Cr, Cu, Ni, Pb and Zn were assessed. Vegetables were grown at three sites, divided in soil class as follows: class A had all PTE below the Danish soil quality standard (e.g. Pb < 40 mg kg^{-1} DW), soil class B had generally higher content of PTE and two (Cd and Pb) above the Danish soil quality standard (Cd 0.5 mg kg^{-1} DW and Pb 40 mg kg^{-1} DW), and soil C had As, Cd, Cr, Ni (20, 0.5 and 30 mg kg^{-1} DW, respectively) above the quality standard and Zn and Pb even above the Danish intervention value for soils (Zn 1000 mg kg^{-1} DW and Pb 400 mg kg^{-1} DW).

Exposure of vulnerable groups, i.e. women and children, was determined using measured concentrations of PTE in vegetables grown on these sites, and either 10% of median vegetable consumption, or 100% of 95%-percentile vegetation consumption. Direct soil ingestion was taken as 50 mg day^{-1} for women and 200 mg day^{-1} for children (values suggested by the Danish EPA). Risk was characterised by hazard quotients calculated from daily ingestion of PTE divided by tolerable daily intake (based on literature values). Cd, Cr, Co, Ni and Zn had for none of the sites and neither for women nor children nor 95%-tile of consumption an intake from urban gardening above 10% of tolerable intake. For As, a risk quotient above 0.1 and up to 0.6 was calculated for children, with the main exposure by direct soil ingestion. The highest risk was found for Pb, with intake 7-fold higher than tolerable intake. The intake of Pb by children via direct soil ingestion was about 10 times as high as the intake with vegetables and was identified as the major risk from urban gardening. For women, the intake was not above tolerable intake, but the main Pb intake route was also direct soil ingestion. The people of Copenhagen doing urban gardening were informed about this result and were advised to carefully wash or peel their vegetables, and to wash hands after gardening to minimize risks. The results were partly also published in a scientific paper (Warming et al. 2015).

The calculated concentrations of Cd in vegetables grown in engineered soils, exemplified as home growing and urban farming, are not for any of the scenarios exceeding 100 µg kg^{-1} FW, which is the maximum residue level set by the EU for the Cd content in carrot and potato. Vegetables grown in CE marked growing media (Scenario C3) (ML Pb 120 mg kg^{-1} DW) show predicted concentrations of Pb in potato, carrot and leafy vegetables 230 µg kg^{-1} FW, 145 µg kg^{-1} FW and 297 µg kg^{-1} FW, respectively.

The maximum residue level set by the EU for the Pb content in carrot and potato is 100 µg kg^{-1} FW and for leafy vegetables it is 300 µg kg^{-1} FW (EU regulation 1881/2006 and amendments (section 3.3). This means that calculated residue level for both carrot and potato was higher than the maximum residue level set by the EU, and for leafy vegetable the calculated levels are just below the maximum residue level. The calculated Cd content for potato in this scenario, 104 µg kg^{-1} FW, exceed the maximum residue level of 100 µg kg^{-1} FW (peeled potato). Other maximum residues levels were not exceeded for this scenario.

Comparing MLs in Norwegian regulation organic fertilisers and CE-labelled growing media, MLs of Cd is lower in CE-labelled growing media (1.5 mg kg^{-1} DW) than Norwegian regulation quality class II (2 mg kg^{-1} DW), but higher than in quality class I (0.8 mg kg^{-1} DW). For Pb, the ML for CE-labelled growing media (120 mg kg^{-1} DW) is higher than Norwegian quality class II (80 mg kg^{-1} DW). Predicted concentrations of Pb in carrot were 145 µg kg^{-1} FW grown in CE-labelled growing media and 97 µg kg^{-1} FW grown in growing media with quality class II, respectively. Corresponding predicted concentration in potato were 230 and 155 µg kg^{-1} FW, respectively. Similarly, for Cd the predicted concentrations in carrot were 10.6 (CE-labelled) and 14.1 (quality class II) µg kg^{-1} FW, and in potato 104 (CE-labelled) and 139 µg kg^{-1} FW (quality class II), respectively.

12 Conclusions

Conclusions

VKM has assessed risks in a 100 year perspective connected to the agricultural use of different fertiliser products and soil improvers containing potentially toxic elements (PTEs). The PTEs As, Cd, Cr, Cu. Hg, Ni, Pb and Zn were included in this assessment, which considered different Norwegian regions and agricultural practices. The main conclusions are:

Environmental risk

The risk of adverse effects for organisms in terrestrial and aquatic compartments, including sediments, have been assessed based on measured or predicted environmental concentrations (PEC) of PTEs in soil, surface water and sediment and the predicted no effect concentrations (PNEC) in the same media. Based upon these two parameters, a risk characterisation ratio (RCR) has been calculated as RCR = PEC/PNEC. RCR<1 indicates no risk, while RCR>1 indicates a risk. In the assessment, risk has been further categorised as follows:

- RCR<1	No risk
- 1≤RCR<2	Low risk
- 2≤RCR<5	Significant risk
- RCR≥5	High risk

- **As.** The present concentrations of As in soil is regarded as non-toxic, and only the effect of predicted future increased concentrations has been assessed. The scenario involving application of organic fertilisers with maximum As level quality class II (i.e. 16 mg As kg^{-1} DW), indicates increasing soil concentrations of As in several regions over a 100 year period. However, no risk to terrestrial and aquatic organisms (due to leaching) is indicated.
- **Cd.** There is elevated concentration of geogenic Cd in the alum shale area, but the current concentration in soil is still below the PNEC$_{soil}$, which indicates no risk for adverse effect on terrestrial organisms. For aquatic organisms, the estimated current concentration poses a significant risk (RCR=2.6) in the alum shale area and a low risk at Time (RCR=1.3). However, model simulations indicate decreasing water concentrations in these areas. The model predictions show that the application of mineral P fertilisers, sewage sludge and manure will increase Cd concentrations, especially at Stange, where a low risk (RCR 1.1) is indicated after 100 years with application of organic fertilisers containing 2 mg Cd kg^{-1} DW (maximum Cd-level in quality class II).
- **Cr.** Fate estimates are based on Cr(tot). In the risk assessment, Cr is assumed to exist mainly as Cr(III) in soil and sediments, while the oxidized and most toxic and bioavailable form (Cr(VI)) will dominate in surface water. A current low risk in surface water

is indicated at Melhus, but the concentrations are expected to decrease. Thus, no future risk to aquatic environment is indicated.

- **Cu.** Accumulation of Cu in soil is predicted in several input scenarios with sewage sludge and organic fertilisers containing high Cu levels. Despite this, environmental risk is indicated only for sediment dwelling organisms after 100 years with application of organic fertilisers containing 650 mg Cu kg^{-1} DW (maximum level quality class II), but only at Time and alum shale areas.
- **Hg.** Atmospheric contribution alone is estimated to cause increasing concentrations of Hg in soil, and additional input from fertilisers, especially organic fertilisers at ML class II, sewage sludge and food waste digestate, contribute to additional accumulation. The model predictions are considered uncertain due to deficient data on Hg in fertiliser products and soil improvers and lack of data concerning volatilisation of Hg from soil. Volatilisation will reduce accumulation but was not included in the model.
- For the Time case area in Southwestern Norway, which has high natural presence of Hg in agricultural soil, a risk after 100 years with high application of Hg-rich fertilisers is predicted. Based on the assumption that Hg is transformed to methyl-Hg in the food-chain, a risk for secondary poisoning via terrestrial food-chain is predicted in all regions with application of organic fertilisers with ML class II (3 mg Hg kg^{-1} DW). Due to lack of reliable water/fish bioconcentration factors, a $\text{PNEC}_{\text{sec.pois}}$ for aquatic food-chains has not been established. However, the current exposure to Hg in some Norwegian lakes that are not influenced by known point sources of Hg is high enough to cause accumulation of Hg in fish, reaching concentrations that exceed the European quality standard for secondary poisoning. Thus, all anthropogenic input sources of Hg to the environment should be kept as low as possible.
- **Ni.** Due to present naturally high concentration of Ni at alum shale minerals, a risk to terrestrial and aquatic organisms is indicated in this area. For aquatic organisms a present risk is also indicated at Målselv and Melhus. A risk for secondary poisoning through terrestrial food-chain is indicated in alum shale areas and at Melhus. All scenarios show a decreasing trend of Ni-concentrations in soil and water, reducing the future risk. It should be noted that there are indications that Ni is more strongly bound to the soil matrix in alum shale soil than in other mineral soils. This has not been accounted for in the in the fate model and, consequently, the risk to both the terrestrial and aquatic environments may be overestimated for the alum shale area.
- **Pb.** Atmospheric contribution alone is estimated to cause increasing concentrations of Pb in soil and accumulation is predicted at all regions, except for Time (with high Pb concentration in soil), where high precipitation leads to increased loss by leaching. However, no future (100 years) environmental risk is indicated.
- **Zn.** Model calculations show that several organic fertilisers leads to increased soil concentrations of Zn at most regions. A risk for terrestrial organisms is indicated after 100 years at Stange and alum shale areas when high amount of Zn-rich manure is applied. Risk for sediment-dwelling organisms is indicated at all regions, and with an increasing trend with time. Uncertainty related to use of very conservative predicted no effect concentrations (PNEC) for sediment, and that measured sediment concentrations indicate overestimation of the current estimated sediment (PEC_{sed}) concentration, is highlighted.

Farm animals

An increment of Cu using organic fertilisers with maximum PTE levels quality class II may be harmful for grazing sheep at some regions (Stange and the alum shale area). Also, pig manure with high Cu may increase Cu to levels that pose risk to grazing sheep in the alum shale area with elevated background Cu levels.

For all other PTEs and fertiliser schemes, no animal health concern is expected. However, it must be pointed out that the elements of potentially most toxic concern and non-essential for living organisms (Cd, Hg and Pb), should be kept as low as possible in fertilisers due to risk for enrichment of residues in animal products for human consumption.

Human health risks

The modelling indicates increasing concentrations of As, Cd and Pb in edible plants cultivated on soil using the assessed fertilising schemes.

The dietary intakes of these elements are already high compared to current health-based guidance values (HBGVs) such as Tolerable Daily Intake (TDI), Tolerable Weekly Intake (TWI), and Benchmark dose lower confidence limit (BMDL).

Any increase of intake of these elements from food is therefore not desirable.

This also applies for home-grown and locally grown vegetables.

For Hg, potential increase of metals following the fertilising schemes is low compared to intake from seafood and is of minor importance.

Bacterial resistance

The increment of Zn and Cu by use of pig manure is due to high supply of Zn and Cu in pig diets. Use of these elements in animal feed above physiological requirement may potentially induce bacterial resistance problems, but this situation is not very likely under the assessed conditions where the elements in grass and feed after 100 years pig manure fertilisation still are within the animals´ requirement. Thus, the risk that available Zn or Cu could create microbial resistance against these elements in the gut and environmental microbiota or possible co-resistance against antimicrobial drugs, is considered low.

Regional differences

The six Norwegian regions considered in the risk assessment differed with respect to PTE soil concentrations, application of fertilisers and PTE loss due to leaching. At present, soil concentrations of several PTEs are high in the Alum shale area (As, Cd, Cu, Hg, Ni, Pb, Zn), at Ås (Southeastern Norway) (As, Cu, Hg, Zn) and at Målselv (Northern Norway) (Cr, Ni and Zn). The PTE input is highest in the areas, which have the highest yields of agricultural production (Stange and Alum shale area, Ås and Time). The greatest PTE losses occur due to leaching and run-off and are thus connected to precipitation excess, which is highest at Time, followed by Melhus and Ås. Erosion does not influence PTE concentrations in the soil but increases transport rates of PTEs to recipient surface waters. The predicted PTE concentrations approach steady state, which is equivalent to the ratio of input to loss. If the initial PTE concentrations in soil are above the steady state, the predicted concentrations will decline, while in the opposite case, they will increase. This explains why the same input of PTE leads to an increase of environmental concentrations in Stange, whereas a decline is predicted for the Alum shale region.

Evaluation of fertiliser products

The availability of analytical data varies for the different PTEs. Moreover, the reported concentration ranges differ considerably between the fertiliser products evaluated in this assessment, reflecting the sensitivities and quality of the used analytical methods and the huge variation within some of the fertiliser products. This issue is discussed thoroughly in the main text. If not otherwise stated, modelling simulations were conducted using mean and median PTE concentrations. An estimated atmospheric contribution of the PTEs was included in the modelling, and the contribution were particularly high for Hg and Pb.

Characteristics of different fertiliser products included in this assessment and main points considered:

- **Mineral P fertilisers:** Focus on Cd content. Increased concentrations are expected due to the use of phosphate rock with higher level of impurities.
- **Cattle manure:** Few samples available with low concentrations of PTEs. No analyses of Hg reported.
- **Pig manure:** Contain relatively high concentrations of Cd, Cu, Cr and Zn, as compared to cattle manure. The average Zn concentration for available samples were in quality class 2. No analyses of Hg reported.
- **Poultry manure:** Contain higher concentrations than cattle manure, but lower than pig manure, except for Pb. No analyses of Hg reported.

  Horse manure/horse manure compost: Modelling was based on very few analyses of horse manure, which originated from only a few locations

  Fish sludge: Increased utilisation of fish sludge and other marine-based resources as fertiliser products is expected in the near future, which might lead to higher transfer of As to agricultural soil. This would increase exposure of animals, humans and the environment than modelled in the current assessment.
- **Digestate:** The raw substrates used for the anaerobic digestion process (biogas production) determine the PTE concentration in the digestate. Organic matter is degraded during anaerobic digestion, thus, the concentration of slowly degradable or non-degradable compounds/elements might slightly increase during the process. The uncertainty in modelling the fates of As, Cr and Hg is high due to lack of knowledge on the prevalent Hg species and their fate and toxicity. Based on literature, it is expected that As and Cr will be present in soil and surface water as As(V) and Cr(III), the oxidised and less toxic forms.

- **Sewage sludge:** The concentrations of Cd, Hg and Pb have decreased since the analyses of sewage sludge had been started and entered into the KOSTRA database (1993). The concentrations of Ni and Zn have slightly increased during this period. The variation in concentrations is however low.

An overview of fertiliser products with most relevance to the indicated increased of all evaluated PTEs, except for Ni where no increase or risk was obtained, is summarised with comments in the Summary Table below.

It was decided by Norwegian Food Safety Authority to use different application rates for different fertiliser products; maximum allowed dry weight per hectare per year (2000 kg DW ha^{-1} yr^{-1}), based on P limitation (30 kg P ha^{-1} yr^{-1}) and based on today's fertiliser practise and nutrient demand for different crops. It is important to have this in mind since the evaluated scenarios is therefore not directly comparable. It is high variation in input of PTEs, depending on the application rates, in addition to e.g. mean of 95%-tile PTE concentrations, which is addressed in the report.

Generally, for all fertilisers and environmental matrixes, the uncertainty in modelling fate of As, Cr and Hg is high due to lack of knowledge on Hg speciation and their fate and toxicity. It is assumed that As and Cr will be present as arsenate, As(V), and Cr(III), the less toxic forms, in soil and sediment. In organic fertilisers in an anaerobic form, e.g. digestate after anaerobic digestion and stored cattle and pig manure, Cr is expected to be present as Cr(III) (the reduced form). However, whether As might be present as As(III), and methyl-Hg can be formed during anaerobic digestion, is not known.

Summary Table. Overview of fertiliser products and content of PTEs with most relevance to indicated risks, concerns, and unwanted events.

PTE	Fertiliser products	Comments
As: no further exposure of farm animals and human is desirable. The speciation of As is important for its fate and toxicity, and more analyses and knowledge are needed. High uncertainty in modelling and risk evaluation of As due to lack of knowledge of the presence of As speciation and their fate and toxicity.	Fish sludge	12 samples > LOQ, range 0.6-3.2 mg kg^{-1} DW. Increased use of fish sludge as fertilisers by moving post-smolt production and salmon farms on land, development of closed production units in the sea. Contain mainly organic As. More knowledge related to transformation of non-toxic organic As to more toxic inorganic As. Speciation of As in anaerobic fertilisers, and environmental fate, is needed.
	Horse manure	Few analyses, 5 out of 5 samples > LOQ, range 0.6-2.0 mg kg^{-1} DW. Only commercial products based on locally collected horse manure at one location.
	Cow, pig, poultry manure	One out of 35 samples > LOQ. UB-values[1] are used.
	Sewage sludge	Analyses from KOSTRA database. Decreasing trend since in 1993.

PTE	Fertiliser products	Comments
Cd: no further exposure of farm animals and human is desirable. Fertiliser regulation ML QC II[2]: envir. risk for aquatic organisms	Mineral P fertiliser	Increasing trend in Cd concentration in mineral fertilisers in Norway. Cd content depending on the source of phosphate rock. Assumed increasing proportion of mineral fertiliser production based on P rock with higher content of impurities including Cd. In the modelling, highest measured Cd concentration in Yara's NPK fertiliser from NFSA report (2017) is used.
	Pig manure	Most samples > LOQ (12 out of 14 samples). A few samples in quality class I (restriction 4000 kg DW ha^{-1} yr^{-1}).
Cu: Potential harmful for grazing sheep at some regions.	Pig manure	All 14 samples in quality class I (51-138 mg kg^{-1} DW) (restriction 4000 kg DW ha^{-1} yr^{-1})
Hg: no further exposure of farm animals and humans is desirable, and for ML QC II[2]: envir. risk for terrestrial organisms and sec. pois. Speciation of Hg is important for its fate and toxicity, and more knowledge is required, particularly in fertilisers with anaerobic treatment and/or storage. Atm. contribution indicate increase alone.	Digestate (food waste)	Few analyses, 1 out of 4 samples > LOQ, max. 0.69 mg kg^{-1} DW. UB-conc. was not used. With use of UB-conc. mean conc. had been higher.
	Sewage sludge	Analyses from KOSTRA database. Decreasing trend since 1993.
	Horse manure	Few samples, 6 out of 11 samples > LOQ, range 0.01-0.11 mg kg^{-1} DW. UB-conc. was not used. With use of UB-conc. mean conc. had been higher. Products from a few locations.
	Fish sludge	21 out of 49 samples > LOQ, range 0.01-0.26 mg kg^{-1} DW. UB-conc. was not used. With use of UB-conc. mean conc. had been higher.
Pb: no further exposure of farm animals and humans is desirable. Atm. contribution indicate increase alone.	Horse manure	Few samples. 8 out of 11 samples > LOQ, range 0.5-72 mg kg^{-1} DW. High variation in concentration. Products from a few locations.
	Sewage sludge	Analyses from KOSTRA database. Decreasing trend since in 1993.
	Digestate (food waste)	Few analyses, 3 of 4 samples > LOQ, range 7.9-16.3 mg kg^{-1} DW. UB-concentration was not used. With use of UB-conc. mean conc. had been higher.

[1]UB values: Upper Bound concentrations have been used. [2]ML QC II: evaluation of P.

Evaluation of maximum levels (MLs) for the selected PTEs in the regulation for organic fertilisers

Norwegian regulation of organic fertiliser quality class II:

Application of organic fertilisers according to maximum allowed dry weight per hectare per year and MLs for PTEs according to quality class II in Norwegian regulation of organic fertiliser, gave the highest predicted increase in environmental concentration and in crops for all PTEs except for Zn by application of high amount of pig manure.

The MLs for Hg and Cd and suggested ML for As were considerable higher than measured values in the evaluated fertiliser products. Therefore, ML values would cause a much higher increase in concentrations than estimated for the evaluated fertiliser products. This was especially the case for Hg where ML caused a predicted increase in soil concentration >1000%. No further increase in human exposure is desirable for As, Cd, Hg and Pb elements.

Evaluation of MLs in engineered soils and growing media for cultivation of vegetables and garden fruits (comparison with CE-labelled growth media):

- Comparison of five sets of MLs for organic fertilisers regulation, shows highest MLs in *quality class II in Norwegian regulation* (growing media for home growing vegetables and garden fruits) (Scenario C2) for Cd and Hg, and for As and Pb, highest MLs for *CE-labelled growing media (EU regulation)* (Scenario C3).
- The MLs for engineered soil *Norwegian regulation engineered soil* (scenario exemplifying home growing vegetables and garden fruits for own consume) (Scenario A), has similar or lower MLs than these sets of MLs.
- The MLs in *Norwegian regulation organic fertiliser quality class 0* applied for engineered soil (scenario exemplifying urban farming for locally sold vegetables and garden fruits) (Scenario B) and as growing media (scenario home growing) (Scenario C3), are lower for all PTEs except for Zn.

Annual fertilising with *Norwegian regulation organic fertiliser quality class II* up to 50 and 100 may have an impact on adsorption and plant uptake (either reduction due to more organic carbon, or an increase due to reduction of pH) but this was not investigated and also not considered in the model simulations.

Comparison with measured data of PTE in fields

Given the uncertainty in the modelling and input data and parameters, overall, the comparison of estimated and measured concentrations in crops was considered satisfactory, despite a few obvious deviations.

Human exposure via home and urban grown vegetable and cultivated mushroom

Use of engineered soil and growing media is expected to lead to an increase in concentration of PTEs in vegetables and fruits and expected to increase exposure for persons eating such crops. For mushroom enthusiasts (people who often eat mushroom), cultivated mushrooms might be an important additional dietary source for some PTEs, but more knowledge regarding of transfer of these elements to cultivated mushroom, and if people with high intake of cultivated mushroom have an additional exposure source for these PTEs.

Based on a study in Copenhagen, the main identified risk for humans was exposure to Pb from direct soil ingestion, which was of particularly concern for children.

Uncertainty

Major known uncertainties are due to few or absence of measured PTE-concentrations in input sources, variability of soil and environment (regressions were used to estimate Kd-values but based on mean or median values for key parameters of whole regions). For knowledge gaps, there is little information available on the speciation of PTEs As, Hg, Cr, as well as the significance of Hg volatilization as a removal process from soil. Climate change results in changes in temperature and precipitation that will affect the release and transport/fate of PTEs. These effects are complex and are not represented in the long-term predictions presented in the report. Other known issues include the integration of atmospheric deposition over long time periods (deposition has declined the last decade) and the variability in observed toxic effects (TDI, TWI, PNEC were estimated for whole populations). For humans, the consumption of locally produced or home-grown vegetables or mushrooms is not known.

13 Data gaps

Risk assessments of hazard substances, in this case PTEs, covering environmental, farm animals and human, require a wide range of knowledge from physicochemical properties, micro(biological) transformation processes influencing the fate and transfer of the hazards between different phases and matrixes to the toxicity and negative impact of the substances. In addition, the present occurrence of the PTEs in soil and water recipients and in fertilisers and soil improvers is required.

VKM has previous published environmental, animal and human risk assessments related to soil improver and fertiliser (sewage sludge, VKM, 2009; Zn and Cu in pig and poultry production, VKM, 2014b, maximum limit concentration of Cd in mineral fertilisers, VKM, 2019) and some data gaps have been addressed over time and repeated. The project group has identified the following data and knowledge gaps related to the present risk assessment:

Present concentration of hazard (PTEs) in the environment; soil, ground and surface water

- At present, there are no regional or national harmonized datasets available that provide the present natural ("background") concentration levels of the potentially toxic elements (PTE) in Norwegian agricultural soil. The PTE concentrations in agricultural soil used in this risk assessment have been obtained from several independent projects, where they have been collected without any harmonized procedures (agricultural soil, soil depth, sampling preparation practice, analytical techniques), and many of the data back to 1996. Harmonising monitoring programmes/campaigns of soils – but also ground and surface water – in Norway would help to decrease uncertainty for further risk assessments.
- Analyses should be included in monitoring programme for groundwater (including private drinking water wells) and surface water, including lakes, as well in programmes or other larger projects funded by the authority. In addition of real environmental data, these analyses are required to verify and possibly adjust estimations performed during risk assessment.
- A soil moisture monitoring program should be established in order to be able to (1) quantify the dynamics and heterogeneous behaviour in soil hydraulic functioning, (2) provide ground-truthing of remotely-sensed soil moisture monitoring data, and (3) serve as calibration data to numerical simulation models and their parameterization that are eventually used to quantify the transport of PTE and other dissolvable agents.

Improved data set for input sources that contain hazard (PTEs)

Generally, extremely few analyses are available for present concentrations of PTEs in different fertilisers products, and particularly few for As and Hg. There is no harmonised sampling and analysis procedure for such samples, and many of the few analyses that is available are old. Characterisation of speciation of the elements Cr, Hg and As is missing but is important and urgent to include in order to understand and predict their fate and thus potential hazard.

To evaluated increased human exposure of PTE via high consume of cultivated mushroom, more knowledge of substrates that are used or more likely to be used in future, and analyses of PTEs of these substrates.

Environment fate processes (PTEs)

- More knowledge about elements that change toxicity and mobility related to speciation, e.g As, Cr and Hg.
    - Characterisation of speciation of the element’s Cr, As and Hg
    - Fate parameters for describing mobility (Kd) and bioavailability (TF, BCF) for these different species.
    - For Hg, specifically, knowledge on the formation on Hg_2 and subsequent evaporation from agricultural soils has been ignored here but might be a key removal process.
    - There is a lack of data from field studies with Norwegian soils that could verify the Kd-values and estimated concentrations of PTE in drainage waters. Also, inclusion of analysis of PTEs in the long-term Norwegian monitoring program of plant nutrients and pesticides in small watercourses draining agricultural areas would be helpful for verification of the predicted concentrations in surface waters (PEC_{sw}).
- Soil with natural high present concentration Bioavailability and mobility and aging of geogenic and anthropogenic Cd (as well as other PTE with geogenic presence) in Norwegian soil types, particularly alum shale soil (e.g., Stange) should be studied in order to obtain better predictions of environmental fate and transfer to crops and further exposure of farm animals and humans, and also for consideration of effects on terrestrial predators (secondary poisoning).
- Improved TFs for selected plant species and the effect of pH, OM and clay content.
- Bioavailability, mobility, and aging of geogenic and anthropogenic Cd (as well as other PTE with geogenic presence) in Norwegian soil types, particularly alum shale soil (e.g., Stange) should be studied in order to obtain better predictions of environmental fate and transfer to crops and further exposure of farm animals and humans, and also for consideration of effects on terrestrial predators (secondary poisoning).

Environment effects (PTEs)

- Some of the determined environmental tolerance thresholds (PNECs) are based on limited data sets. For As, Hg and Cr, particularly for sediment dwelling organisms, the calculated PNECs are therefore associated with a larger uncertainty.

Farm animal (PTEs)

- For the risk assessment of the elements in farm animals' diets, the data gaps of major concern are related to uncertainties in the element levels in the soil after long time use of the various fertiliser schemes, due to relatively few data on basis concentrations in the soils, on concentrations in the inputs, uncertainties in the model for estimation of the elements fate in the soil and on uptake in grazing and fodder plants.
- There are also uncertain data on grazing animals´ intake of soil, which strongly influence of the animals´ intake of the elements. Maximal tolerable levels are uncertain and thus among the data gaps for several elements, animal species and their physiological stages, but these factors are not considered as critical uncertainty in the present assessment.

Humans (PTEs)

- Data gaps in the hazard assessments are stated in the risk assessments cited.
- The consumption of home-grown or locally produced vegetables is not known.
- The consumption of mushroom from cultivation is not known.
- Few measured analyses of PTEs in cultivated crops, and no measured data for Hg was available.

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Appendix I

Background PTE soil concentrations

There are generally few data available on the content of PTEs in Norwegian agricultural soil. An overview of number of samples from each municipality in the different regions is given in Table AI-1 to A1-5. All data are available through the references given in the tables. Figure AI-1 to AI-8 gives the minimum, median, mean, and maximum concentrations of As, Cd, Cu, Cr, Hg, Ni, Pb and Zn in each region based on the data presented in Table AI-6.

Alum shale contains naturally high levels of PTEs and is thus of special importance in this risk assessment. In and around e.g. Hedmark, Innlandet County, large agricultural areas is underlayed by alum shale, and, due to the interest in PTE concentrations in these soils, there is a high number of sample locations from this area. Agricultural soil samples identified as alum shale soil is treated as a separate case in this study.

Sandefjord municipality in the southeastern region has more sample locations than most other municipalities. Results from this municipality might therefore have a skewing effect on the statistics on the Southeastern Norway region.

Table AI-1. Number of sample locations in each municipality in Northern Norway (Troms).

Municipality	As	Cd	Cr	Cu	Hg*	Ni	Pb	Zn	Reference
Balsfjord	3	3	3	3	2	3	3	3	Reimann et al. 2003, 2014
Kvænangen	2	2	2	2	2	2	2	2	Reimann et al. 2014
Lenvik	3	3	3	3	2	3	3	3	Reimann et al. 2003, 2014
Målselv	3	3	3	3	2	3	3	3	Reimann et al. 2003, 2014
Nordreisa	3	3	3	3	2	3	3	3	Reimann et al. 2003, 2014
Salangen	3	3	3	3	2	3	3	3	Reimann et al. 2003, 2014
Skjervøy	1	1	1	1	0	1	1	1	Reimann et al. 2003
Storfjord	3	3	3	3	2	3	3	3	Reimann et al. 2003, 2014
Tromsø	3	3	3	3	2	3	3	3	Reimann et al. 2003, 2014
Total	24	24	24	24	16	24	24	24	

*Hg not reported in Reimann et al., 2003

Table AI-2. Number of sample locations in each municipality municipalities in Mid-Norway (Trøndelag).

Municipality	As	Cd	Cr	Cu	Hg*	Ni	Pb	Zn	Reference
Grong	3	3	3	3	2	3	3	3	Reimann et al. 2003, 2014
Hemne	3	3	3	3	2	3	3	3	Reimann et al. 2014
Hitra	2	2	2	2	2	2	2	2	Reimann et al. 2014
Leksvik	2	2	2	2	2	2	2	2	Esser, 1996
Levanger	3	3	3	3	2	3	3	3	Reimann et al. 2003, 2014
Lierne	5	5	5	5	4	5	5	5	Reimann et al. 2003, 2014
Melhus	3	3	3	3	2	3	3	3	Esser, 1996; Reimann et al. 2003
Mosvik	1	1	1	1	1	1	1	1	Esser, 1996
Namsos	1	1	1	1	1	1	1	1	Reimann et al. 2003
Namsskogan	3	3	3	3	2	3	3	3	Reimann et al. 2003, 2014
Oppdal	1	1	1	1	0	1	1	1	Reimann et al. 2003
Orkdal	2	2	2	2	1	2	2	2	Reimann et al. 2003; 2014
Overhalla	2	2	2	2	1	2	2	2	Reimann et al. 2003; 2014
Rennebu	4	4	4	4	3	4	4	4	Reimann et al. 2003, 2014
Rissa	7	7	7	7	6	7	7	7	Esser, 1996; Reimann et al. 2003, 2014
Røros	3	3	3	3	2	3	3	3	Reimann et al. 2003, 2014
Røyrvik	3	3	3	3	2	3	3	3	Reimann et al. 2003, 2014
Selbu	4	4	4	4	4	4	4	4	Esser, 1996; Reimann et al. 2014
Snåsa	1	1	1	1	1	1	1	1	Esser, 1996
Steinkjer	7	7	7	7	6	7	7	7	Esser, 1996; Reimann et al. 2003, 2014
Stjørdal	4	4	4	4	4	4	4	4	Esser, 1996
Trondheim	3	3	3	3	3	3	3	3	Esser, 1996
Tydal	1	1	1	1	0	1	1	1	Reimann et al. 2003
Verdal	7	7	7	7	6	7	7	7	Esser, 1996; Reimann et al. 2003, 2014
Åfjord	3	3	3	3	2	3	3	3	Reimann et al. 2003, 2014
Total	**78**	**78**	**78**	**78**	**61**	**78**	**78**	**78**	

*Hg not reported in Reimann et al., 2003

Table AI-3a. Number of sample locations in each municipality in Hedmark (before 2020), now part of Innlandet county.

Municipality	As	Cd	Cr	Cu	Hg*	Ni	Pb	Zn	Reference
Elverum	5	5	5	5	4	5	5	5	Esser, 1996; Reimann et al. 2003, 2014
Engerdal	6	6	6	6	4	6	6	6	Reimann et al., 2003, 2014
Folldal	5	5	5	5	4	5	5	5	Reimann et al., 2003, 2014
Grue	2	2	2	2	2	2	2	2	Esser, 1996
Kongsvinger	2	2	2	2	1	2	2	2	Reimann et al., 2003, 2014
Ringsaker	4	4	4	4	3	4	4	4	Esser, 1996; Reimann et al. 2003, 2014
Stange	2	2	2	2	2	2	2	2	Reimann et al., 2014
Stor-Elvdal	4	4	4	4	2	4	4	4	Reimann et al., 2003, 2014
Tolga	2	2	2	2	2	2	2	2	Reimann et al., 2014
Tolga-Os	2	2	2	2	2	2	2	2	Esser, 1996
Trysil	3	3	3	3	2	3	3	3	Reimann et al., 2003, 2014
Tynset	4	4	4	4	2	4	4	4	Reimann et al., 2003, 2014
Åmot	3	3	3	3	2	3	3	3	Reimann et al., 2003, 2014
Åsnes	3	3	3	3	2	3	3	3	Reimann et al., 2003, 2014
Total	**47**	**47**	**47**	**47**	**34**	**47**	**47**	**47**	

*Hg not reported in Reimann et al. 2003

Table AI-3b. Number of sample locations in each municipality in and around Hedmark county (before 2020), now part of Innlandet county. Sampled specifically to study alum shale.

Municipality	As	Cd	Cr	Cu	Hg*	Ni	Pb	Zn	Reference
Hamar	14	14	14	14	4	14	14	14	E.Joner 2018; HIAS 2020
Løten	3	3	3	3	3	3	3	3	HIAS 2020; Esser, 1996
Ringsaker	3	3	3	3	3	3	3	3	HIAS 2020
Stange	45	46	46	46	9	46	46	46	E.Joner 2018; HIAS 2020; Esser, 1996
Østre Toten	2	2	2	2	2	2	2	2	Esser, 1996
Ås	3	3	3	3	0	3	3	3	E.Joner 2018
Total	**70**	**71**	**71**	**71**	**21**	**71**	**71**	**71**	

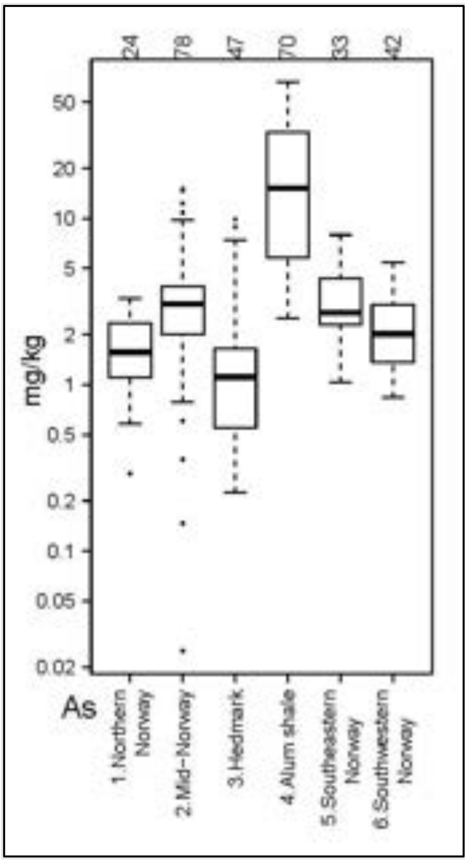
Table AI-4. Number of sample locations in each municipality in Southeastern Norway

Municipality	As	Cd	Cr	Cu	Hg^*	Ni	Pb	Zn	Reference
Andebu	2	2	2	2	2	2	2	2	Reimann et al. 2014
Aurskog-Høland	2	2	2	2	2	2	2	2	Reimann et al. 2014
Eidsvoll	2	2	2	2	2	2	2	2	Esser, 1996
Enebakk	2	2	2	2	2	2	2	2	Reimann et al. 2014
Fredrikstad	2	2	2	2	2	2	2	2	Reimann et al. 2014
Hof	3	3	3	3	2	3	3	3	Reimann et al. 2003, 2014
Holmestrand	0	2	2	2	2	2	2	2	Fylkesmannen, Vestfold, 2000
Horten	0	3	3	3	3	3	3	3	Fylkesmannen, Vestfold, 2000
Hurdal	3	3	3	3	2	3	3	3	Reimann et al. 2003, 2014
Larvik	0	0	16	16	0	16	16	16	Fylkesmannen, Vestfold, 2000
Nittedal	3	3	3	3	2	3	3	3	Reimann et al. 2003, 2014
Rakkestad	2	2	2	2	2	2	2	2	Reimann et al., 2014
Sandefjord	0	47	42	42	46	42	51	46	Fylkesmannen, Vestfold, 2000
Ski	1	1	1	1	0	1	1	1	Reimann et al. 2003
Skien	3	3	3	3	3	3	3	3	Esser, 1996
Trøgstad	2	2	2	2	2	2	2	2	Esser, 1996
Tønsberg	0	7	7	7	7	7	7	7	Fylkesmannen, Vestfold, 2000
Våle	2	2	2	2	2	2	2	2	Esser, 1996
Våler	2	2	2	2	2	2	2	2	Reimann et al., 2014
Ås	2	2	2	2	0	2	0	2	Dragievic, 2015; 2016
Total	33	92	103	103	85	103	110	107	

*Hg not reported in Reimann et al. 2003

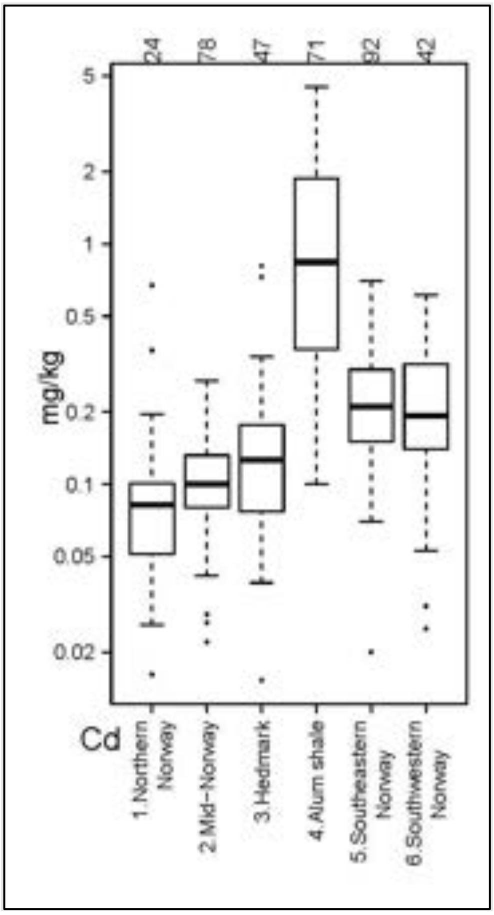
Table AI-5. Number of sample locations in each municipality in Southwestern Norway

Municipality	**As**	**Cd**	**Cr**	**Cu**	**Hg***	**Ni**	**Pb**	**Zn**	**Reference**
Audnedal	3	3	3	3	2	3	3	3	Reimann et al. 2003, 2014
Bjerkreim	1	1	1	1	1	1	1	1	Reimann et al., 2014
Farsund	2	2	2	2	2	2	2	2	Reimann et al., 2014
Flekkefjord	2	2	2	2	0	2	2	2	Reimann et al. 2003
Haugesund	2	2	2	2	2	2	2	2	Reimann et al., 2014
Hjelmeland	3	3	3	3	2	3	3	3	Reimann et al. 2003, 2014
Iveland	1	1	1	1	1	1	1	1	Esser, 1996
Karmøy	1	1	1	1	1	1	1	1	Esser, 1996
Kvinesdal	2	2	2	2	2	2	2	2	Esser, 1996
Lyngdal	4	4	4	4	4	4	4	4	Esser, 1996; Reimann et al. 2014
Sirdal	4	4	4	4	4	4	4	4	Reimann et al. 2014
Sola	2	2	2	2	2	2	2	2	Esser, 1996
Songdalen	3	3	3	3	2	3	3	3	Reimann et al. 2003, 2014
Suldal	2	2	2	2	1	2	2	2	Esser, 1996; Reimann et al. 2003
Time	5	5	5	5	4	5	5	5	Esser, 1996; Reimann et al., 2003; 2014
Vindafjord	5	5	5	5	4	5	5	5	Esser, 1996; Reimann et al., 2003; 2014
Total	**42**	**42**	**42**	**42**	**34**	**42**	**42**	**42**	



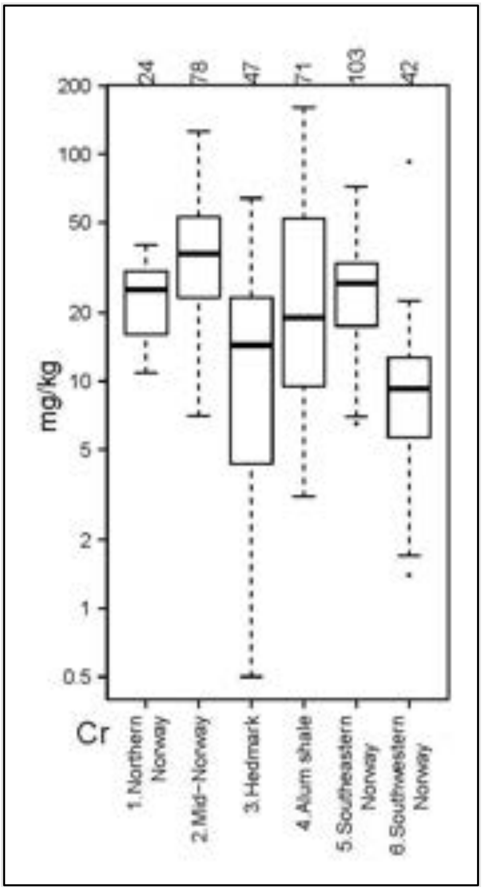
REGION	MIN mg/kg	MEDIAN mg/kg	MEAN mg/kg	MAX mg/kg
1.Northern Norway	0.29	1.6	1.7	3.3
2.Mid-Norway	0.025	3.0	3.7	15
3.Hedmark	0.22	1.1	1.7	9.8
4.Alum shale	2.5	15	21	66
5.Southeastern Norway	1.0	2.7	3.3	8.0
6.Southwestern Norway	0.83	2.0	2.3	5.4

Figure AI-1. Arsenic (As) concentration in agricultural soil for the focus regions. Graphical illustration as boxplots given at the left.



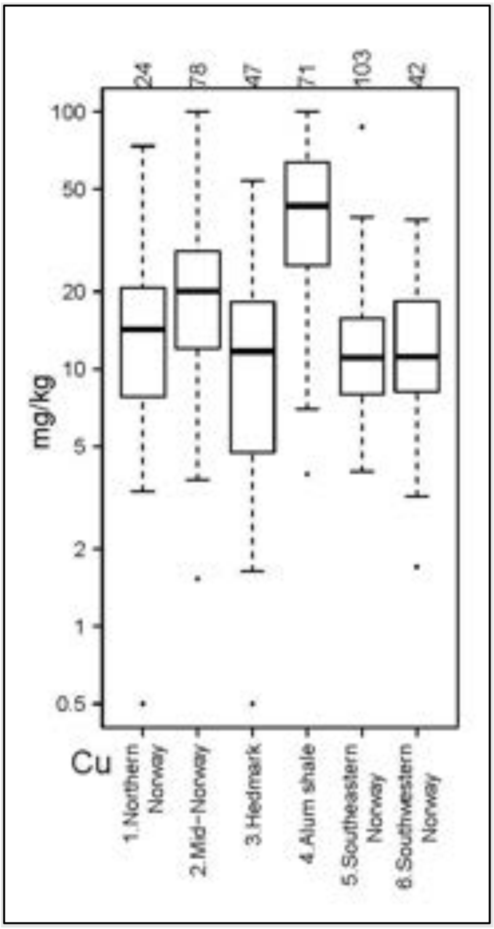
REGION	MIN mg/kg	MEDIAN mg/kg	MEAN mg/kg	MAX mg/kg
1.Northern Norway	0.016	0.082	0.12	0.67
2.Mid-Norway	0.022	0.10	0.11	0.27
3.Hedmark	0.015	0.13	0.16	0.81
4.Alum shale	0.10	0.84	1.2	4.5
5.Southeastern Norway	0.020	0.21	0.25	0.70
6.Southwestern Norway	0.025	0.19	0.22	0.61

Figure AI-2. Cadmium (Cd) concentration in agricultural soil for the focus regions. Graphical illustration as boxplots given at the left.



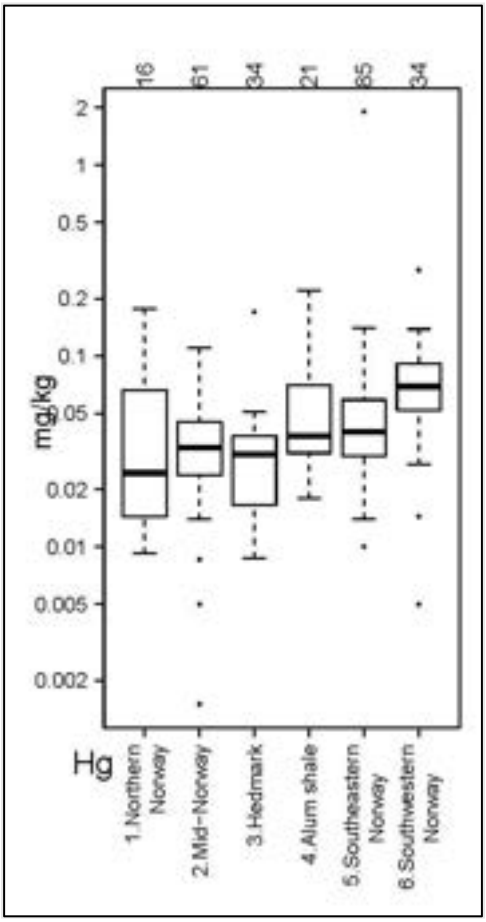
REGION	MIN mg/kg	MEDIAN mg/kg	MEAN mg/kg	MAX mg/kg
1.Northern Norway	11	25	24	40
2.Mid-Norway	7.0	36	41	130
3.Hedmark	0.50	14	18	64
4.Alum shale	3.1	19	33	160
5.Southeastern Norway	6.5	27	27	72
6.Southwestern Norway	1.4	9.3	12	92

Figure AI-3. Chromium (Cr) concentration in agricultural soil for the focus regions. Graphical illustration as boxplots given at the left.



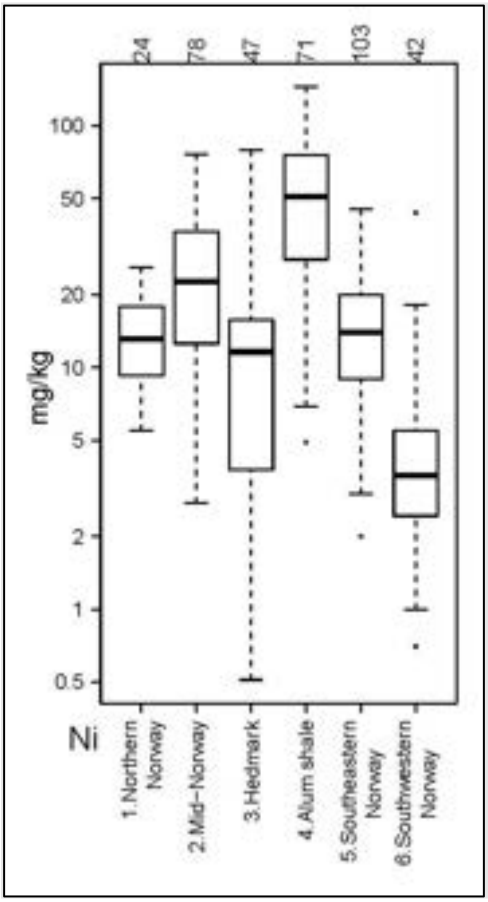
REGION	MIN mg/kg	MEDIAN mg/kg	MEAN mg/kg	MAX mg/kg
1.Northern Norway	0.50	14	16	74
2.Mid-Norway	1.5	20	22	100
3.Hedmark	0.50	12	13	54
4.Alum shale	3.9	43	44	100
5.Southeastern Norway	4.0	11	13	87
6.Southwestern Norway	1.7	11	14	38

Figure A-I-4. Chromium (Cr) concentration in agricultural soil for the focus regions. Graphical illustration as boxplots given at the left.



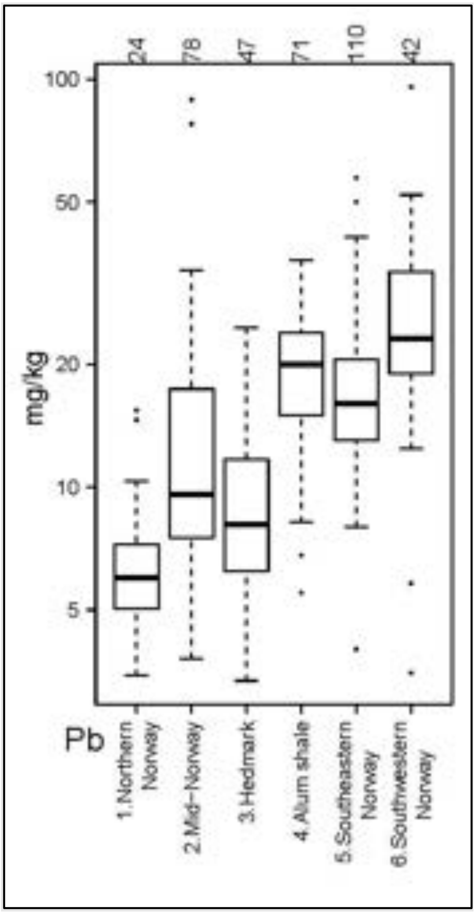
REGION	MIN mg/kg	MEDIAN mg/kg	MEAN mg/kg	MAX mg/kg
1.Northern Norway	0.009	0.025	0.047	0.18
2.Mid-Norway	0.002	0.033	0.036	0.11
3.Hedmark	0.009	0.03	0.032	0.17
4.Alum shale	0.018	0.038	0.058	0.22
5.Southeastern Norway	0.01	0.04	0.071	1.9
6.Southwestern Norway	0.005	0.069	0.075	0.28

Figure AI-5. Mercury (Hg) concentration in agricultural soil for the focus regions. Graphical illustration as boxplots given at the left.



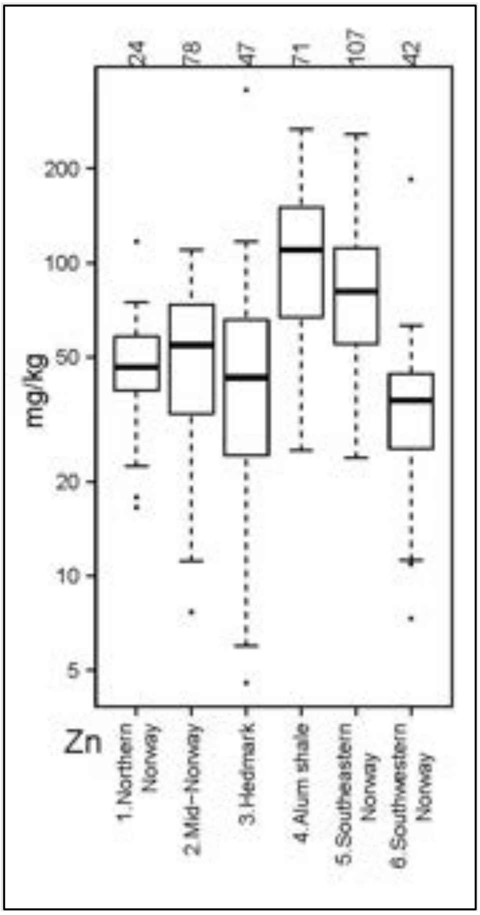
REGION	MIN mg/kg	MEDIAN mg/kg	MEAN mg/kg	MAX mg/kg
1.Northern Norway	5.5	13	14	26
2.Mid-Norway	2.7	23	25	77
3.Hedmark	0.51	12	13	79
4.Alum shale	4.9	51	54	150
5.Southeastern Norway	2.0	14	15	45
6.Southwestern Norway	0.70	3.6	5.3	44

Figure AI-6. Nickel (Ni) concentration in agricultural soil for the focus regions. Graphical illustration as boxplots given at the left.



REGION	MIN mg/kg	MEDIAN mg/kg	MEAN mg/kg	MAX mg/kg
1.Northern Norway	3.5	6.0	6.8	15
2.Mid-Norway	3.8	9.6	14	89
3.Hedmark	3.4	8.1	10	25
4.Alum shale	5.5	20	19	36
5.Southeastern Norway	4.0	16	19	57
6.Southwestern Norway	3.5	23	27	96

Figure AI-7. Lead (Pb) concentration in agricultural soil for the focus regions. Graphical illustration as boxplots given at the left.



REGION	MIN mg/kg	MEDIAN mg/kg	MEAN mg/kg	MAX mg/kg
1.Northern Norway	17	46	49	120
2.Mid-Norway	7.7	55	54	110
3.Hedmark	4.6	43	53	360
4.Alum shale	25	110	110	270
5.Southeastern Norway	24	81	87	260
6.Southwestern Norway	7.3	36	38	180

Figure AI–8. Zinc (Zn) concentration in agricultural soil for the focus regions. Graphical illustration as boxplots given at the left.

Table AI-6. All agricultural soil data used for the elements As, Cd, Cr, Cu, Hg, Ni, Pb and Zn with references.

Reference	Municipality	REGION	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg
Reimann et al., 2014	Balsfjord	Northern Norway	1.5	0.089	31	26	0.0094	24	8.6	46
Reimann et al., 2014	Kvænangen	Northern Norway	1.1	0.67	13	74	0.12	13	6.8	120
Reimann et al., 2014	Lenvik	Northern Norway	1.4	0.36	11	16	0.18	5.5	15	22
Reimann et al., 2014	Målselv	Northern Norway	0.59	0.047	26	13	0.015	13	6.4	56
Reimann et al., 2014	Nordreisa	Northern Norway	1.9	0.085	25	14	0.021	12	4.9	62
Reimann et al., 2014	Salangen	Northern Norway	1.6	0.11	35	28	0.029	26	10	60
Reimann et al., 2014	Storfjord	Northern Norway	1.1	0.016	14	5.4	0.012	7.9	4.2	18
Reimann et al., 2014	Tromsø	Northern Norway	1.3	0.10	25	7.8	0.058	9.7	6.0	41
Reimann et al., 2014	Balsfjord	Northern Norway	3.1	0.096	18	10	0.021	11	9.6	75
Reimann et al., 2014	Målselv	Northern Norway	0.29	0.026	19	7.9	0.014	8.9	4.1	37
Reimann et al., 2014	Storfjord	Northern Norway	0.98	0.056	13	4.7	0.028	6.5	4.1	27
Reimann et al., 2014	Nordreisa	Northern Norway	2.6	0.085	39	21	0.020	21	6.0	48
Reimann et al., 2014	Kvænangen	Northern Norway	1.3	0.36	11	28	0.091	7.1	5.0	53
Reimann et al., 2014	Tromsø	Northern Norway	2.8	0.046	30	4.9	0.041	15	6.3	45
Reimann et al., 2014	Lenvik	Northern Norway	2.7	0.20	22	15	0.075	11	7.3	29
Reimann et al., 2014	Salangen	Northern Norway	1.5	0.086	25	26	0.0092	18	5.6	46
Reimann et al., 2003	Balsfjord	Northern Norway	2.1	0.065	18	8.4	NA	12	7.2	44
Reimann et al., 2003	Lenvik	Northern Norway	0.92	0.037	14	0.50	NA	6.2	3.5	17
Reimann et al., 2003	Målselv	Northern Norway	0.58	0.068	26	11	NA	15	5.2	67
Reimann et al., 2003	Nordreisa	Northern Norway	2.2	0.040	37	16	NA	18	5.0	47
Reimann et al., 2003	Salangen	Northern Norway	1.8	0.079	29	20	NA	18	6.0	49
Reimann et al., 2003	Skjervøy	Northern Norway	2.5	0.071	40	15	NA	22	5.1	43
Reimann et al., 2003	Storfjord	Northern Norway	1.9	0.079	36	19	NA	22	5.6	53
Reimann et al., 2003	Tromsø	Northern Norway	3.3	0.10	25	3.4	NA	14	15	64
Reimann et al., 2014	Grong	Mid-Norway	3.5	0.13	57	29	0.026	40	10	61
Reimann et al., 2014	Hemne	Mid-Norway	0.79	0.057	30	6.0	0.055	12	7.1	18
Reimann et al., 2014	Hitra	Mid-Norway	1.5	0.10	21	14	0.061	8.4	8.0	32
Reimann et al., 2014	Levanger	Mid-Norway	3.1	0.11	43	28	0.048	36	6.0	61
Reimann et al., 2014	Lierne	Mid-Norway	9.5	0.12	37	15	0.027	30	9.1	54
Reimann et al., 2014	Lierne	Mid-Norway	9.7	0.083	36	15	0.026	30	9.3	51
Reimann et al., 2014	Namsos	Mid-Norway	2.6	0.060	20	7.9	0.034	11	7.0	25
Reimann et al., 2014	Namsskogan	Mid-Norway	4.4	0.14	32	13	0.021	23	11	53
Reimann et al., 2014	Rennebu	Mid-Norway	9.0	0.16	70	40	0.019	43	6.1	64
Reimann et al., 2014	Rennebu	Mid-Norway	3.2	0.046	51	15	0.027	19	7.5	32
Reimann et al., 2014	Rissa	Mid-Norway	1.2	0.16	36	22	0.037	22	7.5	81
Reimann et al., 2014	Røros	Mid-Norway	0.025	0.026	7.0	6.5	0.020	2.7	5.4	7.7
Reimann et al., 2014	Røyrvik	Mid-Norway	0.15	0.20	9.7	12	0.051	7.5	4.9	15

Reference	Municipality	REGION	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg
Reimann et al., 2014	Selbu	Mid-Norway	12	0.27	71	25	0.071	37	8.4	100
Reimann et al., 2014	Steinkjer	Mid-Norway	2.4	0.17	26	64	0.10	14	31	110
Reimann et al., 2014	Verdal	Mid-Norway	5.4	0.10	39	33	0.020	41	14	64
Reimann et al., 2014	Åfjord	Mid-Norway	2.8	0.081	23	9.7	0.041	13	8.7	36
Reimann et al., 2014	Selbu	Mid-Norway	1.3	0.14	43	37	0.021	30	5.4	57
Reimann et al., 2014	Røros	Mid-Norway	0.35	0.029	10	13	0.0086	4.4	4.7	11
Reimann et al., 2014	Rennebu	Mid-Norway	3.1	0.11	66	20	0.024	32	5.5	45
Reimann et al., 2014	Orkdal	Mid-Norway	3.7	0.042	41	16	0.024	18	6.3	25
Reimann et al., 2014	Grong	Mid-Norway	3.7	0.093	73	42	0.0015	63	9.4	81
Reimann et al., 2014	Overhalla	Mid-Norway	3.0	0.045	25	12	0.032	14	6.4	30
Reimann et al., 2014	Rissa	Mid-Norway	5.4	0.11	54	26	0.022	43	11	76
Reimann et al., 2014	Åfjord	Mid-Norway	2.7	0.091	18	16	0.028	11	8.6	31
Reimann et al., 2014	Røyrvik	Mid-Norway	9.5	0.11	110	29	0.014	37	7.6	60
Reimann et al., 2014	Namsskogan	Mid-Norway	3.7	0.097	39	12	0.046	25	11	50
Reimann et al., 2014	Lierne	Mid-Norway	15	0.20	68	33	0.034	60	9.6	77
Reimann et al., 2014	Lierne	Mid-Norway	15	0.20	62	34	0.028	56	8.9	73
Reimann et al., 2014	Steinkjer	Mid-Norway	2.5	0.11	21	27	0.049	14	14	71
Reimann et al., 2014	Levanger	Mid-Norway	5.2	0.16	33	21	0.034	22	7.5	78
Reimann et al., 2014	Verdal	Mid-Norway	5.5	0.13	50	40	0.032	45	14	68
Reimann et al., 2014	Hemne	Mid-Norway	2.3	0.098	30	10.0	0.036	13	6.7	33
Reimann et al., 2014	Hitra	Mid-Norway	0.60	0.15	12	44	0.048	7.5	5.8	21
Reimann et al., 2003	Grong	Mid-Norway	3.0	0.12	25	8.8	NA	9.5	11	35
Reimann et al., 2003	Hemne	Mid-Norway	1.8	0.042	44	24	NA	26	3.8	27
Reimann et al., 2003	Levanger	Mid-Norway	4.8	0.090	47	16	NA	34	10	68
Reimann et al., 2003	Lierne	Mid-Norway	11	0.19	68	25	NA	51	8.5	87
Reimann et al., 2003	Melhus	Mid-Norway	3.0	0.076	38	7.5	NA	14	9.3	25
Reimann et al., 2003	Namsskogan	Mid-Norway	2.2	0.067	29	1.5	NA	15	9.8	41
Reimann et al., 2003	Oppdal	Mid-Norway	4.7	0.12	48	17	NA	31	5.5	84
Reimann et al., 2003	Orkdal	Mid-Norway	3.3	0.083	38	8.3	NA	16	9.6	37
Reimann et al., 2003	Overhalla	Mid-Norway	2.2	0.14	30	22	NA	20	13	81
Reimann et al., 2003	Rennebu	Mid-Norway	1.0	0.090	41	34	NA	27	7.3	76
Reimann et al., 2003	Rissa	Mid-Norway	3.2	0.18	43	22	NA	27	9.6	78
Reimann et al., 2003	Røros	Mid-Norway	1.3	0.19	9.0	21	NA	12	10	33
Reimann et al., 2003	Røyrvik	Mid-Norway	9.3	0.10	130	39	NA	42	6.7	74
Reimann et al., 2003	Steinkjer	Mid-Norway	2.5	0.12	27	22	NA	16	8.5	79
Reimann et al., 2003	Tydal	Mid-Norway	1.6	0.11	50	17	NA	28	8.9	74
Reimann et al., 2003	Verdal	Mid-Norway	8.3	0.11	35	29	NA	28	11	83
Reimann et al., 2003	Åfjord	Mid-Norway	3.1	0.088	54	21	NA	36	7.6	75
Esser 1996	Leksvik	Mid-Norway	4.1	0.022	11	41	0.042	5.4	89	32
Esser 1996	Leksvik	Mid-Norway	2.4	0.097	50	33	0.033	34	29	58
Esser 1996	Melhus	Mid-Norway	3.9	0.17	53	32	0.042	40	25	60
Esser 1996	Melhus	Mid-Norway	3.5	0.14	73	28	0.015	47	17	55

Reference	Municipality	REGION	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg
Esser 1996	Mosvik	Mid-Norway	0.89	0.060	94	100	0.0050	77	22	45
Esser 1996	Rissa	Mid-Norway	3.1	0.097	34	9.0	0.045	18	20	45
Esser 1996	Rissa	Mid-Norway	3.4	0.16	30	16	0.015	16	21	93
Esser 1996	Rissa	Mid-Norway	2.8	0.044	12	9.7	0.018	8.5	8.3	33
Esser 1996	Rissa	Mid-Norway	2.8	0.095	16	13	0.015	11	17	57
Esser 1996	Selbu	Mid-Norway	1.3	0.099	87	20	0.048	38	25	81
Esser 1996	Selbu	Mid-Norway	1.0	0.081	89	22	0.039	40	27	83
Esser 1996	Snåsa	Mid-Norway	4.0	0.13	8.4	3.7	0.11	5.2	18	37
Esser 1996	Steinkjær	Mid-Norway	1.3	0.046	18	16	0.030	10	17	30
Esser 1996	Steinkjær	Mid-Norway	1.3	0.080	13	9.8	0.021	8.3	10	31
Esser 1996	Steinkjær	Mid-Norway	3.2	0.10	28	18	0.057	19	78	52
Esser 1996	Steinkjær	Mid-Norway	3.2	0.15	27	17	0.054	18	25	55
Esser 1996	Stjørdal	Mid-Norway	2.1	0.099	35	18	0.036	20	20	35
Esser 1996	Stjørdal	Mid-Norway	2.1	0.11	38	23	0.024	27	20	43
Esser 1996	Stjørdal	Mid-Norway	3.1	0.048	22	11	0.030	13	9.2	27
Esser 1996	Stjørdal	Mid-Norway	2.4	0.065	19	11	0.039	10	11	27
Esser 1996	Trondheim	Mid-Norway	1.4	0.11	60	38	0.081	34	24	41
Esser 1996	Trondheim	Mid-Norway	1.7	0.059	73	26	0.042	49	34	67
Esser 1996	Trondheim	Mid-Norway	2.0	0.076	67	18	0.033	42	27	54
Esser 1996	Verdal	Mid-Norway	3.5	0.13	35	33	0.048	34	27	65
Esser 1996	Verdal	Mid-Norway	2.7	0.10	28	24	0.033	25	20	57
Esser 1996	Verdal	Mid-Norway	3.2	0.079	21	12	0.042	13	15	56
Esser 1996	Verdal	Mid-Norway	2.7	0.083	19	9.0	0.036	14	9.3	51
Reimann et al., 2014	Elverum	Hedmark	0.34	0.039	4.0	3.4	0.0099	3.2	5.3	19
Reimann et al., 2014	Elverum	Hedmark	0.95	0.051	23	12	0.024	12	6.8	34
Reimann et al., 2003	Elverum	Hedmark	1.1	0.15	19	12	NA	10	7.5	58
Esser 1996	Elverum	Hedmark	1.7	0.12	23	10	0.042	14	12	49
Esser 1996	Elverum	Hedmark	1.8	0.34	17	12	0.029	12	21	360
Reimann et al., 2014	Engerdal	Hedmark	0.27	0.14	2.4	6.7	0.035	3.0	4.8	16
Reimann et al., 2014	Engerdal	Hedmark	0.22	0.041	2.1	1.8	0.0088	0.80	3.7	6.0
Reimann et al., 2014	Engerdal	Hedmark	0.37	0.084	2.7	3.9	0.022	0.51	6.9	10
Reimann et al., 2014	Engerdal	Hedmark	0.45	0.015	3.3	1.6	0.011	1.4	3.4	6.7
Reimann et al., 2003	Engerdal	Hedmark	0.31	0.062	0.50	2.0	NA	1.0	7.0	4.6
Reimann et al., 2003	Engerdal	Hedmark	0.45	0.075	6.7	0.50	NA	3.6	5.3	13
Reimann et al., 2014	Folldal	Hedmark	0.51	0.19	23	14	0.035	14	9.6	37
Reimann et al., 2014	Folldal	Hedmark	0.44	0.19	26	14	0.048	14	16	41
Reimann et al., 2014	Folldal	Hedmark	1.6	0.16	29	23	0.032	19	6.3	50
Reimann et al., 2014	Folldal	Hedmark	1.4	0.13	30	21	0.034	18	6.1	52
Reimann et al., 2003	Folldal	Hedmark	1.1	0.10	37	19	NA	19	5.8	52
Esser 1996	Grue	Hedmark	1.6	0.11	23	13	0.038	13	19	43
Esser 1996	Grue	Hedmark	1.6	0.10	10	7.5	0.013	7.2	9.9	46
Joner, 2018	Hamar	Hedmark	9.9	0.34	50	33	NA	44	12	96

Reference	Municipality	REGION	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg
Joner, 2018	Hamar	Hedmark	22	0.57	60	49	NA	52	33	95
Joner, 2018	Hamar	Hedmark	18	0.55	55	40	NA	54	18	93
Joner, 2018	Hamar	Hedmark	15	0.71	56	47	NA	45	26	120
Joner, 2018	Hamar	Hedmark	10	0.54	63	38	NA	49	23	110
Joner, 2018	Hamar	Hedmark	9.6	0.62	100	48	NA	67	17	110
Joner, 2018	Hamar	Hedmark	8.9	1.1	100	43	NA	71	17	110
Joner, 2018	Hamar	Hedmark	5.3	0.40	63	33	NA	42	16	63
Joner, 2018	Hamar	Hedmark	9.7	0.22	160	80	NA	120	24	120
Joner, 2018	Hamar	Hedmark	8.8	0.25	120	80	NA	97	20	100
HIAS, 2020	Hamar	Hedmark	4.1	0.10	8.2	9.8	0.018	12	9.1	37
HIAS, 2020	Hamar	Hedmark	5.8	0.31	11	9.8	0.022	14	10	54
HIAS, 2020	Hamar	Hedmark	4.3	0.10	7.0	7.0	0.036	7.1	11	39
HIAS, 2020	Hamar	Hedmark	2.5	0.10	5.7	7.3	0.018	9.8	5.5	28
Reimann et al., 2014	Kongsvinger	Hedmark	1.1	0.079	9.5	6.1	0.033	4.9	10	21
Reimann et al., 2003	Kongsvinger	Hedmark	0.85	0.064	17	13	NA	13	5.6	30
Esser 1996	Løten	Hedmark	2.8	0.25	4.2	15	0.061	13	16	25
Esser 1996	Løten	Hedmark	4.0	0.17	3.1	7.4	0.038	6.9	19	35
HIAS, 2020	Løten	Hedmark	4.5	0.10	6.6	7.6	0.031	7.2	10	38
Reimann et al., 2014	Ringsaker	Hedmark	7.0	0.24	64	24	0.048	79	18	120
Reimann et al., 2003	Ringsaker	Hedmark	2.9	0.32	14	17	NA	14	21	100
Esser 1996	Ringsaker	Hedmark	2.3	0.18	14	12	0.051	12	22	78
Esser 1996	Ringsaker	Hedmark	1.9	0.17	13	12	0.045	14	17	70
HIAS, 2020	Ringsaker	Hedmark	3.1	0.10	11	7.2	0.031	9.5	12	64
HIAS, 2020	Ringsaker	Hedmark	4.3	0.32	46	18	0.031	63	11	85
HIAS, 2020	Ringsaker	Hedmark	3.5	0.10	19	16	0.029	30	8.5	39
Reimann et al., 2014	Stange	Hedmark	8.9	0.73	4.6	22	0.037	16	12	100
Reimann et al., 2014	Stange	Hedmark	9.8	0.81	4.1	25	0.028	19	11	94
Joner, 2018	Stange	Hedmark	48	2.6	15	76	NA	120	26	190
Joner, 2018	Stange	Hedmark	53	3.3	17	94	NA	150	28	230
Joner, 2018	Stange	Hedmark	27	2.0	12	47	NA	54	21	130
Joner, 2018	Stange	Hedmark	18	1.4	14	47	NA	54	17	130
Joner, 2018	Stange	Hedmark	49	2.4	11	70	NA	100	24	160
Joner, 2018	Stange	Hedmark	41	2.2	9.6	66	NA	93	27	150
Joner, 2018	Stange	Hedmark	4.0	0.42	3.8	15	NA	11	8.2	39
Joner, 2018	Stange	Hedmark	15	0.82	8.4	32	NA	26	21	99
Joner, 2018	Stange	Hedmark	26	1.6	8.4	37	NA	48	29	98
Joner, 2018	Stange	Hedmark	49	2.3	10	78	NA	55	27	200
Joner, 2018	Stange	Hedmark	33	1.7	9.2	66	NA	49	23	150
Joner, 2018	Stange	Hedmark	38	2.1	9.8	66	NA	55	21	170
Joner, 2018	Stange	Hedmark	42	2.3	8.6	79	NA	88	23	170
Joner, 2018	Stange	Hedmark	59	2.4	8.2	79	NA	88	31	150
Joner, 2018	Stange	Hedmark	38	3.3	10	72	NA	86	23	200

Reference	Municipality	REGION	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg
Joner, 2018	Stange	Hedmark	40	3.0	9.3	82	NA	120	31	160
Joner, 2018	Stange	Hedmark	39	3.8	9.8	67	NA	78	20	270
Joner, 2018	Stange	Hedmark	32	2.7	15	61	NA	64	21	210
Joner, 2018	Stange	Hedmark	18	1.4	78	49	NA	76	22	140
Joner, 2018	Stange	Hedmark	18	1.1	45	34	NA	60	15	110
Joner, 2018	Stange	Hedmark	39	2.8	60	58	NA	87	28	170
Joner, 2018	Stange	Hedmark	16	0.76	41	45	NA	53	15	88
Joner, 2018	Stange	Hedmark	12	0.90	45	31	NA	46	12	61
Joner, 2018	Stange	Hedmark	59	2.3	48	86	NA	110	30	160
Joner, 2018	Stange	Hedmark	66	2.3	52	100	NA	110	36	150
Joner, 2018	Stange	Hedmark	64	2.7	53	97	NA	130	32	180
Joner, 2018	Stange	Hedmark	27	1.3	46	62	NA	64	20	130
Joner, 2018	Stange	Hedmark	22	1.1	77	59	NA	85	24	130
Joner, 2018	Stange	Hedmark	21	1.7	52	59	NA	76	19	160
Joner, 2018	Stange	Hedmark	9.7	0.90	57	24	NA	36	16	68
Joner, 2018	Stange	Hedmark	19	1.8	40	43	NA	59	18	140
Joner, 2018	Stange	Hedmark	36	0.77	50	49	NA	43	34	140
Joner, 2018	Stange	Hedmark	25	0.68	42	34	NA	36	21	95
Joner, 2018	Stange	Hedmark	15	0.44	29	28	NA	22	11	75
Joner, 2018	Stange	Hedmark	15	0.39	26	36	NA	21	10	79
Joner, 2018	Stange	Hedmark	10	0.84	37	47	NA	28	15	120
Joner, 2018	Stange	Hedmark	8.4	0.85	20	37	NA	27	15	66
Joner, 2018	Stange	Hedmark	81	0.11	64	44	NA	65	40	30
Esser 1996	Stange	Hedmark	6.8	1.3	8.6	27	0.070	29	19	120
Esser 1996	Stange	Hedmark	14	1.8	9.7	41	0.12	50	23	130
HIAS, 2020	Stange	Hedmark	49	1.2	9.4	41	0.11	56	26	88
HIAS, 2020	Stange	Hedmark	5.0	0.33	21	15	0.034	23	9.3	61
HIAS, 2020	Stange	Hedmark	11	0.68	6.2	27	0.039	34	10	65
HIAS, 2020	Stange	Hedmark	20	0.72	15	44	0.11	51	17	93
HIAS, 2020	Stange	Hedmark	33	4.5	12	70	0.22	88	22	150
HIAS, 2020	Stange	Hedmark	8.0	0.51	9.4	20	0.030	23	10	57
HIAS, 2020	Stange	Hedmark	NA	0.10	7.7	3.9	0.040	4.9	6.8	28
Reimann et al., 2014	Stor-Elvdal	Hedmark	0.57	0.067	6.4	4.6	0.016	4.0	6.1	25
Reimann et al., 2014	Stor-Elvdal	Hedmark	1.0	0.17	8.6	5.0	0.044	5.1	8.4	56
Reimann et al., 2003	Stor-Elvdal	Hedmark	1.5	0.17	30	24	NA	19	8.2	84
Reimann et al., 2003	Stor-Elvdal	Hedmark	1.0	0.13	12	6.1	NA	7.6	8.1	39
Reimann et al., 2014	Tolga	Hedmark	2.4	0.082	38	23	0.042	27	9.6	62
Reimann et al., 2014	Tolga	Hedmark	1.0	0.077	23	9.5	0.018	15	9.0	42
Esser 1996	Tolga-Os	Hedmark	1.5	0.22	21	46	0.035	15	15	74
Esser 1996	Tolga-Os	Hedmark	1.5	0.21	59	54	0.016	39	20	74
Reimann et al., 2014	Trysil	Hedmark	0.37	0.14	2.3	3.2	0.013	1.5	10	28
Reimann et al., 2014	Trysil	Hedmark	0.49	0.082	3.5	2.9	0.013	2.5	6.7	20

Reference	Municipality	REGION	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg
Reimann et al., 2003	Trysil	Hedmark	0.73	0.16	4.1	4.9	NA	4.2	8.4	36
Reimann et al., 2014	Tynset	Hedmark	0.62	0.050	34	11	0.17	17	4.9	33
Reimann et al., 2014	Tynset	Hedmark	0.67	0.085	22	4.2	0.020	9.6	4.2	23
Reimann et al., 2003	Tynset	Hedmark	2.8	0.21	27	19	NA	21	7.8	89
Reimann et al., 2003	Tynset	Hedmark	1.2	0.14	54	14	NA	29	4.9	70
Esser 1996	Østre Toten	Hedmark	2.9	1.6	22	48	0.076	51	22	200
Esser 1996	Østre Toten	Hedmark	3.4	0.81	19	44	0.052	45	24	130
Reimann et al., 2014	Åmot	Hedmark	7.4	0.077	4.6	9.6	0.038	2.9	25	47
Reimann et al., 2014	Åmot	Hedmark	0.53	0.052	2.9	3.9	0.022	1.4	6.7	13
Reimann et al., 2003	Åmot	Hedmark	1.1	0.063	2.0	3.8	NA	1.0	7.1	15
Reimann et al., 2014	Åsnes	Hedmark	1.1	0.20	14	13	0.014	10	7.6	62
Reimann et al., 2014	Åsnes	Hedmark	1.1	0.15	16	21	0.018	11	7.3	45
Reimann et al., 2003	Åsnes	Hedmark	1.8	0.088	18	18	NA	12	11	29
Reimann et al., 2014	Andebu	Southeastern	4.1	0.20	19	15	0.025	14	20	87
Reimann et al., 2014	Aurskog-Høland	Southeastern	1.2	0.21	15	13	0.030	11	18	44
Reimann et al., 2014	Enebakk	Southeastern	4.1	0.28	26	21	0.036	20	27	120
Reimann et al., 2014	Fredrikstad	Southeastern	2.2	0.33	12	7.8	0.078	6.9	31	24
Reimann et al., 2014	Hof	Southeastern	2.7	0.19	8.3	4.5	0.023	4.9	17	53
Reimann et al., 2014	Hurdal	Southeastern	4.3	0.19	16	8.6	0.061	11	29	49
Reimann et al., 2014	Nittedal	Southeastern	3.5	0.16	16	5.2	0.042	8.7	27	42
Reimann et al., 2014	Rakkestad	Southeastern	4.4	0.16	28	16	0.030	23	21	63
Reimann et al., 2014	Våler	Southeastern	2.4	0.36	14	11	0.057	8.7	28	45
Reimann et al., 2014	Hurdal	Southeastern	3.2	0.20	16	8.9	0.055	14	16	61
Reimann et al., 2014	Nittedal	Southeastern	5.1	0.28	32	16	0.059	28	27	110
Reimann et al., 2014	Enebakk	Southeastern	4.4	0.28	29	29	0.042	23	27	130
Reimann et al., 2014	Aurskog-Høland	Southeastern	1.0	0.087	15	9.0	0.023	10	11	45
Reimann et al., 2014	Andebu	Southeastern	3.9	0.24	20	11	0.049	12	20	74
Reimann et al., 2014	Hof	Southeastern	3.8	0.26	17	15	0.048	11	20	140
Reimann et al., 2014	Våler	Southeastern	5.1	0.16	30	16	0.040	23	23	81
Reimann et al., 2014	Fredrikstad	Southeastern	4.5	0.15	21	12	0.041	15	16	55
Reimann et al., 2014	Rakkestad	Southeastern	8.0	0.22	37	25	0.038	29	28	100
Reimann et al., 2003	Hof	Southeastern	2.6	0.11	11	7.4	NA	9.5	11	34
Reimann et al., 2003	Hurdal	Southeastern	2.2	0.26	14	11	NA	11	11	92
Reimann et al., 2003	Nittedal	Southeastern	3.8	0.24	22	16	NA	22	24	99
Reimann et al., 2003	Ski	Southeastern	4.4	0.22	38	20	NA	25	30	97
Fylkesmannen, Vestfold, 2000	Larvik	Southeastern	NA	NA	30	8.0	NA	12	16	81
Fylkesmannen, Vestfold, 2000	Larvik	Southeastern	NA	NA	19	13	NA	9.0	41	65
Fylkesmannen, Vestfold, 2000	Larvik	Southeastern	NA	NA	9.0	9.0	NA	2.0	16	40
Fylkesmannen, Vestfold, 2000	Larvik	Southeastern	NA	NA	13	8.0	NA	4.0	20	69
Fylkesmannen, Vestfold, 2000	Larvik	Southeastern	NA	NA	15	13	NA	5.0	19	130
Fylkesmannen, Vestfold, 2000	Larvik	Southeastern	NA	NA	7.0	5.0	NA	2.0	13	27
Fylkesmannen, Vestfold, 2000	Larvik	Southeastern	NA	NA	10	7.0	NA	3.0	13	40

Reference	Municipality	REGION	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg
Fylkesmannen, Vestfold, 2000	Larvik	Southeastern	NA	NA	10	12	NA	4.0	13	41
Fylkesmannen, Vestfold, 2000	Larvik	Southeastern	NA	NA	24	15	NA	9.0	17	99
Fylkesmannen, Vestfold, 2000	Larvik	Southeastern	NA	NA	29	12	NA	15	20	110
Fylkesmannen, Vestfold, 2000	Larvik	Southeastern	NA	NA	15	7.0	NA	6.0	12	62
Fylkesmannen, Vestfold, 2000	Larvik	Southeastern	NA	NA	24	10	NA	8.0	13	62
Fylkesmannen, Vestfold, 2000	Larvik	Southeastern	NA	NA	7.0	7.0	NA	3.0	8.0	34
Fylkesmannen, Vestfold, 2000	Larvik	Southeastern	NA	NA	20	11	NA	8.0	20	76
Fylkesmannen, Vestfold, 2000	Larvik	Southeastern	NA	NA	15	9.0	NA	6.0	16	72
Fylkesmannen, Vestfold, 2000	Larvik	Southeastern	NA	NA	17	10	NA	7.0	14	100
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	NA	33	13	NA	16	13	110
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	NA	34	13	NA	16	12	150
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	NA	40	21	NA	26	20	120
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	NA	19	8.0	NA	6.0	12	60
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.11	30	6.0	NA	11	20	61
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.20	39	9.0	0.014	15	15	51
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.18	37	8.0	0.080	14	18	110
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.20	27	8.0	0.040	8.0	12	110
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.22	17	10	0.060	4.0	14	71
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.14	32	5.0	0.040	7.0	12	28
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.30	27	12	0.038	10	16	170
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.17	38	9.0	0.040	14	12	84
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.26	48	13	0.030	17	14	110
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.24	33	9.0	0.020	11	17	54
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.13	33	9.0	0.030	13	12	57
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.14	31	7.0	0.030	12	11	46
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.14	35	14	0.020	16	12	96
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.14	27	7.0	0.030	9.0	12	32
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.12	45	15	0.040	21	24	96
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.070	39	12	0.050	20	20	85
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.020	36	16	0.030	21	18	83
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.45	28	39	1.9	12	50	260
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.21	35	8.0	0.040	11	20	49
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.27	42	18	0.030	18	25	87
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.22	37	11	0.030	16	21	52
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	NA	NA	NA	NA	NA	NA	140
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	NA	NA	NA	NA	NA	NA	79
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	NA	NA	NA	NA	NA	NA	69
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	NA	NA	NA	NA	NA	NA	87
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.40	14	4.0	0.030	6.0	9.0	68
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.26	32	17	0.040	22	16	190
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.23	14	7.0	0.040	4.0	9.0	58
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.30	27	8.0	0.040	11	16	110

Reference	Municipality	REGION	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
			mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.31	32	9.0	0.060	17	13	96
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.19	27	7.0	0.090	13	11	120
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.40	NA	NA	0.14	NA	13	NA
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.10	NA	NA	0.090	NA	13	NA
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.70	NA	NA	0.090	NA	13	NA
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.60	NA	NA	0.11	NA	18	NA
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.50	NA	NA	0.090	NA	14	NA
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.50	NA	NA	0.080	NA	15	NA
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.60	NA	NA	0.040	NA	8.0	NA
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.60	NA	NA	0.030	NA	4.0	NA
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.60	NA	NA	0.080	NA	11	NA
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.12	30	19	0.050	22	16	150
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.12	32	22	0.050	21	18	170
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.30	35	22	0.060	22	18	180
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.44	22	7.0	0.060	9.0	16	110
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.50	30	7.0	0.050	16	16	160
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.30	34	7.0	0.050	18	14	130
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.30	20	7.0	0.040	9.0	10	140
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.42	18	8.0	0.040	8.0	12	110
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.44	27	12	0.040	11	16	140
Fylkesmannen, Vestfold, 2000	Horten	Southeastern	NA	0.13	32	13	0.035	17	12	65
Fylkesmannen, Vestfold, 2000	Horten	Southeastern	NA	0.11	20	8.0	0.023	9.0	10	48
Fylkesmannen, Vestfold, 2000	Horten	Southeastern	NA	0.25	40	19	0.034	18	21	120
Fylkesmannen, Vestfold, 2000	Holmestrand	Southeastern	NA	0.21	21	14	0.019	11	30	99
Fylkesmannen, Vestfold, 2000	Holmestrand	Southeastern	NA	0.080	29	17	0.029	17	14	90
Fylkesmannen, Vestfold, 2000	Tønsberg	Southeastern	NA	0.020	39	10	0.050	19	13	38
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.28	39	17	0.040	17	24	120
Fylkesmannen, Vestfold, 2000	Sandefjord	Southeastern	NA	0.13	33	11	0.030	14	14	80
Fylkesmannen, Vestfold, 2000	Tønsberg	Southeastern	NA	0.080	33	18	0.010	25	17	130
Fylkesmannen, Vestfold, 2000	Tønsberg	Southeastern	NA	0.34	38	22	0.12	27	18	70
Fylkesmannen, Vestfold, 2000	Tønsberg	Southeastern	NA	0.19	36	16	0.060	29	16	91
Fylkesmannen, Vestfold, 2000	Tønsberg	Southeastern	NA	0.18	26	12	0.080	20	14	55
Fylkesmannen, Vestfold, 2000	Tønsberg	Southeastern	NA	0.21	25	11	0.080	20	14	48
Fylkesmannen, Vestfold, 2000	Tønsberg	Southeastern	NA	0.16	26	12	0.050	22	16	55
Joner, 2018	Ås	Southeastern	3.4	0.13	62	15	NA	26	16	59
Joner, 2018	Ås	Southeastern	4.4	0.19	67	16	NA	28	21	70
Joner, 2018	Ås	Southeastern	4.2	0.19	70	16	NA	30	20	73
Dragicevic 2015	Ås	Southeastern	2.7	0.14	62	10	NA	24	NA	77
Dragicevic 2016	Ås	Southeastern	2.5	0.16	72	15	NA	28	NA	84
Esser 1996	Eidsvoll	Southeastern	2.4	0.21	26	31	0.054	32	30	69
Esser 1996	Eidsvoll	Southeastern	2.1	0.18	20	15	0.048	21	31	55
Esser 1996	Skien	Southeastern	2.0	0.15	6.5	5.7	0.038	4.0	14	27

Reference	Municipality	REGION	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg
Esser 1996	Skien	Southeastern	2.2	0.13	7.6	6.8	0.048	4.0	21	27
Esser 1996	Skien	Southeastern	4.9	0.38	72	87	0.037	45	57	87
Esser 1996	Trøgstad	Southeastern	2.6	0.21	26	16	0.054	19	34	66
Esser 1996	Trøgstad	Southeastern	2.5	0.18	31	26	0.051	26	37	75
Esser 1996	Våle	Southeastern	2.3	0.33	24	21	0.099	20	37	120
Esser 1996	Våle	Southeastern	2.2	0.32	21	18	0.045	18	39	170
Reimann et al., 2014	Audnedal	Southwestern	2.2	0.61	5.4	23	0.14	2.9	96	180
Reimann et al., 2014	Bjerkreim	Southwestern	3.8	0.33	9.5	11	0.076	3.0	35	46
Reimann et al., 2014	Farsund	Southwestern	3.4	0.36	8.7	5.4	0.12	2.9	28	39
Reimann et al., 2014	Haugesund	Southwestern	3.7	0.32	18	29	0.099	4.1	23	20
Reimann et al., 2014	Hjelmeland	Southwestern	0.83	0.40	4.3	27	0.091	2.5	38	26
Reimann et al., 2014	Lyngdal	Southwestern	2.0	0.18	3.3	6.5	0.027	1.0	24	39
Reimann et al., 2014	Sirdal	Southwestern	1.8	0.32	5.8	10	0.10	2.4	46	21
Reimann et al., 2014	Sirdal	Southwestern	1.2	0.18	6.3	10	0.059	2.0	33	15
Reimann et al., 2014	Songdalen	Southwestern	5.4	0.36	7.8	7.0	0.11	5.8	41	45
Reimann et al., 2014	Time	Southwestern	2.7	0.25	9.1	12	0.049	3.9	28	40
Reimann et al., 2014	Vindafjord	Southwestern	4.4	0.12	22	13	0.091	10	19	36
Reimann et al., 2014	Haugesund	Southwestern	4.8	0.52	10.0	38	0.28	5.0	34	42
Reimann et al., 2014	Vindafjord	Southwestern	2.7	0.11	22	18	0.044	13	12	47
Reimann et al., 2014	Hjelmeland	Southwestern	1.5	0.22	11	21	0.074	3.8	22	44
Reimann et al., 2014	Time	Southwestern	3.2	0.33	10	22	0.12	3.8	30	60
Reimann et al., 2014	Vindafjord	Southwestern	3.4	0.36	15	19	0.075	5.9	36	39
Reimann et al., 2014	Sirdal	Southwestern	1.7	0.17	13	11	0.072	2.7	19	25
Reimann et al., 2014	Sirdal	Southwestern	1.2	0.13	12	11	0.073	3.3	15	26
Reimann et al., 2014	Farsund	Southwestern	2.6	0.20	8.5	6.4	0.052	2.7	17	37
Reimann et al., 2014	Lyngdal	Southwestern	1.5	0.16	3.2	5.9	0.014	1.0	23	31
Reimann et al., 2014	Audnedal	Southwestern	1.2	0.23	5.6	14	0.033	1.7	19	30
Reimann et al., 2014	Songdalen	Southwestern	2.6	0.30	6.3	13	0.058	3.8	30	29
Reimann et al., 2003	Audnedal	Southwestern	1.5	0.19	4.2	11	NA	1.0	25	36
Reimann et al., 2003	Flekkefjord	Southwestern	3.0	0.26	23	26	NA	5.1	52	47
Reimann et al., 2003	Flekkefjord	Southwestern	2.0	0.18	8.5	5.5	NA	2.8	20	11
Reimann et al., 2003	Hjelmeland	Southwestern	0.88	0.15	12	8.2	NA	5.6	15	34
Reimann et al., 2003	Songdalen	Southwestern	1.4	0.27	3.8	7.2	NA	3.4	20	29
Reimann et al., 2003	Suldal	Southwestern	1.8	0.13	17	9.9	NA	8.2	18	41
Reimann et al., 2003	Time	Southwestern	2.3	0.21	15	11	NA	4.3	14	34
Reimann et al., 2003	Vindafjord	Southwestern	2.4	0.19	10	18	NA	5.3	23	37
Esser 1996	Iveland	Southwestern	1.4	0.11	17	16	0.034	6.0	32	29
Esser 1996	Karmøy	Southwestern	1.4	0.15	92	26	0.061	44	44	46
Esser 1996	Kvinesdal	Southwestern	2.6	0.17	5.9	11	0.064	2.1	25	25
Esser 1996	Kvinesdal	Southwestern	1.7	0.33	4.8	11	0.095	3.1	36	63
Esser 1996	Lyngdal	Southwestern	3.4	0.23	5.9	8.9	0.058	1.2	23	21
Esser 1996	Lyngdal	Southwestern	2.2	0.12	4.1	3.2	0.055	0.70	23	11

Reference	Municipality	REGION	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg
Esser 1996	Sola	Southwestern	1.3	0.025	1.4	1.7	0.0050	1.5	3.5	7.3
Esser 1996	Sola	Southwestern	1.0	0.053	1.7	3.8	0.0050	1.2	5.8	16
Esser 1996	Suldal	Southwestern	0.91	0.031	12	9.7	0.055	9.9	15	39
Esser 1996	Time	Southwestern	1.3	0.16	13	13	0.089	5.5	18	48
Esser 1996	Time	Southwestern	1.2	0.13	11	11	0.067	4.1	20	44
Esser 1996	Vindafjord	Southwestern	3.3	0.14	14	22	0.083	18	34	62

Appendix II

Atmospheric PTE deposition data from Norway

During the 1970s it became evident that the southernmost part of Norway was considerably affected by air pollutants originating from other parts of Europe. Substantial efforts have been made to study the extent of this pollution: source areas, geographical distribution within Norway, and possible effects. Whereas the emphasis during the first period was on acidic deposition and its effects on freshwater ecosystems, the establishment of air monitoring programmes and development of gradually improved analytical techniques revealed that some PTEs were also among the pollutants transported into Norway and supplied to terrestrial ecosystems by atmospheric deposition.

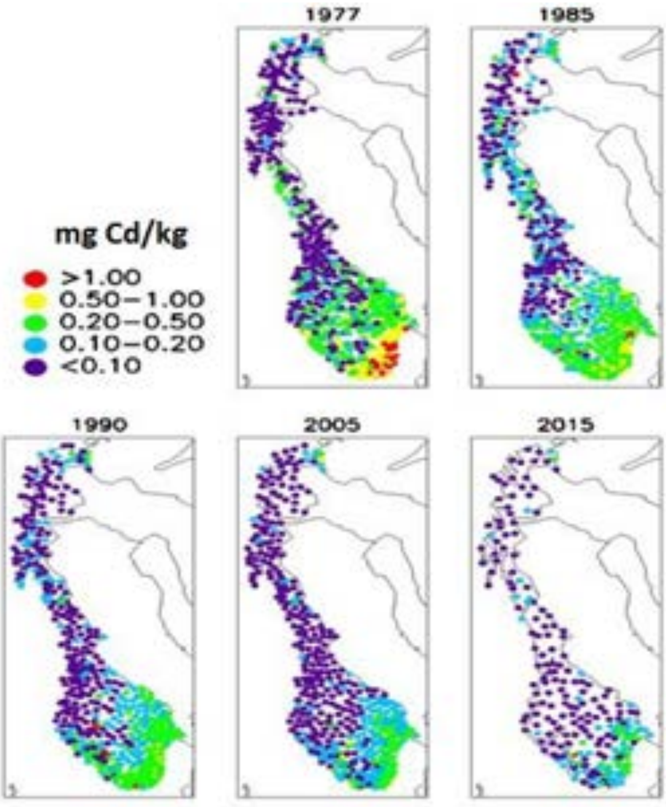


Figure AII-1. Decrease in atmospheric deposition of Cd in Norway from 1977 to 2015, illustrated by Cd concentrations in moss samples, units in mg Cd kg^{-1} moss (Steinnes et al., 2016).

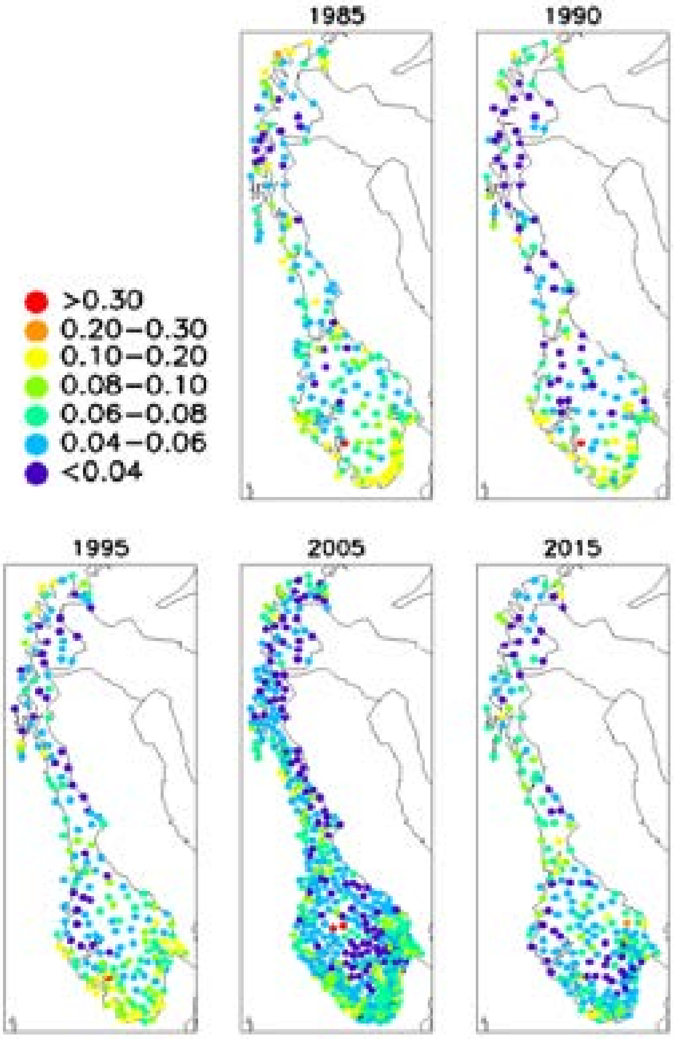


Figure AII-2. Decrease in atmospheric deposition of Hg in Norway from 1985 to 2015, illustrated by Cd concentrations in moss samples, units in mg Hg kg^{-1} moss (Steinnes et al., 2016).

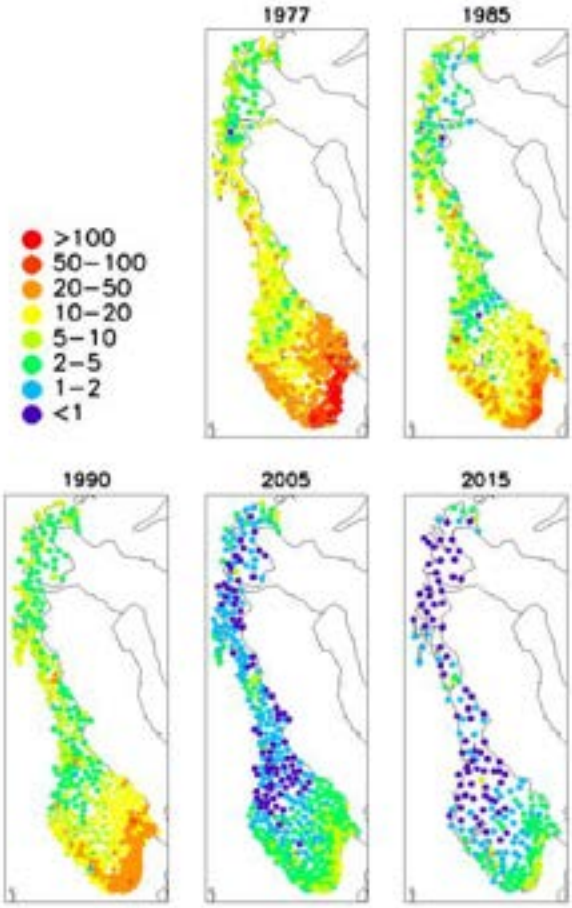
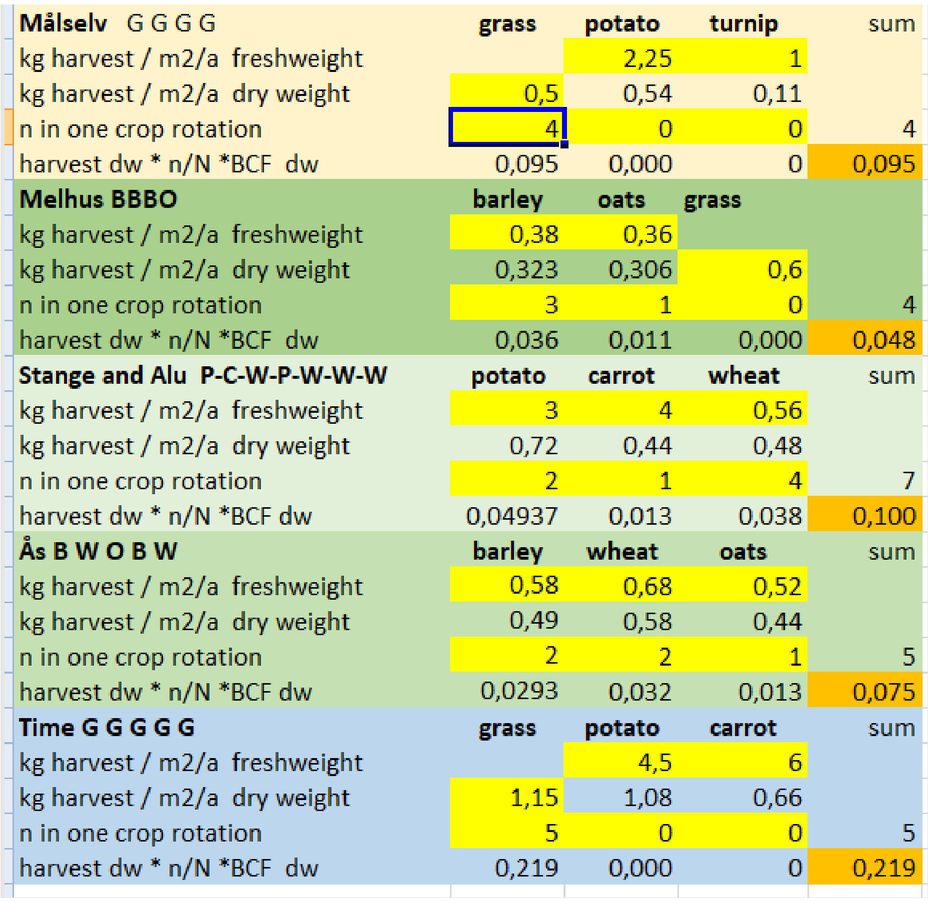


Figure AII-3. Decrease in atmospheric deposition of Pb in Norway from 1977 to 2015, illustrated by Cd concentrations in moss samples, units in mg Pb kg^{-1} moss (Steinnes et al., 2016).

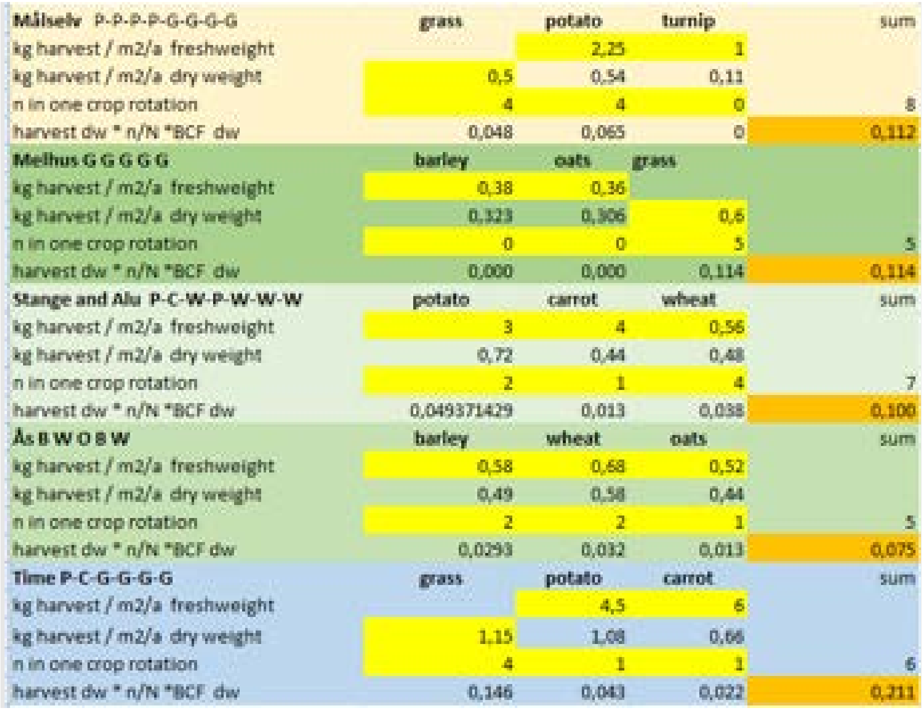
Appendix III

Calculation of removal of PTEs via plant harvesting – crop rotations

Table AIII-I. Input parameters: yield biomass (kg m^2 yr^{-1} FW and DW), crop rotation and total harvest DW per crop rotation selected as crop rotation 1 (a) ang crop rotation 2 (b). G:grass, B:barley, O:oat, W:wheat, P:potatoe, C:carrot.



Målselv G G G G	**grass**	**potato**	**turnip**	sum
kg harvest / m2/a freshweight		2,25	1	
kg harvest / m2/a dry weight	0,5	0,54	0,11	
n in one crop rotation	4	0	0	4
harvest dw * n/N *BCF dw	0,095	0,000	0	0,095
Melhus BBBO	**barley**	**oats**	**grass**	
kg harvest / m2/a freshweight	0,38	0,36		
kg harvest / m2/a dry weight	0,323	0,306	0,6	
n in one crop rotation	3	1	0	4
harvest dw * n/N *BCF dw	0,036	0,011	0,000	0,048
Stange and Alu P-C-W-P-W-W-W	**potato**	**carrot**	**wheat**	sum
kg harvest / m2/a freshweight	3	4	0,56	
kg harvest / m2/a dry weight	0,72	0,44	0,48	
n in one crop rotation	2	1	4	7
harvest dw * n/N *BCF dw	0,04937	0,013	0,038	0,100
Ås B W O B W	**barley**	**wheat**	**oats**	sum
kg harvest / m2/a freshweight	0,58	0,68	0,52	
kg harvest / m2/a dry weight	0,49	0,58	0,44	
n in one crop rotation	2	2	1	5
harvest dw * n/N *BCF dw	0,0293	0,032	0,013	0,075
Time G G G G G	**grass**	**potato**	**carrot**	sum
kg harvest / m2/a freshweight		4,5	6	
kg harvest / m2/a dry weight	1,15	1,08	0,66	
n in one crop rotation	5	0	0	5
harvest dw * n/N *BCF dw	0,219	0,000	0	0,219



Målselv P-P-P-P-G-G-G-G	grass	potato	turnip	sum
kg harvest / m2/a freshweight		2,25	1	
kg harvest / m2/a dry weight	0,5	0,54	0,11	
n in one crop rotation	4	4	0	8
harvest dw * n/N *BCF dw	0,048	0,065	0	0,112
Melhus G G G G G	barley	oats	grass	
kg harvest / m2/a freshweight	0,38	0,36		
kg harvest / m2/a dry weight	0,323	0,306	0,6	
n in one crop rotation	0	0	5	5
harvest dw * n/N *BCF dw	0,000	0,000	0,114	0,114
Stange and Alu P-C-W-P-W-W-W	potato	carrot	wheat	sum
kg harvest / m2/a freshweight	3	4	0,56	
kg harvest / m2/a dry weight	0,72	0,44	0,48	
n in one crop rotation	2	1	4	7
harvest dw * n/N *BCF dw	0,049371429	0,013	0,038	0,100
Ås B W O B W	barley	wheat	oats	sum
kg harvest / m2/a freshweight	0,58	0,68	0,52	
kg harvest / m2/a dry weight	0,49	0,58	0,44	
n in one crop rotation	2	2	1	5
harvest dw * n/N *BCF dw	0,0293	0,032	0,013	0,075
Time P-C-G-G-G-G	grass	potato	carrot	sum
kg harvest / m2/a freshweight		4,5	6	
kg harvest / m2/a dry weight	1,15	1,08	0,66	
n in one crop rotation	4	1	1	6
harvest dw * n/N *BCF dw	0,146	0,043	0,022	0,211

Crop rotations considered

Målselv (crop 1)	G-G-G-G-G
Målselv (crop 2)	P-P-P-P-G-G-G-G
Melhus (crop 1)	B-B-B-O
Melhus (crop 2)	G-G-G-G-G
Stange	P-C-W-P-W-W-W
Alun shale	P-C-W-P-W-W-W
Ås	B-W-O-B-W
Time (crop 1)	G-G-G-G-G
Time (crop 2)	P-C-G-G-G-G

where G is grass, P is potato, B is barley, O is oats, C is carrots, and W is wheat

Kinetics removal from soil

Table AIII-2. Kinetic rates removal of PTEs from soil via runoff and leaching and plant uptake and harvesting, given as yr^{-1}. Values in bold is > 0.01 yr^{-1}.

		Målselv	**Melhus**	**Stange**	**Alum shale**	**Ås**	**Time**
As	Runoff/leaching	2.0E-03	2.9E-03	1.1E-03	1.1E-03	2.2E-03	7.6E-03
	Plant removal	7.6E-05	3.5E-05	3.4E-05	3.4E-05	5.3E-05	2.6E-04
Cd	Runoff/leaching	**1.2E-02**	9.3E-03	3.9E-03	3.9E-03	8.5E-03	**5.0E-02**
	Plant removal	4.9E-04	1.7E-04	4.4E-04	4.4E-04	3.0E-04	1.6E-03
Cr	Runoff/leaching	1.8E-03	2.8E-03	1.1E-03	1.1E-03	2.1E-03	6.8E-03
	Plant removal	1.7E-05	4.0E-06	8.6E-06	8.6E-06	6.2E-06	5.7E-05
Cu	Runoff/leaching	1.6E-03	2.4E-03	9.7E-04	9.7E-04	1.7E-03	7.2E-03
	Plant removal	4.0E-04	2.0E-04	4.0E-04	4.0E-04	3.0E-04	1.4E-03
Hg[1]	Runoff/leaching	1.7E-04	2.7E-04	1.0E-04	1.0E-04	2.0E-04	6.5E-04
	Plant removal	1.7E-05	1.1E-04	9.8E-05	9.8E-05	1.8E-04	5.7E-05
Ni	Runoff/leaching	**1.2E-02**	**1.4E-02**	5.7E-03	5.7E-03	**1.1E-02**	**4.2E-02**
	Plant removal	1.1E-04	1.3E-05	2.7E-05	2.7E-05	1.9E-05	3.6E-04
Pb	Runoff/leaching	3.2E-04	3.5E-04	1.4E-04	1.4E-04	2.9E-04	1.2E-03
	Plant removal	2.1E-05	8.0E-06	1.5E-05	1.5E-05	1.1E-05	7.1E-05
Zn	Runoff/leaching	4.4E-03	3.3E-03	1.4E-03	1.4E-03	2.7E-03	**1.4E-02**
	Plant removal	5.3E-04	4.3E-04	5.0E-04	5.0E-04	6.5E-04	1.8E-03

[1] Evaporation is not taken account for in the modelling.

Loss of PTEs from soil (g ha^{-1} yr^{-1})

Table AIII-3. Loss of PTEs from soil via runoff and leaching and plant uptake and harvesting, given as g ha^{-1} yr^{-1}.

		Målselv	**Melhus**	**Stange**	**Alum shale**	**Ås**	**Time**
As	Runoff + leaching	7.7	20.9	3.1	42.9	15.1	38.3
	Plant removal	0.29	0.25	0.09	1.26	0.36	1.28
	Sum	8.0	21.2	3.2	44.1	15.4	39.5
Cd	Runoff + leaching	2.3	2.2	1.3	8.1	4.5	24.0
	Plant removal	0.09	0.04	0.14	0.92	0.16	0.78
	Sum	2.4	2.3	1.4	9.1	4.6	24.8
Cr	Runoff + leaching	104.7	243.6	38.1	51.7	144.4	159.6
	Plant removal	1.00	0.34	0.30	0.41	0.42	1.33
	Sum	105.7	244.0	38.4	52.1	144.8	160.9
Cu	Runoff + leaching	54.5	116.2	29.1	104.4	46.3	199.3
	Plant removal	13.30	9.56	12.00	43.01	8.24	37.26
	Sum	67.8	125.7	41.1	147.4	54.6	236.6
Hg	Runoff + leaching	0.01	0.02	0.01	0.01	0.02	0.11
	Plant removal	0.00	0.01	0.01	0.01	0.02	0.01
	Sum	0.01	0.03	0.02	0.02	0.04	0.12
Ni	Runoff + leaching	357.5	772.8	170.1	722.9	383.6	378.7
	Plant removal	3.25	0.73	0.82	3.46	0.66	3.21
	Sum	360.7	773.5	170.9	726.4	384.3	381.9
Pb	Runoff + leaching	4.5	8.0	2.9	7.1	11.5	71.5
	Plant removal	0.30	0.18	0.30	0.74	0.46	4.10
	Sum	4.8	8.2	3.2	7.8	12.0	75.6
Zn	Runoff + leaching	473.2	428.9	153.4	392.5	543.8	1260.0
	Plant removal	57.5	56.1	54.3	138.8	131.6	160.5
	Sum	530.7	485.0	207.7	531.2	675.4	1420.4

Appendix IV

Selection of TFs for use in risk assessmen

Selection of TFs are based on literature research performed by Philip Gjedde, DTU, with Prof. Stefan Trapp, as supervisor (Gjedde, 2020). Table AIV-1 gives a summary of TFs for different vegetables. TFs selected for use in the risk assessment in red.

Table AIV-1. Summary of selected TFs of vegetables.

	As	Cd	Cr total	Cu	Hg	Ni	Pb	Zn	REF
Carrot	0.008	0.064	0.005	0.2	0.014	0.008	0.011	0.044	VKM 2022 median
Carrot		0.25							VKM 2019 Legind, Trapp, 2010
Carrot		0.69-1.14		0.09-0.43			0.004-0.07	0.47-2.49	Intawongse & Dean, 2005
Potato	0.004	0.29	0.005	0.24	0.002	0.02	0.008	0.19	VKM 2022 median
Potato		0.27							VKM 2019
Potato		0.18	0.02	0.17			0.16	0.04	Cheshmazar et al. (2018)
Radish		0.39-2.25		0.03-0.64			0.01-0.94	0.74-2.93	Intawongse & Dean, 2005
Lettuce				0.03-0.76 (leaves); 0.25-1.89 (root)			0.03-0.66 (leaves), 0.12-0.15 (roots)	0.67-3.75 (leaves), 0.83-3.54 (roots)	Intawongse & Dean, 2005
Lettuce		0.15	0.02	0.15			0.45	0.14	Cheshmazar et al. (2018)
Spinach				0.02-0.38 (leaves), 0.06-2.17 (roots)			0.02-0.59 (leaves), 0.02-0.28 (roots)	1.1-5.07 (leaves), 0.47-4.86 (roots)	Intawongse & Dean, 2005
Spinach		0.57	0.01	0.17			0.51	0.28	Cheshmazar et al. (2018)
Cabbage		0.13	0.01	0.14			0.35	0.02	Cheshmazar et al. (2018)

	As	Cd	Cr total	Cu	Hg	Ni	Pb	Zn	REF
Onion		0.07	0.01	0.08			0.2	0.07	Cheshmazar et al. (2018)
Tomato		0.1	0.02	0.14			0.17	0.07	Cheshmazar et al. (2018)
Green Pepper		0.15	0.01	0.22			0.18	0.02	Cheshmazar et al. (2018)
Potato		0.34	0.01	0.29		0.06	0.01	0.25	Novotna 2015 mean (not median)
Leafy vegetables	0.0001–0.103	mean 0.374 (0.010 to 3.10)	0.0002–0.027		mean 0.010 (0.0005-0.0716)		0.0001–0.0648		Chang, 2014
Lettuce	n.a.=6 (0.01-0.13)	(3.88-12.82)		(0.03-0.93)			(0.003-0.036)		Gaw 2008
Radish hopocotyl	n.a.=4 (0.01-0.12)	(0.082-11.41)		(0.04-0.6)			(0.002-0.48)		Gaw 2009
Radish leaf		n.a.=5 (1.49-12.41)		(0.09-0.94)			n.a.=3 (0.002-0.19)		Gaw 2010

Appendix V

Soil properties

The soil properties/parameters pH and mould% from NIBIO Soil database was collected and summarised in Table A V-1-2. Number of samples, minimum, maximum and mean for the four municipality cases and the six regions in Norway, is shown.

Table AV-1. Mean, minimum, and maximum pH(H_2O) in agricultural soils in different municipalities, regions, and for the whole country (NIBIO Soil database). Values with pH<3.8 and >8.2 are removed because they are unlikely values for Norwegian agricultural soils. pH used for risk assessment is adjusted for pH ($CaCl_2$) (Eq.1).

Municipality	Minimum	Maximum	Mean	#of samples
MÅLSELV	3.8	7.8	5.7	2 088
MELHUS	4.3	8.2	6.2	2 245
STANGE	3.8	8.1	6.1	7 699
ÅS	3.9	8.2	6.1	8 821
TIME	4	7.8	5.8	4 388

Region	Minimum	Maximum	Mean	#of samples
Northern Norway	3.8	8.2	5.8	52 352
Trøndelag (Mid Norway)	3.9	8.2	6.0	120 375
Southeastern Norway	3.8	8.2	6.1	531 312
Southern Norway	3.8	8.1	5.7	25 831
Western Norway	3.8	8.2	5.8	201 125

Table AV-2. Mean, minimum, and maximum of mould% (same as SOM%) in agricultural soils for different municipalities, regions, and for the whole country (NIBIO Soil database). Values <0.5 are removed because they are unlikely values for Norwegian agricultural soils.

Municipality	**Minimum**	**Maximum**	**Mean**	**#of samples**
MÅLSELV	0.71	73	5.6	1 986
MELHUS	0.6	92	6.3	2 205
STANGE	0.51	97.1	6.5	7 503
ÅS	0.7	85.2	5.4	8 799
TIME	1	31.35	4.1	4 383

Region	**Minimum**	**Maximum**	**Mean**	**#of samples**
Northern Norway	0.55	98.8	9.9	47 939
Trøndelag (Mid Norway)	0.58	98.8	8.0	114 801
Southeastern Norway	0.51	99	6.0	517 982
Southern Norway	0.57	98.8	11.0	23 636
Western Norway	0.59	98.8	10.6	187 627

Country	0.51	99	7.6	891 985

Table AV-3. Mean, minimum and maximum of adjusted volume weight* (Soil dry density, kg dm^{-3}) in agricultural soils for different municipalities, regions and for the whole country (NIBIO Soil database). Values <0.2 and >1.65 are removed because they are unlikely values for Norwegian agricultural soils.

Municipality	**Minimum**	**Maximum**	**Mean**	**#of samples**
MÅLSELV	0.23	1.65	1.18	2 084
MELHUS	0.24	1.6	1.19	2 232
STANGE	0.21	1.65	1.25	7 532
ÅS	0.24	1.65	1.25	8 797
TIME	0.51	1.09	0.81	11

Region	**Minimum**	**Maximum**	**Mean**	**#of samples**
Northern Norway	0.21	1.65	1.07	51 944
Trøndelag (Mid Norway)	0.21	1.65	1.15	118 852
Southeastern Norway	0.21	1.65	1.20	525 785
Southern Norway	0.21	1.65	1.05	25 753
Western Norway	0.21	1.65	1.02	178 430

*Adjusted volume weight is a corrected volume weight measured in lab. The correction is made according to a relationship between volume weight measured in lab and volume weight measured in field.

Appendix VI

PTE content in mineral fertilisers, lime products and sewage sludge, applied P fertiliser, manure and PTE amounts in the fertiliser scenarios and selected crop rotations

Mineral P fertilisers

Table AVI-1. Cd concentration, Cd kg P^{-1}, in different mineral fertilisers and crops for which they are commonly used. Results from marked surveillance activity in 2015 (NFSA, 2017).

Fertiliser NPK	mg Cd kg^{-1} P	Crop
Yara 22-3-10	25	Grain
Yara 20-4-11	84	Grain
Yara 25-2-6	27	Grain, grass
Yara 12-4-18	50	Potato, carrot
Yara 23-2-10	82	
Yara 8-3-15	85	

Table AVI-2. Concentration of PTEs given as mg PTE kg^{-1} P in Yara NPK 8-5-19 and 25-2-6 given by Yara (Personal communication, 2021).

PTE	Yara 8-5-19 (potato and vegetables)	Yara 25-2-6 (grain and grass)
	mg PTE kg^{-1} P	
As	19.00	23.5
Cd[1]	3.40	17.65
Cr	138.00	621.18
Cu	0.90	220.00
Hg	0.20	0.29
Ni	58.00	124.71
Pb	3.80	63.53
Zn	1520.00	1352.94

[1] for Cd, not used data from Yara but analysis from NFSA 2017.

Lime products

Table AVI-3. Mean concentration of PTEs given as mg PTE kg^{-1} DW in lime products (Erstad, 1992). N.a.=not analysed.

PTE	mg PTE kg^{-1} DW
As	1.13
Cd	0.13
Cr	1.58
Cu	2.71
Hg	0.00
Ni	3.34
Pb	1.83
Zn	n.a.

Sewage sludge

Table AVI-4. Mean concentration and 95% percentiles of PTEs given as mg PTE kg^{-1} DW in sewage sludge (Berge & Sæther, 2019).

	95%-percentile (lower)	Mean	95%-percentile (upper)
Cd	0.50	0.56	0.61
Cr	14.4	16.9	19.4
Cu	146	165	184
Hg	0.28	0.33	0.38
Ni	11.4	12.9	14.5
Pb	11.7	13.8	15.9
Zn	347	391	436

Applied mineral P fertiliser and manure

Table AVI-5. Overview of applications of mineral P fertilisers (#0b is scenario without atm. contribution, and #1, with atm. contribution) and cattle and pig manure (scenario #4, max. measured PTE values and #5, mean measured PTE values). *Scenario with pig manure were included also in cases where it was not given by the extension service.

	Mineral P	**Cattle manure**	**Pig manure**
	kg P/ha/yr	kg dw/ha/yr	
Målselv			
Grass – cattle manure (#4/5)	5	1800	
Grass – pig manure (#4/5)			1500*
Potato - mineral P (#0b/1)	28		
Melhus			
Oat – mineral P (#0b/1)	11		
Barley – mineral P (#0b/1)	13		
Grass – cattle manure (#4/5)	6	3000	
Grass – pig manure (#4/5)			2500*
Stange			
Wheat – mineral P (#0b/1)	18		
Wheat – pig manure (#4/5)			1750
Oat – mineral P (#0b/1)	16		
Barley – mineral P (#0b/1)	16		
Barley – pig manure (#4/5)	6		1750
Potato – mineral P (#0b/1)	34		
Potato – pig manure (#4/5)			4000*
Carrot – mineral P (#0b/1)	24		
Carrot – pig manure (#4/5)			4000*
Ås			
Wheat – mineral P (#0a/1)	14,3		
Oat – mineral P (#0a/1)	15,6		
Barley – mineral P (#0a/1)	14,3		
Time			
Potato – mineral P (#0a/1)	40		
Potato – cattle manure (#4/5)			4000*
Carrot – mineral P (#0a/1)	26		
Carrot – cattle manure (#4/5)			4000*
Grass – cattle manure (#4/5)		3000	
Grass – pig manure (#4/5)			2500*

Applied PTE per ha per year

Table AVI-6. PTEs added to agricultural soil, given as g PTE ha^{-1} yr^{-1}, for selected fertiliser schemes and scenarios. In Table A, scenarios #1 to #10 are include atmospheric contribution and lime application. In Table B, atmospheric contribution is not included. N.a.=no analyses. Analyses of As in sewage sludge and digestate (#3,7,8), and of Hg in cattle, pig and poultry manure (#4,5,9) were missing.

Table AVI-6A. PTE added to agricultural soil, given as g PTE ha^{-1} yr^{-1}, for selected fertiliser schemes and scenarios; atmospheric contribution included.

Regions	PTE	#0a	#0b	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
Målselv	As	2.4	0.12	2.6	34.6	n.a.	3.2	3.2	4.6	n.a.	n.a.	4.8	3.4
Melhus		2.4	0.29	2.9	34.9	n.a.	3.8	3.8	4.7	n.a.	n.a.	5.0	3.6
Stange		2.4	0.57	3.1	40.4	n.a.	3.8	3.8	4.6	n.a.	n.a.	4.8	3.4
Ås		2.4	0.34	2.9	34.9	n.a.	**n.i.**	**n.i.**	4.6	n.a.	n.a.	4.9	3.5
Time		2.4	**n.i.**	**n.i.**	34.8	n.a.	4.1	4.4	4.9	n.a.	n.a.	5.1	3.7
Målselv	Cd	0.34	0.43	0.77	4.77	1.97	0.71	0.58	1.31	1.42	1.71	1.39	0.71
Melhus		0.34	1.06	1.43	5.43	2.63	0.97	0.75	1.33	1.44	1.73	1.41	0.73
Stange		0.34	2.32	2.68	7.34	4.08	2.54	1.23	1.31	1.42	1.71	1.39	0.71
Ås		0.34	1.24	1.59	5.59	2.79	**n.i.**	**n.i.**	1.32	1.42	1.72	1.40	0.72
Time		0.34	**n.i.**	**n.i.**	4.38	1.58	0.98	0.77	1.34	1.45	1.74	1.42	0.74
Målselv	Cr	30	3.1	33.2	233	67.0	32.3	31.3	40.7	45.2	66.8	58.2	33.7
Melhus		30	7.8	38.1	238	71.9	33.9	32.3	40.9	45.4	67.0	58.5	34.0
Stange		30	9.6	39.7	273	79.1	38.6	33.0	40.7	45.2	66.8	58.3	33.8
Ås		30	9.0	39.2	239	73.0	**n.i.**	**n.i.**	40.8	45.3	66.9	58.4	33.8
Time		30	**n.i.**	**n.i.**	231	64.3	34.1	32.4	41.1	45.6	67.2	58.7	34.1
Målselv	Cu	12	1.10	13.3	1313	343	133	82.4	38.6	179	199	235	148
Melhus		12	2.75	15.3	1315	345	214	130	39.0	180	200	235	149
Stange		12	2.65	14.9	1532	399	598	314	38.6	179	199	235	148
Ås		12	3.20	15.6	1316	345	**n.i.**	**n.i.**	38.7	180	199	235	148
Time		12	**n.i.**	**n.i.**	1313	342	213.9	129.9	39.3	180	200	236	149
Målselv	Hg	0.36	0.0015	0.36	6.4	0.96	n.a.	n.a.	0.44	0.65	2.06	0.48	n.a.
Melhus		0.36	0.0037	0.36	6.4	0.96	n.a.	n.a.	0.44	0.65	2.06	0.48	n.a.
Stange		0.36	0.0066	0.37	7.4	1.07	n.a.	n.a.	0.44	0.65	2.06	0.48	n.a.
Ås		0.36	0.0043	0.36	6.4	0.96	**n.i.**	**n.i.**	0.44	0.65	2.06	0.48	n.a.
Time		0.36	**n.i.**	**n.i.**	6.4	0.96	n.a.	n.a.	0.44	0.65	2.06	0.48	n.a.
Målselv	Ni	17	0.62	17.8	118	43.6	24.9	19.8	22.2	36.2	23.4	33.7	24.3
Melhus		17	1.56	19.3	119	45.1	30.6	22.2	22.7	36.7	24.0	34.2	24.8
Stange		17	2.39	19.7	136	49.8	34.1	22.4	22.3	36.3	23.5	33.8	24.4
Ås		17	1.82	19.3	119	45.1	**n.i.**	**n.i.**	22.4	36.4	23.7	33.9	24.5
Time		17	**n.i.**	**n.i.**	118	43.9	31.0	22.5	23.1	37.1	24.3	34.6	25.2
Målselv	Pb	40	0.32	40.4	200	68.0	41.4	41.4	43.7	53.1	58.7	98.7	41.8
Melhus		40	0.79	41.2	201	68.8	42.5	42.5	44.0	53.4	59.0	99.0	42.1
Stange		40	0.82	41.0	228	73.2	42.4	42.4	43.8	53.2	58.8	98.8	41.9
Ås		40	0.92	41.2	201	68.8	**n.i.**	**n.i.**	43.8	53.3	58.9	98.8	42.0
Time		40	**n.i.**	**n.i.**	201	68.2	42.7	42.7	44.2	53.6	59.2	99.2	42.3
Målselv	Zn	60	6.76	66.8	1667	849	456	392	673	783	1284	376	814
Melhus		60	16.9	76.9	1677	859	720	613	673	783	1284	376	814
Stange		60	39.5	99.5	1966	1012	4943	2076	673	783	1284	376	814
Ås		60	19.7	79.7	1680	862	**n.i.**	**n.i.**	673	783	1284	376	814
Time		60	**n.i.**	**n.i.**	1660	842	720	613	673	783	1284	376	814

Table AVI-6B. PTE added to agricultural soil, given as g PTE ha^{-1} yr^{-1}, for selected fertiliser schemes and scenarios; atmospheric contribution not included.

Regions	PTE	#0a	#0b	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
Målselv	As	2.4	0.1	0.19	32.2	n.a.	1.51	1.51	2.2	n.a.	n.a.	2.4	1.77
Melhus		2.4	0.3	0.54	32.5	n.a.	2.65	2.65	2.3	n.a.	n.a.	2.6	1.95
Stange		2.4	0.6	0.68	38.0	n.a.	2.64	2.64	2.2	n.a.	n.a.	2.4	1.81
Ås		2.4	0.6	0.49	32.5	n.a.	**0.1**	**0.1**	2.2	n.a.	n.a.	2.5	1.85
Time		2.4	**0.3**	**0.4**	32.4	n.a.	2.77	2.77	2.5	n.a.	n.a.	2.7	2.08
Målselv	Cd	0.3	0.4	0.43	4.4	1.6	0.37	0.24	0.97	1.1	1.37	1.0	0.37
Melhus		0.3	1.1	1.09	5.1	2.3	0.63	0.41	0.99	1.1	1.39	1.1	0.39
Stange		0.3	2.3	2.34	7.0	3.7	2.20	0.89	0.97	1.1	1.37	1.1	0.37
Ås		0.3	1.2	1.25	5.3	2.5	**n.i.**	**n.i.**	0.98	1.1	1.38	1.1	0.38
Time		0.3	**n.i.**	**n.i.**	4.0	1.2	0.64	0.43	1.00	1.1	1.40	1.1	0.40
Målselv	Cr	30.0	3.1	3.20	203	37.0	2.3	1.3	10.7	15.2	36.8	28.2	3.7
Melhus		30.0	7.8	8.11	208	41.9	3.9	2.3	10.9	15.4	37.0	28.5	4.0
Stange		30.0	9.6	9.71	243	49.1	8.6	3.0	10.7	15.2	36.8	28.3	3.8
Ås		30.0	9.0	9.25	209	43.0	**n.i.**	**n.i.**	10.8	15.3	36.9	28.4	3.8
Time		30.0	**n.i.**	**n.i.**	201	34.3	4.1	2.4	11.1	15.6	37.2	28.7	4.1
Målselv	Cu	12.0	1.1	1.26	1301	331	121	70.4	26.6	167	187	223	136
Melhus		12.0	2.8	3.35	1303	333	202	117.6	27.0	168	188	223	137
Stange		12.0	2.7	2.90	1520	387	586	302	26.6	167	187	223	136
Ås		12.0	3.2	3.56	1304	333	**n.i.**	**n.i.**	26.7	168	187	223	136
Time		12.0	**n.i.**	**n.i.**	1301	330	202	118	27.3	168	188	224	137
Målselv	Hg	0.36	0.0015	0.0016	6.0	0.60	n.a.	n.a.	0.08	0.29	1.7	0.12	n.a.
Melhus		0.36	0.0037	0.0042	6.0	0.60	n.a.	n.a.	0.08	0.29	1.7	0.12	n.a.
Stange		0.36	0.0066	0.0068	7.0	0.71	n.a.	n.a.	0.08	0.29	1.7	0.12	n.a.
Ås		0.36	0.0043	0.0046	6.0	0.60	**n.i.**	**n.i.**	0.08	0.29	1.7	0.12	n.a.
Time		0.36	**n.i.**	**n.i.**	6.0	0.60	n.a.	n.a.	0.08	0.29	1.7	0.12	n.a.
Målselv	Ni	17.0	0.6	0.82	101	27	7.94	2.85	5.2	19.2	6.4	16.7	7.3
Melhus		17.0	1.6	2.29	102	28	13.64	5.15	5.7	19.7	7.0	17.2	7.8
Stange		17.0	2.4	2.69	119	33	17.07	5.39	5.3	19.3	6.5	16.8	7.4
Ås		17.0	1.8	2.25	102	28	**n.i.**	**n.i.**	5.4	19.4	6.7	16.9	7.5
Time		17.0	**n.i.**	**n.i.**	101	27	14.00	5.52	6.1	20.1	7.3	17.6	8.2
Målselv	Pb	40.0	0.3	0.43	160	28	1.37	1.37	3.7	13.1	18.7	58.7	1.8
Melhus		40.0	0.8	1.20	161	29	2.50	2.50	4.0	13.4	19.0	59.0	2.1
Stange		40.0	0.8	0.99	188	33	2.38	2.38	3.8	13.2	18.8	58.8	1.9
Ås		40.0	0.9	1.16	161	29	**n.i.**	**n.i.**	3.8	13.3	18.9	58.8	2.0
Time		40.0	**n.i.**	**n.i.**	161	28	2.70	2.70	4.2	13.6	19.2	59.2	2.3
Målselv	Zn	60.0	6.8	6.76	1607	789	396	332	613	723	1224	316	754
Melhus		60.0	16.9	16.91	1617	799	660	553	613	723	1224	316	754
Stange		60.0	39.5	39.54	1906	952	4883	2016	613	723	1224	316	754
Ås		60.0	19.7	19.70	1620	802	**n.i.**	**n.i.**	613	723	1224	316	754
Time		60.0	**n.i.**	**n.i.**	1600	782	660	553	613	723	1224	316	754

Table AVI-6C. Example Hg added to case-area Time, given as g Hg ha^{-1} yr^{-1}, via application of fish sludge, digestates, horse manure and sewage sludge with different application rates and measured mean and maximum Hg concentration. Atmospheric contribution included. Percent increase in soil over 100 years is included. Numbers in bold are the selected fertilisers scenarios used in the evaluation.

	Application rates	**Mean conc.**		**Max. conc.**	
		g PTE ha^{-1} yr^{-1}	% increase 100 yr	g PTE ha^{-1} yr^{-1}	% increase 100 yr

	Application rates	**Mean conc.**		**Max. conc.**	
Fish sludge	**30 kg P ha^{-1} yr^{-1}**	**0.44**	**32**	0.68	52
Fish sludge	70 kg P ha^{-1} yr^{-1}	0.55	41	1.10	89
Digestate (FW&M)	**30 kg P ha^{-1} yr^{-1}**	**0.65**	**49**	1.34	109
Digestate (FW&M)	70 kg P ha^{-1} yr^{-1}	1.03	83	2.65	222
Digestate (FW)	**30 kg P ha^{-1} yr^{-1}**	**2.06**	**171**	2.25	188
Digestate (FW)	70 kg P ha^{-1} yr^{-1}	4.33	368	4.78	406
Horse Manure	30 kg P ha^{-1} yr^{-1}	0.75	58	1.09	88
Horse Manure	70 kg P ha^{-1} yr^{-1}	1.26	102	2.07	172
Horse Manure	**2000 kg DW ha^{-1} yr^{-1}**	**0.48**	**34**	0.58	43
Sewage sludge	**2000 kg DW ha^{-1} yr^{-1}**	**0.96**	**76**	1.12	90
Sewage sludge	30 kg P ha^{-1} yr^{-1}	0.77	60	0.88	69
Sewage sludge	70 kg P ha^{-1} yr^{-1}	1.32	107	1.57	129

Applied PTEs via lime

Table AVI-7. Mean lime application (kg ha^{-1} yr^{-1}) and estimated mean input of PTEs via lime products, given as g ha^{-1} yr^{-1}, based on results from marked surveillance activity in 2010-2014 (NFSA, 2015) and measured concentration in lime products (n=16) (Erstad, 1992).

	Lime	**As**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**
	kg ha^{-1}	g ha^{-1} yr^{-1}						
Målselv	60	0.068	0.008	0.095	0.163	0.000	0.201	0.110
Melhus	220	0.249	0.029	0.347	0.597	0.001	0.736	0.403
Stange	90	0.102	0.012	0.142	0.244	0.000	0.301	0.165
Ås	130	0.147	0.017	0.205	0.353	0.000	0.435	0.238
Time	330	0.373	0.044	0.521	0.896	0.001	1.104	0.605

Table AVI-8. Overview of crop rotations and yields* (kg ha^{-1}), which are used in the scenarios for the different regions.

	Målselv	**Melhus**	**Stange**	**Ås**	**Time**
Crop rotation 1	G-G-G-G-G	B-B-B-O	P-C-W-P-W-W-W	B-W-O-B-W	G-G-G-G-G
Crop rotation 2	P-P-P-P-G-G-G-G	G-G-G-G-G			P-C-G-G-G-G
Wheat (W)			5 600	6 800	
Barley (B)		3 800	5 100	5 750	
Oat (O)		3 600		5 200	
Potato (P)	22 500		30 000		45 000
Carrot (C			40 000		60 000
Gras (G)	5 000	6 000			11 500

*Grain yields (barley (B), wheat (W), oat (O)) given with 85% DW, grass (G) given in DW, potatoes (P) and carrots (C) in fresh weight.

Table AVI-9. Total agricultural area (ha) and share (%) of Norway's total number of animals within each category for the counties where the case municipalities are located. Data from 2019.

	Area	**Horses**	**Cattle**	**Sheep**	**Pig**	**Hen**	**Chicken**	**Goat**
	ha	%						
Akershus	78.000	9.9	2.5	1.0	3.8	3.3	2.2	1.0
Hedmark	105.000	9.7	7.4	5.3	14.6	12.4	16.1	3.7
Rogaland	100.000	7.4	17.0	20.2	27.8	26.7	24.8	5.4
Trøndelag	161.000	12.3	20.4	11.6	17.9	22.0	30.6	4.1
Troms	25.000	3.0	1.7	5.0		0.9		17.2

Appendix VII

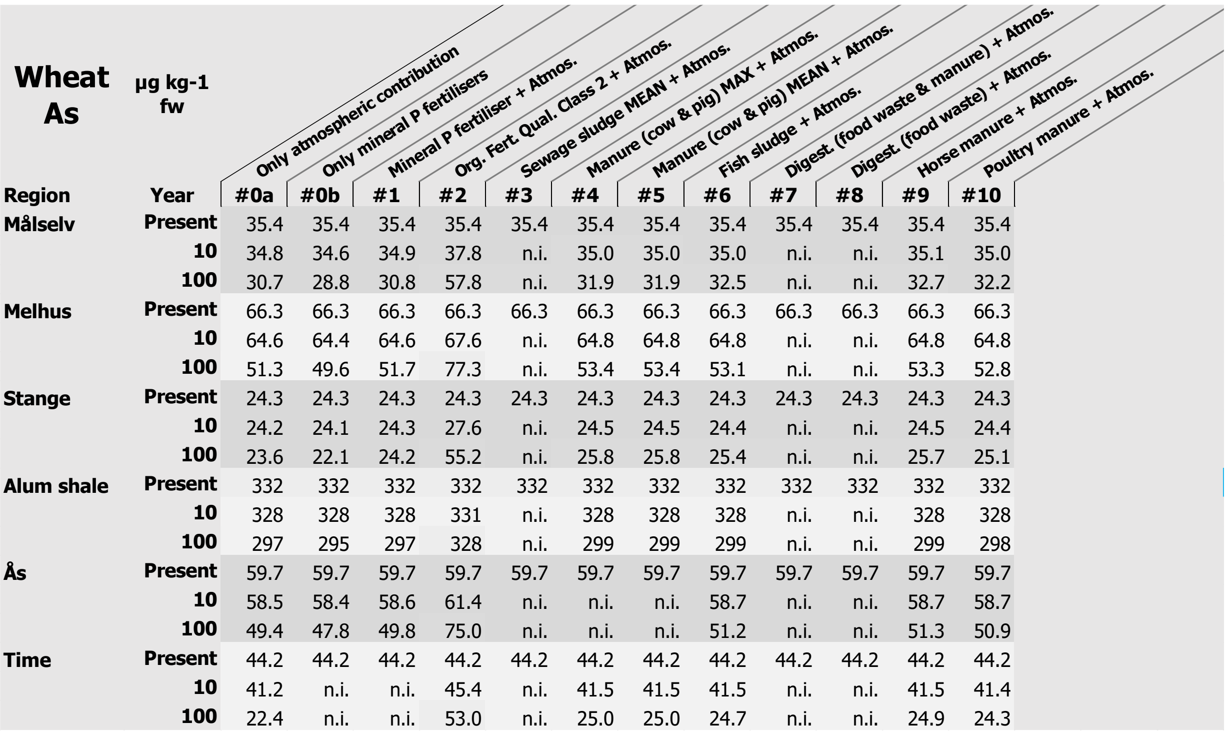
Concentration of PTEs in selected crops and vegetables

Estimated concentration of PTEs in selected crops was based on present and predicted soil concentration up to 100 year (Table 8.1.1-1 to Table 8.1.8) and the chosen TFs (Table 5.1.1.1-1). In Time, mineral P fertilisers (#0b and 1, without and with atmospheric contribution, respectively) was not included as a scenario, and in Ås manure (#4,5) was not included (in Table marked n.i.=not included).

Evaluation of organic fertiliser application of maximum amount and ML quality class II (#2) were based on established MLs for all selected PTEs, except for As where suggested ML was used.

As predicted concentrations in crops; PEC$_{plant}$

Table AVII-1. Predicted As concentration in wheat that was selected as an example for cereals, given as µg kg^{-1} FW.



Wheat As	**µg kg-1 fw**	Only atmospheric contribution	Only mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. Fert. Qual. Class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digest. (food waste) + Atmos.	Horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4
	10	34.8	34.6	34.9	37.8	n.i.	35.0	35.0	35.0	n.i.	n.i.	35.1	35.0
	100	30.7	28.8	30.8	57.8	n.i.	31.9	31.9	32.5	n.i.	n.i.	32.7	32.2
Melhus	**Present**	66.3	66.3	66.3	66.3	66.3	66.3	66.3	66.3	66.3	66.3	66.3	66.3
	10	64.6	64.4	64.6	67.6	n.i.	64.8	64.8	64.8	n.i.	n.i.	64.8	64.8
	100	51.3	49.6	51.7	77.3	n.i.	53.4	53.4	53.1	n.i.	n.i.	53.3	52.8
Stange	**Present**	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3
	10	24.2	24.1	24.3	27.6	n.i.	24.5	24.5	24.4	n.i.	n.i.	24.5	24.4
	100	23.6	22.1	24.2	55.2	n.i.	25.8	25.8	25.4	n.i.	n.i.	25.7	25.1
Alum shale	**Present**	332	332	332	332	332	332	332	332	332	332	332	332
	10	328	328	328	331	n.i.	328	328	328	n.i.	n.i.	328	328
	100	297	295	297	328	n.i.	299	299	299	n.i.	n.i.	299	298
Ås	**Present**	59.7	59.7	59.7	59.7	59.7	59.7	59.7	59.7	59.7	59.7	59.7	59.7
	10	58.5	58.4	58.6	61.4	n.i.	n.i.	n.i.	58.7	n.i.	n.i.	58.7	58.7
	100	49.4	47.8	49.8	75.0	n.i.	n.i.	n.i.	51.2	n.i.	n.i.	51.3	50.9
Time	**Present**	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2
	10	41.2	n.i.	n.i.	45.4	n.i.	41.5	41.5	41.5	n.i.	n.i.	41.5	41.4
	100	22.4	n.i.	n.i.	53.0	n.i.	25.0	25.0	24.7	n.i.	n.i.	24.9	24.3

Table AVII-2. Predicted As concentration in carrot, given as µg kg^{-1} FW.

Carrot As	µg kg-1 fw	Only atmospheric contribution	Only mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. Fert. Qual. Class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digest. (food waste) + Atmos.	Horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
	10	1.4	1.4	1.4	1.5	n.i.	1.4	1.4	1.4	n.i.	n.i.	1.4	1.4
	100	1.2	1.1	1.2	2.3	n.i.	1.3	1.3	1.3	n.i.	n.i.	1.3	1.3
Melhus	**Present**	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
	10	2.6	2.6	2.6	2.7	n.i.	2.6	2.6	2.6	n.i.	n.i.	2.6	2.6
	100	2.0	2.0	2.1	3.1	n.i.	2.1	2.1	2.1	n.i.	n.i.	2.1	2.1
Stange	**Present**	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	10	1.0	1.0	1.0	1.1	n.i.	1.0	1.0	1.0	n.i.	n.i.	1.0	1.0
	100	0.9	0.9	1.0	2.2	n.i.	1.0	1.0	1.0	n.i.	n.i.	1.0	1.0
Alum shale	**Present**	13	13	13	13	13	13	13	13	13	13	13	13
	10	13	13	13	13	n.i.	13	13	13	n.i.	n.i.	13	13
	100	12	12	12	13	n.i.	12	12	12	n.i.	n.i.	12	12
Ås	**Present**	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
	10	2.3	2.3	2.3	2.4	n.i.	n.i.	n.i.	2.3	n.i.	n.i.	2.3	2.3
	100	2.0	1.9	2.0	3.0	n.i.	n.i.	n.i.	2.0	n.i.	n.i.	2.0	2.0
Time	**Present**	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
	10	1.6	n.i.	n.i.	1.8	n.i.	1.7	1.7	1.7	n.i.	n.i.	1.7	1.7
	100	0.9	n.i.	n.i.	2.1	n.i.	1.0	1.0	1.0	n.i.	n.i.	1.0	1.0

Table AVII-3. Predicted As concentration in potato, given as µg kg^{-1} FW.

Potato As	µg kg-1 fw	Only atmospheric contribution	Only mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. Fert. Qual. Class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digest. (food waste) + Atmos.	Horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	10	1.5	1.5	1.5	1.6	n.i.	1.5	1.5	1.5	n.i.	n.i.	1.5	1.5
	100	1.3	1.2	1.3	2.5	n.i.	1.4	1.4	1.4	n.i.	n.i.	1.4	1.4
Melhus	**Present**	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9
	10	2.8	2.8	2.8	2.9	n.i.	2.8	2.8	2.8	n.i.	n.i.	2.8	2.8
	100	2.2	2.2	2.2	3.4	n.i.	2.3	2.3	2.3	n.i.	n.i.	2.3	2.3
Stange	**Present**	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
	10	1.1	1.0	1.1	1.2	n.i.	1.1	1.1	1.1	n.i.	n.i.	1.1	1.1
	100	1.0	1.0	1.1	2.4	n.i.	1.1	1.1	1.1	n.i.	n.i.	1.1	1.1
Alum shale	**Present**	14	14	14	14	14	14	14	14	14	14	14	14
	10	14	14	14	14	n.i.	14	14	14	n.i.	n.i.	14	14
	100	13	13	13	14	n.i.	13	13	13	n.i.	n.i.	13	13
Ås	**Present**	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
	10	2.5	2.5	2.5	2.7	n.i.	n.i.	n.i.	2.6	n.i.	n.i.	2.6	2.5
	100	2.1	2.1	2.2	3.3	n.i.	n.i.	n.i.	2.2	n.i.	n.i.	2.2	2.2
Time	**Present**	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
	10	1.8	n.i.	n.i.	2.0	n.i.	1.8	1.8	1.8	n.i.	n.i.	1.8	1.8
	100	1.0	n.i.	n.i.	2.3	n.i.	1.1	1.1	1.1	n.i.	n.i.	1.1	1.1

Table AVII-4. Predicted As concentration in grass, given as µg kg^{-1} FW.

Grass As	µg kg-1 fw	Only atmospheric contribution	Only mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. Fert. Qual. Class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digest. (food waste) + Atmos.	Horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
	10	11.4	11.3	11.4	12.3	n.i.	11.4	11.4	11.4	n.i.	n.i.	11.4	11.4
	100	10.0	9.4	10.0	18.8	n.i.	10.4	10.4	10.6	n.i.	n.i.	10.7	10.5
Melhus	**Present**	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6
	10	21.0	21.0	21.1	22.0	n.i.	21.1	21.1	21.1	n.i.	n.i.	21.1	21.1
	100	16.7	16.1	16.8	25.2	n.i.	17.4	17.4	17.3	n.i.	n.i.	17.4	17.2
Stange	**Present**	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9
	10	7.9	7.8	7.9	9.0	n.i.	8.0	8.0	8.0	n.i.	n.i.	8.0	7.9
	100	7.7	7.2	7.9	18.0	n.i.	8.4	8.4	8.3	n.i.	n.i.	8.4	8.2
Alum shale	**Present**	108	108	108	108	108	108	108	108	108	108	108	108
	10	107	107	107	108	n.i.	107	107	107	n.i.	n.i.	107	107
	100	97	96	97	107	n.i.	97	97	97	n.i.	n.i.	97	97
Ås	**Present**	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4
	10	19.1	19.0	19.1	20.0	n.i.	n.i.	n.i.	19.1	n.i.	n.i.	19.1	19.1
	100	16.1	15.6	16.2	24.4	n.i.	n.i.	n.i.	16.7	n.i.	n.i.	16.7	16.6
Time	**Present**	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4
	10	13.4	n.i.	n.i.	14.8	n.i.	13.5	13.5	13.5	n.i.	n.i.	13.5	13.5
	100	7.3	n.i.	n.i.	17.3	n.i.	8.1	8.1	8.0	n.i.	n.i.	8.1	7.9

Cd predicted concentrations in crops; PEC$_{plant}$

Table AVII-5. Predicted Cd concentration in wheat, given as µg kg^{-1} FW.

Wheat Cd	µg kg-1 fw	Only atmospheric contribution	Only mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. Fert. Qual. Class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digest. (food waste) + Atmos.	Horse manure + Atmos.	Poultry manure + Atmos.
Region		**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8
	10	10.7	10.7	10.9	13.2	11.6	10.9	10.8	11.2	11.3	11.4	11.3	10.9
	100	4.6	4.9	6.1	20.1	10.3	5.9	5.4	8.0	8.3	9.4	8.2	5.9
Melhus	**Present**	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5
	10	13.3	13.8	14.0	16.3	14.7	13.7	13.6	13.9	14.0	14.1	14.0	13.6
	100	6.9	9.8	11.2	26.9	15.9	9.4	8.6	10.8	11.2	12.4	11.1	8.5
Stange	**Present**	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8
	10	18.2	19.3	19.5	22.1	20.3	19.4	18.7	18.7	18.8	19.0	18.8	18.4
	100	13.8	23.1	24.8	46.6	31.3	24.1	18.0	18.4	18.9	20.2	18.7	15.6
Alum shale	**Present**	121	121	121	121	121	121	121	121	121	121	121	121
	10	116	118	118	120	119	118	117	117	117	117	117	117
	100	81	90	91	113	98	91	85	85	86	87	85	82
Ås	**Present**	30.3	30.3	30.3	30.3	30.3	30.3	30.3	30.3	30.3	30.3	30.3	30.3
	10	28.0	28.5	28.7	30.9	29.3	n.i.	n.i.	28.5	28.6	28.7	28.6	28.2
	100	13.9	17.4	18.8	34.1	23.4	n.i.	n.i.	17.7	18.1	19.2	18.0	15.4
Time	**Present**	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5
	10	16.6	n.i.	n.i.	19.4	17.4	17.0	16.9	17.3	17.3	17.5	17.3	16.8
	100	0.7	n.i.	n.i.	7.6	2.9	1.8	1.5	2.4	2.6	3.1	2.6	1.4

Table AVII-6. Predicted Cu concentration in carrot, given as µg kg^{-1} FW.

Carrot Cd	µg kg-1 fw	Only atmospheric contribution	Only mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. Fert. Qual. Class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digest. (food waste) + Atmos.	Horse manure + Atmos.	Poultry manure + Atmos.
Region		**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
	10	0.5	0.5	0.5	0.6	0.6	0.5	0.5	0.5	0.5	0.6	0.5	0.5
	100	0.2	0.2	0.3	1.0	0.5	0.3	0.3	0.4	0.4	0.5	0.4	0.3
Melhus	**Present**	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
	10	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
	100	0.3	0.5	0.5	1.3	0.8	0.5	0.4	0.5	0.5	0.6	0.5	0.4
Stange	**Present**	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	10	0.9	0.9	1.0	1.1	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	100	0.7	1.1	1.2	2.3	1.5	1.2	0.9	0.9	0.9	1.0	0.9	0.8
Alum shale	**Present**	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9
	10	5.7	5.7	5.7	5.9	5.8	5.7	5.7	5.7	5.7	5.7	5.7	5.7
	100	3.9	4.4	4.5	5.5	4.8	4.4	4.1	4.1	4.2	4.2	4.2	4.0
Ås	**Present**	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	10	1.4	1.4	1.4	1.5	1.4	n.i.	n.i.	1.4	1.4	1.4	1.4	1.4
	100	0.7	0.8	0.9	1.7	1.1	n.i.	n.i.	0.9	0.9	0.9	0.9	0.8
Time	**Present**	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
	10	0.8	n.i.	n.i.	0.9	0.8	0.8	0.8	0.8	0.8	0.9	0.8	0.8
	100	0.0	n.i.	n.i.	0.4	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1

Table AVII-7. Predicted Cd concentration in potato, given as µg kg^{-1} FW.

Potato Cd	µg kg-1 fw	Only atmospheric contribution	Only mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. Fert. Qual. Class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digest. (food waste) + Atmos.	Horse manure + Atmos.	Poultry manure + Atmos.
Region		**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7
	10	5.1	5.2	5.3	6.4	5.6	5.2	5.2	5.4	5.4	5.5	5.4	5.2
	100	2.2	2.3	2.9	9.7	5.0	2.8	2.6	3.8	4.0	4.5	4.0	2.8
Melhus	**Present**	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
	10	6.4	6.6	6.7	7.8	7.1	6.6	6.5	6.7	6.7	6.8	6.7	6.5
	100	3.3	4.7	5.4	12.9	7.7	4.5	4.1	5.2	5.4	6.0	5.4	4.1
Stange	**Present**	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
	10	8.8	9.3	9.4	10.7	9.8	9.4	9.0	9.0	9.1	9.1	9.0	8.9
	100	6.7	11.1	11.9	22.5	15.1	11.6	8.7	8.8	9.1	9.7	9.0	7.5
Alum shale	**Present**	58	58	58	58	58	58	58	58	58	58	58	58
	10	56	57	57	58	57	57	56	56	56	56	56	56
	100	39	43	44	55	47	44	41	41	41	42	41	40
Ås	**Present**	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6
	10	13.5	13.7	13.8	14.9	14.1	n.i.	n.i.	13.7	13.8	13.8	13.8	13.6
	100	6.7	8.4	9.0	16.4	11.3	n.i.	n.i.	8.5	8.7	9.3	8.7	7.4
Time	**Present**	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2
	10	8.0	n.i.	n.i.	9.3	8.4	8.2	8.1	8.3	8.3	8.4	8.3	8.1
	100	0.4	n.i.	n.i.	3.7	1.4	0.9	0.7	1.2	1.3	1.5	1.2	0.7

Table AVII-8. Predicted Cd concentration in grass, given as µg kg^{-1} FW.

Grass Cd	**µg kg-1 fw**	Only atmospheric contribution	Only mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. Fert. Qual. Class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digest. (food waste) + Atmos.	Horse manure + Atmos.	Poultry manure + Atmos.
Region		**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
	10	3.4	3.4	3.5	4.2	3.7	3.5	3.4	3.6	3.6	3.6	3.6	3.5
	100	1.5	1.6	1.9	6.4	3.3	1.9	1.7	2.5	2.7	3.0	2.6	1.9
Melhus	**Present**	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6
	10	4.2	4.4	4.4	5.2	4.7	4.4	4.3	4.4	4.4	4.5	4.4	4.3
	100	2.2	3.1	3.6	8.6	5.1	3.0	2.7	3.4	3.6	3.9	3.5	2.7
Stange	**Present**	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
	10	5.8	6.1	6.2	7.0	6.5	6.2	5.9	6.0	6.0	6.0	6.0	5.9
	100	4.4	7.4	7.9	14.8	10.0	7.7	5.7	5.8	6.0	6.4	6.0	5.0
Alum shale	**Present**	39	39	39	39	39	39	39	39	39	39	39	39
	10	37	37	37	38	38	37	37	37	37	37	37	37
	100	26	29	29	36	31	29	27	27	27	28	27	26
Ås	**Present**	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7
	10	8.9	9.1	9.1	9.8	9.3	n.i.	n.i.	9.1	9.1	9.2	9.1	9.0
	100	4.4	5.5	6.0	10.9	7.4	n.i.	n.i.	5.6	5.8	6.1	5.7	4.9
Time	**Present**	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7
	10	5.3	n.i.	n.i.	6.2	5.5	5.4	5.4	5.5	5.5	5.6	5.5	5.4
	100	0.2	n.i.	n.i.	2.4	0.9	0.6	0.5	0.8	0.8	1.0	0.8	0.5

Cr predicted concentrations in crops; PEC$_{plant}$

Table AVII-9. Predicted Cr concentration in wheat, given as µg kg^{-1} FW.

Wheat Cr	**µg kg-1 fw**	Only atmospheric contribution	Only mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. Fert. Qual. Class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digest. (food waste) + Atmos.	Horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	63.8	63.8	63.8	63.8	63.8	63.8	63.8	63.8	63.8	63.8	63.8	63.8
	10	62.9	62.7	63.0	65.1	63.3	63.0	63.0	63.1	63.1	63.3	63.2	63.0
	100	56.3	53.6	56.6	76.3	59.9	56.5	56.4	57.3	57.8	59.9	59.1	56.6
Melhus	**Present**	91.8	91.8	91.8	91.8	91.8	91.8	91.8	91.8	91.8	91.8	91.8	91.8
	10	89.5	89.3	89.6	91.7	90.0	89.6	89.6	89.7	89.7	89.9	89.8	89.6
	100	71.9	69.8	72.7	91.3	75.8	72.3	72.1	72.9	73.3	75.3	74.6	72.3
Stange	**Present**	35.7	35.7	35.7	35.7	35.7	35.7	35.7	35.7	35.7	35.7	35.7	35.7
	10	35.6	35.4	35.7	38.1	36.1	35.7	35.6	35.7	35.8	36.0	35.9	35.7
	100	34.9	32.9	35.8	58.3	39.6	35.7	35.2	35.9	36.4	38.4	37.6	35.3
Alum shale	**Present**	48	48	48	48	48	48	48	48	48	48	48	48
	10	48	48	48	51	49	48	48	48	48	49	49	48
	100	46	44	47	70	51	47	47	47	48	50	49	47
Ås	**Present**	68.9	68.9	68.9	68.9	68.9	68.9	68.9	68.9	68.9	68.9	68.9	68.9
	10	67.7	67.5	67.8	69.8	68.1	n.i.	n.i.	67.8	67.8	68.1	68.0	67.7
	100	58.3	56.4	59.2	77.5	62.3	n.i.	n.i.	59.3	59.7	61.7	60.9	58.7
Time	**Present**	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7
	10	22.6	n.i.	n.i.	25.6	23.1	22.7	22.6	22.8	22.8	23.2	23.0	22.7
	100	15.3	n.i.	n.i.	38.1	19.2	15.8	15.6	16.6	17.1	19.6	18.6	15.8

Table AVII-10. Predicted Cr concentration in carrot, given as µg kg^{-1} FW.

Carrot Cr	**µg kg-1 fw**	Only atmospheric contribution	Only mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. Fert. Qual. Class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digest. (food waste) + Atmos.	Horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8
	10	13.6	13.5	13.6	14.0	13.7	13.6	13.6	13.6	13.6	13.7	13.6	13.6
	100	12.1	11.6	12.2	16.5	12.9	12.2	12.2	12.4	12.5	12.9	12.7	12.2
Melhus	**Present**	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8
	10	19.3	19.3	19.3	19.8	19.4	19.3	19.3	19.3	19.3	19.4	19.4	19.3
	100	15.5	15.1	15.7	19.7	16.3	15.6	15.6	15.7	15.8	16.3	16.1	15.6
Stange	**Present**	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
	10	7.7	7.6	7.7	8.2	7.8	7.7	7.7	7.7	7.7	7.8	7.7	7.7
	100	7.5	7.1	7.7	12.6	8.5	7.7	7.6	7.7	7.8	8.3	8.1	7.6
Alum shale	**Present**	10	10	10	10	10	10	10	10	10	10	10	10
	10	10	10	10	11	11	10	10	10	10	10	10	10
	100	10	10	10	15	11	10	10	10	10	11	11	10
Ås	**Present**	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9
	10	14.6	14.6	14.6	15.1	14.7	n.i.	n.i.	14.6	14.6	14.7	14.7	14.6
	100	12.6	12.2	12.8	16.7	13.4	n.i.	n.i.	12.8	12.9	13.3	13.1	12.7
Time	**Present**	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
	10	4.9	n.i.	n.i.	5.5	5.0	4.9	4.9	4.9	4.9	5.0	5.0	4.9
	100	3.3	n.i.	n.i.	8.2	4.1	3.4	3.4	3.6	3.7	4.2	4.0	3.4

Table AVII-11. Predicted Cr concentration in potato, given as µg kg^{-1} FW.

Potato Cr	**µg kg-1 fw**	Only atmospheric contribution	Only mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. Fert. Qual. Class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digest. (food waste) + Atmos.	Horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
	10	29.6	29.5	29.6	30.6	29.8	29.6	29.6	29.7	29.7	29.8	29.8	29.6
	100	26.5	25.2	26.6	35.9	28.2	26.6	26.5	27.0	27.2	28.2	27.8	26.7
Melhus	**Present**	43.2	43.2	43.2	43.2	43.2	43.2	43.2	43.2	43.2	43.2	43.2	43.2
	10	42.1	42.0	42.2	43.2	42.3	42.2	42.2	42.2	42.2	42.3	42.3	42.2
	100	33.8	32.9	34.2	42.9	35.7	34.0	33.9	34.3	34.5	35.5	35.1	34.0
Stange	**Present**	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8
	10	16.8	16.7	16.8	17.9	17.0	16.8	16.8	16.8	16.8	16.9	16.9	16.8
	100	16.4	15.5	16.9	27.4	18.6	16.8	16.6	16.9	17.1	18.1	17.7	16.6
Alum shale	**Present**	23	23	23	23	23	23	23	23	23	23	23	23
	10	23	23	23	24	23	23	23	23	23	23	23	23
	100	22	21	22	33	24	22	22	22	22	23	23	22
Ås	**Present**	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4
	10	31.9	31.8	31.9	32.8	32.1	n.i.	n.i.	31.9	31.9	32.0	32.0	31.9
	100	27.5	26.6	27.9	36.5	29.3	n.i.	n.i.	27.9	28.1	29.0	28.7	27.6
Time	**Present**	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2
	10	10.6	n.i.	n.i.	12.1	10.9	10.7	10.6	10.7	10.7	10.9	10.8	10.7
	100	7.2	n.i.	n.i.	18.0	9.0	7.4	7.3	7.8	8.0	9.2	8.7	7.4

Table AVII-12. Predicted Cr concentration in grass, given as µg kg^{-1} FW.

Grass Cr	**µg kg-1 fw**	**Only atmospheric contribution**	**Only mineral P fertilisers**	**Mineral P fertiliser + Atmos.**	**Org. Fert. Qual. Class 2 + Atmos.**	**Sewage sludge MEAN + Atmos.**	**Manure (cow & pig) MAX + Atmos.**	**Manure (cow & pig) MEAN + Atmos.**	**Fish sludge + Atmos.**	**Digest. (food waste & manure) + Atmos.**	**Digest. (food waste) + Atmos.**	**Horse manure + Atmos.**	**Poultry manure + Atmos.**
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
	10	39.5	39.3	39.5	40.9	39.7	39.5	39.5	39.6	39.6	39.7	39.7	39.5
	100	35.3	33.6	35.5	47.9	37.6	35.4	35.4	36.0	36.2	37.6	37.1	35.5
Melhus	**Present**	57.6	57.6	57.6	57.6	57.6	57.6	57.6	57.6	57.6	57.6	57.6	57.6
	10	56.2	56.0	56.2	57.6	56.5	56.2	56.2	56.3	56.3	56.4	56.4	56.2
	100	45.1	43.8	45.6	57.3	47.6	45.3	45.2	45.8	46.0	47.3	46.8	45.3
Stange	**Present**	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4
	10	22.3	22.2	22.4	23.9	22.7	22.4	22.4	22.4	22.4	22.6	22.5	22.4
	100	21.9	20.7	22.5	36.6	24.9	22.4	22.1	22.5	22.8	24.1	23.6	22.1
Alum shale	**Present**	30	30	30	30	30	30	30	30	30	30	30	30
	10	30	30	30	32	31	30	30	30	30	30	30	30
	100	29	28	30	44	32	30	29	30	30	31	31	29
Ås	**Present**	43.2	43.2	43.2	43.2	43.2	43.2	43.2	43.2	43.2	43.2	43.2	43.2
	10	42.5	42.3	42.5	43.8	42.7	n.i.	n.i.	42.5	42.6	42.7	42.7	42.5
	100	36.6	35.4	37.1	48.6	39.1	n.i.	n.i.	37.2	37.5	38.7	38.2	36.8
Time	**Present**	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9
	10	14.2	n.i.	n.i.	16.1	14.5	14.2	14.2	14.3	14.3	14.5	14.4	14.2
	100	9.6	n.i.	n.i.	23.9	12.1	9.9	9.8	10.4	10.7	12.3	11.7	9.9

Cu predicted concentrations in crops; PEC$_{plant}$

Table AVII-13. Predicted Cu concentration in wheat, given as µg kg^{-1} FW.

Wheat Cu	**µg kg-1 fw**	**Only atmospheric contribution**	**Only mineral P fertilisers**	**Mineral P fertiliser + Atmos.**	**Org. Fert. Qual. Class 2 + Atmos.**	**Sewage sludge MEAN + Atmos.**	**Manure (cow & pig) MAX + Atmos.**	**Manure (cow & pig) MEAN + Atmos.**	**Fish sludge + Atmos.**	**Digest. (food waste & manure) + Atmos.**	**Digest. (food waste) + Atmos.**	**Horse manure + Atmos.**	**Poultry manure + Atmos.**
Region		**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	1666	1666	1666	1666	1666	1666	1666	1666	1666	1666	1666	1666
	10	1638	1633	1639	2287	1803	1698	1673	1651	1722	1732	1749	1706
	100	1412	1362	1418	7338	2919	1962	1732	1533	2174	2265	2428	2032
Melhus	**Present**	2380	2380	2380	2380	2380	2380	2380	2380	2380	2380	2380	2380
	10	2324	2320	2326	2965	2488	2423	2382	2337	2407	2416	2434	2391
	100	1882	1841	1896	7593	3341	2765	2397	2000	2617	2704	2861	2481
Stange	**Present**	1428	1428	1428	1428	1428	1428	1428	1428	1428	1428	1428	1428
	10	1414	1410	1416	2131	1597	1691	1557	1427	1493	1503	1520	1479
	100	1299	1257	1312	8043	3018	3900	2640	1417	2042	2130	2289	1904
Alum shale	**Present**	5117	5117	5117	5117	5117	5117	5117	5117	5117	5117	5117	5117
	10	5053	5049	5055	5770	5236	5330	5196	5066	5132	5142	5158	5117
	100	4516	4475	4529	11261	6236	7117	5857	4634	5259	5348	5506	5121
Ås	**Present**	1309	1309	1309	1309	1309	1309	1309	1309	1309	1309	1309	1309
	10	1289	1285	1291	1901	1445	n.i.	n.i.	1302	1368	1377	1394	1353
	100	1126	1088	1141	6736	2559	n.i.	n.i.	1241	1847	1933	2086	1713
Time	**Present**	1309	1309	1309	1309	1309	1309	1309	1309	1309	1309	1309	1309
	10	1210	n.i.	n.i.	2127	1443	1352	1293	1229	1328	1342	1368	1306
	100	615	n.i.	n.i.	7039	2247	1612	1197	750	1445	1543	1720	1291

Table AVII-14. Predicted Cu concentration in carrot, given as µg kg^{-1} FW.

Carrot Cu	**µg kg-1 fw**	Only atmospheric contribution	Only mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. Fert. Qual. Class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digest. (food waste) + Atmos.	Horse manure + Atmos.	Poultry manure + Atmos.
Region		**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	308	308	308	308	308	308	308	308	308	308	308	308
	10	303	302	303	423	333	314	309	305	318	320	323	315
	100	261	252	262	1357	540	363	320	283	402	419	449	376
Melhus	**Present**	440	440	440	440	440	440	440	440	440	440	440	440
	10	430	429	430	548	460	448	440	432	445	447	450	442
	100	348	340	351	1404	618	511	443	370	484	500	529	459
Stange	**Present**	264	264	264	264	264	264	264	264	264	264	264	264
	10	261	261	262	394	295	313	288	264	276	278	281	273
	100	240	232	242	1487	558	721	488	262	378	394	423	352
Alum shale	**Present**	946	946	946	946	946	946	946	946	946	946	946	946
	10	934	933	934	1067	968	985	961	937	949	951	954	946
	100	835	827	837	2082	1153	1316	1083	857	972	989	1018	947
Ås	**Present**	242	242	242	242	242	242	242	242	242	242	242	242
	10	238	238	239	351	267	n.i.	n.i.	241	253	255	258	250
	100	208	201	211	1245	473	n.i.	n.i.	229	341	357	386	317
Time	**Present**	242	242	242	242	242	242	242	242	242	242	242	242
	10	224	n.i.	n.i.	393	267	250	239	227	246	248	253	242
	100	114	n.i.	n.i.	1301	415	298	221	139	267	285	318	239

Table AVII-15. Predicted Cu concentration in potato, given as µg kg^{-1} FW.

Potato Cu	**µg kg-1 fw**	Only atmospheric contribution	Only mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. Fert. Qual. Class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digest. (food waste) + Atmos.	Horse manure + Atmos.	Poultry manure + Atmos.
Region		**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	806	806	806	806	806	806	806	806	806	806	806	806
	10	793	790	793	1107	873	822	810	799	833	838	847	826
	100	683	659	686	3552	1413	950	839	742	1052	1096	1175	984
Melhus	**Present**	1152	1152	1152	1152	1152	1152	1152	1152	1152	1152	1152	1152
	10	1125	1123	1126	1435	1204	1173	1153	1131	1165	1170	1178	1157
	100	911	891	918	3675	1617	1338	1160	968	1267	1309	1385	1201
Stange	**Present**	691	691	691	691	691	691	691	691	691	691	691	691
	10	685	682	685	1031	773	818	754	691	723	727	735	716
	100	629	609	635	3893	1461	1888	1278	686	988	1031	1108	921
Alum shale	**Present**	2477	2477	2477	2477	2477	2477	2477	2477	2477	2477	2477	2477
	10	2446	2444	2447	2793	2534	2580	2515	2452	2484	2489	2497	2477
	100	2186	2166	2192	5451	3018	3445	2835	2243	2546	2588	2665	2479
Ås	**Present**	634	634	634	634	634	634	634	634	634	634	634	634
	10	624	622	625	920	700	n.i.	n.i.	630	662	667	675	655
	100	545	527	552	3260	1239	n.i.	n.i.	601	894	935	1010	829
Time	**Present**	634	634	634	634	634	634	634	634	634	634	634	634
	10	586	n.i.	n.i.	1029	698	655	626	595	643	650	662	632
	100	298	n.i.	n.i.	3407	1088	780	579	363	699	747	833	625

Table AVII-16. Predicted Cu concentration in gras, given as μg kg^{-1} FW.

Grass Cu Region	μg kg-1 fw	Only atmospheric contribution #0a	Only mineral P fertilisers #0b	Mineral P fertiliser + Atmos. #1	Org. Fert. Qual. Class 2 + Atmos. #2	Sewage sludge MEAN + Atmos. #3	Manure (cow & pig) MAX + Atmos. #4	Manure (cow & pig) MEAN + Atmos. #5	Fish sludge + Atmos. #6	Digest. (food waste & manure) + Atmos. #7	Digest. (food waste) + Atmos. #8	Horse manure + Atmos. #9	Poultry manure + Atmos. #10
Målselv	**Present**	532	532	532	532	532	532	532	532	532	532	532	532
	10	523	521	523	730	576	542	534	527	550	553	559	545
	100	451	435	453	2343	932	626	553	490	694	723	775	649
Melhus	**Present**	760	760	760	760	760	760	760	760	760	760	760	760
	10	742	741	743	947	794	774	761	746	768	772	777	764
	100	601	588	606	2425	1067	883	765	639	836	864	914	792
Stange	**Present**	456	456	456	456	456	456	456	456	456	456	456	456
	10	452	450	452	680	510	540	497	456	477	480	485	472
	100	415	401	419	2568	964	1245	843	452	652	680	731	608
Alum shale	**Present**	1634	1634	1634	1634	1634	1634	1634	1634	1634	1634	1634	1634
	10	1614	1612	1614	1842	1672	1702	1659	1618	1639	1642	1647	1634
	100	1442	1429	1446	3596	1991	2273	1870	1480	1679	1708	1758	1635
Ås	**Present**	418	418	418	418	418	418	418	418	418	418	418	418
	10	412	410	412	607	462	n.i.	n.i.	416	437	440	445	432
	100	359	347	364	2151	817	n.i.	n.i.	396	590	617	666	547
Time	**Present**	418	418	418	418	418	418	418	418	418	418	418	418
	10	386	384	384	679	461	432	413	393	424	429	437	417
	100	196	177	177	2248	717	515	382	239	461	493	549	412

Hg predicted concentrations in crops; PEC_{plant}

Table AVII-17. Predicted Hg concentration in wheat, given as μg kg^{-1} FW.

Wheat Hg Region	μg kg-1 fw Year	Only atmospheric contribution #0a	Only mineral P fertilisers #0b	Mineral P fertiliser + Atmos. #1	Org. Fert. Qual. Class 2 + Atmos. #2	Sewage sludge MEAN + Atmos. #3	Manure (cow & pig) MAX + Atmos. #4	Manure (cow & pig) MEAN + Atmos. #5	Fish sludge + Atmos. #6	Digest. (food waste & manure) + Atmos. #7	Digest. (food waste) + Atmos. #8	Horse manure + Atmos. #9	Poultry manure + Atmos. #10
Målselv	**Present**	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
	10	1.9	1.8	1.9	3.8	2.1	n.i.	n.i.	1.9	2.0	2.4	2.0	n.i.
	100	2.9	1.8	2.9	21.1	4.7	n.i.	n.i.	3.1	3.8	8.1	3.2	n.i.
Melhus	**Present**	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
	10	2.5	2.4	2.5	4.3	2.7	n.i.	n.i.	2.5	2.6	3.0	2.5	n.i.
	100	3.4	2.3	3.4	21.3	5.2	n.i.	n.i.	3.6	4.2	8.5	3.7	n.i.
Stange	**Present**	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
	10	2.3	2.2	2.3	4.3	2.5	n.i.	n.i.	2.3	2.4	2.8	2.3	n.i.
	100	3.2	2.2	3.2	23.3	5.2	n.i.	n.i.	3.4	4.0	8.0	3.5	n.i.
Alum shale	**Present**	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
	10	2.9	2.8	2.9	4.9	3.1	n.i.	n.i.	2.9	2.9	3.3	2.9	n.i.
	100	3.7	2.7	3.8	23.8	5.8	n.i.	n.i.	4.0	4.6	8.6	4.1	n.i.
Ås	**Present**	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9
	10	3.0	2.9	3.0	4.7	3.2	n.i.	n.i.	3.0	3.1	3.5	3.0	n.i.
	100	3.8	2.8	3.8	20.9	5.5	n.i.	n.i.	4.1	4.6	8.6	4.1	n.i.
Time	**Present**	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
	10	5.1	n.i.	n.i.	7.8	5.4	n.i.	n.i.	5.2	5.3	5.9	5.2	n.i.
	100	6.2	n.i.	n.i.	32.2	8.8	n.i.	n.i.	6.6	7.5	13.6	6.7	n.i.

Table AVII-18. Predicted Hg concentration in carrot, given as µg kg^{-1} FW.

Carrot Hg	**µg kg-1 fw**	Only atmospheric contribution	Only mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. Fert. Qual. Class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digest. (food waste) + Atmos.	Horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	10	0.04	0.04	0.04	0.08	0.04	n.i.	n.i.	0.04	0.04	0.05	0.04	n.i.
	100	0.06	0.04	0.06	0.45	0.10	n.i.	n.i.	0.07	0.08	0.17	0.07	n.i.
Melhus	**Present**	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	10	0.05	0.05	0.05	0.09	0.06	n.i.	n.i.	0.05	0.05	0.06	0.05	n.i.
	100	0.07	0.05	0.07	0.45	0.11	n.i.	n.i.	0.08	0.09	0.18	0.08	n.i.
Stange	**Present**	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	10	0.05	0.05	0.05	0.09	0.05	n.i.	n.i.	0.05	0.05	0.06	0.05	n.i.
	100	0.07	0.05	0.07	0.49	0.11	n.i.	n.i.	0.07	0.08	0.17	0.07	n.i.
Alum shale	**Present**	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	10	0.06	0.06	0.06	0.10	0.06	n.i.	n.i.	0.06	0.06	0.07	0.06	n.i.
	100	0.08	0.06	0.08	0.51	0.12	n.i.	n.i.	0.08	0.10	0.18	0.09	n.i.
Ås	**Present**	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	10	0.06	0.06	0.06	0.10	0.07	n.i.	n.i.	0.06	0.07	0.07	0.06	n.i.
	100	0.08	0.06	0.08	0.44	0.12	n.i.	n.i.	0.09	0.10	0.18	0.09	n.i.
Time	**Present**	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
	10	0.11	n.i.	n.i.	0.17	0.11	n.i.	n.i.	0.11	0.11	0.13	0.11	n.i.
	100	0.13	n.i.	n.i.	0.68	0.19	n.i.	n.i.	0.14	0.16	0.29	0.14	n.i.

Table AVII-19. Predicted Hg concentration in potato, given as µg kg^{-1} FW.

Potato Hg	**µg kg-1 fw**	Only atmospheric contribution	Only mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. Fert. Qual. Class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digest. (food waste) + Atmos.	Horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
	10	0.013	0.012	0.013	0.025	0.014	n.i.	n.i.	0.013	0.013	0.016	0.013	n.i.
	100	0.019	0.012	0.019	0.140	0.031	n.i.	n.i.	0.021	0.025	0.053	0.021	n.i.
Melhus	**Present**	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
	10	0.017	0.016	0.017	0.029	0.018	n.i.	n.i.	0.017	0.017	0.020	0.017	n.i.
	100	0.022	0.015	0.022	0.141	0.034	n.i.	n.i.	0.024	0.028	0.056	0.025	n.i.
Stange	**Present**	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
	10	0.015	0.014	0.015	0.028	0.016	n.i.	n.i.	0.015	0.016	0.018	0.015	n.i.
	100	0.021	0.014	0.021	0.154	0.034	n.i.	n.i.	0.023	0.026	0.053	0.023	n.i.
Alum shale	**Present**	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018
	10	0.019	0.018	0.019	0.032	0.020	n.i.	n.i.	0.019	0.019	0.022	0.019	n.i.
	100	0.025	0.018	0.025	0.158	0.038	n.i.	n.i.	0.026	0.030	0.057	0.027	n.i.
Ås	**Present**	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
	10	0.020	0.019	0.020	0.031	0.021	n.i.	n.i.	0.020	0.020	0.023	0.020	n.i.
	100	0.025	0.019	0.025	0.138	0.037	n.i.	n.i.	0.027	0.031	0.057	0.027	n.i.
Time	**Present**	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
	10	0.034	n.i.	n.i.	0.052	0.036	n.i.	n.i.	0.034	0.035	0.039	0.034	n.i.
	100	0.041	n.i.	n.i.	0.213	0.058	n.i.	n.i.	0.044	0.049	0.090	0.044	n.i.

Table AVII-20. Predicted Hg concentration in grass, given as µg kg^{-1} FW.

Grass Hg	**µg kg-1 fw**	**Only atmospheric contribution**	**Only mineral P fertilisers**	**Mineral P fertiliser + Atmos.**	**Org. Fert. Qual. Class 2 + Atmos.**	**Sewage sludge MEAN + Atmos.**	**Manure (cow & pig) MAX + Atmos.**	**Manure (cow & pig) MEAN + Atmos.**	**Fish sludge + Atmos.**	**Digest. (food waste & manure) + Atmos.**	**Digest. (food waste) + Atmos.**	**Horse manure + Atmos.**	**Poultry manure + Atmos.**
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
	10	0.042	0.040	0.042	0.083	0.046	n.i.	n.i.	0.043	0.044	0.054	0.043	n.i.
	100	0.063	0.039	0.064	0.466	0.104	n.i.	n.i.	0.069	0.083	0.178	0.071	n.i.
Melhus	**Present**	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053
	10	0.055	0.053	0.055	0.095	0.059	n.i.	n.i.	0.056	0.057	0.066	0.056	n.i.
	100	0.074	0.051	0.075	0.469	0.114	n.i.	n.i.	0.080	0.093	0.186	0.082	n.i.
Stange	**Present**	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048
	10	0.050	0.048	0.050	0.095	0.055	n.i.	n.i.	0.051	0.052	0.061	0.051	n.i.
	100	0.070	0.047	0.070	0.513	0.114	n.i.	n.i.	0.075	0.088	0.177	0.077	n.i.
Alum shale	**Present**	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061
	10	0.063	0.061	0.063	0.108	0.067	n.i.	n.i.	0.064	0.065	0.074	0.064	n.i.
	100	0.082	0.060	0.083	0.525	0.127	n.i.	n.i.	0.088	0.101	0.190	0.090	n.i.
Ås	**Present**	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064
	10	0.066	0.064	0.066	0.104	0.070	n.i.	n.i.	0.067	0.068	0.077	0.067	n.i.
	100	0.084	0.062	0.084	0.460	0.122	n.i.	n.i.	0.089	0.102	0.191	0.091	n.i.
Time	**Present**	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110
	10	0.113	n.i.	n.i.	0.172	0.119	n.i.	n.i.	0.114	0.116	0.130	0.114	n.i.
	100	0.137	n.i.	n.i.	0.710	0.195	n.i.	n.i.	0.145	0.165	0.300	0.148	n.i.

Ni predicted concentrations in crops; PEC$_{plant}$

Table AVII-21. Predicted Ni concentration in wheat, given as µg kg^{-1} FW.

Wheat Ni	**µg kg^{-1} fw**	**Only atmospheric contribution**	**Only mineral P fertilisers**	**Mineral P fertiliser + Atmos.**	**Org. Fert. Qual. Class 2 + Atmos.**	**Sewage sludge MEAN + Atmos.**	**Manure (cow & pig) MAX + Atmos.**	**Manure (cow & pig) MEAN + Atmos.**	**Fish sludge + Atmos.**	**Digest. (food waste & manure) + Atmos.**	**Digest. (food waste) + Atmos.**	**Horse manure + Atmos.**	**Poultry manure + Atmos.**
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	88.4	88.4	88.4	88.4	88.4	88.4	88.4	88.4	88.4	88.4	88.4	88.4
	10	79.1	78.6	79.1	81.8	79.8	79.3	79.1	79.2	79.6	79.2	79.5	79.3
	100	30.2	27.4	30.3	47.3	34.7	31.5	30.7	31.1	33.4	31.3	33.0	31.4
Melhus	**Present**	156	156	156	156	156	156	156	156	156	156	156	156
	10	136	136	136	139	137	137	136	136	137	136	137	137
	100	40.8	38.5	41.2	56.5	45.1	42.9	41.6	41.7	43.8	41.9	43.5	42.0
Stange	**Present**	81.6	81.6	81.6	81.6	81.6	81.6	81.6	81.6	81.6	81.6	81.6	81.6
	10	77.5	77.2	77.6	80.7	78.4	78.0	77.7	77.7	78.0	77.7	78.0	77.7
	100	49.7	46.7	50.3	74.4	56.5	53.3	50.9	50.8	53.7	51.1	53.2	51.3
Alum shale	**Present**	347	347	347	347	347	347	347	347	347	347	347	347
	10	328	328	328	331	329	329	328	328	329	328	329	328
	100	200	197	201	225	207	203	201	201	204	201	203	201
Ås	**Present**	95.2	95.2	95.2	95.2	95.2	95.2	95.2	95.2	95.2	95.2	95.2	95.2
	10	85.8	85.4	85.8	88.4	86.5	n.i.	n.i.	85.9	86.3	85.9	86.2	86.0
	100	34.7	32.2	35.1	51.5	39.3	n.i.	n.i.	35.6	37.9	35.8	37.5	35.9
Time	**Present**	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5
	10	16.6	n.i.	n.i.	20.1	17.5	17.1	16.8	16.8	17.3	16.9	17.2	16.9
	100	2.0	n.i.	n.i.	11.9	4.7	3.4	2.6	2.6	4.0	2.7	3.7	2.8

Table AVII-22. Predicted Ni concentration in carrot, given as µg kg^{-1} FW.

Carrot Ni	**µg kg^{-1} fw**	Only atmospheric contribution	Only mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. Fert. Qual. Class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digest. (food waste) + Atmos.	Horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4
	10	10.2	10.2	10.2	10.6	10.3	10.3	10.2	10.3	10.3	10.3	10.3	10.3
	100	3.9	3.5	3.9	6.1	4.5	4.1	4.0	4.0	4.3	4.0	4.3	4.1
Melhus	**Present**	20	20	20	20	20	20	20	20	20	20	20	20
	10	18	18	18	18	18	18	18	18	18	18	18	18
	100	5.3	5.0	5.3	7.3	5.8	5.6	5.4	5.4	5.7	5.4	5.6	5.4
Stange	**Present**	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
	10	10.0	10.0	10.0	10.4	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1
	100	6.4	6.0	6.5	9.6	7.3	6.9	6.6	6.6	7.0	6.6	6.9	6.6
Alum shale	**Present**	45	45	45	45	45	45	45	45	45	45	45	45
	10	42	42	42	43	43	43	42	42	43	42	43	42
	100	26	25	26	29	27	26	26	26	26	26	26	26
Ås	**Present**	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3
	10	11.1	11.0	11.1	11.4	11.2	n.i.	n.i.	11.1	11.2	11.1	11.2	11.1
	100	4.5	4.2	4.5	6.7	5.1	n.i.	n.i.	4.6	4.9	4.6	4.8	4.6
Time	**Present**	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
	10	2.2	n.i.	n.i.	2.6	2.3	2.2	2.2	2.2	2.2	2.2	2.2	2.2
	100	0.3	n.i.	n.i.	1.5	0.6	0.4	0.3	0.3	0.5	0.4	0.5	0.4

Table AVII-23. Predicted Ni concentration in potato, given as µg kg^{-1} FW.

Potato Ni	**µg kg^{-1} fw**	Only atmospheric contribution	Only mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. Fert. Qual. Class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digest. (food waste) + Atmos.	Horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	62.4	62.4	62.4	62.4	62.4	62.4	62.4	62.4	62.4	62.4	62.4	62.4
	10	55.8	55.5	55.8	57.7	56.3	56.0	55.9	55.9	56.2	55.9	56.1	56.0
	100	21.3	19.4	21.4	33.4	24.5	22.3	21.7	21.9	23.6	22.1	23.3	22.2
Melhus	**Present**	110	110	110	110	110	110	110	110	110	110	110	110
	10	96	96	96	98	97	96	96	96	97	96	97	96
	100	28.8	27.2	29.1	39.9	31.9	30.3	29.4	29.4	31.0	29.6	30.7	29.7
Stange	**Present**	57.6	57.6	57.6	57.6	57.6	57.6	57.6	57.6	57.6	57.6	57.6	57.6
	10	54.7	54.5	54.8	57.0	55.3	55.1	54.8	54.8	55.1	54.9	55.0	54.9
	100	35.1	33.0	35.5	52.6	39.9	37.6	35.9	35.9	37.9	36.1	37.6	36.2
Alum shale	**Present**	245	245	245	245	245	245	245	245	245	245	245	245
	10	232	231	232	234	232	232	232	232	232	232	232	232
	100	141	139	142	159	146	144	142	142	144	142	144	142
Ås	**Present**	67.2	67.2	67.2	67.2	67.2	67.2	67.2	67.2	67.2	67.2	67.2	67.2
	10	60.5	60.3	60.6	62.4	61.1	n.i.	n.i.	60.6	60.9	60.7	60.9	60.7
	100	24.5	22.7	24.7	36.4	27.7	n.i.	n.i.	25.1	26.7	25.3	26.4	25.4
Time	**Present**	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3
	10	11.7	n.i.	n.i.	14.2	12.4	12.1	11.9	11.9	12.2	11.9	12.2	11.9
	100	1.4	n.i.	n.i.	8.4	3.3	2.4	1.8	1.8	2.8	1.9	2.6	2.0

Table AVII-24. Predicted Ni concentration in grass, given as µg kg^{-1} FW.

Grass Ni	**µg kg^{-1} fw**	**Only atmospheric contribution**	**Only mineral P fertilisers**	**Mineral P fertiliser + Atmos.**	**Org. Fert. Qual. Class 2 + Atmos.**	**Sewage sludge MEAN + Atmos.**	**Manure (cow & pig) MAX + Atmos.**	**Manure (cow & pig) MEAN + Atmos.**	**Fish sludge + Atmos.**	**Digest. (food waste & manure) + Atmos.**	**Digest. (food waste) + Atmos.**	**Horse manure + Atmos.**	**Poultry manure + Atmos.**
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	130.0	130.0	130.0	130.0	130.0	130.0	130.0	130.0	130.0	130.0	130.0	130.0
	10	116.3	115.6	116.3	120.3	117.3	116.6	116.4	116.5	117.0	116.5	116.9	116.6
	100	44.4	40.3	44.6	69.5	51.0	46.4	45.1	45.7	49.2	46.0	48.6	46.2
Melhus	**Present**	230	230	230	230	230	230	230	230	230	230	230	230
	10	200	200	201	204	202	201	201	201	201	201	201	201
	100	60.1	56.6	60.6	83.0	66.4	63.1	61.2	61.3	64.5	61.6	63.9	61.8
Stange	**Present**	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0
	10	114.0	113.5	114.1	118.7	115.3	114.7	114.2	114.2	114.8	114.3	114.7	114.3
	100	73.1	68.7	74.0	109.5	83.1	78.3	74.8	74.8	79.0	75.1	78.3	75.4
Alum shale	**Present**	510	510	510	510	510	510	510	510	510	510	510	510
	10	482	482	483	487	484	483	483	483	483	483	483	483
	100	294	290	295	330	304	299	296	296	300	296	299	296
Ås	**Present**	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0
	10	126.1	125.6	126.2	130.0	127.2	n.i.	n.i.	126.3	126.9	126.4	126.8	126.4
	100	51.0	47.3	51.5	75.8	57.8	n.i.	n.i.	52.3	55.7	52.6	55.1	52.8
Time	**Present**	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0
	10	24.4	n.i.	n.i.	29.5	25.8	25.1	24.7	24.8	25.5	24.8	25.3	24.9
	100	3.0	n.i.	n.i.	17.5	6.8	5.0	3.8	3.9	5.9	4.0	5.5	4.2

Pb predicted concentrations in crops; PEC$_{plant}$

Table AVII-25. Predicted Pb concentration in wheat, given as µg kg^{-1} FW.

Wheat Pb	**µg kg^{-1} fw**	**Only atmospheric contribution**	**Only mineral P fertilisers**	**Mineral P fertiliser + Atmos.**	**Org. Fert. Qual. Class 2 + Atmos.**	**Sewage sludge MEAN + Atmos.**	**Manure (cow & pig) MAX + Atmos.**	**Manure (cow & pig) MEAN + Atmos.**	**Fish sludge + Atmos.**	**Digest. (food waste & manure) + Atmos.**	**Digest. (food waste) + Atmos.**	**Horse manure + Atmos.**	**Poultry manure + Atmos.**
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5
	10	26.1	25.4	26.1	29.0	26.6	26.2	26.2	26.2	26.4	26.5	27.2	26.2
	100	31.7	24.7	31.8	60.1	36.7	32.0	32.0	32.4	34.0	35.0	42.1	32.0
Melhus	**Present**	41	41	41	41	41	41	41	41	41	41	41	41
	10	41	41	41	44	42	41	41	41	42	42	42	41
	100	46.4	39.5	46.6	74.5	51.5	46.9	46.9	47.1	48.7	49.6	56.6	46.7
Stange	**Present**	34.4	34.4	34.4	34.4	34.4	34.4	34.4	34.4	34.4	34.4	34.4	34.4
	10	35.0	34.4	35.1	38.2	35.6	35.1	35.1	35.1	35.3	35.4	36.0	35.1
	100	40.6	34.0	40.8	72.2	46.2	41.0	41.0	41.3	42.8	43.8	50.5	40.9
Alum shale	**Present**	85	85	85	85	85	85	85	85	85	85	85	85
	10	86	85	86	89	86	86	86	86	86	86	87	86
	100	90	84	91	122	96	91	91	91	93	94	100	91
Ås	**Present**	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0
	10	68.5	67.8	68.5	71.2	69.0	n.i.	n.i.	68.5	68.7	68.8	69.5	68.5
	100	72.7	66.2	72.9	99.6	77.5	n.i.	n.i.	73.3	74.9	75.8	82.5	73.0
Time	**Present**	97.8	97.8	97.8	97.8	97.8	97.8	97.8	97.8	97.8	97.8	97.8	97.8
	10	97.5	n.i.	n.i.	101.7	98.3	97.6	97.6	97.6	97.9	98.0	99.1	97.6
	100	95.6	n.i.	n.i.	135.1	102.5	96.3	96.3	96.6	98.9	100.3	110.2	96.2

Table AVII-26. Predicted Pb concentration in carrot, given as µg kg^{-1} FW.

Carrot Pb	**µg kg^{-1} fw**	**Only atmospheric contribution**	**Only mineral P fertilisers**	**Mineral P fertiliser + Atmos.**	**Org. Fert. Qual. Class 2 + Atmos.**	**Sewage sludge MEAN + Atmos.**	**Manure (cow & pig) MAX + Atmos.**	**Manure (cow & pig) MEAN + Atmos.**	**Fish sludge + Atmos.**	**Digest. (food waste & manure) + Atmos.**	**Digest. (food waste) + Atmos.**	**Horse manure + Atmos.**	**Poultry manure + Atmos.**
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3
	10	7.4	7.2	7.4	8.3	7.6	7.4	7.4	7.5	7.5	7.5	7.7	7.4
	100	9.0	7.0	9.1	17.1	10.4	9.1	9.1	9.2	9.7	10.0	12.0	9.1
Melhus	**Present**	12	12	12	12	12	12	12	12	12	12	12	12
	10	12	12	12	13	12	12	12	12	12	12	12	12
	100	13.2	11.2	13.3	21.2	14.7	13.3	13.3	13.4	13.9	14.1	16.1	13.3
Stange	**Present**	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8
	10	10.0	9.8	10.0	10.9	10.1	10.0	10.0	10.0	10.0	10.1	10.3	10.0
	100	11.6	9.7	11.6	20.6	13.2	11.7	11.7	11.7	12.2	12.5	14.4	11.7
Alum shale	**Present**	24	24	24	24	24	24	24	24	24	24	24	24
	10	24	24	24	25	25	24	24	24	24	24	25	24
	100	26	24	26	35	27	26	26	26	26	27	29	26
Ås	**Present**	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4
	10	19.5	19.3	19.5	20.3	19.6	n.i.	n.i.	19.5	19.6	19.6	19.8	19.5
	100	20.7	18.8	20.7	28.4	22.1	n.i.	n.i.	20.9	21.3	21.6	23.5	20.8
Time	**Present**	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8
	10	27.8	n.i.	n.i.	29.0	28.0	27.8	27.8	27.8	27.9	27.9	28.2	27.8
	100	27.2	n.i.	n.i.	38.5	29.2	27.4	27.4	27.5	28.2	28.6	31.4	27.4

Table AVII-27. Predicted Pb concentration in potato, given as µg kg^{-1} FW.

Potato Pb	**µg kg^{-1} fw**	**Only atmospheric contribution**	**Only mineral P fertilisers**	**Mineral P fertiliser + Atmos.**	**Org. Fert. Qual. Class 2 + Atmos.**	**Sewage sludge MEAN + Atmos.**	**Manure (cow & pig) MAX + Atmos.**	**Manure (cow & pig) MEAN + Atmos.**	**Fish sludge + Atmos.**	**Digest. (food waste & manure) + Atmos.**	**Digest. (food waste) + Atmos.**	**Horse manure + Atmos.**	**Poultry manure + Atmos.**
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
	10	11.8	11.5	11.8	13.1	12.0	11.8	11.8	11.8	11.9	12.0	12.3	11.8
	100	14.3	11.2	14.4	27.1	16.6	14.4	14.4	14.6	15.4	15.8	19.0	14.5
Melhus	**Present**	18	18	18	18	18	18	18	18	18	18	18	18
	10	19	18	19	20	19	19	19	19	19	19	19	19
	100	20.9	17.8	21.0	33.7	23.3	21.2	21.2	21.3	22.0	22.4	25.6	21.1
Stange	**Present**	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6
	10	15.8	15.5	15.8	17.3	16.1	15.9	15.9	15.9	15.9	16.0	16.3	15.8
	100	18.4	15.4	18.4	32.6	20.9	18.5	18.5	18.6	19.4	19.8	22.8	18.5
Alum shale	**Present**	38	38	38	38	38	38	38	38	38	38	38	38
	10	39	38	39	40	39	39	39	39	39	39	39	39
	100	41	38	41	55	43	41	41	41	42	42	45	41
Ås	**Present**	30.7	30.7	30.7	30.7	30.7	30.7	30.7	30.7	30.7	30.7	30.7	30.7
	10	30.9	30.6	30.9	32.2	31.2	n.i.	n.i.	31.0	31.0	31.1	31.4	30.9
	100	32.8	29.9	32.9	45.0	35.0	n.i.	n.i.	33.1	33.8	34.3	37.3	33.0
Time	**Present**	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2
	10	44.1	n.i.	n.i.	45.9	44.4	44.1	44.1	44.1	44.2	44.3	44.8	44.1
	100	43.2	n.i.	n.i.	61.0	46.3	43.5	43.5	43.7	44.7	45.3	49.8	43.4

Table AVII-28. Predicted Pb concentration in grass, given as µg kg^{-1} FW.

Grass Pb	µg kg^{-1} fw	Only atmospheric contribution	Only mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. Fert. Qual. Class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digest. (food waste) + Atmos.	Horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
	10	12.3	12.0	12.3	13.7	12.5	12.3	12.3	12.3	12.4	12.5	12.8	12.3
	100	14.9	11.6	15.0	28.3	17.3	15.0	15.0	15.2	16.0	16.5	19.8	15.1
Melhus	**Present**	19	19	19	19	19	19	19	19	19	19	19	19
	10	19	19	19	21	20	19	19	20	20	20	20	19
	100	21.8	18.6	21.9	35.1	24.2	22.1	22.1	22.2	22.9	23.4	26.6	22.0
Stange	**Present**	16.2	16.2	16.2	16.2	16.2	16.2	16.2	16.2	16.2	16.2	16.2	16.2
	10	16.5	16.2	16.5	18.0	16.8	16.5	16.5	16.5	16.6	16.6	17.0	16.5
	100	19.1	16.0	19.2	34.0	21.7	19.3	19.3	19.4	20.2	20.6	23.8	19.3
Alum shale	**Present**	40	40	40	40	40	40	40	40	40	40	40	40
	10	40	40	40	42	41	40	40	40	40	40	41	40
	100	43	39	43	57	45	43	43	43	44	44	47	43
Ås	**Present**	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0
	10	32.2	31.9	32.2	33.5	32.5	n.i.	n.i.	32.3	32.3	32.4	32.7	32.2
	100	34.2	31.1	34.3	46.9	36.5	n.i.	n.i.	34.5	35.2	35.7	38.8	34.4
Time	**Present**	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0
	10	45.9	n.i.	n.i.	47.9	46.2	45.9	45.9	45.9	46.1	46.1	46.6	45.9
	100	45.0	n.i.	n.i.	63.6	48.3	45.3	45.3	45.5	46.6	47.2	51.8	45.3

Zn predicted concentrations in crops; PEC$_{plant}$

Table AVII-29. Predicted Zn concentration in wheat, given as µg kg^{-1} FW.

Wheat Zn	µg kg^{-1} fw	Only atmospheric contribution	Only mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. Fert. Qual. Class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digest. (food waste) + Atmos.	Horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	12 121	12 121	12 121	12 121	12 121	12 121	12 121	12 121	12 121	12 121	12 121	12 121
	10	11 609	11 551	11 616	13 358	12 467	12 040	11 970	12 276	12 396	12 941	11 953	12 429
	100	7 968	7 498	8 028	22 145	14 929	11 462	10 895	13 376	14 349	18 769	10 757	14 622
Melhus	**Present**	14 493	14 493	14 493	14 493	14 493	14 493	14 493	14 493	14 493	14 493	14 493	14 493
	10	14 032	13 985	14 050	15 784	14 898	14 747	14 631	14 696	14 816	15 358	14 374	14 849
	100	10 570	10 173	10 726	25 490	17 944	16 660	15 672	16 226	17 243	21 866	13 487	17 529
Stange	**Present**	11 331	11 331	11 331	11 331	11 331	11 331	11 331	11 331	11 331	11 331	11 331	11 331
	10	11 177	11 155	11 218	13 162	12 168	16 262	13 276	11 815	11 930	12 452	11 506	11 962
	100	9 918	9 722	10 296	28 150	19 024	56 621	29 200	15 780	16 835	21 626	12 941	17 130
Alum shale	**Present**	28 985	28 985	28 985	28 985	28 985	28 985	28 985	28 985	28 985	28 985	28 985	28 985
	10	28 494	28 473	28 535	30 480	29 486	33 580	30 594	29 133	29 247	29 769	28 823	29 280
	100	24 478	24 282	24 856	42 709	33 584	71 180	43 760	30 340	31 395	36 186	27 501	31 690
Ås	**Present**	21 344	21 344	21 344	21 344	21 344	21 344	21 344	21 344	21 344	21 344	21 344	21 344
	10	20 708	20 666	20 728	22 381	21 536	n.i.	n.i.	21 341	21 455	21 972	21 034	21 487
	100	15 844	15 484	16 020	30 318	23 010	n.i.	n.i.	21 321	22 306	26 783	18 669	22 583
Time	**Present**	9 486	9 486	9 486	9 486	9 486	9 486	9 486	9 486	9 486	9 486	9 486	9 486
	10	8 196	n.i.	n.i.	10 607	9 375	9 190	9 029	9 119	9 286	10 040	8 672	9 332
	100	2 461	n.i.	n.i.	15 590	8 879	7 876	6 997	7 490	8 395	12 505	5 054	8 648

Table AVII-30. Predicted Zn concentration in carrot, given as µg kg^{-1} FW.

Carrot Zn	µg kg^{-1} fw	Only atmospheric contribution	Only mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. Fert. Qual. Class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digest. (food waste) + Atmos.	Horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	223	223	223	223	223	223	223	223	223	223	223	223
	10	213	212	213	245	229	221	220	225	228	238	220	228
	100	146	138	147	407	274	211	200	246	264	345	198	269
Melhus	**Present**	266	266	266	266	266	266	266	266	266	266	266	266
	10	258	257	258	290	274	271	269	270	272	282	264	273
	100	194	187	197	468	330	306	288	298	317	402	248	322
Stange	**Present**	208	208	208	208	208	208	208	208	208	208	208	208
	10	205	205	206	242	224	299	244	217	219	229	211	220
	100	182	179	189	517	349	1040	536	290	309	397	238	315
Alum shale	**Present**	532	532	532	532	532	532	532	532	532	532	532	532
	10	523	523	524	560	542	617	562	535	537	547	529	538
	100	450	446	457	784	617	1307	804	557	577	665	505	582
Ås	**Present**	392	392	392	392	392	392	392	392	392	392	392	392
	10	380	380	381	411	396	n.i.	n.i.	392	394	404	386	395
	100	291	284	294	557	423	n.i.	n.i.	392	410	492	343	415
Time	**Present**	174	174	174	174	174	174	174	174	174	174	174	174
	10	151	n.i.	n.i.	195	172	169	166	168	171	184	159	171
	100	45	n.i.	n.i.	286	163	145	129	138	154	230	93	159

Table AVII-31. Predicted Zn concentration in potato, given as µg kg^{-1} FW.

Potato Zn	µg kg^{-1} fw	Only atmospheric contribution	Only mineral P fertilisers	Mineral P fertiliser + Atmos.	Org. Fert. Qual. Class 2 + Atmos.	Sewage sludge MEAN + Atmos.	Manure (cow & pig) MAX + Atmos.	Manure (cow & pig) MEAN + Atmos.	Fish sludge + Atmos.	Digest. (food waste & manure) + Atmos.	Digest. (food waste) + Atmos.	Horse manure + Atmos.	Poultry manure + Atmos.
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	2098	2098	2098	2098	2098	2098	2098	2098	2098	2098	2098	2098
	10	2009	1999	2010	2312	2158	2084	2071	2124	2145	2240	2068	2151
	100	1379	1298	1389	3832	2584	1984	1885	2315	2483	3248	1862	2530
Melhus	**Present**	2508	2508	2508	2508	2508	2508	2508	2508	2508	2508	2508	2508
	10	2428	2420	2431	2731	2578	2552	2532	2543	2564	2658	2488	2570
	100	1829	1760	1856	4411	3105	2883	2712	2808	2984	3784	2334	3033
Stange	**Present**	1961	1961	1961	1961	1961	1961	1961	1961	1961	1961	1961	1961
	10	1934	1930	1941	2278	2106	2814	2298	2045	2065	2155	1991	2070
	100	1716	1683	1782	4871	3292	9799	5053	2731	2913	3742	2240	2965
Alum shale	**Present**	5016	5016	5016	5016	5016	5016	5016	5016	5016	5016	5016	5016
	10	4931	4927	4938	5275	5103	5811	5294	5042	5061	5152	4988	5067
	100	4236	4202	4301	7391	5812	12318	7573	5250	5433	6262	4759	5484
Ås	**Present**	3694	3694	3694	3694	3694	3694	3694	3694	3694	3694	3694	3694
	10	3584	3576	3587	3873	3727	n.i.	n.i.	3693	3713	3802	3640	3718
	100	2742	2680	2772	5247	3982	n.i.	n.i.	3690	3860	4635	3231	3908
Time	**Present**	1642	1642	1642	1642	1642	1642	1642	1642	1642	1642	1642	1642
	10	1418	n.i.	n.i.	1836	1622	1590	1563	1578	1607	1738	1501	1615
	100	426	n.i.	n.i.	2698	1537	1363	1211	1296	1453	2164	875	1497

Table AVII-32. Predicted Zn concentration in grass, given as µg kg^{-1} FW.

Grass Zn	**µg kg^{-1} fw**	**Only atmospheric contribution**	**Only mineral P fertilisers**	**Mineral P fertiliser + Atmos.**	**Org. Fert. Qual. Class 2 + Atmos.**	**Sewage sludge MEAN + Atmos.**	**Manure (cow & pig) MAX + Atmos.**	**Manure (cow & pig) MEAN + Atmos.**	**Fish sludge + Atmos.**	**Digest. (food waste & manure) + Atmos.**	**Digest. (food waste) + Atmos.**	**Horse manure + Atmos.**	**Poultry manure + Atmos.**
Region	**Year**	**#0a**	**#0b**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Målselv	**Present**	2300	2300	2300	2300	2300	2300	2300	2300	2300	2300	2300	2300
	10	2203	2192	2204	2535	2366	2285	2271	2329	2352	2456	2268	2359
	100	1512	1423	1523	4202	2833	2175	2067	2538	2723	3561	2041	2775
Melhus	**Present**	2750	2750	2750	2750	2750	2750	2750	2750	2750	2750	2750	2750
	10	2663	2654	2666	2995	2827	2798	2776	2789	2811	2914	2728	2818
	100	2006	1930	2035	4837	3405	3161	2974	3079	3272	4149	2559	3326
Stange	**Present**	2150	2150	2150	2150	2150	2150	2150	2150	2150	2150	2150	2150
	10	2121	2117	2129	2498	2309	3086	2519	2242	2264	2363	2183	2270
	100	1882	1845	1954	5342	3610	10744	5541	2994	3194	4104	2456	3251
Alum shale	**Present**	5500	5500	5500	5500	5500	5500	5500	5500	5500	5500	5500	5500
	10	5407	5403	5415	5784	5595	6372	5805	5528	5550	5649	5469	5556
	100	4645	4608	4717	8104	6373	13507	8304	5757	5957	6866	5218	6013
Ås	**Present**	4050	4050	4050	4050	4050	4050	4050	4050	4050	4050	4050	4050
	10	3929	3921	3933	4247	4087	n.i.	n.i.	4050	4071	4169	3991	4077
	100	3006	2938	3040	5753	4366	n.i.	n.i.	4046	4233	5082	3542	4285
Time	**Present**	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
	10	1555	n.i.	n.i.	2013	1779	1744	1713	1730	1762	1905	1646	1771
	100	467	n.i.	n.i.	2958	1685	1495	1328	1421	1593	2373	959	1641

The scenarios with increasing predicted PTE concentrations in crops (PEC_{plants}) over time follows same trend as PEC_{soil}. Table AVII-33 present which scenarios – input sources and regions – show increasing PEC_{plants} with time.

TABLE VII-33. Summary of scenarios with enhanced concentration in crops (and soil) with time.

	Fertiliser scheme	**Application**	**Scenarios**					
			Måls-elv	**Mel - hus**	**Stange**	**Alum shale**	**Ås**	**Time**
As	Org.fertil.reg. qual. Class II	Max amount & ML PTE quality Cl. 2[1]			x			
	Manure cattle, pig	C.f recommendation[2] & Meas. max conc.[7] Used upper bond for values < LOQ			x			
	Manure cattle, pig	C.f recommendation[2] & Meas. mean conc.[7] Used upper bond for values < LOQ			x			
	Manure poultry	Suggested limit.[8] & collected data[9] Used upper bond for values < LOD			x			

	Fertiliser scheme	**Application**	**Scenarios**					
	Horse manure	Max amount[1]* & mean PTE [6]* No only composted manure data			x			
	Fish sludge	Suggested limit.[8] & collected data[9]			x			
Cd	Min. P fertiliser	C.f recommendation[2] & data from Yara[3]			x			
	Min. P fertiliser & lime	C.f recommendation [2,4] & data from Yara[4]						
	Org.fertil.reg. qual. Class II	Max amount & ML PTE quality Cl. 2[1]	x	x	x			
	Sewage sludge	Max amount[1] & mean PTE[6]		x	x			
	Manure	C.f recommendation[2] & Meas. max conc.[7]			x			
	Manure	C.f recommendation[2] & Meas. mean conc.[7]		x	x			
Cr	Org.fertil.reg. qual. Class II	Max amount & ML PTE quality Cl. 2[1]	x		x	x	x	x
	Sewage sludge	Max amount[1] & mean PTE[6]			x			
Cu	Sewage sludge	Max amount & ML PTE quality Cl. 2[1]	x	x	x	x	x	x
	Sewage sludge	Max amount[1] & mean PTE[6]	x	x	x	x	x	x
	Manure	C.f recommendation[2] & Meas. max conc.[7]	x	x	x	x		x
	Manure	C.f recommendation[2] & Meas. mean conc.[7]			x	x		x
	Digestate	Suggested limit.[8] & collected data[9]	x	x	x		x	x
	Digestate	Suggested limit.[8] & collected data[9]	x	x	x		x	x
	Hourse manure	Max amount[1] & mean PTE[6]	x	x	x	x	x	x
	Poultry	Suggested limit.[8] & collected data[9]	x		x		x	
Hg	Atm	Atmospheric contribution[10]		x	x	x	x	x
	Min. P fertiliser	C.f recommendation[2] & data from Yara[3]	x	x	x	x	x	
	Min. P fertiliser & lime	C.f recommendation [2,4] & data from Yara[4]	x	x	x	x	x	

	Fertiliser scheme	**Application**	**Scenarios**					
	Org.fertil.reg. qual. Class II	Max amount & ML PTE quality Cl. 2[1]	x	x	x	x	x	x
	Sewage sludge	Max amount[1] & mean PTE[6]	x	x	x	x	x	x
	Manure	C.f recommendation[2] & Meas. max conc.[7]	x	x	x	x		
	Manure	C.f recommendation[2] & Meas. mean conc.[7]	x	x	x	x	x	x
	Digestate	Suggested limit.[8] & collected data[9]	x	x	x	x	x	x
	Digestate	Suggested limit.[8] & collected data[9]	x	x	x	x	x	x
	Horse manure	Max amount[1*] & mean PTE[6*]	x	x	x	x	x	x
	Poultry	Suggested limit.[8] & collected data[9]	x	x	x	x	x	x
Ni	NO INCREASE							
Pb	Atm	Atmospheric contribution[10*]	x	x	x			
	Min. P fertiliser	C.f recommendation[2] & data from Yara[3]	x	x	x			
	Min. P fertiliser & lime	C.f recommendation [2,4] & data from Yara[4]	x	x	x			
	Org.fertil.reg. qual. Class II	Max amount & ML PTE quality Cl. 2[1*]	x	x	x	x	x	x
	Sewage sludge	Max amount[1*] & mean PTE[6*]	x	x	x	x	x	
	Manure	C.f recommendation[2*] & Meas. max con.[7*]	x	x	x			
	Manure	C.f recommendation[2*] & Meas. max con.[7*]	x	x	x			
	Digestate	Suggested limit.[8] & collected data[9]	x	x	x		x	
	Digestate	Suggested limit.[8] & collected data[9]	x	x	x	x	x	
	Horse manure	Max amount[1*] & mean PTE [6*]	x	x	x	x	x	x
	Poultry	Suggested limit.[8] & collected data[9]	x	x	x			
Zn	Org.fertil.reg. qual. Class II	Max amount & ML PTE quality Cl. 2 [1*]	x	x	x	x	x	x
	Sewage sludge	Max amount1* & mean PTE [6*]	x	x	x	x		

	Fertiliser scheme	**Application**	**Scenarios**					
	Manure	C.f recommendation[2]* & Meas. max con.[7]*		x	x	x		
	Manure	C.f recommendation[2]* & Meas. mean con.[7]*			x	x		
	Fish sludge	Suggested limit.[8] & collected data[9]	x	x				
	Digestate	Suggested limit.[8] & collected data[9]	x	x	x			
	Digestate	Suggested limit.[8] & collected data[9]	x	x	x	x	x	x
	Horse manure	Max amount[1]* & mean PTE [6]*			x			
	Poultry	Suggested limit.[8] & collected data[9]	x	x	x			

Measured concentrations in edible mushroom

Table VII-35. Measured concentrations in edible mushroom presented as mg/kg DW, collected from literature. For estimating concentration in fresh weight, 10% DW is used in literature.

	Type of edible mushroom	**Measured conc. in mushroom**	**Measured conc. in substrate or soil**	**References**
		mg/kg DW	**mg/kg DW**	
As	Oyster mushroom (*P. ostreatus*)	0.09-0.13 and 0.11-0.52	0.04-0.1 and 0.94-3.5	Sakellari et al., 2019
As	Oyster mushroom (*P. ostreatus*)	<LOD -0.19	<LOD-2.62	Koutrotsios et al. 2020
Cd	Oyster mushroom (*P. ostreatus*)	0.30-0.62	0.09-0.23	Koutrotsios et al. 2020

	Type of edible mushroom	Measured conc. in mushroom	Measured conc. in substrate or soil	References
Cd	Parasol Mushroom, Macrolepiota procera, Champigong family. (* collected, wilde)	1.1-4.9	0.36-2.3	Gucia et al., 2012
Cd	Oyster mushroom (*P. ostreatus*)	0.28-0.31 and 0.31-0.48	0.05-0.09 and 0.07-0.18	Sakellari et al., 2019
Cd	King trumpet mushroom *(Pleurotus eryngii)* (NO: kongeøstersopp)	0.58 and 0.68	0.56 and 0.55	Siwulski et al., 2019
Cr total	Parasol Mushroom, Macrolepiota procera, Champigong family	0.10-0.80	0.92-2.6	Gucia et al., 2012
Cr total	Oyster mushroom (*P. ostreatus*)	0.15-0.29 and 0.20-0.26	9.8-16 and 15-58	Sakellari et al., 2019
Cr total	King trumpet mushroom *(Pleurotus eryngii)* (NO: kongeøstersopp)	21.0 and 19.0	18.3 and 16.6	Siwulski et al., 2019
Cu	Oyster mushroom (*P. ostreatus*)	15.86-39.05	5.67-27.28	Koutrotsios et al. 2020
Cu	Parasol Mushroom, Macrolepiota procera, Champigong family	100-200	0.95-5.7	Gucia et al., 2012
Cu	Oyster mushroom (*P. ostreatus*)	7.4-53 and 20-35	1.7-9.9 and 5.2-9.0	Sakellari et al., 2019

	Type of edible mushroom	**Measured conc. in mushroom**	**Measured conc. in substrate or soil**	**References**
Cu	28 species collected from soil incl. *Agaricus bisporus* and *Pleorotus ostreatus* (*collected)	72.81 and 26.28		Alonso et al. (2003)
Hg	King trumpet mushroom *(Pleurotus eryngii)* (NO: kongeøstersopp)	0.57 and 0.95	0.57 and 0.95	Siwulski et al., 2019
Hg	Parasol Mushroom, Macrolepiota procera, Champigong family (*collected)	2.7- 7.0		Falandysz et al., 2007a; Falandysz and Gucia, 2008
Ni	Parasol Mushroom, Macrolepiota procera, Champigong family	<0.01, 0.15-0.43	0.74-2.1	Gucia et al., 2012
Ni	Oyster mushroom (*P. ostreatus*)	0.19-0.41 and 0.33-1.7		Sakellari et al., 2019
Ni	Oyster mushroom (*P. ostreatus*)	0.28-0.69	3.46-93.95	Koutrotsios et al. 2020;
Pb	Parasol Mushroom, *Macrolepiota procera*	1.9-8.5	6.8-16	Gucia et al., 2012
Pb	Oyster mushroom (*P. ostreatus*)	0.01-0.15 and 0.43-0.51	0.66-1.2 and 11-41	Sakellari et al., 2019

	Type of edible mushroom	Measured conc. in mushroom	Measured conc. in substrate or soil	References
Pb	King trumpet mushroom *(Pleurotus eryngii)* (NO: kongeøstersopp)	3.08 and 2.15	5.2 and 4.3	Siwulski et al., 2019
Zn	28 species collected from soil incl. *Agaricus bisporus* and *Pleorotus ostreatus* (*collected)	75.83 and 96.56		Alonso et al. 2003
Zn	Oyster mushroom (*P. ostreatus*)	73.38-118.26	1.76-75.03	Koutrotsios et al. 2020
Zn	Parasol Mushroom, Macrolepiota procera, Champigong family	74-190	6.7- 46	Gucia et al., 2012
Zn	Oyster mushroom (*P. ostreatus*)	56-125 and 74-107	18-21 and 26-47	Sakellari et al., 2019
Zn	King trumpet mushroom *(Pleurotus eryngii)* (NO: kongeøstersopp)	92 and 66	29.3 and 22.6	Siwulski et al., 2019

Appendix VIII

Uncertainly and sencitity

Monte Carlo Method

Introduction to the Method

The sensitivity of input data on the results was also assessed by a Monte Carlo analysis. Hereby, the input data are not a fixed value, but following a pre-defined distribution. In the Monte Carlo analysis, the model is run repeatedly (5000 runs in this case), and the start values of the distributed data are randomly chosen following overall the pre-defined distribution. The strength of the method is that the input parameters are not varied one by one, but those selected are varied simultaneously. Hence, the result shows the possible variation of the output with variation of the input and can serve also as uncertainty analysis.

The calculated 5000 results are of course also distributed. Therefore, the outcome is shown as frequency distribution f(x), where f is the output parameter, and x is the vector of distributed input data. Moreover, the output statistics and the percentiles will be shown. Finally, a Spearman rank correlation r between input data vector x and predicted variable allows to quantify the explained variance of the output due to variance of the input because the coefficient of determination is ideally r2, and the sum of r2(x1), r2(x2) ... r2(xn) is 1, or 100%. However, as no random generator is completely random, and a high amount of random numbers need to be generated, small deviations from this rule have to be accepted. Nonetheless, the major influencing parameters, i.e. those with the highest sensitivity, can easily be identified.

Sensitivity is defined here as S = dy/dx, where y is the predicted variable, and x is the input data, and dy and dx are the change hereof.

The Monte Carlo simulations were conducted using the commercial software Crystal Ball (Oracle), which runs as an add-in to Excel.

Input data selection

As priority scenario for the Monte Carlo analysis was chosen Input scenario #2 (#2 sewage sludge, max ML) in Ås for all three metals, Cd, Cu and Zn.

Only input data can be varied. Calculated parameters (those derived from other input data) can not be chosen. Hence, if for example Kd is calculated from a regression, the regression was replaced with a fixed value (the one calculated by this regression) and then varied from 50% to 200% of the original value. For all selected input parameters, we run the Crystal Ball analysis with equal probability (uniform distribution) from 50% to 200% of the default value for the selected parameters. This is useful, because otherwise the sensitivity depends on the chosen range of the distribution, which would make the result very difficult to interprete. The simulations at the same time serve as uncertainty analysis. Though in a true uncertainty analysis, the parameters would be varied according to their (known) uncertainty. However, the uncertainty is not given, and thus a factor two (50% to 200%) was assumed.

Run 1. PEC Soil, concentration in crops and loss from soil

Randomly varied input parameters were:

1. Kd, 2. Precipitation, 3. Etot, 4. TF.

Forecast values were Loss rates (g/ha/year) and PECsoil (mg/kg) and concentration in wheat (µg/kg dw).

Output probability distributions are shown for for Loss rates (g/ha/yr) for runoff and leaching and plant uptake, and for PECsoil, and initially also for k-rates for plants, leaching/runoff.

Etot was later omitted because it has no relation to PECsoil.

Run 2. PEC Surface Water (PECsw) and PEC Sediment (PECsed)

Kd, Precipitation, Etot, Transfer factors were set back to their default values.

Randomly varied input parameters were:

1 E_{tot}, 2. Kp_{susp}, 3. Kp_{sed}.

Output were the probability distributions for PEC_{sw} and PEC_{sed}

Some illustrative examples

Before the finale sensitivity analysis is shown, some illustrative examples will further explain the method. All these examples were made for cadmium, Ås, scenario #2, 10 years.

Step 1, variation of Kd only

In step 1, solely Kd was randomly varied (1000 runs) from 50% to 200%, uniform distribution. The default Kd value is 214.3 L/kg. Note that a distribution from 50% to 200% is not symmetrical, thus, the median and mean of the random Kd is at 125% of the default value (50% + 200% = 250% divide by 2). This will be the same for all random input parameters.

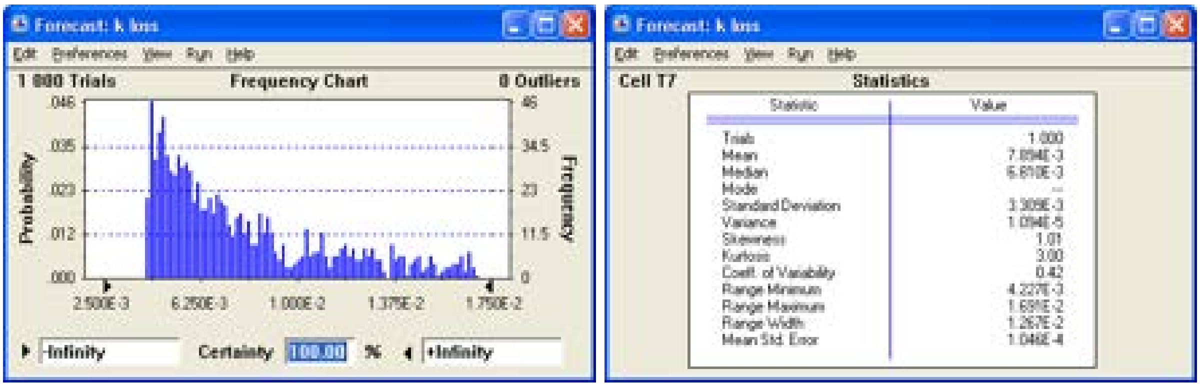
Kd has a strong impact on the kloss (loss from soil due to leaching and runoff, unit 1/year), as seen from Figure AVIII-1ab. The resulting frequency distribution (AVIII-1a) is ranging from about 50% of the default kloss to 200%. Thus, the sensitivity S is about 1 (or 100%):

kloss changes with the same range as does Kd. This makes sense, because there is an indirect proportional relation between both (see equation chapter 5.2.1).

Contrary, the loss rate with plant uptake kplant does not change at all when Kd is varied (Figure AVIII-2). There is no relation between Kd and kplant, kplant is calculated from transfer factors TF and harvested plant mass but does not depend on Kd. Thus, kplant stays the same value even though Kd is varied.

Figure AVIII-3abc shows the calculated PECsoil for randomly varied Kd. The range of results is best seen from the statistics, Figure AVIII-3b or from the percentiles, displayed in Figure AVIII-3c, and it is from 0.199 to 0.224 mg/kg. That is 93% to 103% of the median – thus, S is about 0.05 or 5% only, the calculated PECsoil depends mainly on the initial concentration at t = 0 ("background value soil", input data, at Aas 0.21 mg/kg) and changes only slowly over the years. The calculated mean of the random distribution is at 2.16 mg/kg, while the default value was at 2.15 mg/kg, practically equal.

Figure AVIII-4 shows the sensitivity chart, i.e. the rank correlation between input and output. As only one parameter, the Kd, was varied, and as the relation is invers, the correlation coefficient r is -1. The sum of all r2 –values give 100%, and -12 is 1 = 100%, thus here this rule holds. It means that in this simulation, all variation of PECsoil stems from a variation of Kd. This is of course true, as Kd was the only parameter that was varied.

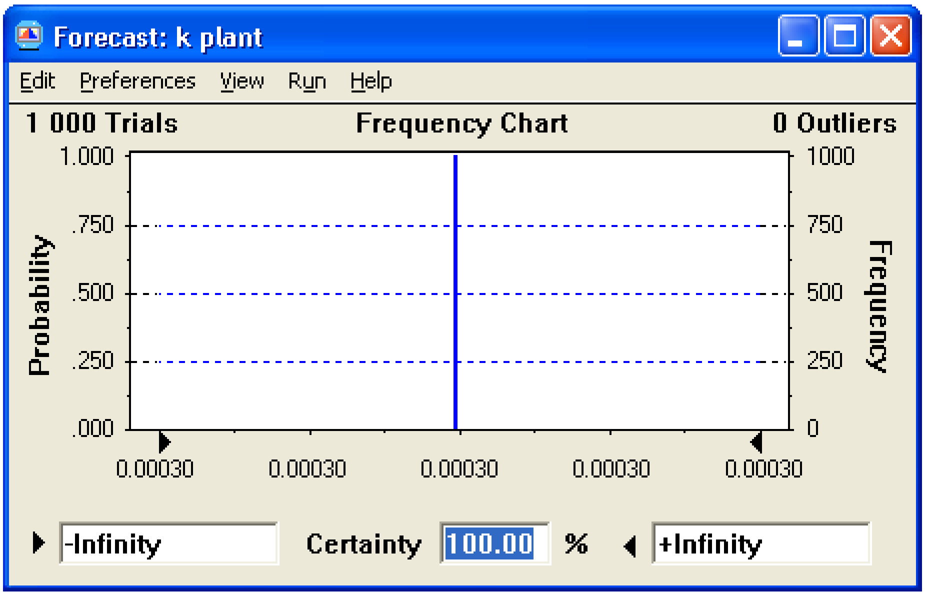


Cell T7

Statistics

Statistic	Value
Trials	1.000
Mean	7.094E-3
Median	6.810E-3
Mode	---
Standard Deviation	3.308E-3
Variance	1.094E-5
Skewness	1.01
Kurtosis	3.00
Coeff. of Variability	0.47
Range Minimum	4.227E-3
Range Maximum	1.690E-2
Range Width	1.267E-2
Mean Std. Error	1.046E-4

Figure AVIII-1a,b. Distribution of kloss when Kd is varied. a) Frequency distribution b) Statistics.

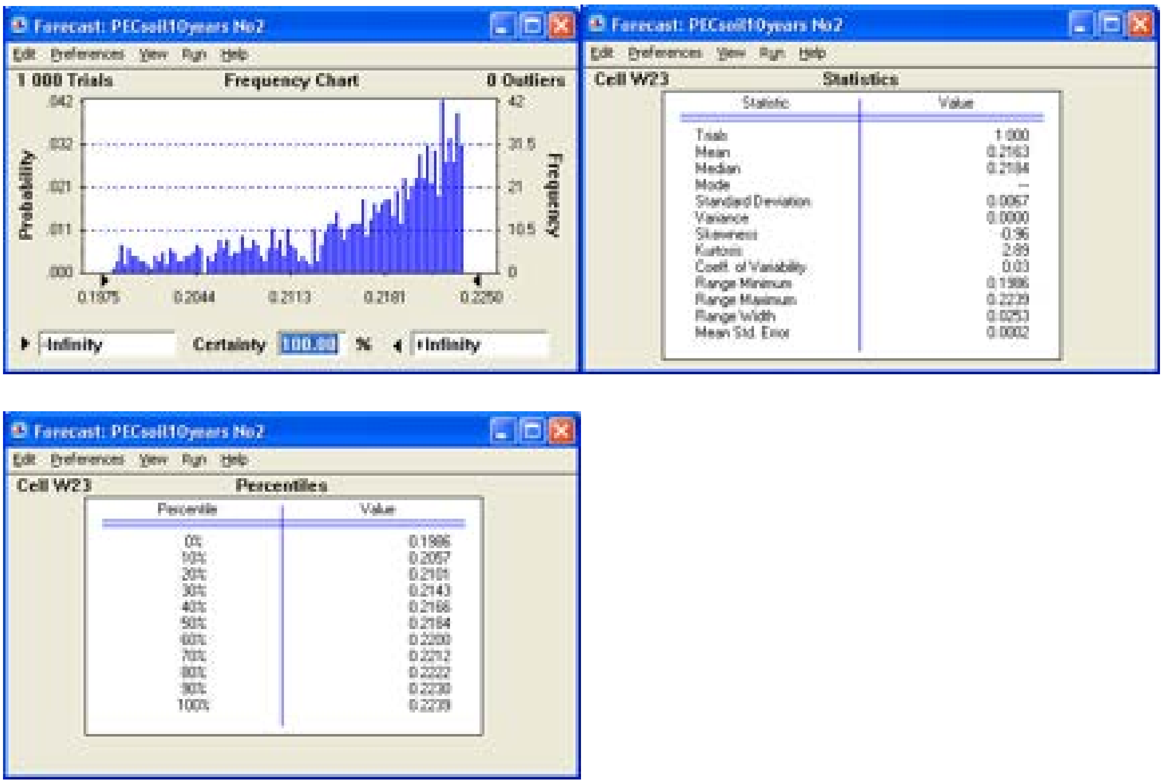


1 000 Trials

0 Outliers

-Infinity Certainty 100.00 % +Infinity

Figure AVIII-2. Distribution of kplant when Kd is varied (default 0.0003 1/year).



1 000 Trials

0 Outliers

-Infinity Certainty 100.00 % +Infinity

Cell W23 Statistics

Statistic	Value
Trials	1 000
Mean	0.2163
Median	0.2184
Mode	---
Standard Deviation	0.0067
Variance	0.0000
Skewness	-0.96
Kurtosis	2.89
Coeff. of Variability	0.03
Range Minimum	0.1986
Range Maximum	0.2239
Range Width	0.0253
Mean Std. Error	0.0002

Cell W23 Percentiles

Percentile	Value
0%	0.1986
10%	0.2057
20%	0.2101
30%	0.2143
40%	0.2166
50%	0.2184
60%	0.2200
70%	0.2212
80%	0.2222
90%	0.2230
100%	0.2239

Figure AVIII-3 a,b,c. PECsoil after 10 years. Default 0.215 mg/kg.

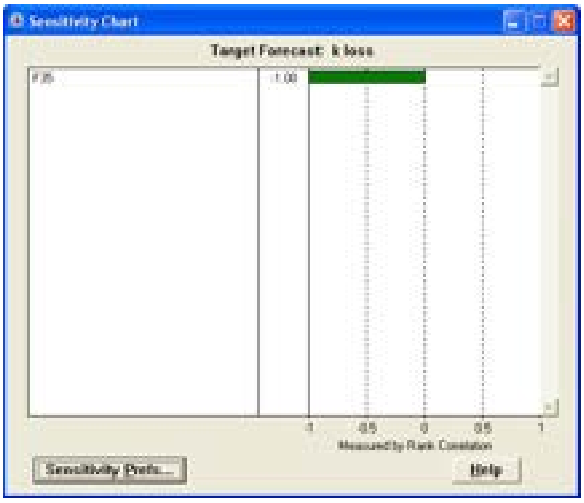


Figure AVIII-4. Sensitivity chart PECsoil after 10 years. F35 is Kd.

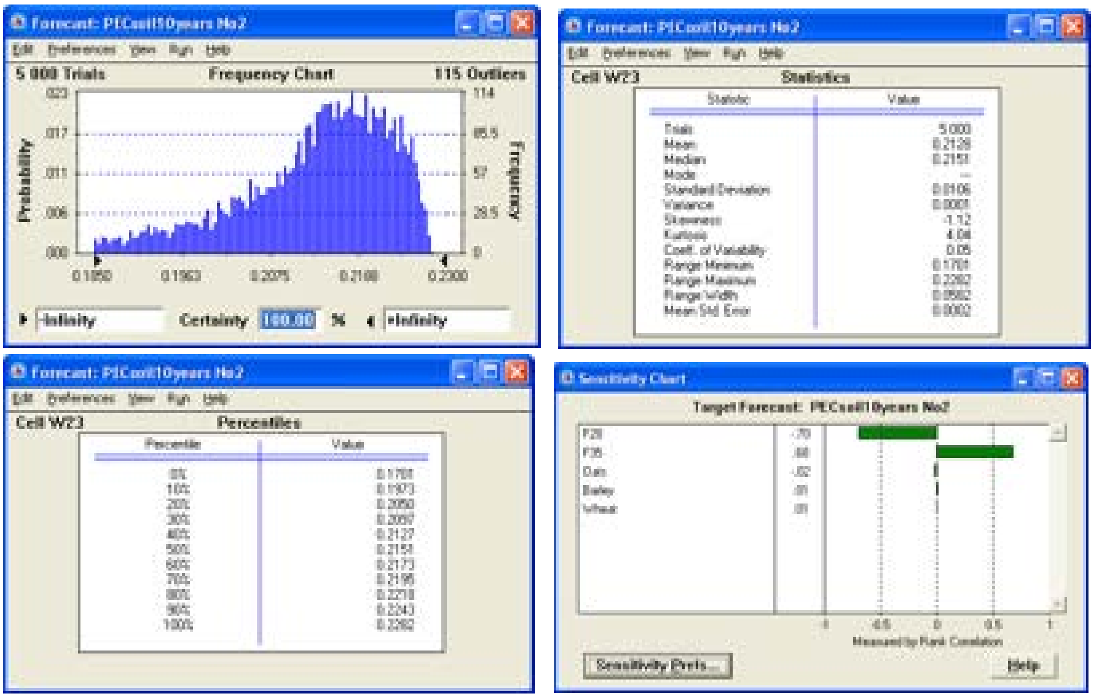
Cadmium results of the Monte Carlo Analysis

Cadmium in Soil, Ås, #2, 10 years

The results in this section relate to the metal cadmium, for the site Ås, the scenario #2, after 10 years of application. Variation of input parameters is for precipitation, Kd, TF wheat, TF oats and TF barley (uniform, 50% to 200% of default). The number of Monte Carlo runs is from now on 5000.

Figure AVIII-5 shows the results for the forecast of PECsoil. In AVIII-5a, the frequency distribution is displayed. The range is from 0.185 to 0.23 mg/kg dw, with a right skweded distribution. The median is at 0.2188 mg/kg, which is very close to the default value (without Monte Carlo) at 0.215 mg/kg. Figure AVIII-5b shows the statistics, AVIII-5c the percentiles. Remarkably, the 90%-ile is at 0.224 mg/kg, that is only 0.07 mg/kg higher than the default value. Thus, the uncertainty of the calculated result, originating from uncertain Kd, precipitation and transfer factors TF, is rather low, and there is little reason for concern. Finally, Figure AVIII-5d shows the sensitivity chart. The most sensitive parameters are precipitation and Kd, which together explain > 95% of the variation (0.72 + 0.682 = 0.952). The transfer factors have no influence on the calculated PECsoil after 10 years, they are insensitive (explanation see below).

Figure AVIII-6 shows the results for the forecast of the concentration in wheat. The frequency distribution displayed in 10.1.3.1-2a is showing a uniform distribution. The range is from 12.9 to 64.9 µg/kg fw, which is only slightly broader than 50% to 200% of the default value (default is 31.1 µg/kg). The 90%-ile is at 57.2 µg/kg. The variation of the calculated concentration in wheat is almost exclusively (r2 is 98%) due to the variation of the TF wheat (Figure 10.1.3.1-2d). The remaining 2% of r2 are shared by precipitation and Kd.



Forecast: PECsoil10years No2

Cell W23 Statistics

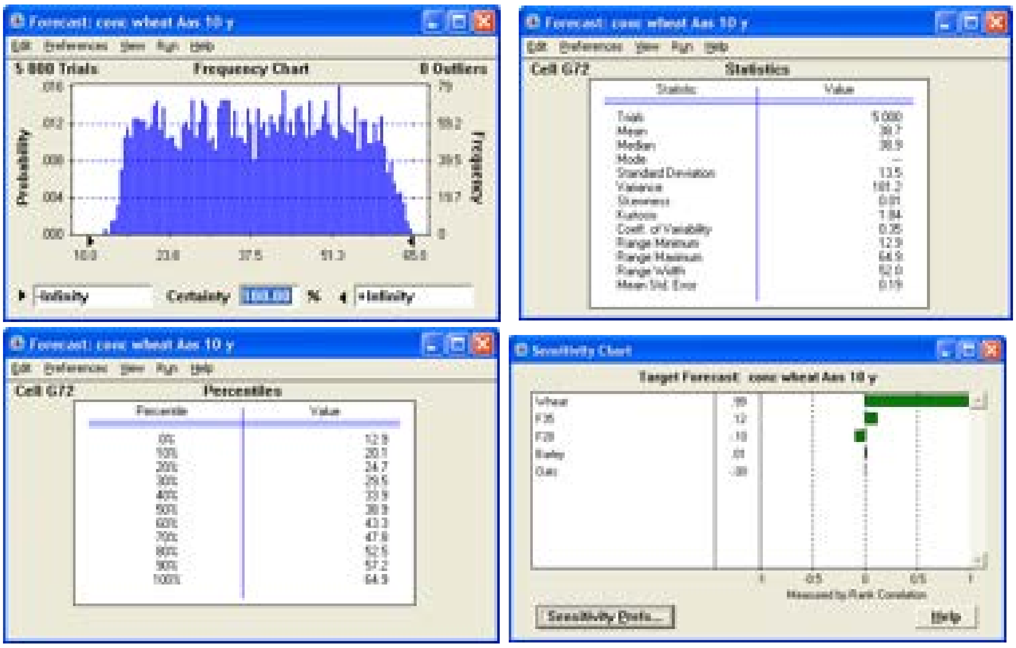
Statistic	Value
Trials	5 000
Mean	0.2128
Median	0.2151
Mode	---
Standard Deviation	0.0106
Variance	0.0001
Skewness	-1.12
Kurtosis	4.08
Coeff. of Variability	0.05
Range Minimum	0.1701
Range Maximum	0.2282
Range Width	0.0582
Mean Std. Error	0.0002

Forecast: PECsoil10years No2

Cell W23 Percentiles

Percentile	Value
0%	0.1701
10%	0.1973
20%	0.2050
30%	0.2097
40%	0.2127
50%	0.2151
60%	0.2173
70%	0.2195
80%	0.2218
90%	0.2243
100%	0.2282

Figure AVIII-5 at,b,c,d. Forecast of PECsoil, Cd. a) Frequency distribution b) statistics c) percentiles d) sensitivity chart. F28 is precipitation, F35 is Kd, oats, wheat and barley are the transfer factors for these plants. Default value is at 0.215 mg/kg dw.



Forecast: conc wheat Aas 10 y

Cell G72 Statistics

Statistic	Value
Trials	5 000
Mean	38.7
Median	38.9
Mode	---
Standard Deviation	13.5
Variance	181.2
Skewness	0.01
Kurtosis	1.84
Coeff. of Variability	0.35
Range Minimum	12.9
Range Maximum	64.9
Range Width	52.0
Mean Std. Error	0.19

Forecast: conc wheat Aas 10 y

Cell G72 Percentiles

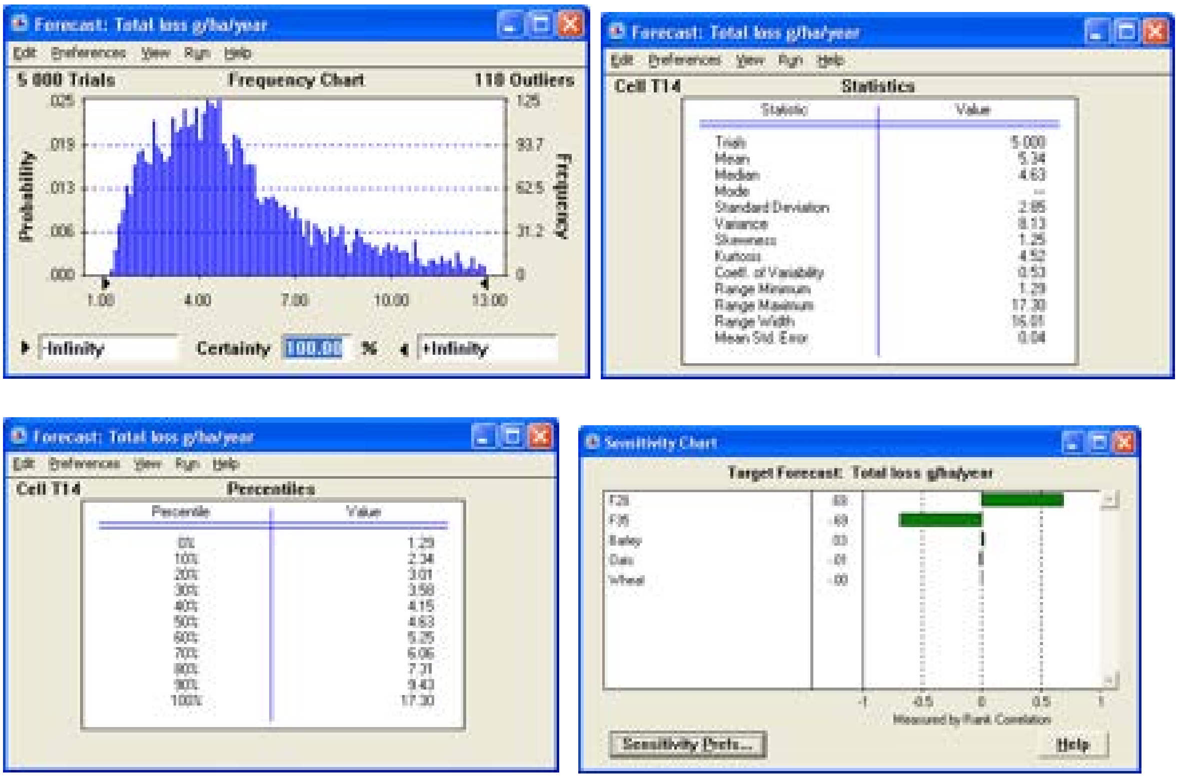
Percentile	Value
0%	12.9
10%	20.1
20%	24.7
30%	29.5
40%	33.9
50%	38.9
60%	43.3
70%	47.8
80%	52.5
90%	57.2
100%	64.9

Figure AVIII-6 a,b,c,d. Forecast of concentration in wheat (µg/kg fw). a) Frequency distribution b) statistics c) percentiles d) sensitivity chart. F28 is precipitation, F35 is Kd; oats, wheat and barley are the transfer factors for these plants.

Figure AVIII-7 shows the forecast of the total loss from soil (g/ha/year); The range of the loss is rather high (from 1 to 13 g/ha/year) (Figure 10.1.3.1-3abc). The underlying reason is the variation of precipitation and of Kd, which to equal parts, but in opposite direction, explain most of the variance. The transfer factors from soil to plant are not sensitive for the total loss.

This is explainable by comparing Figure II-7 and AVIII-8: the range of loss by plant uptake is only from 0.08 to 0.33 g/ha/year and thus 40times lower than the total loss. The loss withj uptake by plants does depend largely on the transfer factors TF. The lowest sensitivity has oats, which occurs only once in the crop rotation, while wheat and barley are twice.

The loss from soil is dominated by leaching and runoff (Figure AVIII-9) – the numbers differ only very little from total loss (Figure AVIII-8), and like there, the sensitive parameters are Kd and precipitation.



Cell T14 **Statistics**

Statistic	Value
Trials	5 000
Mean	5.34
Median	4.63
Mode	---
Standard Deviation	2.85
Variance	8.13
Skewness	1.25
Kurtosis	4.52
Coeff. of Variability	0.53
Range Minimum	1.29
Range Maximum	17.30
Range Width	16.01
Mean Std. Error	0.04

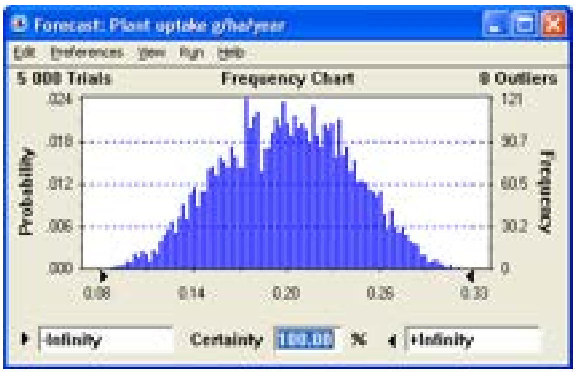
Cell T14 **Percentiles**

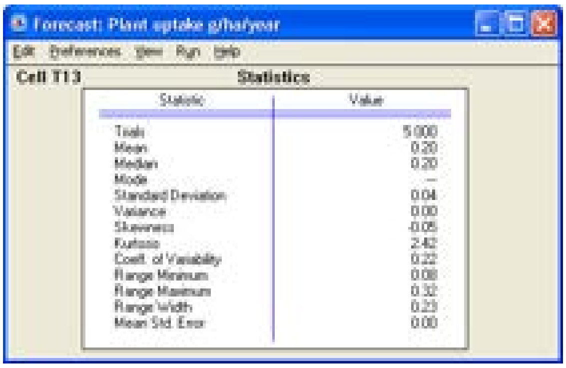
Percentile	Value
0%	1.29
10%	2.34
20%	3.01
30%	3.58
40%	4.15
50%	4.63
60%	5.25
70%	6.06
80%	7.31
90%	9.43
100%	17.30

Target Forecast: Total loss g/ha/year

F28	.69
F35	-.69
Barley	.03
Oats	-.01
Wheat	-.00

Figure AVIII-7 a,b,c,d. Forecast of total loss from soil (g/ha/year) a) Frequency distribution b) statistics c) percentiles d) sensitivity chart. F28 is precipitation, F35 is Kd; oats, wheat and barley are the transfer factors for these plants. Default value is 4.61 g/ha/year.





Cell T13 **Statistics**

Statistic	Value
Trials	5 000
Mean	0.20
Median	0.20
Mode	---
Standard Deviation	0.04
Variance	0.00
Skewness	-0.05
Kurtosis	2.42
Coeff. of Variability	0.22
Range Minimum	0.08
Range Maximum	0.32
Range Width	0.23
Mean Std. Error	0.00

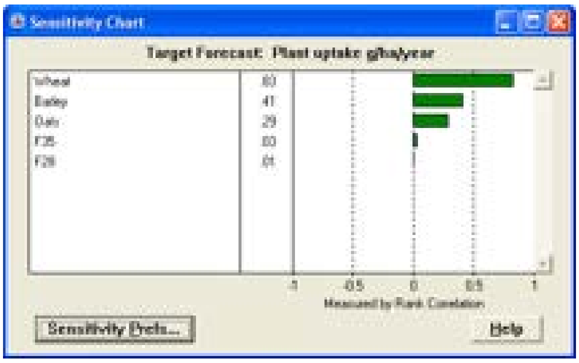
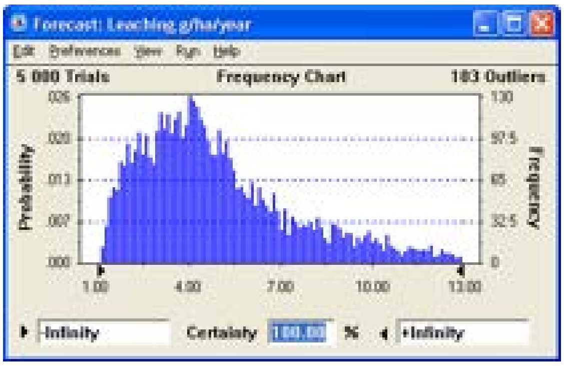
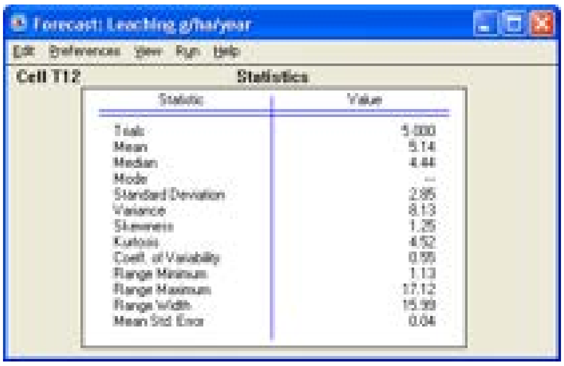


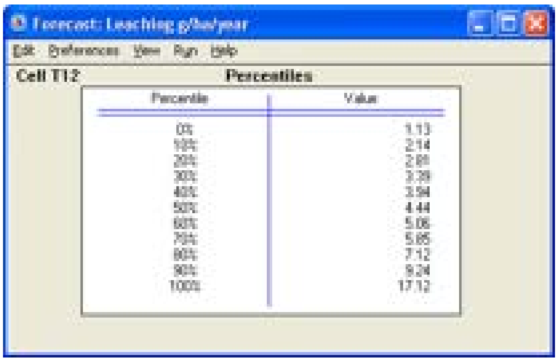
Figure AVIII-8 a,b,c. Forecast of loss from soil by plant uptake (g/ha/year) a) Frequency distribution b) statistics c) percentiles d) sensitivity chart. F28 is precipitation, F35 is Kd; oats, wheat and barley are the transfer factors for these plants. Default value is 0.16 g/ha/year.





Cell T12 **Statistics**

Statistic	Value
Trials	5 000
Mean	5.14
Median	4.44
Mode	---
Standard Deviation	2.85
Variance	8.13
Skewness	1.25
Kurtosis	4.52
Coeff. of Variability	0.55
Range Minimum	1.13
Range Maximum	17.12
Range Width	15.99
Mean Std. Error	0.04



Cell T12 **Percentiles**

Percentile	Value
0%	1.13
10%	2.14
20%	2.81
30%	3.39
40%	3.94
50%	4.44
60%	5.06
70%	5.85
80%	7.12
90%	9.24
100%	17.12

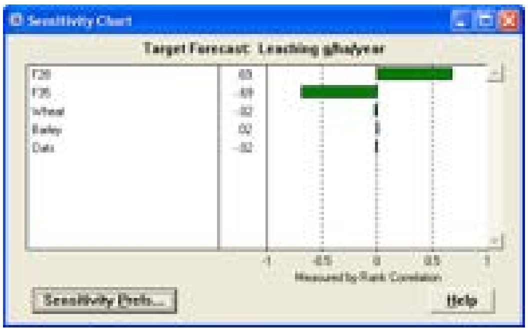
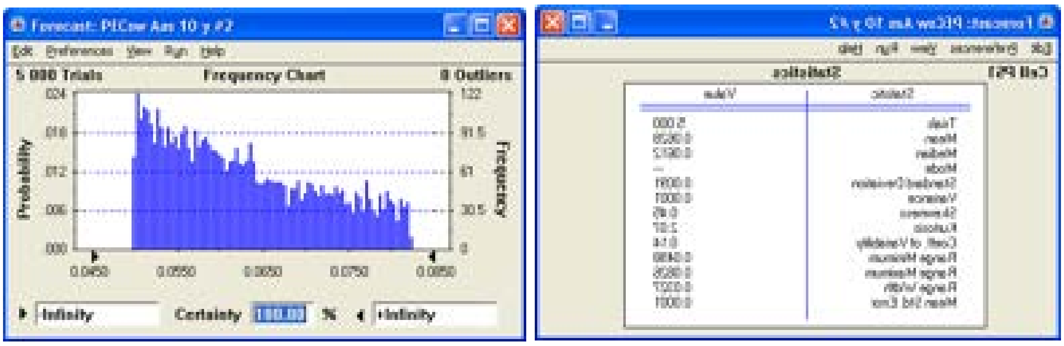


Figure AVIII-9 a,b,c,d. Forecast of loss from soil by leaching and runoff (g/ha/year) a) Frequency distribution b) statistics c) percentiles d) sensitivity chart. F28 is precipitation, F35 is Kd; oats, wheat and barley are the transfer factors for these plants. Default value is 4.45 g/ha/year.

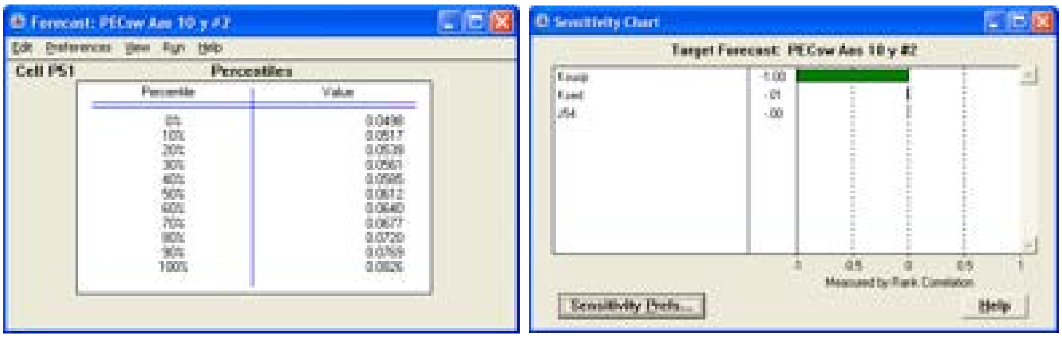
Cadmium in Surface Water, Ås #2, 10 years

Now the focus is on surface water, and here on concentrations in water and sediment. The scenario is Cadmium, Ås, #2, after 10 years. Varied input parameters are Kpsusp, Kp_{sed}, E_{tot} and the dilution factor, all of them uniform distribution 50% to 200% of default. Forecast values are predicted concentrations in surface water ($PECs_{w}$, µg L^{-1}) and sediment (PEC_{sed}, µg kg^{-1} DW).

Figure AVIII-10 shows the forecast of PEC_{sw} (µg L^{-1}). Figure AVIII-10a displays the frequency distribution, which ressembles a left-squewed uniform distribution. From Figure AVIII-10bc can be seen that the predicted range of PECsw is from 0.05 to 0.083 µg L^{-1} (default 0.067 µg L^{-1}). This means, despite an uncertainty of the input data of factor 2, the outcome varies by only 30%, i.e. the uncertainty of the result is lower than the uncertainty of the input data. A major reason for this is again that the initial concentration at t = 0 (Ås 0.0657 µg L^{-1}) and the change in ten years is not very big. A surprising result shows the sensitivity chart in Figure AVIII-10d: the only relevant parameter (among those chosen for variation) is the Kp_{susp}. the total erosion E_{tot} plays a very minor role and can be neglected.



Statistic	Value
Trials	5 000
Mean	0.0658
Median	[illegible]
Mode	---
Standard Deviation	0.0091
Variance	0.0001
Skewness	[illegible]
Kurtosis	[illegible]
Coeff. of Variability	0.14
Range Minimum	[illegible]
Range Maximum	[illegible]
Range Width	[illegible]
Mean Std. Error	0.0001

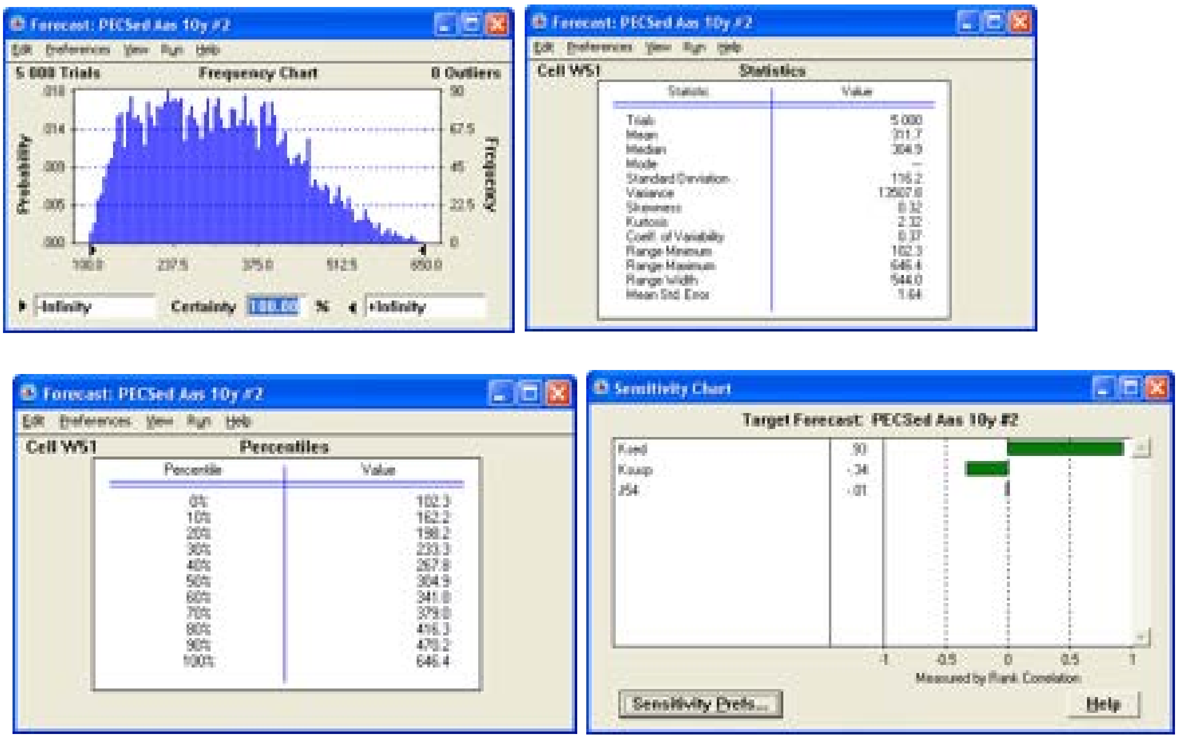


Cell PS1 Percentiles

Percentile	Value
0%	0.0498
10%	0.0517
20%	0.0539
30%	0.0561
40%	0.0585
50%	0.0612
60%	0.0640
70%	0.0677
80%	0.0720
90%	0.0769
100%	0.0826

Figure AVIII-10 a,b,c,d. Forecast of PECsw (µg L^{-1}), Ås, #2, 10 years. a) Frequency distribution b) statistics c) percentiles d) sensitivity chart. Kp_{susp} is the only relevant parameter for PEC_{sw}, j54 is E_{tot} (at Ås). Default value is 0.067 µg L^{-1}.

The range of predicted sediment concentration PEC_{sed} is displayed in Figure AVIII-11abc, and is from 100 to 650 µg kg^{-1} DW. The default value was at PEC Sed 266.7 ug kg^{-1} DW, thus, the sensitivity S is 2.4, which is a comparatively high value. The depicted range is also much larger than the variation of the concentration in water (PEC_{sw}, Figure AVIII-10), which can be explained by the sensitivity shown in Figure AVIII-11d: on top of the variation due to Kpsusp (r^2 = 12%) comes the variation in Kpsed, which account for 87% of the explained variance. However, the distribution shows a strong right-skew: the 90%-ile (Figure AVIII-11c) is only at 407 µg kg^{-1}, which is only a bit more than 2/3rd of the maximum. The uncertainty of the total erosion E_{tot} again does not matter for PEC_{sed} (Figure AVIII-11d).



Cell WS1 Statistics

Statistic	Value
Trials	5.000
Mean	311.7
Median	304.9
Mode	---
Standard Deviation	116.2
Variance	12507.8
Skewness	0.32
Kurtosis	2.32
Coeff. of Variability	0.37
Range Minimum	102.3
Range Maximum	646.4
Range Width	544.0
Mean Std. Error	1.64

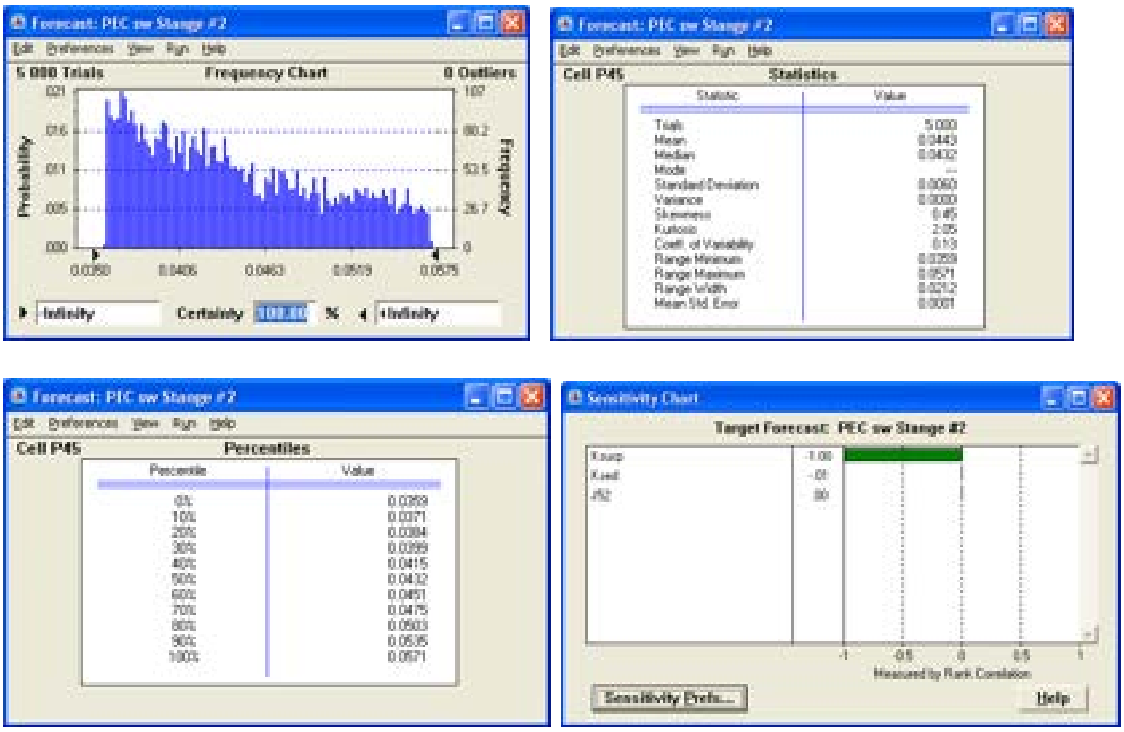
Cell WS1 Percentiles

Percentile	Value
0%	102.3
10%	162.2
20%	198.2
30%	233.3
40%	267.8
50%	304.9
60%	341.0
70%	379.0
80%	416.3
90%	470.2
100%	646.4

Figure AVIII-11 a,b,c,d. Forecast of PEC_{sed} (µg kg^{-1} DW); a) Frequency distribution b) statistics c) percentiles d) sensitivity chart. j54 is E_{tot} (at Ås). Default value is 266.7 µg kg^{-1} DW.

Cadmium in Surface Water at Stange #2 10 years

Figures AVIII-12 and AVIII-13 show the same simulations of Cd for the site Stange, input scenario #2, after 10 years of continuous application. The results resemble very much those obtained for Ås, only the concentrations are generally lower. However, any conclusions drawn from the previous simulations also hold for Stange. The results are therefore not further described or discussed here.

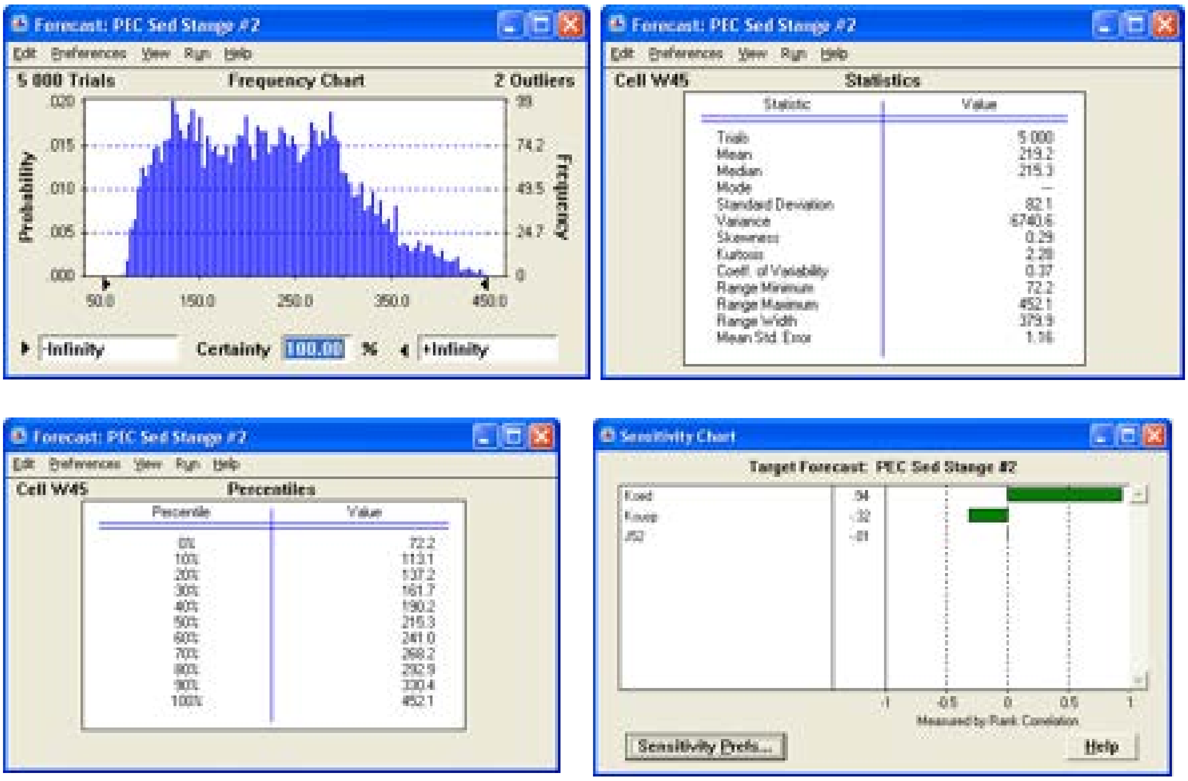


Statistic	Value
Trials	5,000
Mean	0.0443
Median	0.0432
Mode	---
Standard Deviation	0.0060
Variance	0.0000
Skewness	0.45
Kurtosis	2.05
Coeff. of Variability	0.13
Range Minimum	0.0359
Range Maximum	0.0571
Range Width	0.0212
Mean Std. Error	0.0001

Percentile	Value
0%	0.0359
10%	0.0371
20%	0.0384
30%	0.0399
40%	0.0415
50%	0.0432
60%	0.0451
70%	0.0475
80%	0.0503
90%	0.0535
100%	0.0571

Kpsusp	-1.00
Kssed	-.01
j52	.00

Figure AVIII-12 a,b,c,d. Forecast of PEC_{sw} (µg L^{-1}) at Stange, scenario #2, 10 years. a) Frequency distribution b) statistics c) percentiles d) sensitivity chart. Kpsusp is the only relevant parameter for PEC_{sw}, j52 is E_{tot} (at Stange). Default value is 0.047 µg L^{-1}.



Statistic	Value
Trials	5 000
Mean	219.2
Median	215.3
Mode	---
Standard Deviation	82.1
Variance	6740.6
Skewness	0.29
Kurtosis	2.28
Coeff. of Variability	0.37
Range Minimum	72.2
Range Maximum	452.1
Range Width	379.9
Mean Std. Error	1.16

Percentile	Value
0%	72.2
10%	113.1
20%	137.2
30%	161.7
40%	190.2
50%	215.3
60%	241.0
70%	268.2
80%	292.9
90%	330.4
100%	452.1

Figure AVIII-13 a,b,c,d. Forecast of PEC_{sed} (µg kg^{-1}) at Stange, scenario #2, 10 years. a) Frequency distribution b) statistics c) percentiles d) sensitivity chart. Kpsusp is the only relevant parameter for PEC_{sw}, j52 is E_{tot} (at Stange). Default value is 187 µg kg^{-1} dw.

Zinc results of the Monte Carlo Analysis

Zinc in Soil, Ås #2, 10 years (PECsoil, loss g/ha/year, Concentration in wheat)

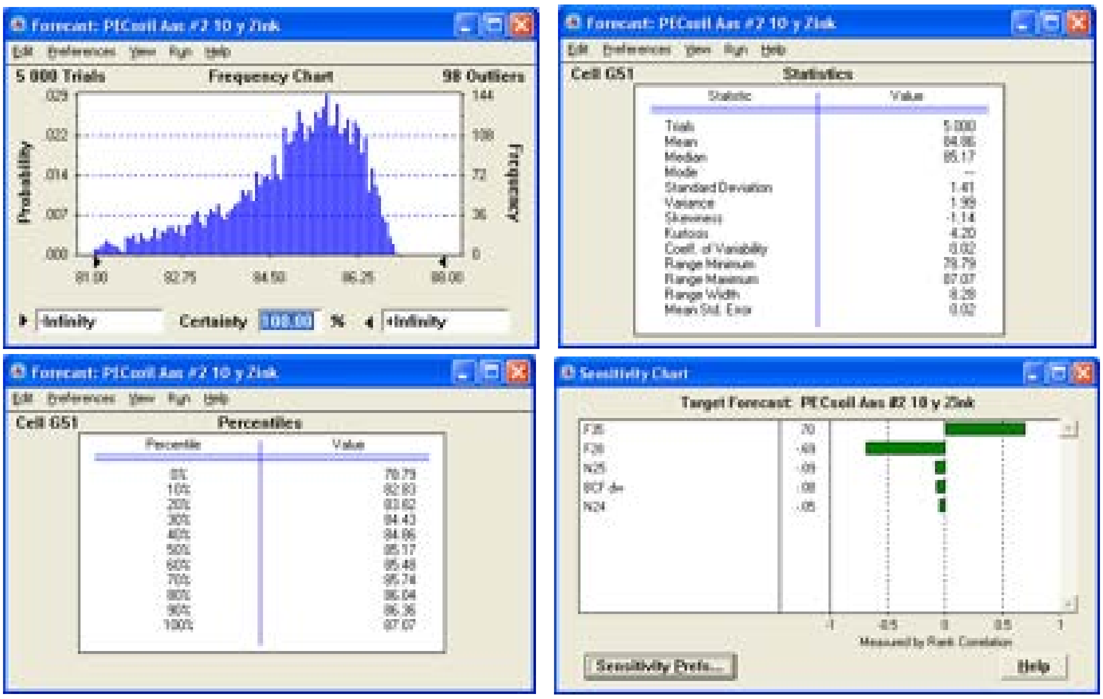
As for the previous Monte Carlo Analysis for cadmium, the input parameters were varied with uniform distribution from 50% to 200% of the default value. In this section, the varied parameters were precipitation, Kd, TF oats, barley, wheat. Simulations were made for zinc at Ås input scenario #2, after 10 years of application. Forecast values were PEC_{soil}, loss from soil (g ha^{-1} yr^{-1}), and concentration in wheat.

The results are shown as figures. The conclusions ressemble those obtained for cadmium.

Figure AVIII-14, brief description: PECsoil, range from 81 to 88 mg kg^{-1} dw. TF values are more sensitive than for Cd, but Kd and precipitation also for Zn are the most sensitive input parameters among those five varied.

Different to Cd, plant uptake plays a relevant role for the loss of Zn from soil (default total loss is 675 g ha^{-1} yr^{-1}, hereof 122 g ha^{-1} yr^{-1} via plant uptake), see Figs. AVIII-16 to AVIII-18. Therefore, TF-values of wheat, barley and oats show some sensitivity for total loss (Figure

AVIII-16d), however, as before, Kd and precipitation are most sensitive, and more than 80% of the loss are with runoff and leaching water (Figure AVIII-18).



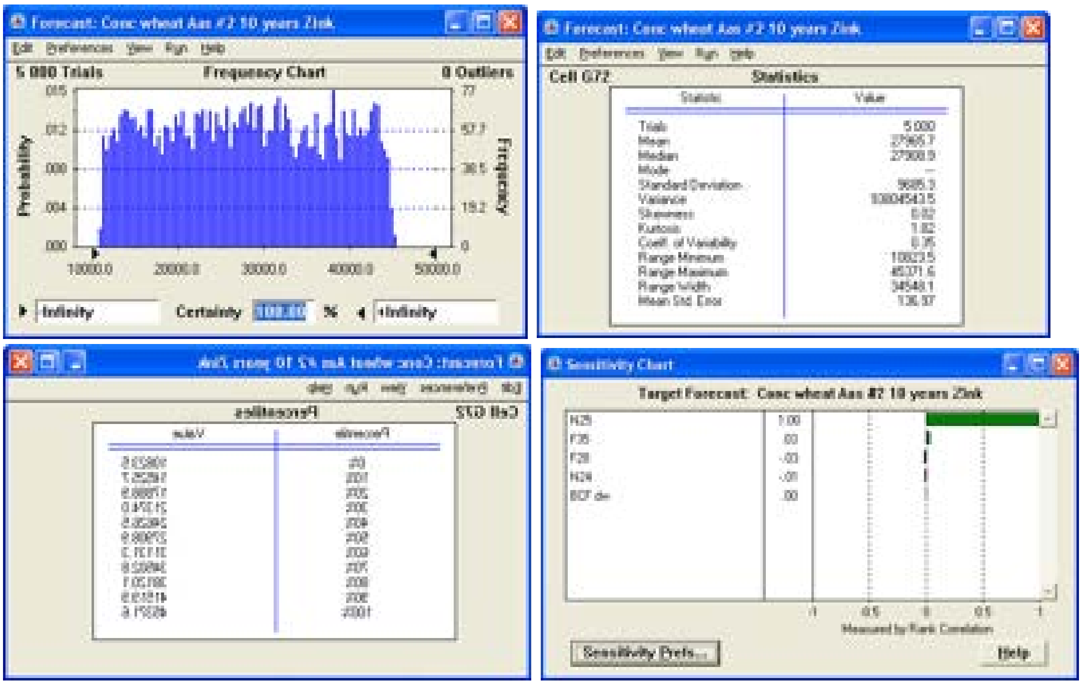
Cell G51 Statistics

Statistic	Value
Trials	5 000
Mean	84.86
Median	85.17
Mode	---
Standard Deviation	1.41
Variance	1.99
Skewness	-1.14
Kurtosis	4.20
Coeff. of Variability	0.02
Range Minimum	79.79
Range Maximum	87.07
Range Width	8.28
Mean Std. Error	0.02

Cell G51 Percentiles

Percentile	Value
0%	79.79
10%	82.83
20%	83.62
30%	84.43
40%	84.86
50%	85.17
60%	85.48
70%	85.74
80%	86.04
90%	86.36
100%	87.07

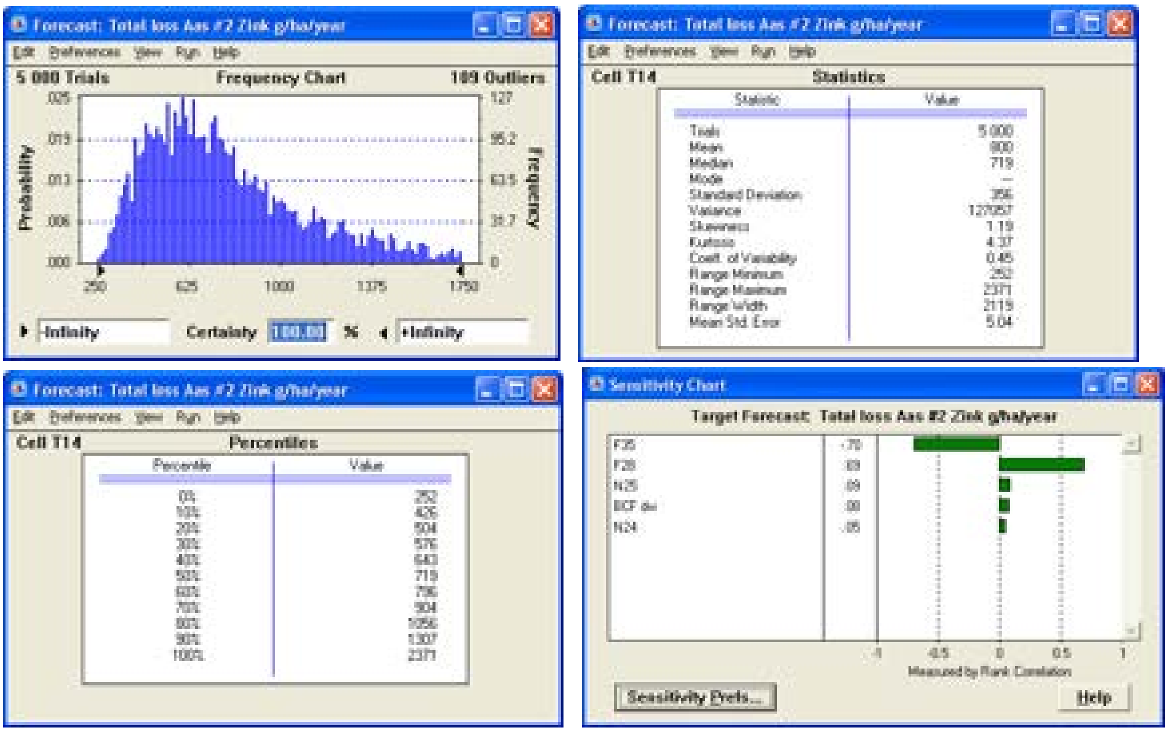
Figure AVIII-14 a,b,c,d. Forecast of PECsoil for Zn. a) Frequency distribution b) statistics c) percentiles d) sensitivity chart, where N25 is TF wheat, N24 is TF oats, BCF DW is TF barley, F28 is precipitation, F35 is Kd. Default PEC_{soil} value Zn is 85.34 mg kg^{-1} DW.



Cell G72 Statistics

Statistic	Value
Trials	5 000
Mean	27965.7
Median	27908.9
Mode	---
Standard Deviation	9685.3
Variance	93804543.5
Skewness	0.02
Kurtosis	1.82
Coeff. of Variability	0.35
Range Minimum	10823.5
Range Maximum	45371.6
Range Width	34548.1
Mean Std. Error	136.97

Figure AVIII-15 a,b,c,d. Forecast of Zn concentration in wheat (Zn µg kg^{-1} FW). a) Frequency distribution b) statistics c) percentiles d) sensitivity chart, where N25 is TF wheat, N24 is TF oats, BCF DW is TF barley, F28 is precipitation, F35 is Kd. Default value: 22488 µg kg^{-1}.



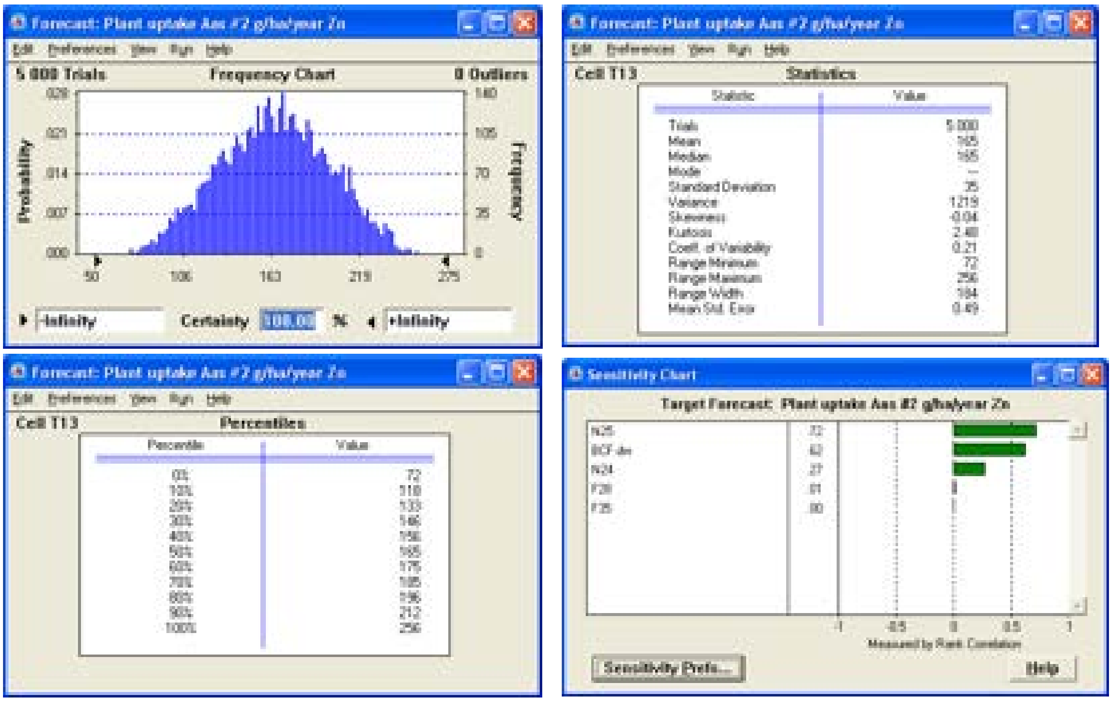
Cell T14 Statistics

Statistic	Value
Trials	5 000
Mean	800
Median	719
Mode	---
Standard Deviation	356
Variance	127057
Skewness	1.19
Kurtosis	4.37
Coeff. of Variability	0.45
Range Minimum	252
Range Maximum	2371
Range Width	2119
Mean Std. Error	5.04

Cell T14 Percentiles

Percentile	Value
0%	252
10%	426
20%	504
30%	576
40%	643
50%	719
60%	796
70%	904
80%	1056
90%	1307
100%	2371

Figure AVIII-16 a,b,c,d. Forecast of total loss of Zn from soil (g ha^{-1} yr^{-1}). a) Frequency distribution b) statistics c) percentiles d) sensitivity chart, where N25 is TF wheat, N24 is TF oats, BCF DW is TF barley, F28 is precipitation, F35 is Kd. Default 675 g ha^{-1} yr^{-1}.



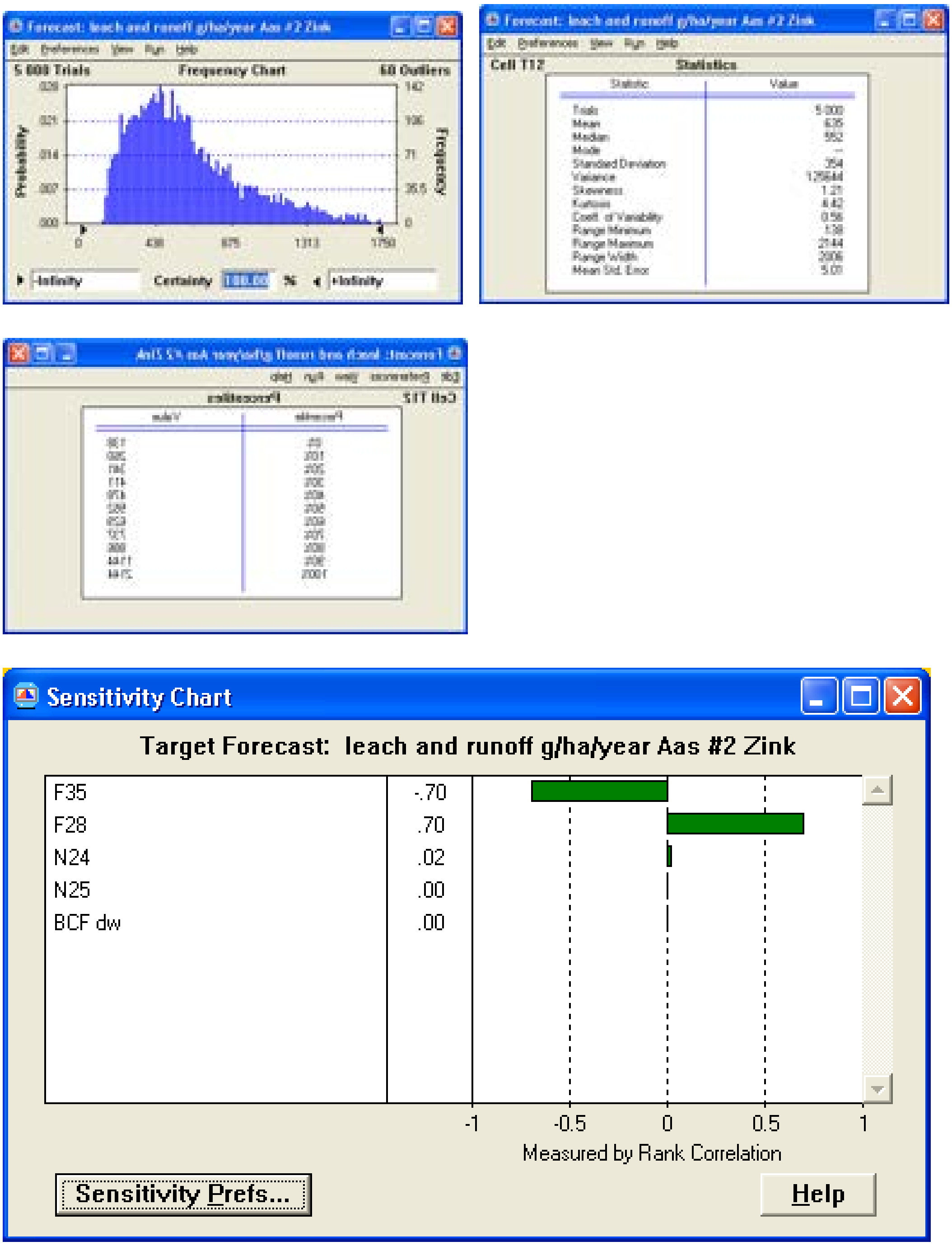
Cell T13 Statistics

Statistic	Value
Trials	5 000
Mean	165
Median	165
Mode	---
Standard Deviation	35
Variance	1219
Skewness	-0.04
Kurtosis	2.40
Coeff. of Variability	0.21
Range Minimum	72
Range Maximum	256
Range Width	184
Mean Std. Error	0.49

Cell T13 Percentiles

Percentile	Value
0%	72
10%	118
20%	133
30%	146
40%	156
50%	165
60%	175
70%	185
80%	196
90%	212
100%	256

Figure AVIII-17 a,b,c,d. Forecast of loss of Zn from soil by plant uptake (g ha^{-1} yr^{-1}). a) Frequency distribution b) statistics c) percentiles d) sensitivity chart, where N25 is TF wheat, N24 is TF oats, BCF DW is TF barley, F28 is precipitation, F35 is Kd. Default 132 g ha^{-1} yr^{-1}.



Statistic	Value
Trials	5 000
Mean	635
Median	552
Mode	---
Standard Deviation	354
Variance	125644
Skewness	1.21
Kurtosis	4.42
Coeff. of Variability	0.56
Range Minimum	138
Range Maximum	2144
Range Width	2006
Mean Std. Error	5.01

Target Forecast: leach and runoff g/ha/year Aas #2 Zink

F35	-.70
F28	.70
N24	.02
N25	.00
BCF dw	.00

Figure AVIII-18 a,b,c,d. Forecast of loss of Zn from soil by plant uptake (g ha^{-1} yr^{-1}). a) Frequency distribution b) statistics c) percentiles d) sensitivity chart, where N25 is TF wheat, N24 is TF oats, BCF DW is TF barley, F28 is precipitation, F35 is Kd. Default 544 g ha^{-1} yr^{-1}.

Zinc in Surface Water, Ås #2, 10 years

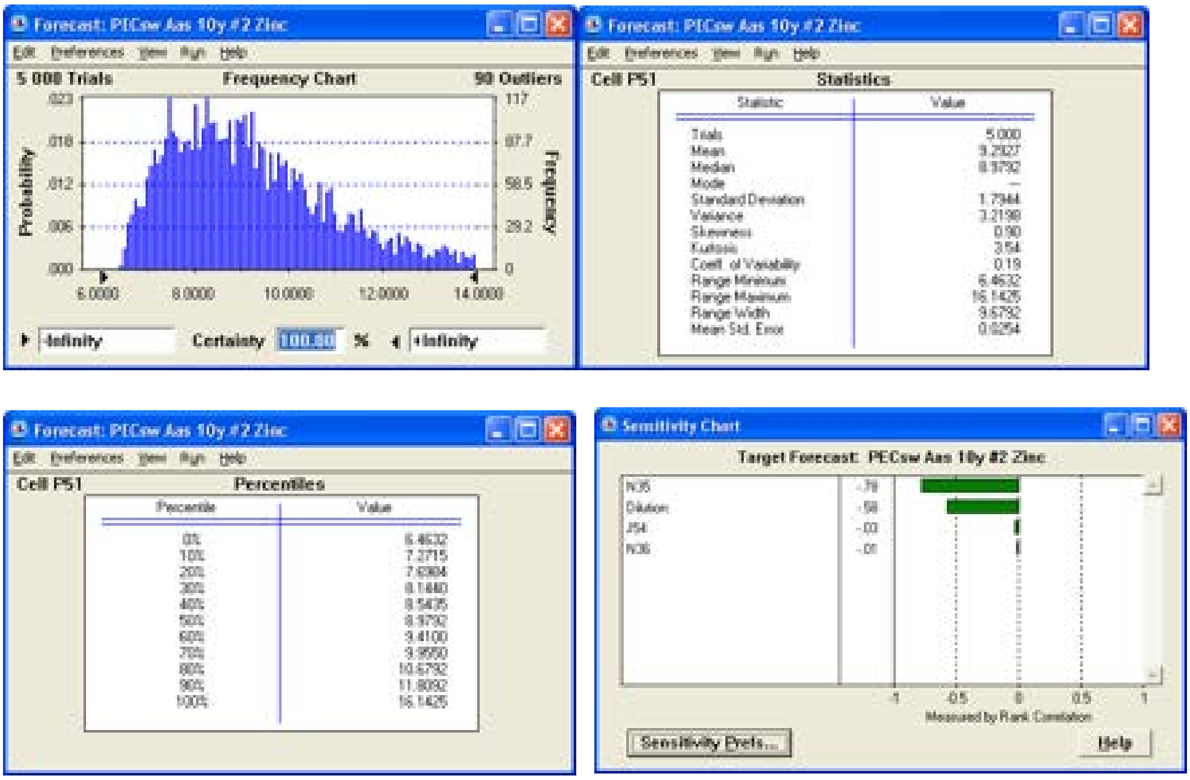
Again, input parameters were varied with uniform distribution from 50% to 200% of the default value. The results are shown as figures. The conclusions resemble those obtained for cadmium. A novelty versus section 10.3.2 is that now also dilution is varied, because it was identified as sensitive parameter by the hand-made sensitivity studies.

Figure AVIII-19, PEC_{sw}

The newly added parameter Dilution (dilution factor surface water) shows a high sensitivity, with a rank correlation coefficient r of -0.58. Even higher sensitivity for PEC_{sw} has Kp_{susp} (r = -0.78). Erosion E_{tot} and Kp_{sed} do not influence PEC_{sw}.

Figure AVIII-20, PEC_{sed}

Kp_{sed} is however the most relevant parameter for the predicted concentration in sediment, PEC_{sed}, and is highly positively correlated (r = +0.89). Other parameters of influence are Kp_{susp} (r = -0.31) and dilution (r = -0.27). Of no relevance is E_{tot} (r = 0.00).



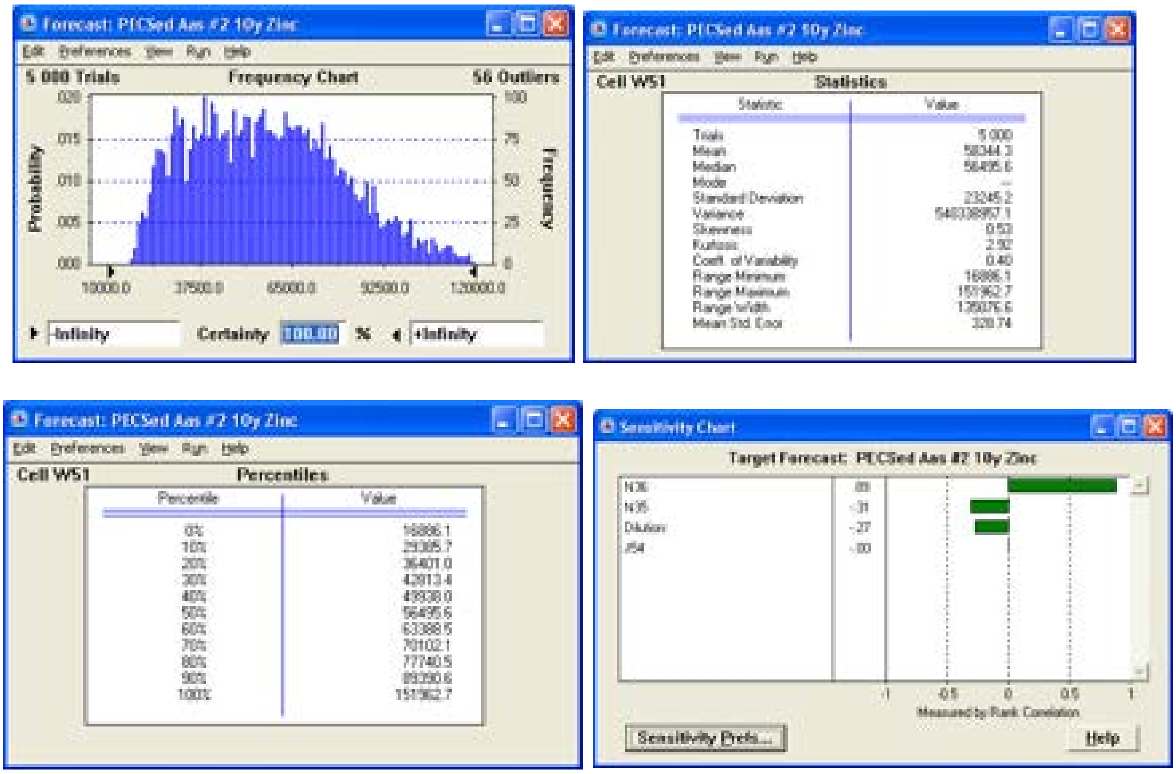
Cell F51 Statistics

Statistic	Value
Trials	5,000
Mean	9.2927
Median	8.9792
Mode	---
Standard Deviation	1.7944
Variance	3.2198
Skewness	0.90
Kurtosis	3.54
Coeff. of Variability	0.19
Range Minimum	6.4632
Range Maximum	16.1425
Range Width	9.6792
Mean Std. Error	0.0254

Cell F51 Percentiles

Percentile	Value
0%	6.4632
10%	7.2715
20%	7.6904
30%	8.1440
40%	8.5435
50%	8.9792
60%	9.4100
70%	9.9550
80%	10.6792
90%	11.8092
100%	16.1425

Figure AVIII-19 a,b,c,d. Forecast of PEC_{sw} for Zn, Ås, #2, 10 years. a) Frequency distribution b) statistics c) percentiles d) sensitivity chart, where N35 is Kp_{susp}, N36 is Kp_{sed}, J54 is E_{tot} (in Ås) and Dilution is dilution factor. Default value of PEC_{sw} is 8.14 ug L^{-1}.



Statistic	Value
Trials	5 000
Mean	58344.3
Median	56495.6
Mode	---
Standard Deviation	23245.2
Variance	540338957.1
Skewness	0.53
Kurtosis	2.52
Coeff. of Variability	0.40
Range Minimum	16886.1
Range Maximum	151962.7
Range Width	135076.6
Mean Std. Error	328.74

Percentile	Value
0%	16886.1
10%	29305.7
20%	36401.0
30%	42913.4
40%	49338.0
50%	56495.6
60%	63388.5
70%	70102.1
80%	77740.5
90%	89390.6
100%	151962.7

N36	.89
N35	-.31
Dilution	-.27
J54	-.00

Figure AVIII-20 a,b,c,d. Forecast of PEC_{sed} for Zn, Ås, #2, 10 years. a) Frequency distribution b) statistics c) percentiles d) sensitivity chart, where N35 is Kp_{susp}, N36 is Kp_{sed}, J54 is E_{tot} (in Ås) and Dilution is dilution factor. Default value of PEC_{sed} 40803 ug kg^{-1}.

Zinc in Surface Water, Stange #2, 10 years

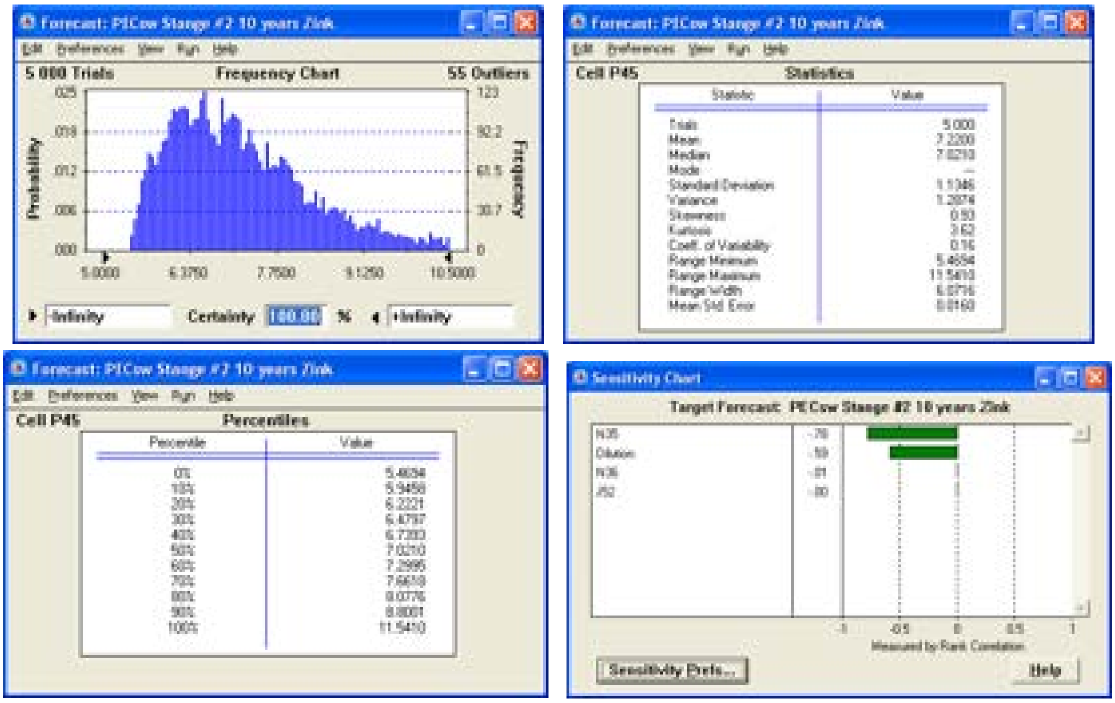
Similar to the previous chapter, but Monte Carlo simulations were made for Stange, scenario #2. Again, input parameters were varied with uniform distribution from 50% to 200% of the default value. The results are shown as figures. The conclusions resemble those obtained before for Zn in Ås, but also those for cadmium in Ås and Stange before. Dilution is also considered here.

Figure AVIII-21, PEC_{sw}

The newly added parameter Dilution (dilution factor surface water) shows again a high sensitivity, with a rank correlation coefficient r of -0.59 (previously, for Ås, -0.58). The same rank correlation coefficient was obtained between PEC_{sw} and Kp_{susp} (r = -0.78). Erosion E_{tot} (r = 0.00) and Kpsed do not influence PEC_{sw} (r = -0.01).

Figure AVIII-22, PEC_{sed}

Kpsed is as before the most relevant parameter for the predicted concentration in sediment, PEC_{sed}, and is highly positively correlated (r = +0.92). Other parameters of influence are Kpsusp (r = -0.28) and dilution (r = -0.21). Of no relevance is E_{tot} (r = 0.00).



Forecast: PECsw Stange #2 10 years Zink

Cell P45 Statistics

Statistic	Value
Trials	5 000
Mean	7.2200
Median	7.0210
Mode	---
Standard Deviation	1.1346
Variance	1.2874
Skewness	0.93
Kurtosis	3.62
Coeff. of Variability	0.16
Range Minimum	5.4694
Range Maximum	11.5410
Range Width	6.0716
Mean Std. Error	0.0160

Forecast: PECsw Stange #2 10 years Zink

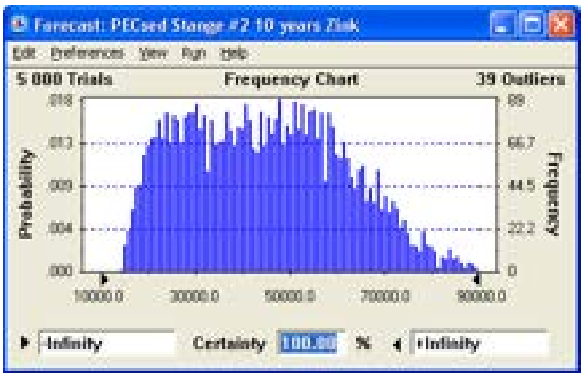
Cell P45 Percentiles

Percentile	Value
0%	5.4694
10%	5.9458
20%	6.2221
30%	6.4797
40%	6.7333
50%	7.0210
60%	7.2995
70%	7.6619
80%	8.0776
90%	8.8001
100%	11.5410

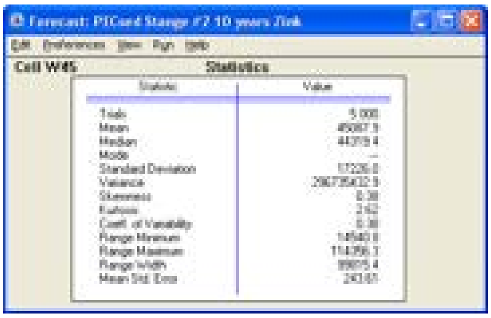
Target Forecast: PECsw Stange #2 10 years Zink

N35	-.78
Dilution	-.59
N36	-.01
J52	-.00

Figure AVIII-21 a,b,c,d. Forecast of PEC_{sw} for Zn, Stange, #2, 10 years. a) Frequency distribution b) statistics c) percentiles d) sensitivity chart, where N35 is Kp_{susp}, N36 is Kp_{sed}, J52 is E_{tot} (in Stange) and Dilution is dilution factor. Default value of PEC_{sw} Zn in Stange is 6.51 ug L^{-1}.



default is 32618 ug kg^{-1} Zinc



Cell W45 Statistics

Statistic	Value
Trials	5 000
Mean	45087.9
Median	44319.4
Mode	---
Standard Deviation	17226.0
Variance	296735432.9
Skewness	0.38
Kurtosis	2.62
Coeff. of Variability	0.38
Range Minimum	14540.8
Range Maximum	114356.3
Range Width	99815.4
Mean Std. Error	243.61

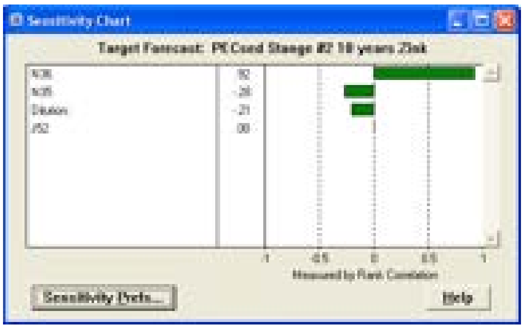


Figure AVIII-22 a,b,c,d. Forecast of PEC_{sed} for Zn, Stange, #2, 10 years. a) Frequency distribution b) statistics c) percentiles d) sensitivity chart, where N35 is Kp_{susp}, N36 is Kp_{sed}, J52 is E_{tot} (in Stange) and Dilution is dilution factor. Default value of PEC_{sed} Zn in Stange is 31619 ug kg^{-1}.

Copper results of the Monte Carlo Analysis

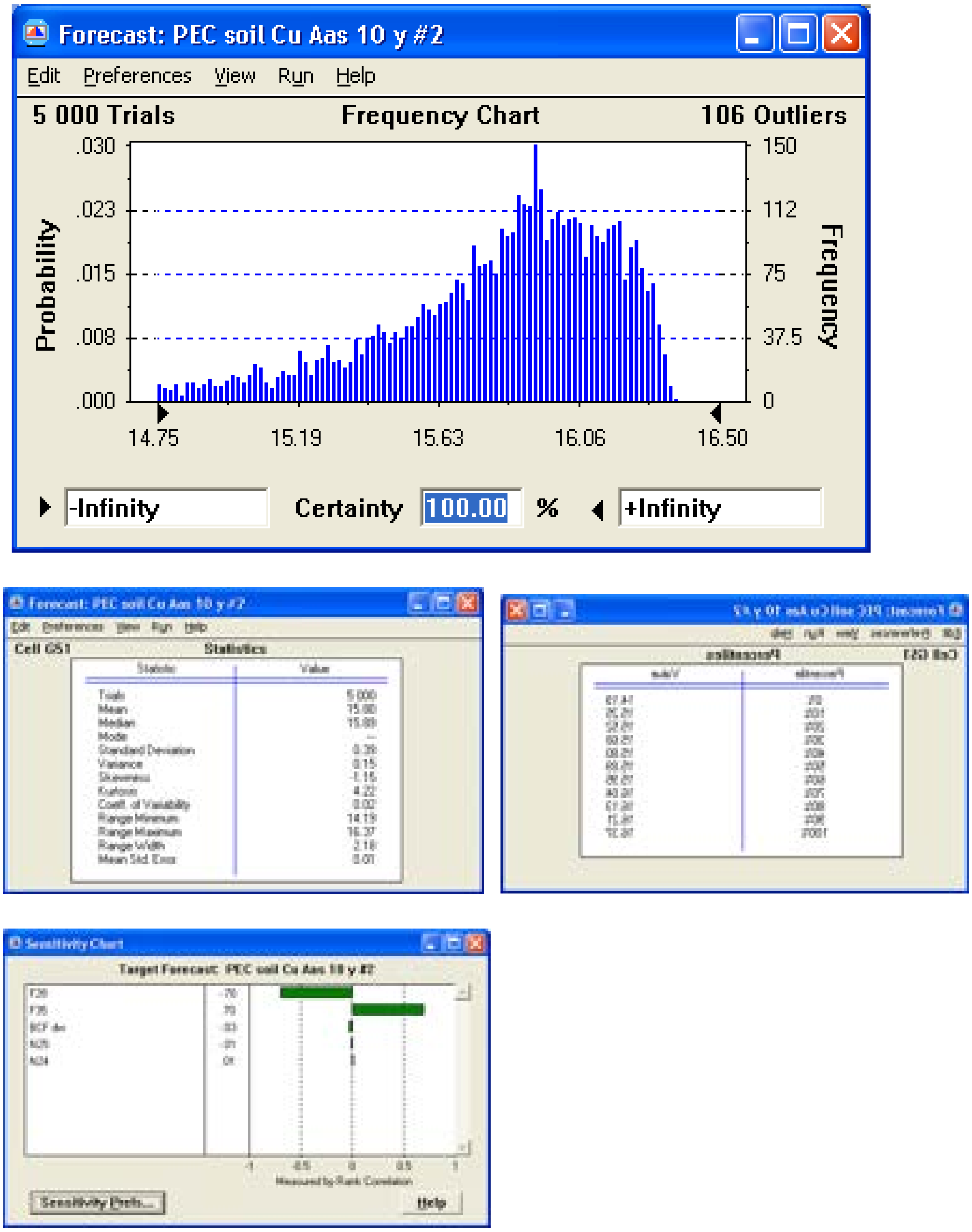
Copper in Soil, Ås #2, 10 years (PEC_{soil}, loss g ha^{-1} $year^{-1}$, Concentration in wheat)

As for the previous Monte Carlo Analysis for cadmium and zinc, the input parameters were varied with uniform distribution from 50% to 200% of the default value. In this section, the varied parameters were precipitation, Kd, TF oats, barley, wheat. Simulations were made for zinc at Ås input scenario #2, after 10 years of application. Forecast values were PEC_{soil}, loss from soil (g ha^{-1} $year^{-1}$), and concentration in wheat.

The results are shown as figures. The conclusions resemble those obtained before.

Figure AVIII-23, PEC_{soil}. The predicted range is from 14.19 to 16.27 mg kg^{-1} DW (default value is at 15.89 mg kg^{-1} DW). Precipitation and Kd explain together 98% of the variance, TF-values are insensitive for Cu.

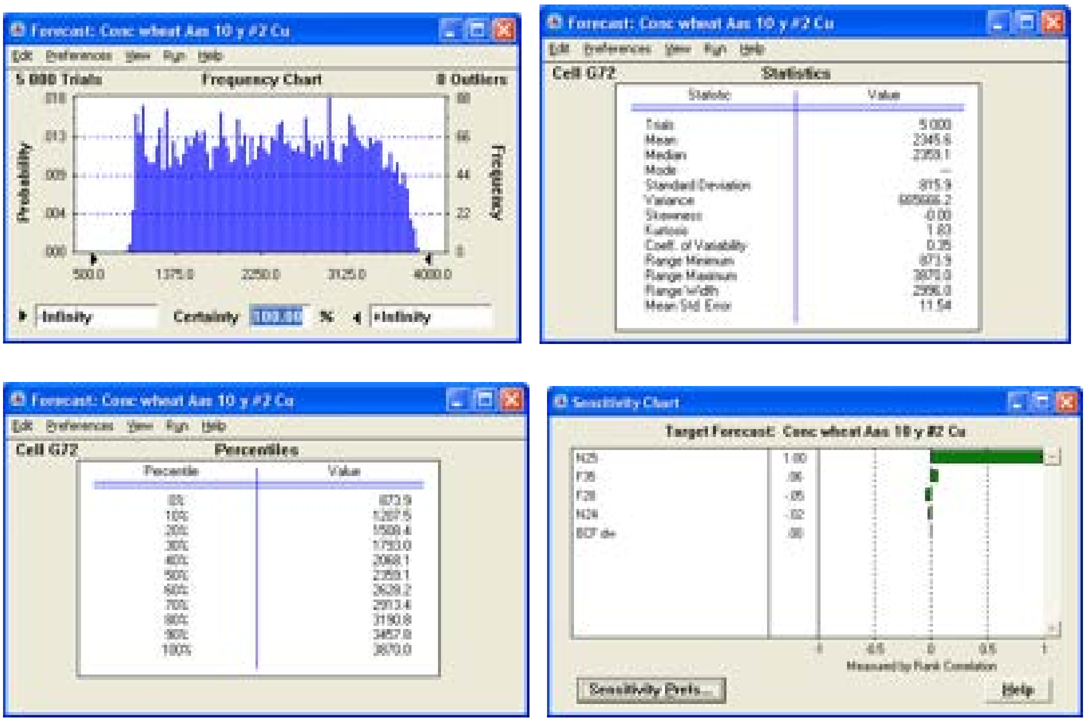
Figure AVIII-24 shows the prediction for concentration of copper in wheat. The range is from 873 to 3870 mg kg^{-1} DW, which is close to ½ to 2 times the default value of 1891 mg kg^{-1} – the sensitivity chart (Figure 10.1.5.1-2d) shows that the TF wheat is by far the most sensitive input parameter for the calculated concentration of copper in wheat.



Statistic	Value
Trials	5 000
Mean	15.80
Median	15.89
Mode	---
Standard Deviation	0.39
Variance	0.15
Skewness	-1.15
Kurtosis	4.22
Coeff. of Variability	0.02
Range Minimum	14.19
Range Maximum	16.37
Range Width	2.18
Mean Std. Error	0.01

F28	-.70
F35	.70
BCF dw	-.03
N25	-.01
N24	.01

Figure AVIII-23 a,b,c,d. Forecast of PEC_{soil} for Cu. a) Frequency distribution b) statistics c) percentiles d) sensitivity chart, where N25 is TF wheat, N24 is TF oats, BCF DW is TF barley, F28 is precipitation, F35 is Kd. Default PECsoil value Cu is 15.89 mg kg^{-1} DW.



Cell G72 Statistics

Statistic	Value
Trials	5 000
Mean	2345.6
Median	2359.1
Mode	---
Standard Deviation	815.9
Variance	665666.2
Skewness	-0.00
Kurtosis	1.83
Coeff. of Variability	0.35
Range Minimum	873.9
Range Maximum	3870.0
Range Width	2996.0
Mean Std. Error	11.54

Cell G72 Percentiles

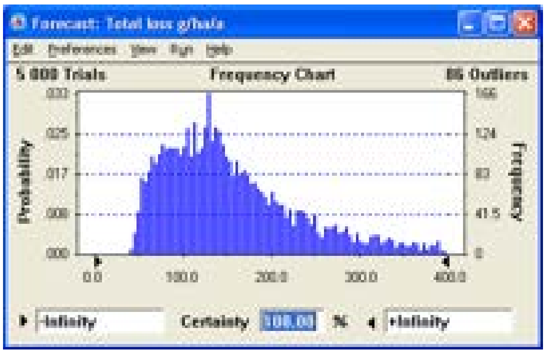
Percentile	Value
0%	873.9
10%	1207.5
20%	1508.4
30%	1793.0
40%	2068.1
50%	2359.1
60%	2628.2
70%	2913.4
80%	3190.8
90%	3457.8
100%	3870.0

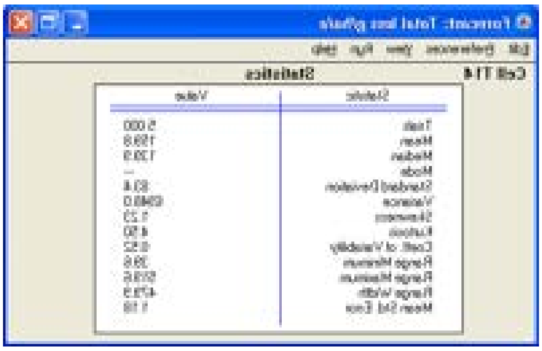
N25	1.00
F35	.06
F28	-.05
N24	-.02
BCF dw	.00

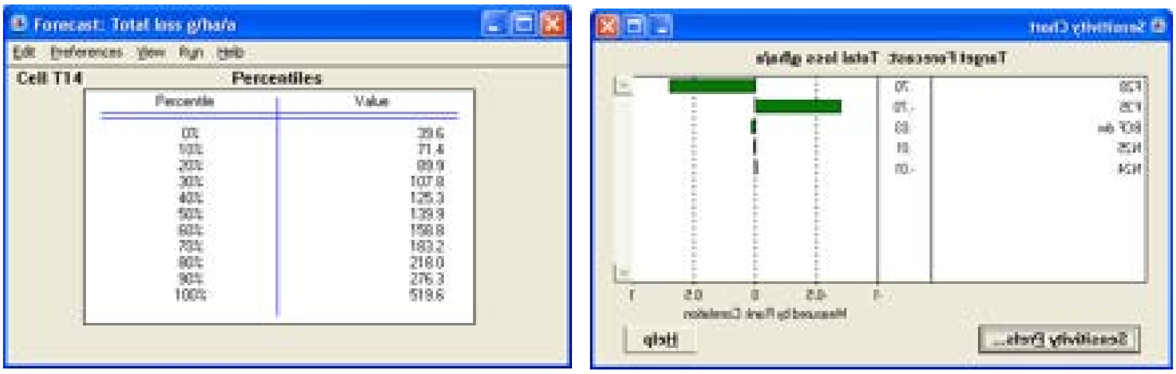
Figure AVIII-24 a,b,c,d. Forecast of Cu concentration in wheat (Zn µg/kg fw). a) Frequency distribution b) statistics c) percentiles d) sensitivity chart, where N25 is TF wheat, N24 is TF oats, BCF DW is TF barley, F28 is precipitation, F35 is Kd. Default value: 1891 µg/kg fw.

Figure 10.1.5.1-3 shows the total loss of Cu from soil, Figure 10.1.5.1-4 shows the loss by plant uptake, and Figure 10.1.5.1-5 shows the loss by runoff and leaching. Overall, runoff and leaching are clearly dominating the loss (default total loss 137.9 g ha^{-1} yr^{-1}, hereoff runoff and leaching 129.7 g ha^{-1} yr^{-1}), plant uptake is of minor relevance (default 8.2 g ha^{-1} yr^{-1}). The range of the predicted values is wide, from 39.6 to 519.6 g ha^{-1} yr^{-1} total loss, with the sensitive parameters being Kd and precipitation, as seen before.

This is of concern, because for scenario #2, the input of copper is about as high as the input for Zn, but the loss is only one fifth. This would, seen over longer time periods, lead to a significant increase of the Cu concentrations in soil, if these scenarios get reality.



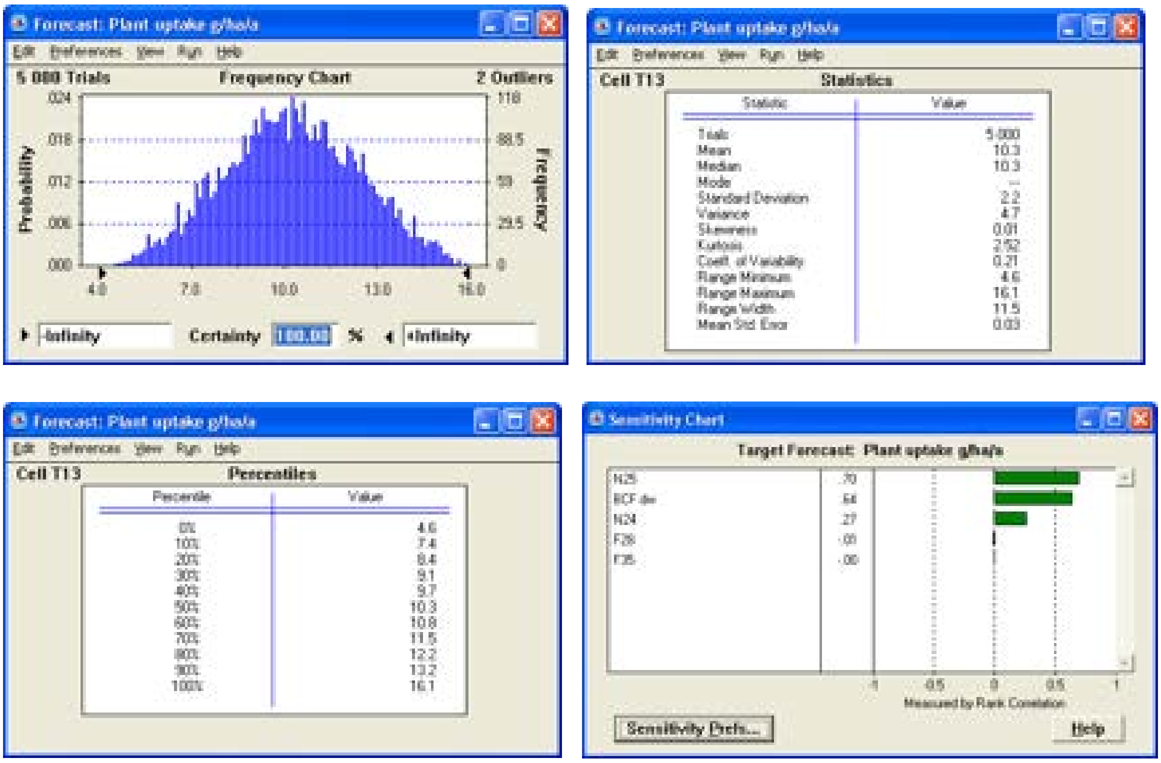




Cell T14 — Percentiles

Percentile	Value
0%	39.6
10%	71.4
20%	89.9
30%	107.8
40%	125.3
50%	139.9
60%	158.8
70%	183.2
80%	218.0
90%	276.3
100%	519.6

Figure AVIII-25 a,b,c,d. Forecast of total loss of Cu from soil (g ha^{-1} yr^{-1}). a) Frequency distribution b) statistics c) percentiles d) sensitivity chart, where N25 is TF wheat, N24 is TF oats, BCF DW is TF barley, F28 is precipitation, F35 is Kd. Default 137.9 g ha^{-1} yr^{-1}.



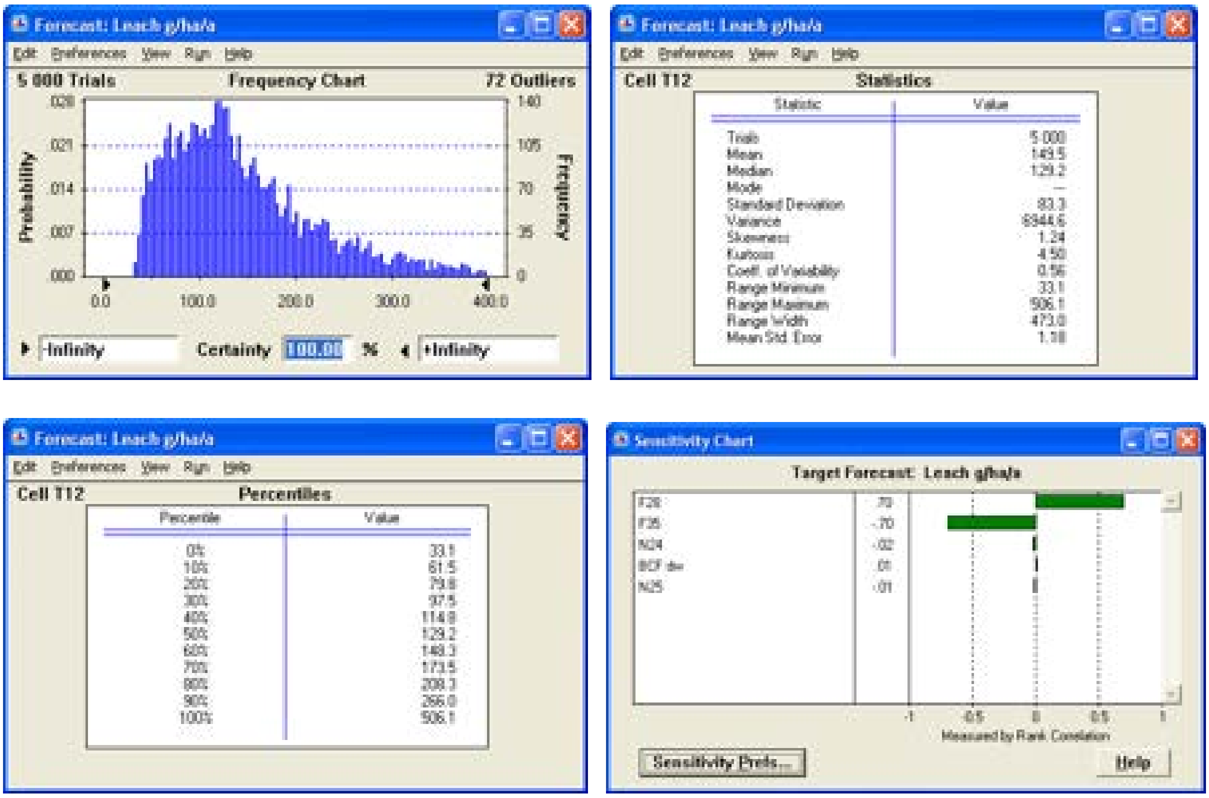
Cell T13 — Statistics

Statistic	Value
Trials	5 000
Mean	10.3
Median	10.3
Mode	---
Standard Deviation	2.2
Variance	4.7
Skewness	0.01
Kurtosis	2.52
Coeff. of Variability	0.21
Range Minimum	4.6
Range Maximum	16.1
Range Width	11.5
Mean Std. Error	0.03

Cell T13 — Percentiles

Percentile	Value
0%	4.6
10%	7.4
20%	8.4
30%	9.1
40%	9.7
50%	10.3
60%	10.8
70%	11.5
80%	12.2
90%	13.2
100%	16.1

Figure AVIII-26 a,b,c,d. Forecast of loss of Cu from soil by plant uptake (g ha^{-1} yr^{-1}). a) Frequency distribution b) statistics c) percentiles d) sensitivity chart, where N25 is TF wheat, N24 is TF oats, BCF DW is TF barley, F28 is precipitation, F35 is Kd. Default 8.2 g ha^{-1} yr^{-1}.



Cell T12 Statistics

Statistic	Value
Trials	5 000
Mean	149.5
Median	129.2
Mode	---
Standard Deviation	83.3
Variance	6944.6
Skewness	1.24
Kurtosis	4.50
Coeff. of Variability	0.56
Range Minimum	33.1
Range Maximum	506.1
Range Width	473.0
Mean Std. Error	1.18

Cell T12 Percentiles

Percentile	Value
0%	33.1
10%	61.5
20%	79.8
30%	97.5
40%	114.8
50%	129.2
60%	148.3
70%	173.5
80%	208.3
90%	266.0
100%	506.1

Figure AVIII-27 a,b,c,d. Forecast of loss of Cu from soil by plant uptake (g ha^{-1} yr^{-1}). a) Frequency distribution b) statistics c) percentiles d) sensitivity chart, where N25 is TF wheat, N24 is TF oats, BCF DW is TF barley, F28 is precipitation, F35 is Kd. Default 129.7 g ha^{-1} yr^{-1}.

Copper in Surface Water, Ås #2, 10 years

Input parameters were varied with uniform distribution from 50% to 200% of the default value. Monte Carlo simulations have been made without and with variation of the dilution factor. As it turns out, dilution is a very important factor, and thus, results are shown with variation of dilution.

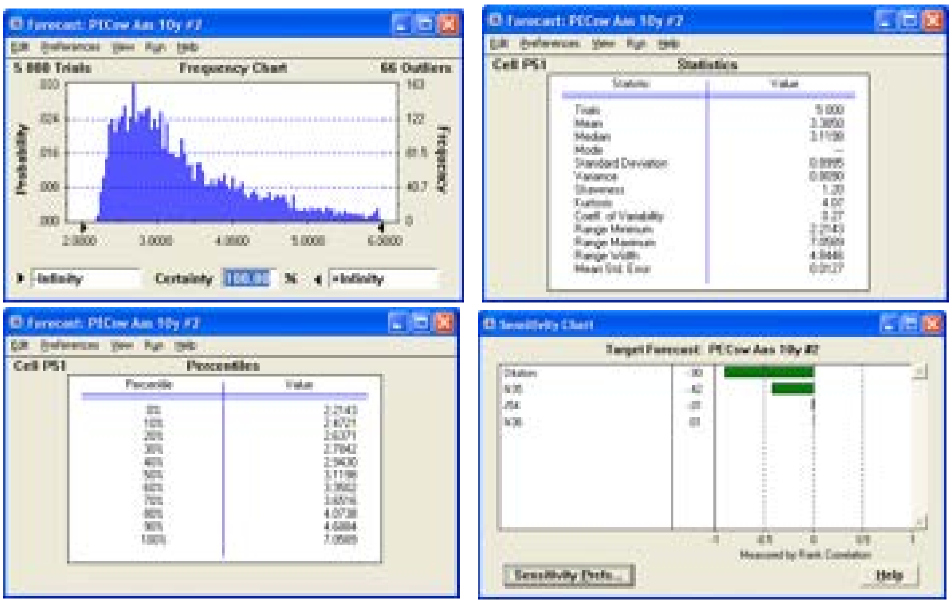
Figure AVIII-28, PECsw

The range of PECsw is from 2.2 to 7 µg L^{-1} (default 3.7 µg L^{-1}). The newly added parameter dilution (dilution factor surface water) shows here the highest sensitivity, with a rank correlation coefficient r of -0.9 (which corresponds to 81% of the explained variance!), followed by Kp_{susp} (r = -0.42). The remaining two parameters, E_{tot} and Kp_{sed}, do not affect PEC_{sw}.

The concentrations in surface water of copper are almost as high as those for zinc. This is of concern because copper is, for some organisms, more toxic. Concentration of Cu in sediment are even almost twice as high as those for Zn.

Figure AVIII-29, PEC_{sed}

Kpsed is the most relevant parameter for the predicted concentration in sediment, PEC_{sed}, with high positive correlation (r = +0.84). Dilution also plays a big role, with r = -0.47. Kp_{susp} is the third parameter with influence, but r is only -0.21, which means only 4.4% explained variance r2. Of no relevance is E_{tot} (r = 0.00).



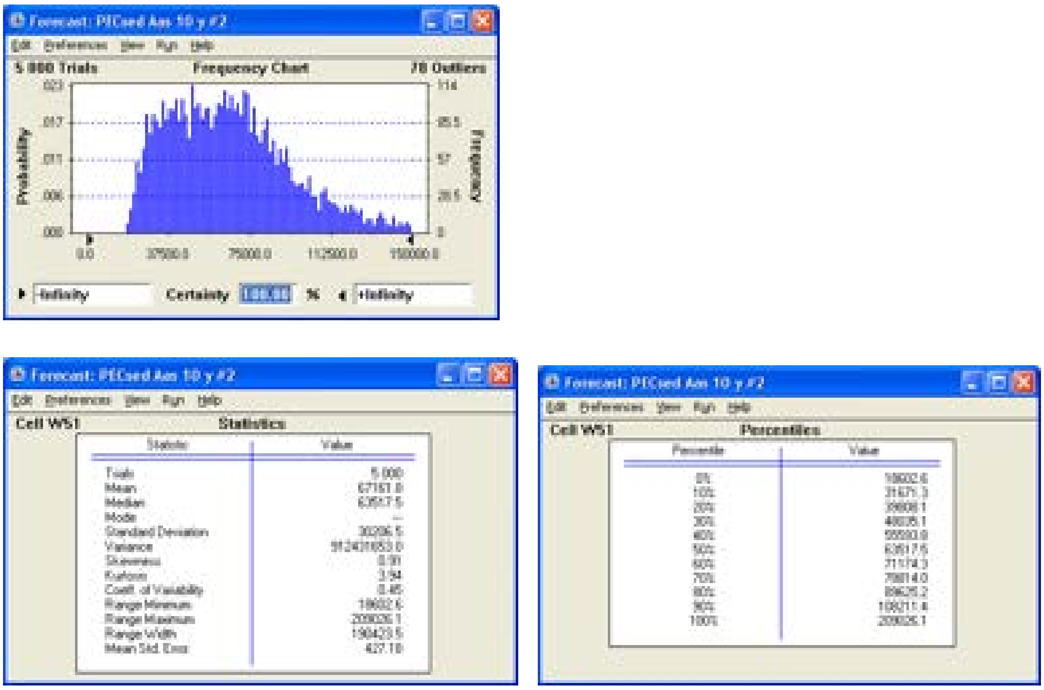
Cell P51 Statistics

Statistic	Value
Trials	5 000
Mean	3.3850
Median	3.1199
Mode	---
Standard Deviation	0.8995
Variance	0.8090
Skewness	1.20
Kurtosis	4.07
Coeff. of Variability	0.27
Range Minimum	2.2143
Range Maximum	7.0589
Range Width	4.8446
Mean Std. Error	0.0127

Cell P51 Percentiles

Percentile	Value
0%	2.2143
10%	2.4721
20%	2.6371
30%	2.7942
40%	2.9430
50%	3.1199
60%	3.3502
70%	3.6516
80%	4.0738
90%	4.6284
100%	7.0589

Figure AVIII-28 a,b,c,d. Forecast of PEC_{sw} for Cu, Ås, #2, 10 years. a) Frequency distribution b) statistics c) percentiles d) sensitivity chart, where N35 is Kp_{susp}, N36 is Kp_{sed}, J54 is E_{tot} (in Ås) and Dilution is dilution factor. Default value of PEC_{sw} is 3.72 ug L^{-1}.



Cell W51 Statistics

Statistic	Value
Trials	5 000
Mean	67161.8
Median	63517.5
Mode	---
Standard Deviation	30206.5
Variance	912431653.0
Skewness	0.91
Kurtosis	3.94
Coeff. of Variability	0.45
Range Minimum	18602.6
Range Maximum	209026.1
Range Width	190423.5
Mean Std. Error	427.18

Cell W51 Percentiles

Percentile	Value
0%	18602.6
10%	31671.3
20%	39808.1
30%	48035.1
40%	55593.0
50%	63517.5
60%	71174.3
70%	79814.0
80%	89625.2
90%	108211.4
100%	209026.1

Figure AVIII-29 a,b,c,d. Forecast of PEC_{sed} for Cu, Ås, #2, 10 years. a) Frequency distribution b) statistics c) percentiles d) sensitivity chart, where N35 is Kp_{susp}, N36 is Kp_{sed}, J54 is E_{tot} (in Ås) and Dilution is dilution factor. Default value of PEC_{sed} 58987 µg kg^{-1}.

Copper in Surface Water, Stange #2, 10 years

Monte Carlo simulations were also made for Stange, scenario #2, with the same variation of input data as in the previous chapter (i.e., including dilution). The results are rather comparable to those obtained for Ås, but at slightly lower level, despite similar input with sewage sludge and even higher background concentration in surface water (Stange 12 versus Ås 11 µg L^{-1}). The reason is the higher Kd at Stange and the lower leaching and runoff at Stange, compared to Ås, which in turn leads to less wash-out of Cu into surface waters. Figure AVIII-30 shows the PEC_{sw}, and Figure 10.1.5.3-2 the PEC_{sed} for copper at Stange, scenario #2 (maximum sewage sludge application) and after 10 years simulation period. The result confirms the previous findings: dilution is by far the most influential parameter for PEC_{sw} (among those varied) (Figure 10.1.5.3-1d), followed by Kp_{sup}. The range is broad but left skewed, with more chance for low values (below the mean) than risk of high values (above the mean).

Figure AVIII-31, PEC_{sed}

Kp_{sed} is as before the most relevant parameter for the predicted concentration in sediment, PEC_{sed}, and is highly positively correlated (r = +0.92). Other parameters of influence are Kp_{susp} (r = -0.28) and dilution (r = -0.21). Of no relevance is E_{tot} (r = 0.00).

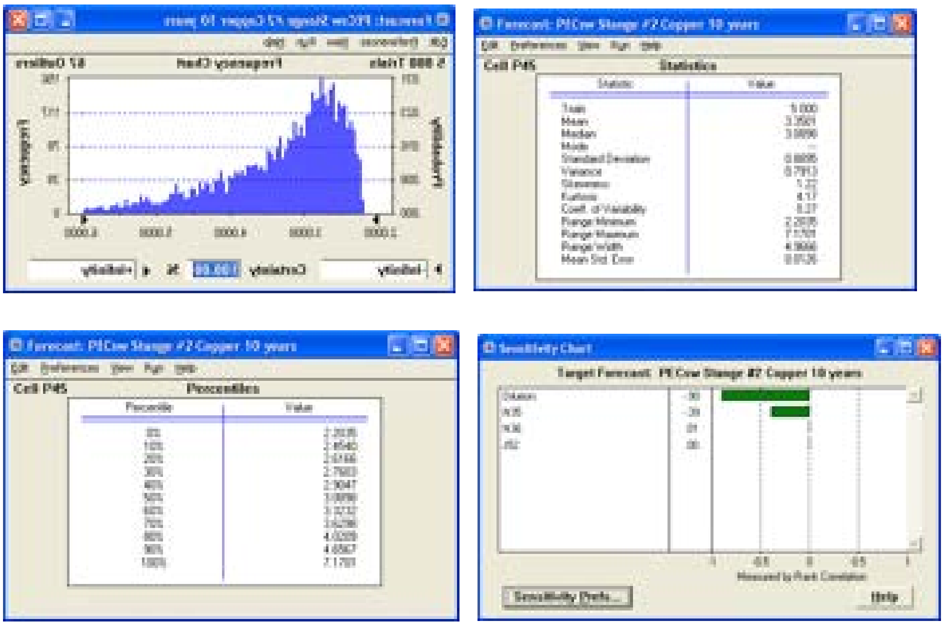
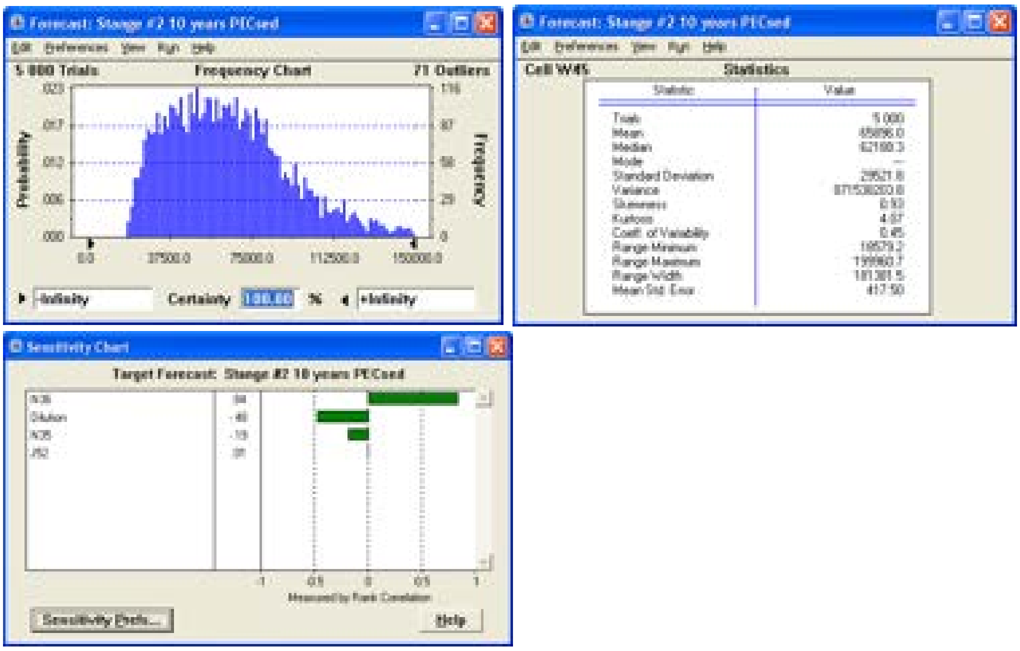


Figure AVIII-30 a,b,c,d. Forecast of PEC_{sw} for Cu, Stange, #2, 10 years. a) Frequency distribution b) statistics c) percentiles d) sensitivity chart, where N35 is Kpsusp, N36 is Kp_{sed}, J52 is E_{tot} (in Stange) and Dilution is dilution factor. Default value of PEC_{sw} Cu in Stange is 3.67 µg L^{-1}.



Forecast: Stange #2 10 years PECsed

Cell W45 Statistics

Statistic	Value
Trials	5 000
Mean	65896.0
Median	62188.3
Mode	---
Standard Deviation	29521.8
Variance	871538203.8
Skewness	0.93
Kurtosis	4.07
Coeff. of Variability	0.45
Range Minimum	18579.2
Range Maximum	199960.7
Range Width	181381.5
Mean Std. Error	417.50

Target Forecast: Stange #2 10 years PECsed

N36	.84
Dilution	-.48
N35	-.19
J52	.01

Figure AVIII-31 a,b,c,d. Forecast of PEC_{sed} for Cu, Stange, #2, 10 years. a) Frequency distribution b) statistics c) percentiles d) sensitivity chart, where N35 is Kp_{susp}, N36 is Kp_{sed}, J52 is E_{tot} (in Stange) and Dilution is dilution factor. Default value of PEC_{sed} Cu in Stange is 58177 µg kg^{-1}.

Appendix IX

Soil loss calculations

In this study, sheet and gully erosion and suffusion are evaluated at the level of the municipality by means of the calibrated models (e.g. those behind the national erosion risk map). An estimation of sediment delivery to the freshwater system is then carried out by evaluating the landscape's sediment connectivity with regard to each of the processes. The sediment balance for each of the municipalities is the expressed as an empirical sum of scaled sediment sources, so that:

$$SDR = a*IC*E_{SHEET} + b*L_{GULLY} + c*E_{DRAIN} + d*E_{BANK} \qquad \text{(Eq. 10)}$$

where SDR is the sediment delivery rate to the freshwater system, E designates the erosion rates according to their process (all in tonne ha-1 y^{-1}). L is the length of the ephemeral gullies (m ha^{-1}). IC is and index of connectivity (-) and *a* to *d* are multipliers. The multiplier c for drainage erosion can be assumed to be 1, since there is no storage between the point of entry to the drain pipe and it's outflow into the stream or lake. The values of the multipliers a, b, and d were estimated by using model results, terrain analysis and measured soil loss from three catchment in NIBIO's Norwegian Agricultural Monitoring Programme; Skuterud and Mørdre in Viken county and Kolstad in Innlandet county.

Sheet erosion

The Pan-European Soil Erosion Risk Assessment is a hybrid process based and empirical model that calculates saturation excess runoff and sheet erosion. The model has a hydrological core that constitutes a monthly soil profile water balance. Infiltration excess is calculated based on inputs that include precipitation (monthly total, distribution and variability), temperature (mean and range) and evapotranspiration. Snow accumulation and melt are accounted for, as well as the effect of frozen soil layers.

The model configuration for Norway consisted of three major tasks: (1) developing the climatic data, (2) converting the available soil physical data (as available from the Norwegian national soil map) into the parameters required by the model, and (3) adjusting the model components that deal with frozen conditions to the Norwegian situation. The climate data used in NIBIO's model configuration are derived from interpolated daily weather maps, provided by the Norwegian Meteorological Institute at a 1x1 km spatial resolution. Soil physical parameters (porosity, plant available soil moisture, erodibility, crustability) were derived from measured data for the mapped soil types and/or pedotransfer functions developed for Norwegian soil data base.

PESERA runoff and erosion rates were calibrated (separately) with data consisting of time series from seven runoff plots situated in Viken, Innlandet and Trøndelag counties.

Drain erosion

As part of the national erosion risk map, drain erosion was estimated with an empirical equation.

$$E_{DRAIN} = 2.24 * e^{0.023\phi} * \log(Q_D) * Q_D * e^{k} * (1 + 1/e^{S}) * 1.67 * 10^{-6} \qquad \text{(Eq. 11)}$$

Where ϕ is the porosity (m^3/m^3), Q_D is annual infiltration (precipitation minus runoff, mm), S slope (m/m) and k is the aggregate stability (-). This equation was calibrated by means of time series data from several runoff plots covering the main agricultural regions of Norway.

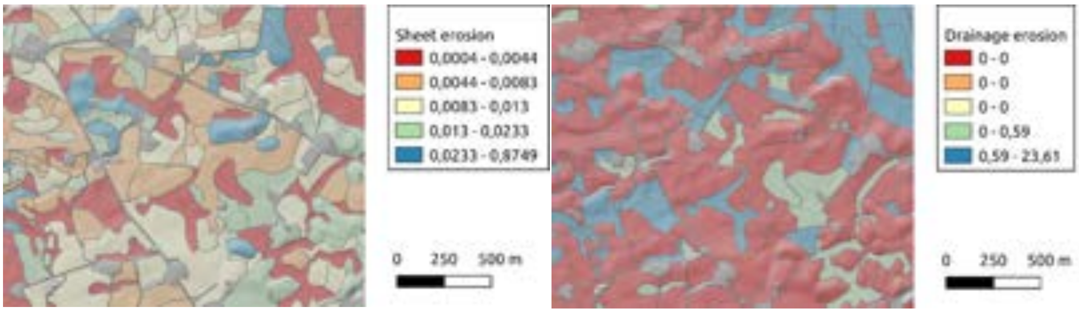


Figure AIX-1a and AIX-1b: *Sheet and drainage erosion risk for a sample area in Stange municipality*.

Ephemeral gully erosion

Ephemeral gully erosion risk is part of the national erosion risk map as well. It is modelled as a separate process, but the simulations do not provide a quantification, only localisation. This is why gully erosion is represented with a length in the sediment delivery equation. Multiplier *b* in the equation then represents soil loss per hectare per meter gully length.

Gully localisation is mapped by applying a simple equation that relates accumulated overland flow (*Q*, m^3) and local slope values (*S*, m/m). If the product exceeds a certain threshold value, the location is classified as prone to ephemeral gully erosion. The equation that is applied to the terrain with 3 by 3 meter resolution is given by:

$$Q^{1.2} * S > 5.0\ 10^{4} \qquad \text{(Eq. 12)}$$

At any location where this equation is evaluated as true, ephemeral gully erosion can be expected. This empirical equation was calibrated by an analysis of harmonised set of measurements and observations of gully erosion in southeast and central Norway.

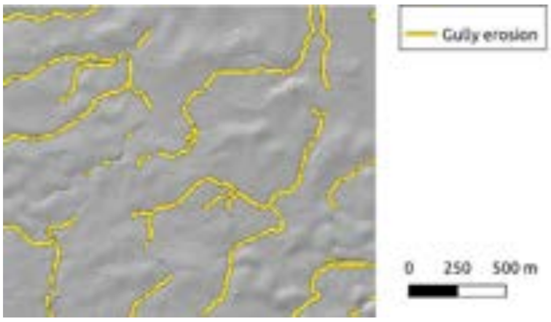


Figure AIX-2

Sediment connectivity

Connectivity as a landscape property is defined as its ability to convey mass from one location to another. Sediment connectivity in this study is defined as the likelihood of a detached soil particle to travel from its source to a recipient water body (a permanent stream or a lake). Several approaches to quantify connectivity can be taken, and the approach proposed by Borselli *et al.* (2008). Borselli's index of connectivity (IC, unitless) is calculated by comparing locations' upstream area with their downstream distances to the recipient water body. IC is defined formally as:

$$IC = \log10 ((W*S*A^{0.5})/(SUM_{i=0,n}\ d_i/(W_i *S_i))) \qquad \text{(Eq. 13)}$$

Here, the left term represents the upslope area (yellow in Figure 5.2.2.4-1a, it's mean slope S and area in m2). The right hand side represents the hydrological path to the recipient as the sum of *n* steps of size *d* (m).

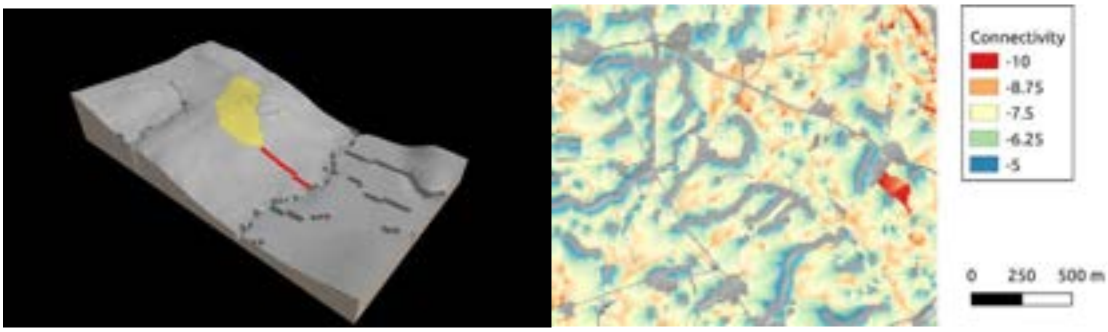


Figure AIX-2: *(a) The topographic principle behind the index of connectivity, and (b) an example of a connectivity map (Stange municipality).*

The weighing term *W* can represent any terrain characteristic that is expected to be spatially variable. In this study, W is assumed 1. Instead of the surface area of the upslope area, we use the accumulated runoff, as modelled with PESERA. This is a better evaluation of an area's ability to bring forth the energy required to transport particles. IC values are standardised to range from 0 to 1 for the analysis in this study (Eq. 13).