Cadmium in mineral fertilisers – human and environmental risk update

SCAHT report for BLW

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1 Executive summary

A report by BUWAL (2003a) estimated that use of phosphorus fertilisers with "medium" or "high" cadmium content (37.5 and 50 mg Cd/kg P, corresponding to Swiss current and limit values, respectively) would produce a long-term (100 years) dose-related increase in Cd content in Swiss arable soils. Despite this projected increase, they concluded that the "high" value of 50 mg Cd/kg P (the Swiss ChemRRV limit) was sufficiently protective for human health and the environment. At the same time, they recommended that in view of the Swiss policy of prevention and best available techniques, cadmium concentrations in phosphorus mineral fertilisers needed to be kept as low as possible.

Results of a Swiss market surveillance campaign in 2011/2012 conducted by eleven participating cantons and the Bundesamt für Landwirtschaft (BLW 2015) showed that 45% (20 of 44) of the P-fertilisers tested had more than 50 mg Cd/kg P, and 34% (15 of 44) had more than 65 mg Cd/kg P. The ChemRRV limit is 50 mg Cd/kg P; including a tolerance margin of +30% to allow for measurement error, measured levels of up to 65 mg Cd/kg P were considered permissible.

SCAHT was requested by the BLW to re-evaluate the BUWAL (2003a) report in the light of the BLW (2015) surveillance data and any other relevant data. The outcome of the present assessment will serve to consolidate the knowledge at BLW level and may be used to develop future market campaigns/monitoring programs.

From a review of data published after BUWAL (2003a), we conclude that BUWAL (2003a) probably underestimated loss of soil cadmium due to leaching, and therefore overestimated the potential for accumulation of soil cadmium. In addition, soil cadmium from aerial deposition now appears to be less than one third the estimate used by BUWAL 2003a. If the current ChemRRV limit of 50 mg Cd/kg P in mineral fertiliser is adhered to, there will most likely be a decrease rather than an increase in soil cadmium over the next 100 years. We therefore conclude that cadmium from use of P fertiliser at current levels will not lead to increased human exposure and human health risk.

In the environment, some data suggest local excessive levels of cadmium in reservoir sediments (Wildi et al 2004), which may be partly attributable to P fertilisers (in addition to cadmium from atmospheric deposition and manure). It is unclear from the BUWAL 2003a and EU (2006) risk assessments whether there is a risk to sediment organisms or not; further risk characterisation is necessary.

EFSA (2011) has proposed a tolerable intake for cadmium which is 2.5 times lower than the current WHO/FAO tolerable intake (also used by BUWAL 2003a). SCHER (2012) concluded that 100 mg Cd/kg P poses no unacceptable risks in Sweden, even taking into account the EFSA (2011) proposed reduced tolerable cadmium intake).

We therefore conclude that the Swiss limit value of 50 mg Cd/kg P (ChemRRV) is sufficiently protective for human health and the environment. However, given that overall cadmium exposure is close to maximum tolerable levels in some human sub-populations and in some environmental compartments, we agree with BUWAL 2003a that it is prudent to continue keeping cadmium concentrations in phosphorus mineral fertilisers as low as possible.

The following potential data gaps have been identified:

In order to quantify the contribution of contaminated batches to Swiss soil cadmium input, it would be helpful if Swiss monitoring campaigns for cadmium in mineral fertiliser could include information on import volumes and application rates, in addition to levels of cadmium contamination.

In the Swiss Soil Monitoring Network program (NABO), measurement of actual soil cadmium concentrations should be used rather than modelling based on assumed inputs and outputs (particularly leaching rates) (cf. Keller et al 2005), and assay sensitivity should ideally be below regulatory limit value (cf. BAFU 2014).

In the Swiss monitoring programs for groundwater (NAQUA) and surface water (NAWA), dissolved cadmium should be measured in addition to total cadmium (i.e. filtered and unfiltered, as in the EU), and assay sensitivity should be increased to enable detection of levels exceeding maximum permissible dissolved concentrations specified in GSchV (cf. BAFU 2009).

In the Swiss monitoring programs for surface water (NAWA), monitoring of cadmium levels should include lakes in addition to rivers.

Relatively high cadmium concentrations have been reported in some reservoir sediments, but It is unclear from the BUWAL 2003a and EU 2006 risk assessments whether there is a risk to sediment organisms or not. There may be a need for further risk assessment in this compartment.

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2 Abbreviations

BUWAL	Bundesamt für Umwelt, Wald und Landschaft (merged 2006 with Bundesamt für Wasser und Geologie BWG to form the Bundesamt für Umwelt BAFU)
Cd	Cadmium
ChemRRV	Chemikalien-Risikoreduktions-Verordnung, SR 814.81
dw	dry weight
EFSA	European Food Safety Authority
EQS	EU water quality standard
EU	European Union
GSchV	Gewässerschutzverordnung, SR 814.201
ha	hectare
JECFA	Joint FAO/WHO Expert Committee on Food Additives
Kd	distribution coefficient (soil:pore water)
NABO	Nationales Bodenbeobachtungsnetz [Swiss Soil Monitoring Network]
NAQUA	Nationale Grundwasserbeobachtung [Swiss National Groundwater Monitoring program]
NAWA	Nationale Beobachtung Oberflächengewässerqualität [Swiss National Surface Water Monitoring program]
P	Phosphorus
P2O5	Phosphorus (V) oxide; phosphorus pentoxide
PEC	Predicted environmental concentration
PNEC	Predicted no-effect concentration
PTMI	Provisional Tolerable Monthly Intake
PTWI	Provisional Tolerable Weekly Intake
Richtwert	guidance value
SCAHT	Swiss Centre for Applied Human Toxicology
SCHER	EU Scientific Committee on Health and Environmental Risks
TWI	Tolerable Weekly Intake
VBBo	Verordnung über Belastungen des Bodens, SR 814.12

3 Introduction

Cadmium is a naturally occurring metal which is not required by organisms, but which may accumulate in the human body or environment, resulting in toxicity. It can be found at relatively high concentrations in some phosphate rocks, depending on the geological deposit type, and thus as a contaminant in commercial phosphate (P) mineral fertilisers. The application of P mineral fertilisers can thus increase input of cadmium to agricultural soils.

BUWAL (2003a) estimated that use of P mineral fertilisers with "medium" or "high" cadmium content (37.5 and 50 mg Cd/kg P, representing current and maximum permitted Swiss levels, respectively) would produce a long-term (100 years) dose-related increase in Cd content in Swiss arable soils. Despite this projected increase, they concluded that the "high" value of 50 mg Cd/kg P (corresponding to the current Swiss ChemRRV limit) was sufficiently protective for human health and the environment. At the same time, they recommended that in view of the Swiss policy of prevention and best available techniques, cadmium concentrations in phosphorus mineral fertilisers needed to be kept as low as possible.

Recent results from a Swiss market campaign conducted by the Bundesamt für Landwirtschaft (BLW) and eleven participating cantons in 2011/2012 showed that 45% of the P-fertilisers tested exceeded the ChemRRV limit of 50 mg Cd/kg P (BLW 2015).

SCAHT was requested by the BLW to re-evaluate the BUWAL (2003a) report in the light of these and any other current relevant data. The outcome of this evaluation will serve to consolidate the knowledge at BLW level and may be used to develop future market campaigns/monitoring programs.

Note: Cadmium concentrations in mineral phosphorus fertilisers are generally expressed at EU and international level in terms of phosphate pentoxide (P2O5), whereas in Swiss reports and legislation it is expressed in terms of elemental phosphorus (P). The conversion factor is P2O5 x 2.291 = P. Table 1 shows relevant cadmium concentrations in P fertiliser in terms of P2O5 and P:

Table 1: Relevant P-fertiliser cadmium levels as mg/kg P2O5 and mg/kg P

mg Cd/kg P_2O_5	mg Cd/kg P
16	37.5 (a)
20 (b)	46
22	50 (c)
26	60 (d)
36 (e)	83
44	100 (f)
60 (g)	137
75 (h)	172

a Swiss 1997 average concentration (BUWAL 2003a)

b Maximum level which will not lead to soil cadmium accumulation in EU member states, according to CSTEE (2002)

c Current limit in Switzerland (ChemRRV) and Finland (see Appendix 1)

d Minimum level which will lead to soil cadmium accumulation in EU member states, according to CSTEE (2002)

e EU mid-2000s average concentration (Nziguheba & Smolders 2008)

f Current limit in Sweden (see Appendix 1)

g Proposed EU limit (2013 presentation on draft revision of Fertilisers Regulation ; http://www.endseurope.com/36671/consultationbacksactiononcadmiuminsoil)

h Current limit in Austria (see Appendix 1)

4 Information updates

Since BUWAL 2003a, relevant new information has appeared on predicted trends in soil cadmium, on measured cadmium levels in water and sediment, on human sources of soil cadmium, and on human toxicity estimates.

4.1 Predicted trends in soil cadmium concentrations

BUWAL 2003a used various scenarios to predict future soil cadmium concentrations (different combinations of soil pH, organic matter content and total soil Cd concentration; crop rotations and amounts of applied fertilisers), for three crop types (cereals, potatoes, and vegetables) and three concentrations of Cd in the fertiliser:

- "Medium" content (1997 Swiss average) 37.5 mg Cd/kg P (=16 mg Cd/kg P_2O_5)
- "High" content (Swiss ChemRRV limit) 50 mg Cd/kg P (=22 mg Cd/kg P_2O_5)
- "Zero" content: assuming availability of Cd-free fertilisers

For all vegetables scenarios, a decrease in soil cadmium was predicted. For cereals and potatoes, an increase was predicted in some scenarios, a decrease in others.

The most critical factor influencing predicted future concentrations (i.e. increased or decreased soil cadmium) was the relative amount of cadmium present in soil versus the amount present in soil pore water, which is expressed as a distribution coefficient (Kd). Kd determines the amount of cadmium lost via soil leaching and to a lesser extent crop uptake; it is derived from measurements in soil in situ or in laboratory studies. BUWAL (2003a) used two different Kd algorithms (McBride et al 1997, and Römkens & Salomons 1998); they chose to use McBride, which predicts less cadmium in pore water and thus much lower leaching loss from soil (factor 3-6 times difference; BUWAL 2003a, Table 10). Based on McBride, BUWAL 2003a reached the conclusion that use of P-fertilisers would lead to long-term accumulation of soil cadmium. However, in view of the major Kd-dependent differences in prediction, they also recommended further development of Kd algorithms[1].

The EU (2008) cadmium risk assessment report concluded that accurate estimation of Kd is critical for prediction of future trends: "*…we feel that* ***more accurately estimating average Cd losses by leaching is critical for predicting future trends in average soil Cd in Europe***." (EU 2008, p.283). The report reviewed soil Kd data and algorithms, and concluded that the laboratory study-based McBride algorithm (used by BUWAL 2003a) probably overestimates in situ Kd values and hence underestimates Cd concentrations in the soil solution and thus leaching (EU 2008, p.190).

Consequently, Degryse et al (2009) published a highly technical review of data and studies on measurement of in situ soil pore water, in order to derive more accurate cadmium soil Kd data. The Degryse et al Kd data were used by Six & Smolders (2014) to predict future soil cadmium concentrations after 100-year application of fertilisers containing 36 mg Cd/kg P_2O_5 (the mean cadmium content in EU P fertilisers in the mid 2000s (Nziguheba & Smolders 2008), which is almost twice the current Swiss limit of 22 mg Cd/kg P_2O_5). Six & Smolders modelled predicted trends in a large number of scenarios (n=540), using various levels of atmospheric deposition, P fertiliser application rate, crop transfer rate and yield, soil organic content and pH, and precipitation excess.

Six & Smolders' model predicted that soil cadmium in European cereal and potato cropping systems will decrease by, on average, 15% over the next 100 years (10th and 90th

[1] Note that many factors must be considered and many assumptions made for predicting soil cadmium trends. For reasons of space, we have omitted many details, for example, that pH is the major determinant of Kd; a two-fold change in pH affects the Kd of Cd by more than 20-fold (Degryse et al 2009). At low pH, both leaching and crop uptake of Cd are increased.

percentiles -64% to +12%), taking into account EU regional soil properties (particularly pH), precipitation excess, crop types, and P-fertiliser use; they considered that average rather than regional predictions are more representative of cadmium exposure in the EU general population scenarios because cumulative lifetime consumption of staple crops, cereal and potato products is only exceptionally derived from a single location, and human risk is determined by chronic (lifetime) cadmium intake rather than single high intake events. Regional predicted trends ranged between 15% increase (Spain) and 21% decrease (United Kingdom) and mainly related to differences in soil pH, precipitation, and fertiliser application rates.

Conclusion: BUWAL 2003a probably underestimated the leaching rate of cadmium from soil, and therefore overestimates the potential for cadmium accumulation in soil. The best current estimates for most EU soils predicts a decrease in soil cadmium using P fertiliser with almost twice the current Swiss limit, so it is likely that soil cadmium in Swiss soils will decrease in future, not increase.

Note: Prof. Eric Smolders (University of Leuven, Belgium) and co-workers have been pivotally involved in much of this work. We note that the Six & Smolders (2014) study was financed by Fertilizers Europe, which might suggest a potential conflict of interest. However, Smolders was a co-author on the EU (2008) cadmium risk assessment report, and was the rapporteur on an EU scientific committee opinion on soil cadmium (SCHER 2012). We have insufficient technical expertise to judge the scientific quality of the Smolders work, but it appears to represent the scientific state of the art consensus; at least we have not found any dissenting opinions in the literature. Although we would prefer a broader-based literature, we use Smolders' work to guide our conclusions.

4.2 Estimated and measured soil cadmium trends in Switzerland

Keller et al (2005) calculated cadmium mass balance between 1996 and 2001 at 48 agricultural monitoring sites of the Swiss Soil Monitoring Network (NABO) (mixed farms, animal husbandry or dairy and arable plough soils). Inputs considered were fertiliser use (compost, manure and mineral fertiliser), and aerial deposition. The only output considered was crop offtake. For each site, fertiliser use and crop collection were quantified annually. Crop Cd concentrations were taken from the literature, and atmospheric deposition rates were derived from the Swiss moss monitoring program. Keller et al reported that the major contributors to Cd input were mineral fertiliser and aerial deposition. At the majority of sites, Cd input and output were nearly balanced. The calculated net soil Cd fluxes ranged between -1.1 and +6,2 g/ha/year. Net Cd fluxes larger than 2 g/ha/year were only found for sites that received augmented amounts of mineral fertilisers. Differences in Cd balances between the farm types were small, but large between the crop types (highest offtake for cereals, root crops, and legumes). [The high offtake for these crops is consistent with the high Cd levels reported in wheat, potato and vegetables by EU 2008 and EFSA 2012].

Keller et al calculated net soil cadmium fluxes over 10 years from their data. They predicted increases in soil cadmium concentrations ≥1% of the Swiss soil guidance value at 9 of the 48 sites, and concluded that these findings indicate a slow but meaningful accumulation of these elements in the top soil.

However, Keller et al did not measure cadmium in the soil, fertilisers, or crops, and critically, they did not consider cadmium output by leaching (which may be substantial; Degryse et al 2009; Six & Smolders 2014). Since Keller et al calculated no accumulation at most sites without taking leaching into consideration, their data suggest that when leaching is included, there will be a net loss of cadmium in Swiss soils over time.

BAFU (2014) measured changes in Swiss soil Cd concentrations in 4 consecutive 5-year sampling periods from 1985 to 2004 at 105 agricultural, forest and grassland monitoring sites of the Swiss Soil Monitoring Network (NABO). In the 54 sites with measurable levels of soil cadmium in 2000-2004[2] (range 0.119-0.511 mg Cd/kg soil dw), there was no significant change in soil Cd between sampling periods. It is however important to note that BAFU (2014) did not report P fertiliser use rates at the NABO monitoring sites (agricultural, forest and grassland), so it is unknown whether soil cadmium at sites with frequent P fertiliser application differs from other sites. The soil Cd concentrations reported by BAFU (2014) are in the same range as reported for other European countries (EU 2008, p.318; mean 0.33 mg Cd/kg soil dw).

Conclusion: Based on actual measurements, cadmium levels are not increasing in Swiss agricultural soil. This is consistent with the predictions of Six & Smolders 2014. However, this raises a question. If soil cadmium output indeed exceeds input, where is the cadmium going? The only possibilities are water and sediment. We therefore reviewed the available data on cadmium levels in water and sediment (EU and Switzerland).

4.3 Cadmium concentrations in water and sediment

Water: The limited available data on cadmium levels in Swiss water suggest that levels are relatively low (<0.2 µg Cd/L).

In European surface waters, reported average Cd concentrations range from 0.03-0.14 µg/L, and have generally decreased since the end of the 1970s; EU 2008 used a value of 0.12 µg Cd/L for their environmental risk assessment.

In Swiss groundwater, BAFU 2009 ("NAQUA" program) reported that cadmium was not detected at any of 50 sampling sites above the assay limit of quantification of 0.2 µg/L[3].

In Swiss surface waters, the national monitoring program (Nationale Beobachtung Oberflächengewässerqualität - "NAWA") currently deals only with rivers but not lakes, and cadmium is not currently monitored (BAFU 2013, p.19).

Sediment: Cadmium levels in Swiss river and lake sediments appear to be lower than in EU, except in some reservoirs (dams), where sediment cadmium exceeds the VBBo guidance value (0.8 mg/kg dw). Overall, it seems plausible that cadmium leaching from agricultural soils tends to end up in slow flow sediments (e.g. reservoirs).

EU (2008) reported European river and lake sediment values between 0.1-34 mg Cd/kg dw; most values were between 1-10 mg Cd/kg dw (>10 in middle and lower Rhine). The average

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[2] In the last sampling period (2000-2004), the cadmium assay method (Inductively Coupled Plasma ICP) was changed from mass spectrometry ICP-MS to Atomic Emission Spectrometry optical detection (ICP-AES), which increased the limit of quantification from 0.01 to 0.19 mg Cd/kg soil dw. As a result, cadmium soil concentration in 2000-2004 samples were below the LOQ at 51 (49%) of the sites, and these sites were omitted from analysis. At the 54 sites with measurable levels of soil cadmium in 2000-2004 (range 0.119-0.511 mg Cd/kg soil dw), there was no significant change in soil Cd between sampling periods. In some grassland sites there was an increase in soil cadmium after 5 years, particularly at La Brévine (increase of 0.2 mg Cd/kg soil dw); this was considered possibly due to contamination with limestone bedrock fragments [which are high in natural cadmium; Quezada-Hinojosa et al 2009]. At the 5 pine forest sites, increased soil cadmium was detected at 5 and 10 but not 15 years.

[3] Note: The NAQUA samples were not filtered, so represent total cadmium; BAFU 2009 (p.95) noted that these values represent worst-case soluble cadmium [i.e. assuming 100% is present as soluble]. If this assumption is accepted, then the assay limit of quantification used for these groundwater samples is 4 times higher than the maximum permissible dissolved concentration in surface waters (0.05 µg Cd dissolved/L and 0.2 µg Cd total/L in Swiss rivers and lakes; GSchV 1998). There are indeed data indicating that a large fraction of cadmium may be present in dissolved form in some Swiss waters; EU (2008) reported that in the late 1980s, the dissolved fraction of Cd ranged between 10-40% in the Rhine, Meuse and Schelde rivers in the Netherlands, about 50% in the rivers Rhine and Arno, 30-40% in Tiber and Elbe, but in the lakes of Constance (Bodensee) and Zurich, the percentage of dissolved Cd was 80 and 84% respectively (EU 2008, p.308). Consistent with the effect of pH on cadmium solubility, high dissolved fractions were found in acid waters, in which total concentrations are also elevated (EU 2008, p.306-308).

of measured 90th percentiles (= "realistic worst case") of sediment cadmium concentrations in various European countries was 2.66 mg/kg dw (EU 2008, p.317)

BUWAL (2003b) reported that the median cadmium concentration in sediment from 10 Swiss rivers was 0.22 mg Cd/kg (range 0.09-0.48 mg/kg). Compared to values in the late 1980s, sediment cadmium levels were reduced by factor 1.5-5 in three locations (Birs at Duggingen, and Rhône at Bouveret and Chancy), and unchanged in the others (BUWAL 2003b, p.33).

AWEL (2006) reported low levels of cadmium in most Zürich river sediments measured in 1989, 1994 and 2004, likely related to street runoff (p.85, 87). They concluded that most cadmium will be retained in the limestone soils of Zürich (high calcium carbonate, high pH) (p.101).

Wildi et al (2004) reported mean cadmium concentrations of 0.2-3.7 mg Cd/kg dw in sediment from four reservoirs and one lake[4]. The highest mean value was 3.7 mg Cd/kg dw in the lake (Lausanne-Vidy, Lake of Geneva). This site is close to a wastewater effluent pipe; sediment core samples showed high concentrations of cadmium at this site since effluent discharge started in 1964. Wildi et al concluded that the Vidy values exceeded the VBBo guidance value (Richtwert) (0.8 mg/kg dw[5]), and are probably toxic to benthic organisms.

Loizeau et al (2007) reported relatively high sediment cadmium concentrations at four reservoirs[6] of about 1-3 mg Cd/kg; concentrations in associated river inflows were about 0.2 mg Cd/kg.

4.4 Sources of cadmium exposure in humans

Cadmium exposure in the general population (i.e. consumers, non-occupational) is mainly via tobacco smoking and diet. The EU risk assessment report concluded that smoking contributes about the same amount of cadmium as dietary exposure, i.e. smokers have twice the exposure of non-smokers, because tobacco bioaccumulates cadmium (EU 2008, p.840). The major dietary sources of cadmium are cereals (mainly wheat), potatoes and vegetables (EFSA 2012), in agreement with BUWAL 2003a.

BUWAL 2003a assumed that about 10% of Swiss arable soils are used for wheat production (100'000 ha), 1.4% for potatoes (14'000 ha), and 1% (8'000 ha) for vegetables. According to BLW (2014), the areas used for cereal and potato production have decreased, while the area used for field vegetables has increased. However, the change is less than 20%, so the assumption of BUWAL 2003a is still considered to be adequate (Table 2).

Table 2: Area under cultivation for wheat, potatoes and vegetables, Switzerland 2000-2013

	2000/02 (ha)	2011 (ha)	2012 (ha)	2013 (ha)	2000/02–2011/13
Wheat	91 045	76 446	78 540	79 134	-14.3%
Potatoes (incl. seed potatoes)	13 799	11 250	10 875	11 039	-19.9%
Field vegetables	8 489	10 008	9 708	9 944	+16.5%

Source: BLW 2014, Appendix 3, Table 3 (p.259)

[4] Reservoirs were Wettingen (upstream city= Zürich), Klingnau (Zürich, Baden, Brugg, Aarau), Wohlen (Bern), Verbois (Geneva). Lake was Vidy Bay in Lake Geneva (Lausanne).

[5] Note: The Swiss VBBo 1998 specifies a guidance value (Richtwert) for cadmium in soil with up to 15% humus of 0.8 mg total Cd/kg soil dw, 0.02 mg soluble Cd/kg soil dw. These values presumably also apply to sediment, although there is no specific reference to in situ sediment in VBBo.

[6] Reservoirs and associated river inputs at Wettingen, Klingnau, Mühleberg, Verbois.

Dietary exposure assessment from cadmium in Swiss agricultural soil needs to consider the contribution of Swiss-grown versus imported foodstuffs. BUWAL 2003a noted that 93% of potatoes were produced in Switzerland, versus 57% for vegetables and 51% for cereals. Statistics for 2000 and 2010 published by the Swiss Farmers Association (Schweizerische Bauernverband, SBV 2010) agree with the data used by BUWAL 2003a and show no marked change since the BUWAL 2003a report; most potatoes on the Swiss market are still produced in Switzerland, versus about half of vegetables and cereals used in food (Table 3).

Table 3: Inland production as percentage of total food use

	Potatoes	Vegetables	Cereals
BUWAL 2003a	93%	57%	51%
2000*	91%	50%	56%
2010*	86%	45%	55%

* SBV 2012, Table 6

Conclusion: Studies since BUWAL 2003a confirm that the major source of cadmium exposure (in non-smokers) is dietary, predominantly from wheat and potato products. There has been no substantial change in land use by crop types or mineral P-fertiliser use in Switzerland since 2003. The BUWAL 2003a exposure assessment assumptions are therefore still considered valid.

4.5 Human risk

Kidney renal tubular damage is the most sensitive toxicological effect of cadmium exposure. Tolerable intakes of cadmium are expressed as weekly or monthly rather than daily values because its human biological half-life is very long (10-33 years; JECFA 2011).

BUWAL 2003a used a Provisional Tolerable Weekly Intake (PTWI) of 7 µg Cd/kg body weight (bw). This value had been proposed in 1988 by JECFA and endorsed in 1995 by the European Commission's Scientific Committee for Food; it was reconfirmed by JECFA in 2003. JECFA (2011) re-evaluated risk based on human urinary biomarkers, and established a slightly lower but still comparable Provisional Tolerable Monthly Intake (PTMI) of 25 µg Cd/kg bw.

However, EFSA (2009) established a 2.5-fold lower Tolerable Weekly Intake (TWI) of 2.5 µg Cd/kg bw, which was reconfirmed by EFSA (2011). This lower TWI is more conservative because it is not based on actual kidney damage, but on an early indicator of changes in kidney function, suggesting possible kidney damage later in life. EFSA noted that the mean dietary exposures in European countries are close to or slightly exceeding the TWI of 2.5 µg/kg bw; subgroups such as vegetarians, children, smokers and people living in highly contaminated areas may exceed the TWI by about 2-fold. EFSA concluded that although adverse effects on kidney function are unlikely to occur for an individual exposed at the TWI, exposure to Cd at the population level should be reduced (EFSA 2011).

In 2011, Sweden submitted human and environmental risk assessments, which included consideration of the EFSA (2011) data, to the European Commission, requesting a derogation to reduce the cadmium limit in mineral phosphate fertilisers from 100 mg Cd/kg P to 46 mg Cd/kg P (approximately the current Swiss limit). This request was rejected (Commission Decision 2012/719/EU) based on an opinion by SCHER (2012), which concluded that the Swedish assessment does not suggest specific reasons for additional concern (see Appendix 1 for details).

Conclusion: SCHER (2012) concluded that use of mineral fertilisers containing 100 mg Cd/kg P poses no unacceptable risks to human health, even taking into account the EFSA (2011) proposed reduced tolerable cadmium intake. We therefore conclude that the current Swiss limit of 50 mg Cd/kg P is adequately protective for human health.

4.6 Environmental risk

Environmental risk assessment is based on predicted environmental concentration (PEC) and predicted no effect concentration (PNEC) in a given compartment (soil, surface water, sediment, etc). Excessive risk is defined as PEC/PNEC >1.

Sources of cadmium in the environment include mineral fertilisers, but also atmospheric deposition, other fertilisers, and geogenic cadmium.

Soil

PECs were 0.09-0.37 mg Cd/kg soil for all soils (pH 4.5-7.2) except Jura, whose PECs were 1.96-2.1 mg Cd/kg soil (pH 7.2) (BUWAL 2003a Appendix 1, Table 1).

Based on the lowest PNEC of 0.06 mg/kg (derived from a study with grasshoppers with a very high bioavailability of Cd), PEC/PNEC = 4–33.

Based on PNEC of 0.18 mg/kg (determined from a study in which the soil pH was 3.3 – for soils a very low pH value indeed), no concern is predicted except for the Jura hill regions (PEC/PNEC > 1, max 5.3).

Based on PNECs of 1.6–2.3 mg/kg (derived from an inventory of all available NOEC values), no risk is expected for any of the soils.

Overall, BUWAL 2003a concluded that in general there is no reason for concern in the Swiss situation, except in the Jura hill region.

Water and sediment

Lakes (BUWAL 2003a, Table 20)

Lake water (PEC=12 ng/L): Using the lowest PNEC of 8.5 ng/L (Daphnia magna NOEC/10 [presumably long-term study]), PEC/PNEC = 1.4. For all other PNECs (16-190 ng/L), PEC/PNEC is <1. (For comparison, the EU 2008 risk assessment used a PNECwater of 190 ng Cd/L; EU 2008, pdf p.407).

Lake sediment (PEC=48 ng/L): For all PNECs (270 ng/L-7.4 mg/L), PEC/PNEC is <1.

The concentration of cadmium in surface waters and sediments is considered of no concern for lakes.

[Sediment PECs in µg Cd/L are presumably converted from measured values of µg Cd/kg sediment (wet weight) by recalculation with a density of 1.3 kg/dm3, cf. BUWAL 2003, p.30).]

Rivers (BUWAL 2003a, Table 20)

"Calculations for the rivers are based on the background concentrations in the rivers since the leaching of cadmium from soils to the rivers is negligible; …no effect on the cadmium concentration in waters is expected due to using fertilisers containing cadmium." (BUWAL 2003a, p.38).

River water (PEC=0.1-0.38 µg/L): Using the lowest PNEC of 8.5 ng/L (Daphnia magna NOEC/10 [presumably long-term study]), PEC/PNEC = 12-45. Using the highest PNEC of 420 ng/L, PEC/PNEC is <1.

River sediment (PEC=58-173 µg/L[7]): Using the lowest PNEC (0.27 µg/L; Chironomus spp. LC50/100), PEC/PNEC = 415–641. Using PNECs of 1257–8798 µg/L, PEC/PNEC is <1.

BUWAL 2003a noted under "Limitations of the risk characterisation" data gaps concerning PNEC sediment and bioavailability.

Concerning PNECsediment, BUWAL 2003a noted: "*The only value that is based on effects in the sediment, is the lowest PNEC based on the EC50 values for Chironomus spp. It should be noted that a publication is available which states that the "safe concentration" might be underestimated by the use of one-generation toxicity experiments.*" BUWAL 2003a derived the PNEC sediment as follows: "For the determination of a PNECsediment several toxicity values for Chironomus spp. are available from the public literature (Watt00, Sue97, Jan01, Wil87). LC50 values vary from 27–740 µg/L. Applying a safety factor of 100 on the lowest LC50 value the **PNECsediment is 0.27 µg/L**."

The lowest "LC50" value is from the reference "Jan01" (Janssens de Bisthoven et al 2001), who reported an increased incidence of split in the mentum (central trifid tooth) (considered as a morphological deformity) in Chironomus riparius exposed to cadmium for nine generations, with an EC50 of 27 µg Cd/L (concentration in water covering a one centimeter layer of shredded paper used as substrate, NOT sediment). The reliability of this endpoint has been questioned: Arambourou et al 2014 reported that exposure of Chironomus to sediment containing 14 mg Cd/kg sediment (dw) reduced larval dry weight and delayed development (longer time to emergence), but had no significant effects on mentum in parent or offspring. They suggested that the use of laboratory strain exhibiting high inbreeding rate, resulting in high rates of mentum deformities in control groups, could partly explain the high sensitivity of phenotypic markers in some laboratory studies. Rebechi & Navarro-Silva (2012) reported the occurrence of the same morphological deformity in untreated C. riparis maintained under laboratory conditions for about two years; they cited the Janssens de Bisthoven et al (2001) cadmium study, and discussed the possibility of inbreeding as a cause of high levels of deformities in cultured chironomids. The reliability of the PNECsediment of 0.27 µg/L used by BUWAL 2003a is thus questionable.

EU 2008 discussed the PNECsediment in detail, and finally chose a value of **2.3 mg Cd/kg dw** (EU 2008, section 3.2.4.3, pp.436-9, pdf p.456-9). Unfortunately, there are insufficient data in BUWAL 2003 to permit conversion of their PNECsediment of 0.27 µg/L to mg Cd/kg sediment (dry weight).

Concerning bioavailability, BUWAL 2003a noted that "*It is very important for the risk calculation of cadmium to know whether cadmium is bioavailable in water and soil. The actual effects depend greatly on this parameter.*" the EU cadmium risk assessment similarly concluded that "*for sediment, there is a need for further information regarding the bioavailability of cadmium in order to possibly refine the assessment at regional and local level*" (EU 2008, pdf p.18). In an amendment to the EU risk assessment, EU (2006) added a bioavailability correction based on the concentration of available acid volatile sulphides (AVS) in the sediment, which reduce the toxicity in sediment (i.e. reduced risk with increasing AVS concentration). Correcting for AVS, EU 2006 derived a PNECsediment of **1.5 mg Cd/kg (dw)** (EU 2006, Table 3.3.1, pdf p.45), versus the original PNECsediment of 2.3 mg Cd/kgdw (EU 2008 p.438, pdf p.458). Taking Cd bioavailability into account, EU 2006 concluded that there was no risk to sediment organisms based on measured regional PECsediment in Belgium, France, Spain, Sweden and the Netherlands; without such bioavailability correction, risk was predicted in some of these regions/locations (EU 2008, Section 3.1.3.1.2, pdf p.202).

[7] BUWAL 2003 reported that mean monitoring values for cadmium in sediments for the rivers Rhine (source, Basel) and Aare (source, Bern) are 75–225 µg/kg wet weight. Recalculation with a density of 1.3 kg/dm3 produces a PECsediment of 58–173 µg/L (BUWAL 2003, p.30).

The PNECsediment used by EU (2006 and 2008) is supported by Marinkovic et al (2012); in a multigeneration experiment where Chironomus riparius cultures were exposed for nine consecutive generations, who reported reduced larval emergence and larval LC50s of approximately 2 mg Cd/kg dw sediment (non-monotonic dose-response).

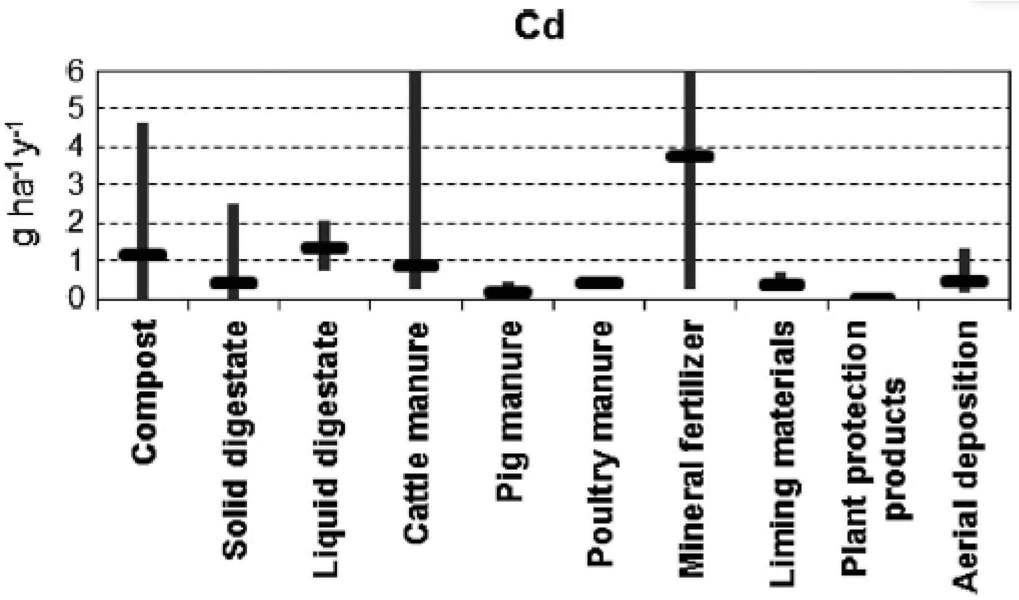
However, the EU (2006 and 2008) PNEC sediment may be too high. Vogt et al (2007), in a study according to OECD Guideline 218, reported that Chironomus riparius exposed via sediment starting with the first larval stage until emergence had reduced oviposition and egg viability at LOEC (the lowest tested dose) of 0.17 mg Cd/kg sediment dw (non-monotonic dose response).

SCAHT conclusion: The PNECsediment estimate by BUWAL 2003 (0.27 µg/L) may overestimate the risks to sediment organisms. By contrast, the EU estimate (1.5 mg Cd/kg dw; EU 2006) may underestimate the risks. Further work on sediment hazard characterisation is necessary.

4.7 Sources of soil cadmium in Switzerland

Cadmium input to agricultural soil is mainly from atmospheric deposition, animal manure and mineral fertilisers. BUWAL 2003a assumed 1.8 g Cd/hectare/year from atmospheric deposition, 1.2 g from mineral fertilisers, 0.5 g from composts, and 1.0 g from sewage sludge. For Swiss agricultural soils, Kupper et al (2014) estimated a higher input from mineral fertiliser and a lower input from aerial deposition than BUWAL 2003a; see Figure x.

Figure 1: Estimated contributions of major inputs to soil cadmium load (Kupper et al 2014)



Source: Kupper et al 2014, Figure 2

For EU agricultural soil, Nziguheba & Smolders (2008) estimated approximately equal input of cadmium from atmospheric deposition and mineral fertilisers (average 1.9 and 1.6 g/hectare/year, respectively), but they did not include manure as a potential source.

These values are summarised in Table 4.

Table 4: Quantitative estimates of cadmium inputs to soil (g Cd/ha/year)

	CH: BUWAL 2003a (Table 4)	CH: Kupper et al 2014*	EU: Nziguheba & Smolders 2008
Atmospheric deposition	1.8	0.5	1.9
Mineral fertiliser	1.2	4	1.6
Animal manure (a)	0.5	<2	no data
Compost+other (b,c)	0.5+1.0(b)	ca 1+1(c)	no data

* estimated visually from Kupper et al 2014, Fig.2
(a) cattle+pig+poultry manure
(b) sewage sludge
(c) solid+liquid digestate

The estimate by Kupper et al (2014) of cadmium input to Swiss soil from atmospheric deposition is substantially lower (less than one half) than that used by BUWAL 2003a and Nziguheba & Smolders 2008. By contrast, the Kupper estimate of input from mineral fertilisers is about twice that of BUWAL 2003a and Nziguheba & Smolders 2008. Why?

Atmospheric deposition

BUWAL 2003a estimated atmospheric deposition as follows: "*In Europe cadmium deposition has been decreasing since 1980. For Switzerland monitoring studies show a cadmium deposit of <0.69 µg/m2 and day (n = 15). For 13 of 15 sample areas a value of <0.5 µg/m2 and day was found (BUWAL98*[8]*). Based on this last value the calculated atmospheric deposition is about 1.8 g Cd/ha/y.*" i.e. deposition rate of 0.5 µg/m2/day = 5 mg/ha/day = 1.825 g/ha/y. Note that this is a "worst-case" overestimate; most samples had value of less than 0.5 µg/m2/day, but the values were assumed to be equal to 0.5 µg/m2/day.

Kupper et al (2014) estimated atmospheric deposition as follows: "*The agricultural surface of 1'051'866 ha was obtained from Kupper et al. (2013). Deposition data were obtained from 11 rural sites of the Swiss air monitoring network (Anières-Débarcadère, Avully-Passeiry, Brigerbad, Eggerberg, Grenchen-Witi, Les-Giettes, Magadino-Cadenazzo, Massongex, Payerne, Rigi-Seebodenalp, Turtmann). Mean values were calculated from the annual means from each of the years 2008, 2009, 2010 and 2011 (available from http://www.bafu.admin.ch/luft/luftbelastung/blick_zurueck/01694/index.html?lang=de). Mean values were calculated from the annual means from each of the years 2009, 2010 and 2011 (BAFU, 2010, BAFU, 2011, BAFU, 2012).*" Mean deposition rate was 0.14 µg Cd/m^2/day (range 0.04-0.37) [1.4 mg/ha/day, about 0.511 g/ha/y] (Kupper et al 2014, online supplementary information 2, Table 9).

The Kupper et al 2014 estimate is more than three times lower than the BUWAL 2003a estimate because the measured mean deposition value (0.14 µg Cd/m^2/day) was used rather than the "worst-case" assumption of 0.5 µg Cd/m^2/day used for missing values by BUWAL 2003a.

The Nziguheba & Smolders 2008 estimate was based on Nicholson et al (2003) data collected in the UK between 1995–1998, the mean deposition rate was 1.9 g Cd/ha/y, range 0.7-6.1 [equivalent to about 0.52 µg Cd/m^2/day]. This rate is about four times higher than the mean deposition rate used by Kupper et al 2014, Both location and timespan may have contributed to this difference (1995-1998 in UK for Nziguheba & Smolders 2008, versus 2008-2011 in Switzerland for Kupper et al 2014).

From these considerations, we conclude that the aerial deposition estimate of Kupper et al 2014 more closely reflects the current situation (2008-2011) than either Nziguheba & Smolders 2008 or BUWAL 2003a, whose estimate of aerial deposition was more than three times higher.

[8] NABEL – Luftbelastung 1998, Schriftenreihe Umwelt Nr. 311, 193 p. (1998).

Mineral fertiliser input

BUWAL 2003a calculated mineral fertiliser Cd input to arable soil to be 1.2 g Cd/ha/y (BUWAL 2003a, Table 4). They assumed a P-fertiliser application rate of 37.5 kg fertiliser/ha/y (based on total Swiss use of 15k tons mineral fertiliser/year on an area of 400k ha), and a cadmium content of 33.3 mg Cd/kg P (BUWAL 2003a, Table 4).

Nziguheba & Smolders 2008 calculated mean mineral fertiliser Cd input to arable soil to be 1.6 g Cd/ha/y (range of EU member state means 0.1-3.1). The mean fertiliser application rate, based on statistics from the European Fertilizer Manufacturer Association for the year 2000, was 43 kg P2O5/ha/y (member state range 20-78). The mean measured cadmium content was 82.7 mg Cd/kg P [36 mg Cd/kg P2O5.]

Kupper et al (2014) calculated mean mineral fertiliser Cd input to arable soil to be about 4 g Cd/ha/y (their Figure 2). Their calculation was based on the most common fertilizer types in Switzerland: ammonium nitrate, 27.5% N, 0.51 t/ha/y; superphosphate 0.14 t/ha/y; potassium chloride, 60% K2O, 0.23 t/ha/y (Kupper et al 2014, online supplementary information 2, Table 10). Kupper et al do not specify what cadmium content was assumed; they only say "*The metal concentrations were obtained from Boysen (1992)*". Based on cadmium content according to Boysen et al1992 (their Table 21) , the following cadmium loads can be calculated:

- ammonium nitrate @ 0.24 mg Cd/kg @ 0.51 t/ha/y = 122.4 mg Cd/ha/y;
- superphosphate+triplesuperphosphate @ 25.0 mg Cd/kg @ 0.14 t/ha/y = 3500 mg Cd/ha/y;
- potassium chloride @ < 0.1 mg Cd/kg @230kg/ha/y= <23 mg Cd/ha/y.

Superphosphate and triplesuperphosphate fertiliser, which is the major contributor to the Kupper cadmium input estimate, were listed by Boysen et al 1992 (their Table 21) as containing measured mean 25.0 mg Cd/kg fertiliser. Boysen 1992 did not specify which superphosphate fertilisers were sampled, but if it is assumed that it is triplesuperphosphate-46 (cf. Boysen 1992, pp.44-45), then the measured amount of 25.0 mg Cd/kg fertiliser is equivalent to 25.0/0.46 = 54 mg Cd/kg P2O5 = 125 mg Cd/kg P. This is higher than the mean cadmium content of 36 mg Cd/kg P_2O_5, [83 mg Cd/kg P] reported in EU P fertilisers in the mid 2000s by Nziguheba & Smolders (2008), and exceeds the German regulatory upper limit (DüMV fertiliser ordinance) of 50 mg Cd/kg P_2O_5 [115 mg Cd/kg P]. Kupper et al 2014 did acknowledge that their estimate of cadmium content based on Boysen 1992 is probably too high: "*The results were crosschecked using more recent data (Nziguheba and Smolders, 2008; Petersen et al., 2009). The calculated data and the results of the crosscheck were largely in agreement. However, unpublished data from the Federal Office for Agriculture FOAG on heavy metals analyses of mineral fertilizers carried out in 2011/12 suggest that numbers for Cd in P fertilizers adopted from Boysen (1992) might be higher than actual contents valid for Switzerland.*" (Kupper et al 2014, online supplementary information 2).

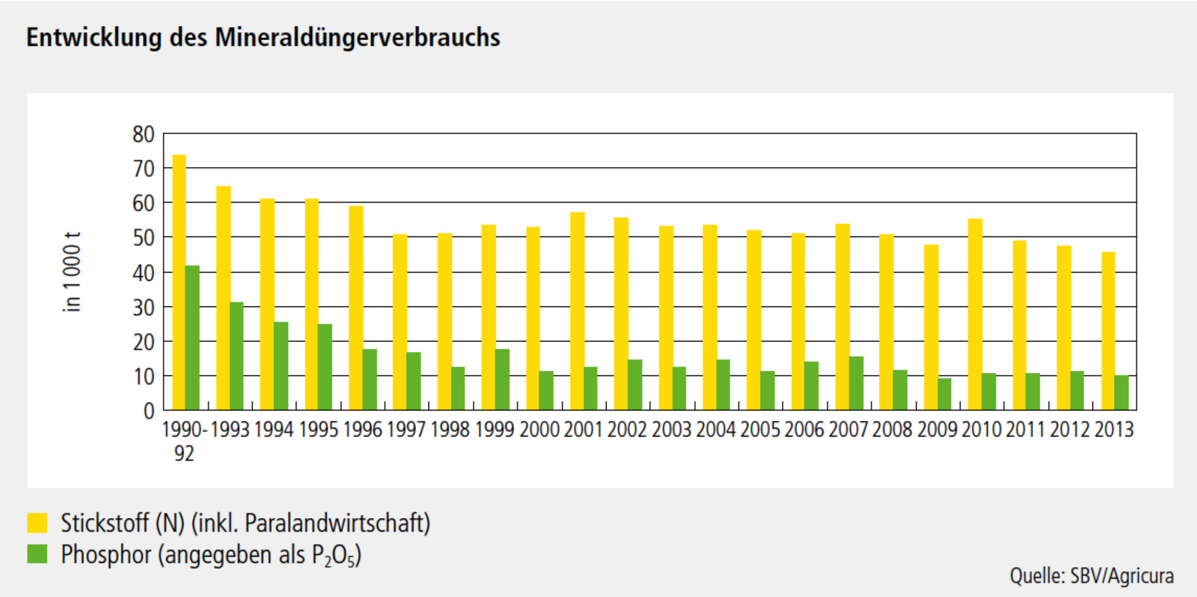
From these considerations, we conclude that the estimated input of cadmium to soil from mineral fertilisers by BUWAL 2003a and Nziguheba & Smolders 2008 more closely reflect the current Swiss situation than Kupper et al 2014, who appear to have overestimated mineral fertiliser input by about a factor of three.

Conclusion: Based on the data in Nziguheba & Smolders 2008 and Kupper et al (2014), the BUWAL 2003a estimate of Cd input into Swiss soil from mineral fertilisers (1.2 g Cd/ha/year) is still valid, but aerial deposition is now lower (0.5 versus 1.8 g Cd/ha/year).

4.8 Mineral P-fertiliser use in Switzerland

There has been no marked change in mineral P-fertiliser use in Switzerland from 2003-2009 (BLW 2010; Figure 2).

Figure 2: Mineral fertiliser use in Switzerland 1990-2009



Source: BLW 2014.

4.9 Cadmium content of P-fertilisers in Switzerland

BLW (2015) reported the results of a Swiss market surveillance campaign in 2011/2012 conducted by eleven participating cantons and the Bundesamt für Landwirtschaft ("Marktkampagne Dünger 2011/2012").

In the 44 P fertilisers with 1% or more P, median cadmium concentration was 47.1 mg Cd/kg P (minimum 0.2, maximum 217.2) g Cd / t P.

The ChemRRV limit is 50 mg Cd/kg P; including a tolerance margin of +30% to allow for measurement error, measured levels of up to 65 mg Cd/kg P were considered permissible.

45% (20 of 44) of the P-fertilisers tested had more than 50 mg Cd/kg P, and 34% (15 of 44) had more than 65 mg Cd/kg P.

29.5 % (13 of 44) had >65–150 mg Cd/kg P, and 4.5 % (2 of 44) had 200–220 mg Cd/kg P.

BLW (2015) concluded that control of product quality by the importers of P mineral fertilisers is in many cases inadequate.

BUWAL (1991) reported mean (range) concentrations (mg Cd/kg P) in superphosphate (n=3) of 99 (99-265), in triple-superphosphate (n=3) of 236 (141-322), and in rock phosphate (n=5) of 96 (80-248). These mean values are all higher than the ChemRRV limit of 50 mg Cd/kg P.

We could find only one other previous report on cadmium levels in Swiss P-fertilisers, by Gsponer 1990 (cited in BUWAL 1991). He assayed cadmium levels in samples of 34 P-mineral fertilisers in Zürich (6 P, 6 PK, 22 NPK). Mean cadmium levels were 84, 89 and 48 mg Cd/kg P_2O_5, respectively. The Swiss limit value (50 mg Cd/kg P = 22 mg Cd/kg P_2O_5) was exceeded in 5 (83%) of the P-, 6 (100%) of the PK- and 17 (77%) of the NPK-fertilisers [in total 28 of 34 P-fertilisers sampled = 82% above limit value]. A total of 6 P-mineral fertilisers (6/34=18%) had >100 mg Cd/kg P_2O_5 (229 mg Cd/kg P). These values from 1990 are higher than the BLW (2015) values for 2011/2012 : 82% of samples exceeded 50 mg Cd/kg P in 1990, versus 45% in 2011/2012.

In the EU, Nziguheba & Smolders (2008) reported that the mean cadmium content in EU P fertilisers in the mid 2000s was 36 mg Cd/kg P_2O_5 (83 mg Cd/kg P), which is above the Swiss limit (ChemRRV).

In Germany, Dittrich & Klose (2008) measured cadmium in 37 P-fertilisers (21 rock phosphate, 11 triple superphosphate, 5 from marine algae). The range of measured values was 27-79 mg Cd/kg P_2O_5 [61-181 mg Cd/kg P]. The German regulatory upper limit (DüMV fertiliser ordinance) of 50 mg Cd/kg P_2O_5 [115 mg Cd/kg P] was exceeded in 10 (48%) of the rock phosphate samples, 9 (82%) of the triple superphosphate samples, and 3 (60%) of the marine algal samples.

Conclusion: The very limited information on previous levels of P-fertiliser cadmium in Switzerland and on current levels in other countries suggests that the cadmium levels measured by BLW 2011/2012 are lower than Swiss levels in 1990/1991 and lower than EU levels in the 2000s.

5 Conclusions

It appears likely that BUWAL 2003a underestimated the loss of soil cadmium due to leaching, and overestimated the input of cadmium into soil from aerial deposition, and therefore overestimated the potential for accumulation of soil cadmium due to mineral fertiliser use. This conclusion is based mainly on the leaching rates used by Six & Smolders (2014). If the current ChemRRV limit of 50 mg Cd/kg P in mineral fertiliser is adhered to, we conclude that there will most likely be a trend to decreasing rather than increasing cadmium in soil over the next 100 years (cf. Six & Smolders 2014). The available monitoring data show no accumulation of cadmium in Swiss soils during the past 10 years, although specific data for sites with frequent P mineral fertiliser use is not available. We therefore conclude that use of P fertiliser at current levels will not lead to soil accumulation of cadmium, and thus there will be no increase human exposure to cadmium due to mineral fertilisers.

Concerning hazards to health, EFSA (2011) has proposed a tolerable intake for cadmium which is 2.5 times lower than the current WHO/FAO tolerable intake (also used by BUWAL 2003a). Current estimated cadmium exposure is close to maximum tolerable levels in some sub-populations (e.g. vegetarians, children, smokers, and people living in highly contaminated areas; EFSA 2011). However, SCHER (2012) concluded that use of mineral fertilisers containing up to 100 mg Cd/kg P poses no unacceptable risks, even taking into account the EFSA (2011) proposed reduced tolerable cadmium intake. We therefore conclude that cadmium input into Swiss soil from use of P fertiliser at current levels will not lead to unacceptable risks to human health.

In the environment, some data suggest local excessive levels of cadmium in reservoir sediments (e.g. Wildi et al 2004), which are likely due to past "historical" inputs including atmospheric deposition and manure as well as P-fertilisers. It is unclear from the BUWAL 2003a and EU 2006 risk assessments whether there is a risk to sediment organisms or not; more refined risk assessment may be necessary.

Overall, we conclude that the Swiss limit value of 50 mg Cd/kg P (ChemRRV) is sufficiently protective for human health and the environment. However, given that overall cadmium exposure is close to maximum tolerable levels in some human sub-populations and in some environmental compartments, we agree with the BUWAL 2003a conclusion that it is prudent to continue keeping cadmium concentrations in phosphorus mineral fertilisers as low as possible.

6 Recommendations

To facilitate assessment of human and environmental risks, Swiss monitoring campaigns for cadmium in mineral fertiliser need to include information on import volumes and application rates, in addition to levels of cadmium contamination.

In the Swiss Soil Monitoring Network program (NABO), measurement of actual soil cadmium concentrations should be used rather than modelling based on assumed inputs and outputs (particularly leaching rates) (cf. Keller et al 2005), and assay sensitivity should ideally be below regulatory limit value (cf. BAFU 2014).

In the Swiss monitoring programs for groundwater (NAQUA) and surface water (NAWA), a should measure dissolved as well as total cadmium, and assay sensitivity should be increased to enable detection of levels exceeding maximum permissible dissolved concentrations specified in GSchV (cf. BAFU 2009).

In the Swiss monitoring program for surface water (NAWA), monitoring of cadmium levels should include lakes in addition to rivers.

Given that relatively high cadmium concentrations have been reported in some reservoir sediments, and that it is unclear from the BUWAL 2003a and EU 2006 risk assessments whether there is a risk to sediment organisms or not, there may be a need for further risk assessment in this compartment.

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Appendix 1: Regulatory aspects, EU

Current EU status

Current EU legislation concerning fertilisers (in particular Regulation (EC) No 2003/2003) does not contain limits on the content of cadmium[9]. A draft proposal relating to cadmium in fertilisers was circulated in 2003[10] but there has been no subsequent regulatory activity (CSES 2010). According to Article 114 (5) of the Treaty of the Functioning of the European Union (TFEU), Member States are not free to impose limits on cadmium in fertilisers within the scope of EU fertiliser legislation, but derogation for introducing national measures may be granted when a Member State provides new scientific evidence relating to the protection of the environment or the working environment on grounds of a problem specific to that Member State. To date, derogations have been granted to three member states:

- **Austria, 2006**: restriction of P-mineral fertilisers containing >75 mg Cd/kg P_2O_5; approved until harmonised measures are applicable at Community level (Commission Decision 2006/349/EC).
  "The risk assessment carried out by Austria shows that PEC value (predicted environmental concentration) from cadmium in mineral fertilisers in Austria, exceeds the PNEC value for water in most investigated regions. This also applies to soil in 5 % of the 52 Austrian arable regions if bio-available values are used. In the view of the Austrian authorities, this means that, according to the European Community risk assessment methodology, the substance is of concern and there is a need to take further steps."
- **Finland, 2006**: restriction of P-mineral fertilisers containing >22 mg Cd/kg P_2O_5; approved until harmonised measures are applicable at Community level (Commission Decision 2006/348/EC).
  "The risk assessment carried out by Finland shows that present cadmium concentrations in Finnish agricultural soil pose a risk for soil organisms and that the leaching of cadmium from the agricultural soil is causing a risk for the aquatic environment. Finland maintains that the risk assessment concludes also that there is a risk of adverse health effects as a result of the present total cadmium exposure in the Finnish population. While the average cadmium intake from food alone does not pose a risk in Finland, some sectors of the population are at risk because of high dietary intake, increased absorption and/or smoking."
- **Sweden, 2006**: restriction of P-mineral fertilisers containing >44 mg Cd/kg P_2O_5; approved until harmonised measures are applicable at Community level (Commission Decision 2006/347/EC).
  "The risk assessment carried out by Sweden shows that if fertilisers with a higher cadmium content than currently permitted would be allowed, this would lead to:
  — a substantial increase in the cadmium concentrations of soils, which in turn would lead to toxic effects on soil organisms. Unacceptable concentrations could also appear in watercourses in agricultural regions,
  — a substantial increase in the dietary intake of cadmium. The safety margin between current exposure and the World Health Organisation provisional tolerable weekly intake level is extremely small. For some high-risk groups, such as women with low body iron stores, there are no safety margins at all. A high dietary intake of cadmium could therefore lead to a larger number of people becoming subject to reduced kidney function and increased osteoporosis."

The Czech Republic and Sweden have unsuccessfully requested derogations, as follows:

- **Czech Republic, 2006**: restriction of P-mineral fertilisers containing >50 mg Cd/kg P_2O_5; decision deferred pending an opinion of the Scientific Committee on Health and

[9] http://ec.europa.eu/enterprise/sectors/chemicals/documents/specific-chemicals/fertilisers/index_en.htm
[10] http://ec.europa.eu/DocsRoom/documents/2524/attachments/1/translations/en/renditions/native

Environmental Risks (Commission Decision 2006/390/EC). The SCHER (2006) opinion questioned the scientific basis of the Czech provisions. The Czech Republic subsequently withdrew its request for a derogation (OJC 2006/C 314/10, 21.12.2006).

- **Sweden, 2012**: restriction of P-mineral fertilisers containing >20 mg Cd/kg P_2O_5; rejected based on an opinion by SCHER (2012) (Commission Decision 2012/719/EU).

Why did the Commission approve derogation limits in Finland (2006) of 22 mg Cd/kg P_2O_5 and in Sweden (2006) of 44 mg Cd/kg P_2O_5, but rejected limit derogation requests from the Czech Republic (2006) for 50 mg Cd/kg P_2O_5 and from Sweden (2011) for 20 mg Cd/kg P_2O_5?

Although it is not highlighted in the Commission decision, one possible reason for the difference between Finland and Sweden is that Finland has been using P-fertilisers containing much less cadmium. "*The average cadmium content in European fertilizers is 138 mg/kg phosphorus. Presently, the P-fertilizers used in Finland are manufactured from phosphate rock of igneous origin, and have a cadmium concentration from 1 to 5 mg/kg P. Due to this low Cd level, fertilizers only contribute about 4% to the total Cd input to Finnish cultivated soils. if the current situation with low cadmium content in fertilizers continues, cadmium concentrations in soil, crops and leachates will gradually decrease in potato and sugar beet cultivation. In wheat cultivation, cadmium inputs and outputs will stay in balance.*"

Some more details are given below.

Commission justification for derogations granted to Austria, Finland and Sweden

The justification for the derogations granted in 2006 to Austria, Finland and Sweden (75, 22 and 44 mg Cd/kg P2O5, respectively) are given in Commission Decisions 2006/349/EC, 2006/348/EC, and 2006/347/EC, respectively. All three decisions contain the following text:

"The validity of the data provided by [Austria/Finland/Sweden] is confirmed by the following scientific basis used to support the preparation of the Commission proposal on cadmium in fertilisers:

— the opinion delivered on 24 September 2002 by the SCTEE (now renamed SCHER) [CSTEE 2002] concerning cadmium accumulation in agricultural soils due to fertiliser application. This opinion was based on risk assessment reports of nine Member States which address only the accumulation and not the possible risks to health and environment; the conclusion of the SCTEE was that the content of cadmium in fertilisers does need to be limited to prevent accumulation of cadmium in the soil,

— the final draft of the general risk assessment of cadmium and cadmium oxide, dated September 2004 produced in accordance with Council Regulation (EEC) No 793/93 and which considers all sources of cadmium[11]. The draft endorses the opinion of the SCTEE concerning the accumulation in soil. Although it states that the contribution from cadmium in fertilisers may not, by itself, be sufficient to cause a severe and immediate risk to human health or to the environment, caution is needed, as the risk to human health cannot be excluded for all local and regional situations because of the large variability in food cadmium concentrations, dietary habits and nutritional status.

Therefore, after having re-examined the scientific evidence in the light of the [Austrian/Finnish/Swedish] request, the Commission considers that the [Austrian/Finnish/Swedish] authorities have shown that cadmium-containing fertilisers pose environmental and human health risks, and that the national provisions notified by the

[11] Final version = EU (2008)

[Austrian/Finnish/Swedish] authorities aiming to limit to the minimum the exposure of the [Austrian/Finnish/Swedish] environment to cadmium-containing fertilisers are justified.

— ongoing work within the Commission for an approximation of Community limit values for the cadmium content in fertilisers does not lead to believe that a less restrictive measure would provide sufficient protection of health and environment in [Austria/Finland/Sweden]. The risk assessment shows that the specific soil and climatic condition of [Austria/Finland/Sweden] require national provision for the protection of the environment because some areas are more vulnerable to cadmium inputs due in particular to the acidic pH of their soil. Under acidic conditions, the solubility of cadmium increases and therefore could be more easily taken up by the crops.

…It is clear that these conclusions refer to the specific situation of the [Austrian/Finnish/Swedish] soil as well as the climatic conditions prevailing in [Austria/Finland/Sweden]."

Member state-specific texts are as follows:

Austria (Commission Decision 2006/349/EC)

"In support of its request, Austria makes reference to the conclusions of an Austrian study published in October 2000[12] *which contains an assessment of the risks posed by cadmium-containing fertilisers. The most relevant information of the risk assessment carried out by Austria can be summarised as follows:*

— concerning water, the report states that 'when fertiliser is applied with an average concentration of 25 mg Cd/kg P2O5 the PNEC value is exceeded both now and in 100 years',

— concerning the soil, the report states that 'when fertiliser is applied with an average concentration of 25 mg Cd/kg P2O5 or of 90 mg Cd/kg P2O5, the PNEC value is exceeded both now and in 100 years'.

…

In conclusion, the risk assessment carried out by Austria shows that PEC value (predicted environmental concentration) from cadmium in mineral fertilisers in Austria, exceeds the PNEC value for water in most investigated regions. This also applies to soil in 5 % of the 52 Austrian arable regions if bio-available values are used. In the view of the Austrian authorities, this means that, according to the European Community risk assessment methodology, the substance is of concern and there is a need to take further steps."

Finland (Commission Decision 2006/348/EC)

"In support of its request, Finland makes reference to the conclusions of a Finnish study published in April 2000[13] *which contains an assessment of the risks posed by cadmium-containing fertilisers. The most relevant information of the risk assessment carried out by Finland can be summarised as follows:*

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[12] Zethner G, Goodchild R (2000). A risk assessment for cadmium in Austria based on the recommendations of ERM [& annex]. Austrian Federal Environment Agency, 10 October 2000.
Report: http://ec.europa.eu/enterprise/sectors/chemicals/files/reports/austria_en.pdf
Annex: http://ec.europa.eu/enterprise/sectors/chemicals/media/photos/austria_annex.gif

[13] Finnish Environment Institute (2000). Cadmium in fertilisers, risks to human health and the environment. Finnish Environment Institute. Study report for the Finnish Ministry of Agriculture and Forestry, 3 October 2000. http://ec.europa.eu/enterprise/sectors/chemicals/files/reports/finland_en.pdf

— concerning water, the Finnish risk assessment report states that 'risk characterisation reveals that there is risk for aquatic environment for all calculated scenarios, both at present time and in the future. In practice this means that no margin of safety can be established, and any increase to the natural background concentrations is likely to present a risk for the aquatic environment',

— concerning the soil, the Finnish risk assessment states that 'based on the available data, the current cadmium concentrations in Finnish agricultural soils present a risk for the soil environment. This conclusion can be reached both by using mean extractable cadmium concentrations (the concentration of cadmium that is available for uptake by plants) and 90 percentile values in the five Finnish cultivation zones for the year 1987. Only in the most northern zone, the PEC/PNEC ratio using the mean concentration is below 1. Risk ratios for the different cultivation zones vary from 1,2 to 2,8',

— concerning human health, the Finnish risk assessment report states that 'in Finland, there is no margin of safety for the risk group (worst cases) between the estimated urinary levels and the critical levels that have been associated with adverse health effects caused by cadmium'. The Finnish risk assessment report also states that 'if phosphorus fertilisers containing average Community level of cadmium were to be used in Finland the dietary intake of cadmium would increase by more than 40 % over one hundred years, based on model calculations'.

…

In conclusion, the risk assessment carried out by Finland shows that present cadmium concentrations in Finnish agricultural soil pose a risk for soil organisms and that the leaching of cadmium from the agricultural soil is causing a risk for the aquatic environment. Finland maintains that the risk assessment concludes also that there is a risk of adverse health effects as a result of the present total cadmium exposure in the Finnish population. While the average cadmium intake from food alone does not pose a risk in Finland, some sectors of the population are at risk because of high dietary intake, increased absorption and/or smoking."

Sweden (Commission Decision 2006/347/EC)

"In support of its request, Sweden makes reference to the conclusions of a Swedish study published in October 2000[14] which contains an assessment of the risks posed by cadmium-containing fertilisers. The most relevant information of the risk assessment carried out by Sweden can be summarised as follows:

— concerning surface water, the Swedish risk assessment report states that 'the chosen PNEC value implies that in most rivers in southern Sweden, certain biota would already be affected by cadmium i.e. risk characterisation ratios (PEC/PNEC) are larger than one. If higher cadmium content in fertilisers would be allowed, a further increase in the exposure of and the concern for effects in the aquatic environment is expected to occur',

— concerning the soil, the Swedish risk assessment report states that 'by using the Swedish fertiliser for 100 years on common Swedish soils (PNEC 0,25 mg/kg), no concern for ecological effects is predicted when potatoes or wheat are grown. A concern is predicted when carrots are grown, but this concern is also present at time zero. With the EC fertiliser, a concern is predicted in all cases. In acid, sandy soils that are poor in clay and organic matter (PNEC 0,06 mg/kg), a risk is predicted even if the cadmium content in fertilisers is zero'.

…

[14] NCI 2000. Assessment of Risks to Health and the Environment in Sweden from Cadmium in Fertilisers. National Chemicals Inspectorate, 4 October 2000.
http://ec.europa.eu/enterprise/sectors/chemicals/files/reports/sweden_en.pdf
http://ec.europa.eu/enterprise/sectors/chemicals/files/reports/sweden_annex_en.pdf

In conclusion, the risk assessment carried out by Sweden shows that if fertilisers with a higher cadmium content than currently permitted would be allowed, this would lead to:

— a substantial increase in the cadmium concentrations of soils, which in turn would lead to toxic effects on soil organisms. Unacceptable concentrations could also appear in watercourses in agricultural regions,

— a substantial increase in the dietary intake of cadmium. The safety margin between current exposure and the World Health Organisation provisional tolerable weekly intake level is extremely small. For some high-risk groups, such as women with low body iron stores, there are no safety margins at all. A high dietary intake of cadmium could therefore lead to a larger number of people becoming subject to reduced kidney function and increased osteoporosis."

Commission justification for derogations not granted to Czech Republic and Sweden

Requested derogations by Czech Republic (2006) and Sweden (2011) were not granted.

The **Czech Republic** requested a derogation limit of 115 mg Cd/kg P (50 mg Cd/kg P2O5) in 2006, which was withdrawn after an opinion from SCHER (2006/390/EC)[15]:

"*In support of its request, the Czech Republic makes reference to the conclusions of a national study, which contains an assessment of the risks posed by cadmium-containing fertilisers. On the basis of the assumptions and scenarios used, the Czech report concludes that there is currently no risk to human health resulting from the use of cadmium in fertilisers; the limit margin of safety MOS ratio of 1 was not exceeded in any of the exposure scenarios, including the upper-bound scenario studied, i.e. assuming that 100 % of supplied food originates from fertiliser-applied areas and that the cadmium content is at the level of 90 mg/kg P2O5. However, given that the value proposed by the Czech Republic to justify the maintenance of national measures is to a PEC/PNEC ratio close to 1, it was deemed appropriate to submit the risk-assessment to the Commission's Scientific Committee on Health and Environmental Risks (SCHER) for a careful evaluation. The evaluation of the position of the Czech Republic is therefore deferred until the Commission receives the opinion of the SCHER*."

The opinion from SCHER (2006[16]) was that

- the Czech report has not made full use of the data which are apparently available. Unlike reports presented by Sweden, Finland and Austria, ***the Czech report has not developed in sufficient detail soil dependent scenarios*** *which would allow to assess the 'extent' (e.g. area of % of arable land) of the risks. It also suggested that the human health part can be considerably improved and that information from the Cd RAR and the CSTEE opinion (2004)[17] on that document should be used. In this document Table 1, a detailed set of scenarios and MOS values are calculated for that Cd-U of 2.5 µg/g creatinine correspond to*

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[15] COMMISSION DECISION of 24 May 2006 on the national provisions notified by the Czech Republic under Article 95(4) of the EC Treaty concerning the maximum admissible content of cadmium in fertilisers (notified under document number C(2006) 2036) (Only the Czech version is authentic) (Text with EEA relevance) (2006/390/EC)

[16] SCHER (2006). Opinion on "Risk to the environment and human health resulting from the use of phosphate fertilizers containing cadmium", Report 285 - Czech Republic -November 2005. EU Scientific Committee on Health and Environmental Risks, adopted 19 September 2006. http://ec.europa.eu/health/ph_risk/committees/04_scher/docs/scher_o_043.pdf

[17] CSTEE 2004. Opinion on the results of the risk assessment of cadmium metal and cadmium oxide, environmental part. European Commission, Scientific Committee on Toxicity, Ecotoxicity and the Environment, adopted 28 May 2004. http://ec.europa.eu/health/archive/ph_risk/committees/sct/documents/out228_en.pdf

about 50 mg/kg in kidney cortex or assuming that 2.5 µg/g creatinine correspond to a long-term daily intake of 50 µg/day.

*- **the scenarios assessed in the Czech report are too scant to allow a reliable evaluation** of the long term Cd accumulation due to application of phosphate fertilizers to Czech soils. It is suggested that realistic scenarios are developed and assessed which reflect both (1) the variability of the soils characteristics (and their relationship with arable soil area) and (2) the potential combinations of the Cd content and the annual fertilizer application quantity. The SCHER also suggests that the human health part of the Czech report can be improved by including more detailed information on the actual intake of cadmium by the Czech population or by using worst case scenarios.*

*- **the PNEC used in the Czech report is a rather conservative 'generic' value** which has not been extensively peer-reviewed. More recent data and discussions reported in the EU draft RAR on Cd (2003) were not taken into account. As such, and given the non-quantified uncertainty associated with both the PEC and PNEC values, the SCHER is of the opinion that the risk quotients presented in the Czech report may not be the most appropriate values to describe the presence or absence of the risk of Cd to soil resulting from the application of the Cd containing phosphate fertilizers. The SCHER should emphasize again that the CSTEE opinion adopted on September 2002 focused on the Cd accumulation in soil only, and not on the risk for human health and the environment caused by the application of Cd containing fertilisers to soils.*"

Following the SCHER (2006) opinion, the Czech Republic withdrew its request for a derogation regarding the limit of cadmium in fertilisers, so the derogation was not granted[18].

Sweden

Sweden requested a derogation limit of 46 mg Cd/P (20 mg Cd/kg P2O5) in 2011, which was rejected after opinions by SCHER 2012 (2012/719/EU[19])

To support their request, the Swedish authorities submitted a new risk assessment of cadmium in the Swedish environment[20] which identified long term risks for aquatic organisms living in extremely soft waters in small brooks with low dilution of the drainage water from the agricultural soil.

[18] http://ec.europa.eu/enterprise/sectors/chemicals/documents/specific-chemicals/fertilisers/index_en.htm#h2-3

[19] COMMISSION DECISION of 17 October 2012 on the national provisions notified by the Kingdom of Sweden pursuant to Article 114(5) of the Treaty on the Functioning of the European Union concerning the maximum admissible content of cadmium in fertilisers (notified under document C(2012) 7177) (Only the Swedish text is authentic) (Text with EEA relevance) (2012/719/EU)

[20] Text from 2012/719/EU: The PNEC for fresh water is dependent on hardness. Since Sweden has very soft fresh waters, toxicity for aquatic organisms is expected to occur at lower cadmium concentration compared to other parts of Europe. It is, therefore, likely that aquatic organisms in Swedish waters are in general more sensitive to cadmium compared to waters in central and southern Europe.
Results of monitoring programmes in Swedish surface waters in 2006 and 2009 show that about 1 % of the lakes and 7 % of the coastal waters show higher cadmium concentrations than the PNEC values. A review conducted in 2008 concluded that emission reduction measures have for most metals led to significant decreased concentrations in aquatic organisms, but for cadmium the situation is less clear. A tendency of increasing effects on the immune system in fish (eelpout) during the last years seems to correlate with increasing concentrations of cadmium in fish. A further report has been produced in 2011 with the aim to describe future trends of cadmium in arable soils and crops to estimate concentrations in 100 years and results have been used in a worst case modelling to estimate the risk to aquatic organisms inhabiting waters close to fields fertilised during 100 years ahead.
The Swedish authorities conclude in their assessment that there might be an increased risk for aquatic organisms living in extremely soft waters (below hardness 5 mg CaCO3/L) in the longer term. But this is only likely in small brooks with low dilution of the drainage water from the agricultural soil. No other risk to the environment resulting from the use of cadmium in fertilisers has been identified by the Swedish authorities.

The Commission requested the Scientific Committee on Health and Environmental Risks (SCHER) for an opinion. The opinion (SCHER 2012a[21]) considered that

*- a number of statements and/or assumptions in the report are **not supported by sufficient evidence** and that for some scenarios rather **worst case conditions were used**.*

*- **the assumptions** proposed by the Swedish authorities to predict cadmium concentration in soft water could lead to an over-estimation of the risks and, consequently, **do not support the results presented by the Swedish authorities for brooks, which is the only environmental compartment for which the Swedish authorities have identified risks.***

Overall, SCHER did not consider the assumptions made in the Swedish report as appropriate for calculating risk in the Swedish environment[22].

In response to the SCHER (2012a) opinion, the Swedish authorities sent a letter (2 July 2012) to the Commission arguing that the notion of '**protection of the environment**' in Article 114(5) TFEU covers health aspects and that an examination of the Swedish notification **should**, therefore, **include arguments relating to the health aspects**. In their justification, the Swedish authorities identified health-related grounds for further reducing cadmium exposure amongst the population in Sweden, such as a high frequency of osteoporosis, increased cases of brittle bones and bone fractures, impacts on the functioning of kidneys in parts of the population where cadmium content exceed 1 mg/g creatinine, as well as risks for sensitive groups of the population (diabetics and people suffering from iron deficiency, both groups being of high proportion in Sweden). According to the Swedish authorities**, the lower pH level in Swedish soils may lead to higher uptake of cadmium in crops, which in turn can lead to higher exposure of the population**, as exposure depends to a great extent on the intake of cadmium through food, above all food of plant origin.

The Commission therefore extended its analysis to the assessment of possible risks posed by cadmium in fertilisers to the Swedish population via the environment, i.e. notably through dietary intake, and requested a further opinion of SCHER (SCHER 2012b[23]). With regard to the question whether the situation in Sweden is different compared to other parts of Europe, **SCHER agreed that soil pH is on average lower in Sweden than in other parts of Europe. However, as cadmium removal from the soil by leaching is also increasing with lower soil pH value, the net cadmium soil accumulation is lower in Sweden than in most parts of Europe at comparable cadmium concentration and fertiliser application rates.** SCHER 2012b noted that the Swedish report itself (summary of Annex IV[24]) supports SCHER's conclusion as it states: 'It was difficult to unambiguously show whether there are specific conditions in Sweden that make Swedish soils more vulnerable to Cd input than those in central Europe. However, pH is a major factor that regulates the uptake of cadmium from soils to crops and **pH in Swedish soil appears to be around one**

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[21] SCHER 2012a. Assessment of Cadmium in Fertilizers. EU Scientific Committee on Health and Environmental Risks, 27 February 2012 (http://ec.europa.eu/health/scientific_committees/environmental_risks/docs/scher_o_156.pdf).

[22] SCHER (2012a) concluded that "most assumptions used in the calculations seem valid (although sometimes worst-case). However, SCHER does not agree with the assumption that there is no adsorption in the soil. This will only occur when the soil is already heavily contaminated and no net adsorption occurs at steady state, which is currently not the case in most Swedish soils. The report also assumes that there is no Cd adsorption in soil occurring deeper than 30 cm; this is also not the case. The latter thus makes that the predicted concentrations in the brooks are over-estimated. Finally, as mentioned above, the soil/brook dilution factor is not substantiated by robust scientific evidence. As such, SCHER cannot support the RCR (Table 7) given in the risk assessment report. Overall, the SCHER does not consider the assumptions made in the Swedish report as appropriate for calculating risk in the Swedish environment."

[23] SCHER (2012). Opinion of cadmium in fertilisers - additional request on the risk assessment report from the Kingdom of Sweden (human health). EU Scientific Committee on Health and Environmental Risks, 24 October 2012.
http://ec.europa.eu/health/scientific_committees/environmental_risks/docs/scher_o_162.pdf

[24] The role of mineral fertilisers for cadmium in Swedish agricultural soil and crops. Swedish Chemical Agency, Institute of Environmental Medicine, Swedish National Food Administration, January 2011. http://ec.europa.eu/enterprise/sectors/chemicals/files/reports/sweden_min_fert_soil_jan2011_en.pdf (page 4)

pH unit lower than the general average for Europe. This is probably related to the scarcity of lime-bearing bedrock in Sweden. Swedish wheat also contains cadmium in levels that are comparable to those in many other European countries, in spite of the fact that cadmium concentrations in Swedish soils are relatively low'. SCHER comments that while input data on atmospheric deposition have been updated in the Swedish report, the scenarios for mass balance calculation were already included in the scenarios considered in the opinion of the CSTEE of 2002, and there is no new information suggesting that these would not be applicable anymore: "*the highest fertiliser application rates considered in the Swedish report (22 kg P/ha/y, equivalent to 52 kg P2O5), are lower than the highest application rates used in the CSTEE report for Europe (69 kg P2O5/ha/y). In addition, the Cd input via atmospheric deposition in Sweden (less than 0.5 g Cd/ha/y) is lower, and not higher, than that used in the CSTEE report for Europe (3 g Cd/ha/y)*."

SCHER (2012b) agreed with the Swedish report that **the lower pH increases cadmium bioavailability and uptake by crops, hence that the soil cadmium availability to wheat is somewhat larger than in most European countries. However, SCHER noted that if that low pH is maintained, the future trends in crop cadmium concentrations are smaller (lower increase) in Sweden compared to most other trends in Europe because soil cadmium increases at a lower rate at equal input.**

With regard to dietary exposure to cadmium, SCHER (2012b) concluded that the Swedish report does not provide data suggesting that dietary cadmium exposure is larger in Sweden than in the rest of Europe neither at the mean nor at the upper percentiles of exposure. Recent trends do not suggest an increasing trend in dietary exposure, including body burden cadmium in the general population. "***If anything, it emerges that the Swedish situation is one where soil and food chain Cd may be expected to increase to a lesser extent in the future (at equal Cd input via phosphate fertilisers) than in most other European countries. The crop Cd may respond similarly. Although body burden may respond differently depending on food habits, no increasing trend in Cd exposure was evidenced in Sweden****.*" (SCHER2012b, p.9).Lastly, SCHER noted that the Swedish report provides evidence that effects of cadmium on human health in Sweden can be noted at a body burden of cadmium that is lower than that reported before, however it does not provide evidence that the Swedish population is more sensitive or became more sensitive to cadmium than those in other European countries.

Overall, SCHER (2012b) concluded that the Swedish report does not provide convincing arguments to show that the Swedish case is a unique one or that data which appeared after the adoption of Regulation (EC) No 2003/2003 suggest specific reasons for additional concern.

On the basis of SCHER 2012a and 2012b, the Commission concluded that the request of the Kingdom of Sweden for introducing national provisions derogating from Regulation (EC) No 2003/2003 is admissible but does not fulfil the conditions set out in Article 114(5) TFEU, as Sweden did not provide new scientific evidence relating to the protection of the environment on grounds of a problem specific to their territory arising after the adoption of Regulation (EC) No 2003/2003), and therefore rejected the proposed limit of 46 mg Cd/P (20 mg Cd/kg P2O5) (2012/719/EU).

SCAHT comments

The Commission denial of the 2011 derogation request by Sweden (20 mg Cd/kg P2O5) implies that this is over-protective. This rejected limit is virtually the same as the Swiss (ChemRRV) limit of 50 mg Cd/P (22 mg Cd/kg P2O5.

Is the situation in Switzerland different to that in Sweden or other European countries? We consider two factors: agricultural soil pH, and background soil cadmium levels.

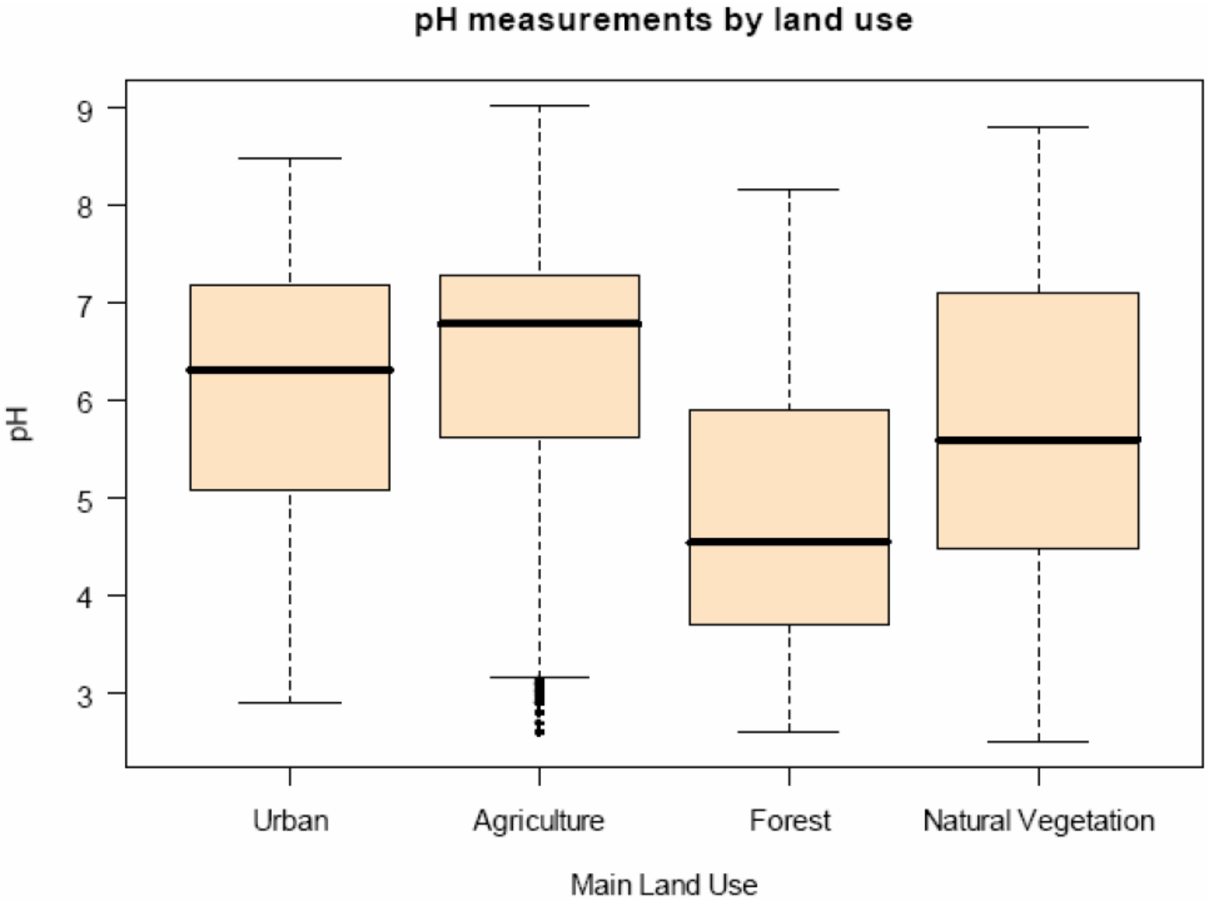
Agricultural soil pH in Switzerland and other European countries

According to Jansa et al (2014)[25], the median pH of Swiss agricultural soil is 6.37 (range 4.70-7.65). Note that Jansa et al measured soil pH in 1:2.5 (v:v) aqueous and CaCl2 (10 mM) soil suspensions, but the values quoted are only for pH in water. Measuring pH in CaCl2 gives values more similar to natural soil solution because the soil solution also contains dissolved Ca2+ and other ions.

JRC 2010[26] collated European soil pH values (including both pH(H2O) and pH(CaCl2) data). All values were reported as pH(CaCl2), using a conversion factor of pH(CaCl2) = 0.9761* pH(H20) - 0.427. Using this conversion factor, the median Swiss poil pH(water) of 6.37 reported by Jansa et al would be equivalent to a median pH(CaCl2) of 5.79.

JRC 2010 reported a median agricultural soil pH(CaCl2) in Europe of between 6.5 and 7 (Figure A1-1).

Figure A1-1: Agricultural soil pH in Europe (JRC 2010)



Source: JRC 2010[27], Figure 5

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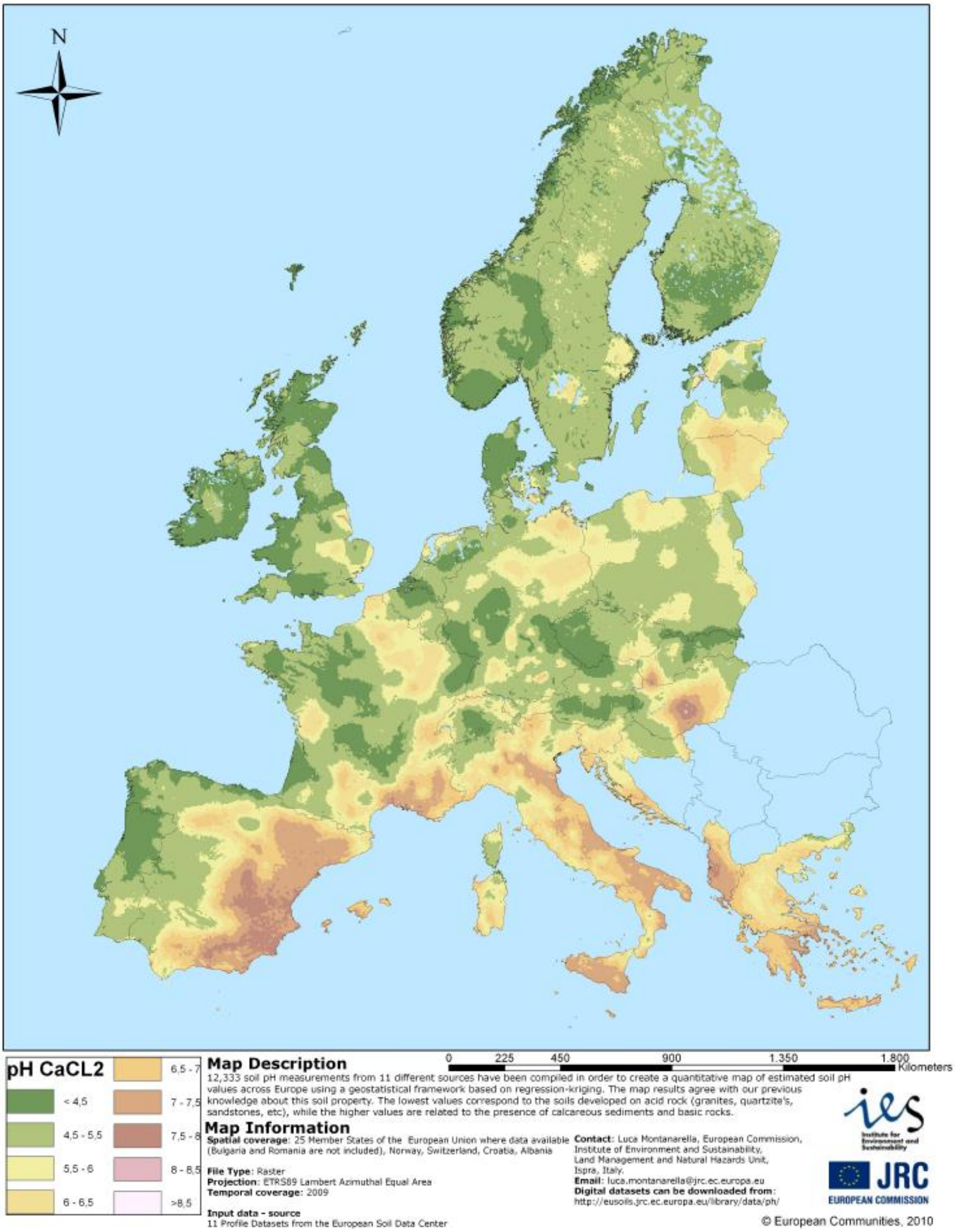
[25] Jansa J, Erb A, Oberholzer HR, Smilauer P, Egli S. Soil and geography are more important determinants of indigenous arbuscular mycorrhizal communities than management practices in Swiss agricultural soils. Mol Ecol. 2014 Apr;23(8):2118-35.

[26] JRC 2010. Soil pH in Europe. http://eusoils.jrc.ec.europa.eu/library/data/ph/Documents/pH_Pub.pdf; http://eusoils.jrc.ec.europa.eu/library/data/ph/. Also published as Reuter HI, Lado LR, Hengl T, Montanarella L (2008). Continental-scale digital Soil Mapping using European Soil Profile Data: Soil pH. In: Böhner J, Blaschke T, Montanarella L [Eds.]; SAGA – Seconds Out. Hamburger Beiträge zur Physischen Geographie und Landschaftsökologie (2008), Vol.19. http://switch.dl.sourceforge.net/project/saga-gis/SAGA%20-%20Documentation/HBPL19/hbpl19_10.pdf

[27] JRC 2010. Soil pH in Europe. http://eusoils.jrc.ec.europa.eu/library/data/ph/Documents/pH_Pub.pdf; http://eusoils.jrc.ec.europa.eu/library/data/ph/

JRC provided a European soil pH map (Figure A1-2). The lowest values correspond to the soils developed on acid rock (granites, quartzites, sandstones, etc), while the higher values are related to the presence of calcareous sediments and basic rocks (JRC 2010). From Figure A1-2, Swiss soil pH appears to be broadly similar to that in central and north European countries, including Sweden. Swiss soil pH is higher in the Jura mountain area, consistent with its calcareous rock geology. (Note that this soil pH map also reflects lower pH found in forest soil.)

Figure A1-2: Soil pH in Europe



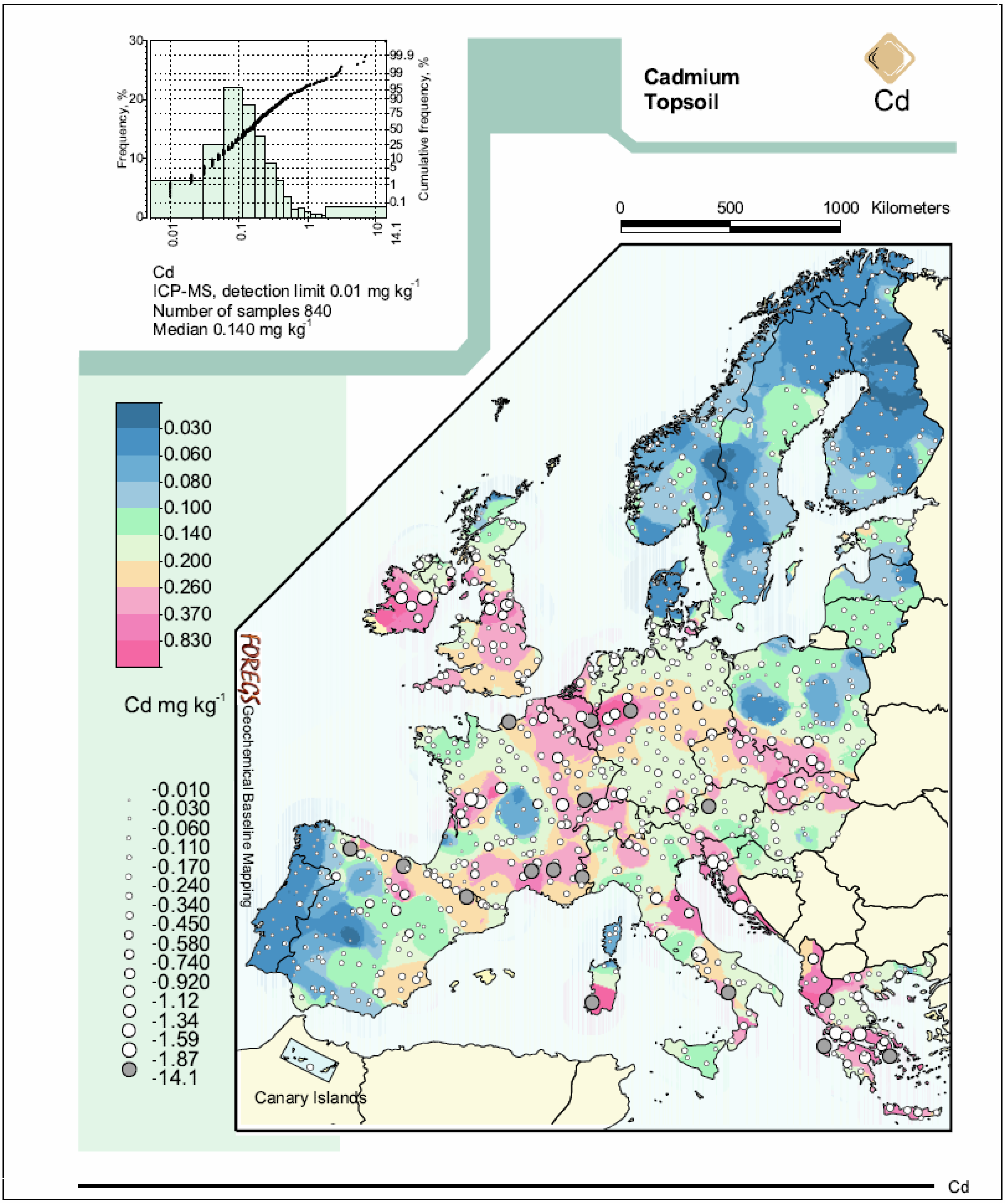
Source: http://eusoils.jrc.ec.europa.eu/library/data/ph/Resources/ph2.jpg (http://eusoils.jrc.ec.europa.eu/library/data/ph/)

Soil pH values are notably higher in east Spain, south France, Italy and Greece than in most other European countries.

Soil cadmium in Europe

The JRC European Soil Portal collates data from the FOREGS Geochemical database on heavy metal content[28]. Figure A1-3 shows the European map for soil cadmium concentrations.

Figure A1-3: Cadmium in European soils (FOREGS Geochemical database)



Source: http://weppi.gtk.fi/publ/foregsatlas/maps/Topsoil/t_icpms_cd_edit.pdf

[28] http://eusoils.jrc.ec.europa.eu/foregshmc/

From Figure A1-3, it appears that the background level of soil cadmium in Scandinavia, including Sweden and Finland, is substantially lower than in most other European countries except Portugal.

Comparing the risk assessments submitted in 2000 by Sweden and Finland and by Sweden in 2011, it is not obvious why Finland was granted a derogation limit of 22 mg Cd/kg P2O5 in 2006, but Sweden was denied a derogation limit of 20 mg Cd/kg P2O5 in 2012. Both have similarly low soil pH, and both have low background soil cadmium levels.

One of the Finland 2000 arguments was that their P-fertilisers currently contained much less cadmium.

"*The average cadmium content in European fertilizers is 138 mg/kg phosphorus. Presently, the P-fertilizers used in Finland are manufactured from phosphate rock of igneous origin, and have a cadmium concentration from 1 to 5 mg/kg P. Due to this low Cd level, fertilizers only contribute about 4% to the total Cd input to Finnish cultivated soils. if the current situation with low cadmium content in fertilizers continues, cadmium concentrations in soil, crops and leachates will gradually decrease in potato and sugar beet cultivation. In wheat cultivation, cadmium inputs and outputs will stay in balance.*

Between 1974 and 1987, the measured extractable cadmium concentration in Finnish cultivated soils increased by 30%. This was mainly caused by exceptional use of fertilizers with high cadmium content, corresponding to the average EU fertilizers.

If phosphorus fertilizers with average cadmium content in the EU (138 mg Cd/kg P) were to be used in Finland, the cadmium balance in agricultural soils would be radically disturbed, according to model calculations. Over 100 years, cadmium concentrations in soil on potato fields would increase by 125%, wheat grain concentrations by 34%, and an increase of 124% in cadmium leaching from potato fields would take place…."

Both Finland and Sweden used conservative algorithms for calculating soil vs soil pore water cadmium.

Finland (2000) said "*Soil cadmium concentrations shown by the 100-year scenarios based on Christensen´s algorithm, but also based on Anderson´s algorithm, were in a good accordance with the respective values obtained in the static mass balance calculations (Tables 14-17) in which the mean value for Cd leaching, 0.060 g/ha/a, was based on a Swedish report (Andersson 1992)….*
Cadmium concentrations in the pore water/leachate obtained by the various algorithms differed from each others by more than 500 to 1000 times depending on the time and the Cd content of P-fertilizers (Table 11). At the initial time (0), the concentration order from the lowest to the highest values by the algorithms was the following: by Anderson´s algorithm 0.000-0.001; by Christensen´s algorithm 0.022- 0.050; by McBride´s algorithm 0.087-0.174; and by Romkens´ algorithm 0.299-0.550 µg/L. The Cd concentrations obtained by Anderson´s algorithm seem to be unrealistic low as compared to the Cd concentrations in the Finnish ground water. Because McBride´s algorithm was developed for the soils with elevated Cd content, this algorithm could not be considered as a proper selection for the Finnish cultivated soils with low Cd concentration. Romkens´ algorithm gave still higher pore water concentrations than McBrides´s algorithm did. These were the reasons why the Finnish scenario calculations will be focussed mainly on the results obtained by Christensen´s algorithm."

Sweden (2000) said:

"*The choice of algorithm for calculating the soluble fraction to total Cd content had a large influence on the predictions of accumulation in soil and leaching losses. The algorithm of*

Römkens and Salomons (1998) gave very high Cd concentrations in the pore water, and hence a lower accumulation in soil and high leaching losses, whereas using the algorithm of McBride et al. (1997) gave more Cd sorbed in the soil….
When using the algorithm by Römkens and Salomons (1998), total soil Cd decreased due to the very high leaching rates, whereas leaching losses had a very small effect on total Cd when using the algorithm of McBride et al. (1997) for the period of 100 years studied….
When using the algorithm of Römkens and Salomons (1998), the leaching loss was very high and Cd did not accumulate in the soil to the same degree, and hence, calculated plant Cd-concentrations were lower….
For this study, the algorithm by McBride et al. (1997) was found to best reflect the Swedish situation when comparing to observations on pore water Cd concentrations and leaching.… The estimations of Cd accumulation and leaching losses were very sensitive to the estimation of the soluble Cd fraction. Calculations made using the algorithm of McBride et al. (1997) were found to best reproduce Swedish available data…."

Sweden (2011) said

"*The magnitude of Cd leaching is acknowledged as being very difficult to constrain with any higher precision (EC, 2007a). It is thus possible both to under- and to overestimate leaching, depending on the selection of data. In the present context where long-term changes in soil Cd are assessed, and where the human exposure of Cd is considered as critical, we suggest that it's most important to not overestimate the Cd leaching. Swedish agricultural soils are somewhat more acidic compared to other parts of Europe indicating a higher mobility, and with that, possibly higher exposure concentrations in soil solution for organisms inhabiting the soil. On the other hand, Swedish soils are rather high in clay which affects the mobility of cadmium in the other direction."*

SCAHT comment

Estimated leaching rates are critically important; the European Commission has based its decisions for granting derogations on CSTEE (2002), which used a low leaching estimate and predicted that P fertiliser cadmium content of 60 mg Cd/kg P would result in long-term accumulation of cadmium in soil. The most recent review (Six & Smolders 2014) chose leaching rates closer to Römkens and Salomons than to McBride; this predicts high leaching loss, lower plant Cd-concentrations, and no net Cd accumulation in the soil. However, both Finland and Sweden used similar low-leaching algorithms, so this does not explain the difference in the Commission's derogation decisions (limit of 22 mg Cd/kg P_2O_5. in Finland approved, 20 mg in Sweden rejected).

Relevant EU legislation

- Commission Regulation (EU) No 463/2013 of 17 May 2013 amending Regulation (EC) No 2003/2003 of the European Parliament and of the Council relating to fertilisers for the purposes of adapting Annexes I, II and IV thereto to technical progress.
- Commission Regulation (EU) No 223/2012 of 14 March 2012 amending Regulation (EC) No 2003/2003 of the European Parliament and of the Council relating to fertilisers for the purposes of adapting Annexes I and IV thereto to technical progress.
- Dutch corrigenda to Commission Regulation (EC) No 137/2011 (OJ L 277, 22.10.2011, p36)
- Czech corrigenda to Commission Regulation (EC) No 137/2011 (OJ L 247, 24.9.2011, p. 59)
- Commission Regulation (EC) No 137/2011 of 16 February 2011 amending Regulation (EC) No 2003/2003 of the European Parliament and of the Council relating to fertilisers for the purposes of adapting Annexes I and IV thereto to technical progress
- Commission Regulation (EC) No 1020/2009 of 28 October 2009 amending Regulation (EC) No 2003/2003 of the European Parliament and of the Council relating to fertilisers for the purposes of adapting Annexes I, III, IV and V thereto to technical progress
- Commission Regulation (EC) No 1107/2008 of 7 November 2008 amending Regulation (EC) No 2003/2003 of the European Parliament and of the Council relating to fertilisers for the purpose of adapting Annexes I and IV thereto to technical progress
- Spanish corrigenda to Regulation (EC) No 2003/2003 of the European Parliament and of the Council relating to fertilisers (OJ L 267, 12.10.2007, p 23)
- Commission Regulation (EC) No 162/2007 of 19 February 2007 amending Regulation (EC) N° 2003/2003 of the European Parliament and of the Council relating to fertilisers for the purpose of adapting Annexes I and IV thereto to technical progress
- Commission Regulation (EC) No 2076/2004 of 3 December 2004 adapting for the first time Annex I of Regulation (EC) No. 2003/2003 of the European Parliament and of the Council relating to fertilisers (EDDHSA and triple superphosphate)
- Regulation (EC) No 2003/2003 of the European Parliament and of the Council of 13 October 2003 relating to fertilisers
- EU Regulation 793/93 on the evaluation and control of the risks of existing substances sets the basis for risk assessment studies on cadmium.

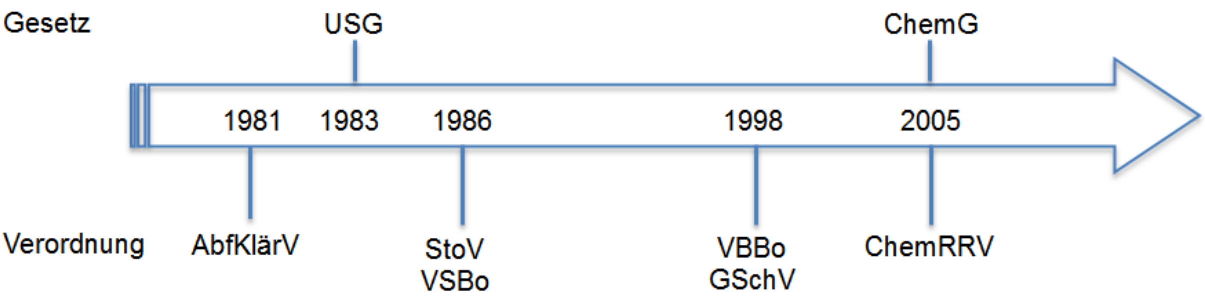
Other EU legislation which is partly relevant includes:

- the Fertiliser Directive (76/116/EEC, free market for fertilisers); this does not address cadmium concentrations, and until now Member States have relied on national measures and regulations
- the Cadmium Directive (91/338/EEC); this deals only with products in which cadmium is being applied deliberately
- the Sewage Sludge Directive (86/278/EEC)
- Council Regulation (EEC) No 2092/91 of 24 June 1991 on organic production of agricultural products
- Commission Regulation (EC) No 466/2001 of 8 March 2001 setting maximum levels for certain contaminants in foodstuffs
- Commission Directive 2001/22/EC of 8 March 2001 laying down the sampling methods and the methods of analysis for the official control of the levels of lead, cadmium, mercury and 3-MCPD in foodstuffs
- the Water Framework Directive (2000/60/EC)

Appendix 2: Regulatory aspects, CH

Relevant legislation

Swiss legislation relevant to cadmium is shown diagrammatically in the following figure. The ordinances which are relevant to soil cadmium risk assessment are particularly those for cadmium levels in P-fertilisers (StoV, ChemRRV), soil (VBBo), and water (GSchV).



The Klärschlammverordnung (AbfKlärV, 1981) set limit values for metals in sewage sludge that could potentially harm soils, including cadmium.

The Stoffverordnung (StoV, 1986) and its successor, the Chemikalien-Risikoreduktions-Verordnung (ChemRRV, 2005) specify a limit of 50 mg Cd/kg P in fertilisers.

The Verordnung über Belastungen des Bodens (VBBo, 1998) specifies a guidance value (Richtwert) for cadmium in soil with up to 15% humus of 0.8 mg total Cd/kg soil dw, 0.02 mg soluble Cd/kg soil dw. These values presumably also apply to sediment, although there is no specific reference to in situ sediment in VBBo.

The Gewässerschutzverordnung (GSchV, 1998) specifies maximum permissible dissolved concentrations in river and lake surface waters (0.05 µg Cd dissolved/L and 0.2 µg Cd total/L).

History

Concern that Cd may enter the food chain through the application of P-fertilisers in agricultural soils arose in the late 1970s (CEC 1981). Soil contamination in Switzerland was examined as part of the national research project NFP-22 "Nutzung des Bodens in der Schweiz"[29].

The first regulatory moves regarding soil protection were in the early 1980s when the Swiss Parliament debated the Umweltschutzgesetz (USG, 1985), the Stoffverordnung (StoV, 1986) and the Verordnung über Schadstoffe im Boden (VSBo, 1986). This also triggered the foundation of the Nationales Bodenbeobachtungsnetz (NABO) [Swiss Soil Monitoring Network] in 1984. All these activities were perceived at the international level as pioneering efforts. With the planned Umweltschutzgesetz (USG, 1985), a new opportunity was seen to harmonize regulation in terms of limitation of the use of Cd use. It was perceived at that time that Cd in mineral fertilisers (Handelsdünger), whose application on Swiss agricultural soils peaked between 1977 and 1985 (Spiess 2005), were not regulated and that a strict regulation and limitation of Cd to minimize human health impact was needed (personal communication J.Dettwiler, BAFU). The Klärschlammverordnung (AbfKlärV, 1981) set limit values for metals that could potentially harm soils, including cadmium.

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[29] http://nfp.snf.ch/D/forschung/Forschungsprogramme/abgeschlossen/Seiten/_xc_nfp22.aspx

In 1981, the Federal Council mandated an ad hoc Working Group[30] to evaluate cadmium contamination in Switzerland and the potential risks for the environment and human health. The Working Group laid down important foundations in preparing the implementation provisions for the USG, 1985) and associated ordinances. The Working Group (BAFU 1984) concluded that:

- the **safety margins** between the present Cd concentrations and the concentrations which can endanger humans and environmental organisms is generally relatively low;
- important **knowledge gaps** existed calling for research efforts to monitor Cd concentrations and effects in soils;
- it is only by means of effective **precautionary measures** that will be prevented that the cadmium burden for humans and the environment increases and eventually reaches a critical value.

Based on these conclusions and following the precautionary principle, BAFU (1984) proposed new legislative provisions and surveillance activities to reduce as much as possible Cd emissions and use, including setting new limits for air and soil. In particular, it recommended monitoring of Cd content in fertilisers, the environment and food, and recommended that the cadmium content as an impurity in mineral fertilisers should be reduced to 50 mg Cd/kg P.

This limit value was adopted in the Stoffverordnung (StoV, 1986) with a transition period until December 1992, later extended to August 1996. The new limit was notified to the EU and the Swiss fertiliser industry expressed its approval for the limit value in 1986 and again in 1992 (BUWAL 2003a). The limit was maintained in the Chemikalien-Risikoreduktions-Verordnung (ChemRRV, 2005) which replaced the StoV.

Several companies from the fertiliser industry in the late 1990s urged that the Swiss regulations for Cd in fertilisers be approximated to those of the EU, despite the fact that no binding EU regulations for cadmium existed at the time. However, no further action were taken and the question was no longer debated (personal communication J.Dettwiler, BAFU).

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Spiess E. Die Phosphorbilanz der Schweiz. Schriftenreihe der FAL. 57, 2005, 82-85. http://www.agroscope.admin.ch/publikationen/einzelpublikation/index.html?pubdownload=NHzLpZeg7t,lnp6I0NTU042l2Z6ln1acy4Zn4Z2rZpnG3s2Rodeln6h1doJ2f3,Nn,aknp6V2tTIjKbXoKimjZybmZWmiKfo

30 The Working Group included the Bundesämter für Umweltschutz und Gesundheitswesen, the Forschungsanstalt für Agrikulturchemie und Umwelthygiene, Liebefeld, and the Eidg. Anstalt für Wasserversorgung, Abwasserreinigung und Gewässerschutz (EAWAG), Dübendorf (BAFU 1984).