6 Calculation of critical loads

6.1 Introduction

It is known for a long time, that heavy metals can cause toxically effects in soil, water and to living organisms if certain concentrations are exceeded. By today's level of air pollution by man, only according to the atmospheric deposition, we can count on long–term accumulation of heavy metals in the soil especially in the forest humus deposit. Parts of the emitted heavy metals can be transported for a long distance. In addition to the atmospheric depositions on the agricultural soils also metals inputs by management measure take part in the gradual enhancement of concentrations in the soils and the joined environment. Under the conditions of increasing acidification the forest soil can become itself the source, at first for more mobile metals (e.g. Cd) for transfer into water, vegetation, soil organisms and food chains. The accumulation of pollutants in wide areas of water and soil are almost not returnable.

Problem of evaluation of long–range transport and deposition of heavy metals has been studied for more than two decades both by means of measurements and modelling activity. According to Protocol of heavy metals signed in 1998 metals of first priority are Pb, Cd, and Hg (GREGOR et al. 1999). These metals show different behaviour in atmosphere. That is connected with their properties. Lead and Cadmium present in the atmosphere being bound to aerosol particles. These particles are subjected to wet and dry deposition. Their lifetime in the atmosphere varies from several days to two weeks. Hence, they can undergo transport on long distances.

The term „critical load“ was developed to set limits on acidic deposition in European forest ecosystems (NILSSON and GRENNFELT 1988). The original definition of critical load can be modified to be applicable to trace metals:

> „The critical load of a trace metal is a calculated atmospheric and agricultural input to a terrestrial or aquatic ecosystems that will increase the concentration of the metal in soil to a steady state level not yet harmful to present organisms, ground water quality, food chains“.

When the real atmospheric and agricultural input is higher than the calculated critical load, the concentration of the metal in soil can reach a toxic level with respect to organisms of the ecosystem. The critical load is an indicator for sensibility in regions where the high input of trace metals is of ecological concern and where a legislation should limit this type of pollution. Exceeding of critical load will occur in areas with high total loads of heavy metals. Exceeding can occur far from sources of pollution via air transported pollutants. Measures for areas with exceed can only refer to management inputs and emission reduction at the sources.

The work by DE VRIES and BAKKER (1998) constitute a useful framework for a determination of critical load for heavy metals for arable and forest soils. The critical load concept refers to the most sensitive component of the environment with respect to a given pollutant. When it comes to heavy metals, it is difficult to define what that component is.

6.2 Definition of critical limits

Environmental soil quality criteria constitute the basis of critical load calculation. Therefore the selection of critical limits is a step of major importance in deriving a critical load. Those critical limits, which depend on the kind of effects considered and the amount of harm accepted, constitute the basis of the critical load calculation and determine their magnitude.

With respect to heavy metals, environmental quality objectives based on total content in relatively unpolluted soils. Most often these are total metal concentration in the soil solid phase, protecting soil organisms. In various countries critical limits for soil have been derived to assure multifunctional use. The overview of these limits is given in Table 6.1.

Tab. 6.1: Environmental quality objectives for heavy metal contents in soil in several countries

Country	Quality objective (mg/kg)						
	Pb	Cd	Cu	Zn	Ni	Cr	Hg
Denmark [1)]	40	0.3	30	100	10	50	0.1
Finland [1)]	38	0.3	32	90	40	80	0.2
Netherlands [1)]	85	0.8	36	140	35	100	0.3
Germany [1)]	40-100	0.4-1.5	20-60	60-200	15-70	30-100	0.1-1.0
Switzerland [1)]	50	0.8	50	200	50	75	0.8
Czech Republic [1)]	70	0.4	70	150	60	130	0.4
Ireland [1)]	50	1.0	50	150	30	100	1.0
Canada [1)]	25	0.5	30	50	20	20	0.1
Bulgaria [2)]	70	2.0	120	200	-	110	1.0

[1)] According to DE VRIES and BAKKER (1998)
[2)] Instruction No. 0011/1994/ MAF (values concern A-horizon of a standard soil with $pH_{(H2O)}$ = 6.0).

Comparison of the data for the various countries in Table 6.1 shows a relatively limited range in critical limits, i.e. 25-100 for Pb, 0.3-2 for Cd, 30-120 for Cu, 50-200 for Zn, 10-70 for Ni, 20-130 for Cr and 0.1-1.0 for Hg (all data in mg/kg).

The above mentioned values are considered to avoid harmful effects in all land use types. Higher values are possible when this criterium of multifunctional use is left. A differentiation has been made in critical limits for Pb, Cd, Cu and Zn n soil for several types of agricultural use in the Netherlands, based on various criteria, such as acceptable daily intake for humans or phytotoxic effects (arable land), or effects on animals (grassland) or loss of production (ornamental culture). Results for Pb, Cd, Cu and Zn indicated higher values for grassland and ornamental culture compared to arable land. In ATANASSOV et al. (1994) were proposed tentative values of threshold concentration of heavy metal in Bulgaria, depending of the land use. This values indicated a strong increase in threshold concentration going from multifunctional land use to industrial areas. In other countries such as Germany suggested critical limits for heavy metals have been derived as a function of land use (e.g. agriculture, gardens and parks), and indicated also a strong increase in critical limits going from multifunctional land use to industrial areas. (EIKMANN and KLOKE 1991).

The problem with the data described above is that they mostly lack an ecotoxicological basis. In approaches used in some countries related to multifunctional soil use, the critical limits are in principle based on risk limits, which are a result of scientific effect assessment. According to this system, the Maximum Permissible Concentration (MPC), is defined as *the concentration above which the risk of adverse effects is considered unacceptable*. Sometimes determined MPC's are lower than "natural background concentrations", i.e. concentrations in relatively unpolluted areas. As it seems pointless to set critical limits at levels that can never be reached due to the presence of a natural background concentration. The reason for this difference may, however, partly be due to differences in metal availability. MPC values are based on laboratory experiments, where a certain amount of metals is added to the soil (bioavailable contents), whereas the background refer to hot aqua regia extractions of soil with a fraction of <2 mm (total content).

At the Workshop on Effects–based Approaches for heavy metals in Schwerin 1999, it was concluded that critical limits expressed as total concentration in the soil solution are most appropriate for use in a critical load approach (GREGOR et al. 1999). The reason is that on one hand it is assumed that most of the known effects of heavy metals in soils are related to the soluble fraction. According to the heavy metals effects in soils the soil organisms, including micro–organisms, food vegetation and also ground waters are the most important receptors. The heavy metals, which come through the food chain, especially Cd, Pb and Hg, can affect also higher organisms, including human health. After regarding all important pathways the most sensitive way should be chosen for establishing the critical concentration in the soil solution (Critical Limits) to protect all other pathways at this concentration. CURLIK et al. (2000), assumed that, depending on the metal regarded (Cd and Pb), soil biota and plants are the most sensitive receptors. This means that in the case of Cd and Pb ground water protection is not the decisive point for the derivation of the Critical Limits, but the conservation of the soil function to act as biotope. The total heavy metal concentration of the soil solution is the most appropriate value to calculate the tolerable leaching flux. In this term both free metal ions and metals bound in dissolved complexes are included. Both parts are relevant to the leaching process. In addition, critical limits could be based on the relationship between concentrations in the organisms and total concentration in the soil.

Up to now there are only few studies, relating effects on plants, soil biota and food chains directly to concentrations in the soil solution. In most cases, effect thresholds are expressed as "total" concentrations (e.g. aqua regia, HNO_3 – extraction). But environmental quality criteria for metal concentrations in soil solution are lacking. Therefore, the total metal content in soil is used. According to recommendation of the Schwerin Workshop (GREGOR et al. 1999) these data can be transformed into bio-availabile concentrations or concentrations in the soil solution using transformation functions incorporating relevant variables of soil characteristics (pH, organic matter, clay etc.).

6.3 Model

For a practical work there is need for a simple approach. The manual of DE VRIES and BAKKER, (1998) describes several options of different complexity levels, based on equilibrium processes. Mass balance models are principally acceptable for critical loads calculation for the heavy metals to combine the ways of pollution with the ways of the effects. The critical load is the acceptable total load of anthropogenic heavy metal inputs (deposition, fertilizers, other anthropogenic sources). It corresponds to the sum of tolerable outputs from the system (harvest, leaching) minus the natural inputs (weathering release).

$$CL(HM)_{tot} = HM_{fu} + HM_{ru} - HM_{lf} + HM_{le(crit)} - HM_{we} \qquad \text{(Eq.1)}$$

Where all terms relate to fluxes of heavy metal HM (in $mg.m^{-2}.yr^{-1}$) due to:

$CL(HM)_{tot}$	= critical total input of the heavy metal by anthropogenic sources.
HM_{fu}	= foliar uptake of the heavy metal directly from atmosphere.
HM_{ru}	= root uptake of heavy metals.
HM_{lf}	= heavy metal flux by litterfall.
$HM_{le(crit)}$	= tolerable (=critical) leaching of heavy metals.
HM_{we}	= weathering release of heavy metals.

Figure 6.1 gives a schematically representation of the steady-state mass balance for heavy metals (Eq.1).

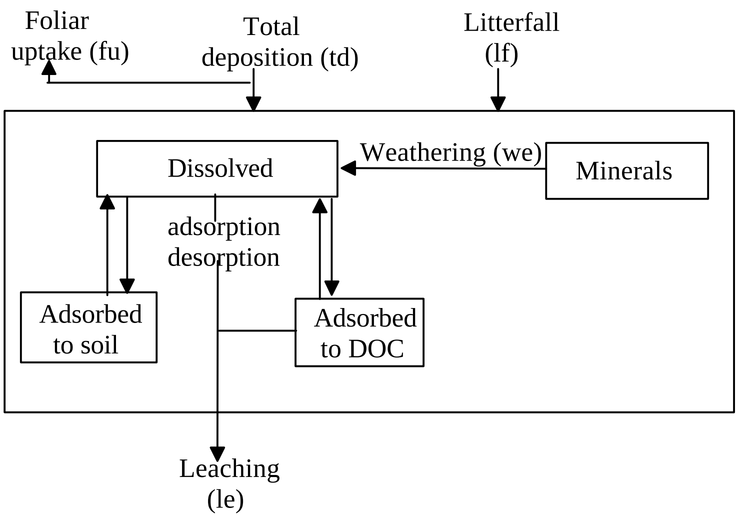

Fig. 6.1: Schematically representation of the steady-state mass balance for heavy metals in soils

The model can, however, be simplified by neglecting the metal cycling within a terrestrial ecosystem and all fluxes of not significant magnitude. Using these assumptions, the critical load of heavy metals, for both non-agricultural and agricultural soils, equals:

$$CL(HM)_{tot} = HM_U - HM_{we} + HM_{le(crit)} \qquad \text{(Eq.2)}$$

HM_U = removal of heavy metals by biomass harvesting or net uptake in forest ecosystems ($mg.m^{-2}.yr^{-1}$).

This approach implies that the critical load equals the net uptake by forest growth or the uptake by agricultural products plus an acceptable metal leaching rate minus weathering release of heavy metals (GREGOR et al. 2000).

6.4 Calculation of Critical load for Pb and Cd

Calculated Critical loads for lead and cadmium on a regional scale for arable and forest soils in South Bulgaria are presented as follows: arable soils are in the impact zone of Pb-Zn-Cu smelters, and forest soils are in background territory, where atmospheric deposition is the only input of heavy metals. Therefore relatively simple model with aggregated descriptions of processes in whole considered compartment was chosen.

6.4.1 Input data

In this study the input data for calculating Critical loads for the selected model include following parameters:

- Parameters about precipitation;
- Data about evapotranspiration in investigated areas;
- Weathering of soil minerals;
- Leaching characteristic;
- Uptake of lead and cadmium by plants.

The input data mentioned above vary as a function of location (receptor area) and receptor (the combination of land use and soil type). The receptors in this calculation were arable land and forest soils. System inputs (and outputs) refer to the location dependent inputs of heavy metals and to hydrological data.

PRECIPITATION AND EVAPOTRANSPIRATION DATA

Data for the precipitation and evapotranspiration are presented in Table 6.2. The flux of leaching water is derived from meteorological data according DVWK (1996).

Tab. 6.2: Values for the meteorological related parameters (AGROCLIMATICAL ATLAS OF BULGARIA 1992)

Soil profile	Location	Precipitation ($m.m^{-2}.yr^{-1}$)	Evapotranspiration ($m.m^{-2}.yr^{-1}$)	Flux of leaching water ($m.m^{-2}.yr^{-1}$)[1)]
1	Zlatitza [1)]	0.670	0.420	0.250
2	Pirdop [1)]	0.670	0.420	0.250
3	Plovdiv [2)]	0.560	0.490	0.070
4	National park "Rogen" [3)]	0.970	0.395	0.575
5	"Haidushki polayny" [3)]	0.970	0.395	0.575

[1)] Meteorological station Pirdop.
[2)] Meteorological station Plovdiv.
[3)] Meteorological station Rogen.

HEAVY METALS AND LAND USE RELATED DATA

Heavy metal and land use related data include all data concerning metal cycling in the ecosystem, i.e. removal of heavy metals by biomass harvesting or net uptake in forest ecosystems. Element output from the ecosystem by biomass harvesting is driven by the yields and the concentration in the harvested parts of the plant.

The natural yield potential, which depends on the location and combination of land use and soil type, is modelled and calculated to be an input term to the calculation the output of heavy metals. The modelled harvest yield of the dry substance multiplies with the content of heavy metals (values from background location), which is specific for every species of the plants.

In Table 6.3 there were presented the average biomass removal for investigated two arable regions in South Bulgaria (ANGELOVA 1994). Presented values consider these parts of the plants which are not remaining in the field. Otherwise if parts of the crops as straw or the leaves of beets are usually not used, but are remaining on the field, they are not be considered and the removal of heavy metals in this case is the product of the yield of grains/beets and the mean contents of these parts of the plants. Contents from investigations on relatively unpolluted areas are implemented. Because those contents in most cases are not following normal distribution, the median value is a suitable value. It can be expected that those values do not exceed limits or guidance values for use as food or feed, thus the export range can be regarded as tolerable. For heavy metals concentration in harvested parts for analysed agricultural crops and grains were used median concentrations measured in background areas or control parcels (SAUERBECK and STYPEREK 1998; LUA NRW 1996).

Tab. 6.3: Annual biomass removal and the contents of Cd and Pb in biomass for two of investigated regions (Plovdiv and Pirdop)

Crops	Pirdop [1]		Plovdiv [2]		Heavy metal content in harvested parts [3]	
	% arable land	Annual biomass removal [1] ($kg.m^{-2}.yr^{-1}$)	% arable land	Annual biomass removal[2] ($kg.m^{-2}.yr^{-1}$)	Cd ($mg.kg^{-1}$)	Pb ($mg.kg^{-1}$)
Winter wheat	30.5	0.45	20.5	0.55	0.08	0.10
Winter barley	15.5	0.42	6.0	0.55	0.02	0.20
Rye	-	-	4.0	0.50	0.03	0.20
Other grains	3.0	0.40	-	-	0.04	0.20
Maize	9.0	0.45	28.5	0.45	0.20	3.80
Potatos	12.0	0.80	8.0	1.00	0.23	0.73
Clover, grass	12.0	0.50	10.0	0.80	0.15	2.49
Vegetables	6.0	0.50	15.0	0.75	0.09 [4]	0.12 [4]
Fruits	12.0	0.40	-	-	0.23	0.73
Vineyards	-	-	8.0	0.80	0.23	0.73

[1] ATANASSOV et al. (2000)
[2] ANGELOVa (1994)
[3] NAGEL and SCHÜTZE (1997) after SAUERBECK and STYPEREK (1988) and LUA NRW (1996)
[4] DELSCHEN and LEISNER-SAABER (1998)

For forest ecosystems only the net increment was considered, but not the uptake into needles, leaves, etc., which also remain in the system. The wood yield in the forest ecosystems in Germany is derived as the annual increment of the dry substance, in average for 100 growth years (SCHLUTOW and SCHÜTZE 1999). Proceed from that leafs or needles and also small branches and barks are staying in the system only the heavy metal reception into stems and strong branches is calculated as removal. For profile 4 and 5 (coniferous forest) were used data for wood yield (SCHLUTOW 1994) and concentration of heavy metals in stem wood (NAGEL and SCHÜTZE, 1997) calculated for German forest in dependence on soil association and climate region (Table 6.4).

Tab. 6.4: Annual wood yield and Cd and Pb content in biomass of coniferous forest

Profile	Soil type	Coniferous trees	Wood yield (dry mass)[1)] ($t.ha^{-1}yr^{-1}$)	Concentration of heavy metals [2)] ($mg.kg^{-1}$)	
				Cd	Pb
4 and 5	Cambisol	Picea abies	2.9	0.43	2.5

[1)] SCHLUTOW (1994)
[2)] Based on literature study by NAGEL and SCHÜTZE (1997)

HEAVY METALS AND SOIL RELATED DATA

Heavy metal and soil related data include weathering rates. In Table 6.5. are presented total content of Pb and Cd, and the ratio of heavy metals and base cation in parent material. They are derived from data about heavy metal content and total chemical analysis of investigated profiles (see appendix Tab. A7).

Tab. 6.5: Estimated values for the base cation weathering rates, total contents of base cation, heavy metals in the parent material and of Cd and Pb in investigated soil profiles

Soil Profile	Weathering rates of base cations[1)] ($mol_c ha^{-1} yr^{-1}$)	Total content of base cation in parent material[2)] ($mol.kg^{-1}$)	Metal contents ($mg.kg^{-1}$) [3)]	
			Cd	Pb
1	750	1.98	3	28
2	750	1.62	2	21
3	750	4.96	1	44
4	750	1.43	0.8	33
5	750	1.50	0.8	29

[1)]Based on literature information using field and laboratory data (VAN DER SALM et al. 1998)
[2)]Based on mineral composition of investigated soils and calculated according DE VRIES and BAKKER (1998).
[3)]Based on lower range of metal content in investigated soils (Tab. A7, appendix).

6.4.2 Calculation of Critical loads

The critical load is the acceptable total load of anthropogenic heavy metal inputs (deposition, fertilizers, other anthropogenic sources). It corresponds to the sum of tolerable outputs from the system (harvest, leaching) minus the natural inputs (weathering release). The simplest mass balance equation was used (Eq. 2) (GREGOR et al. 2000).

$$CL(HM)_{tot} = HM_U - HM_{we} + HM_{le(crit)} \qquad \text{(Eq.2)}$$

HM_U = removal of heavy metals by biomass harvesting or net uptake in forest ecosystems ($mg.m^{-2}.yr^{-1}$).

$HM_{le(crit)}$ = tolerable (=critical) leaching of heavy metals ($mg.m^{-2}.yr^{-1}$).

HM_{we} = weathering release of heavy metals ($mg.m^{-2}.yr^{-1}$).

HEAVY METAL REMOVAL BY HARVEST OF PLANTS

The most simple approach to describe the removal of heavy metals by biomass is to combine the average yield (or increment) of biomass with the heavy metals content in those parts, which will be harvested (GREGOR et al. 2000).

$$HM_U = Y * X_{hpp} \qquad \text{(Eq.3)}$$

where:

Y = annual yield (or increment) of biomass (dry weight) ($kg.m^{-2}.yr^{-1}$).

X_{hpp} = content of the heavy metal in the harvested parts of the plants ($g.kg^{-1}$).

HEAVY METAL RELEASE BY WEATHERING

The weathering release of heavy metals in Bulgaria is significant (see chapter 2.5) and is considered in the mass balance. The weathering rates of heavy metals is calculate (VRUBEL and PACES 1996) according to:

$$HM_{we} = 10^{-4} * BC_{we} * \left(\frac{ctHMp}{ctBCp} \right) \qquad \text{(Eq.4)}$$

where:

BC_{we} = the weathering rate of base cations ($mol_c.ha^{-1}.yr^{-1}$).

$ctBC_p$ = total content of base cations in parent material ($mol.kg^{-1}$).

$ctHM_p$ = total content of heavy metal in parent material ($mg.kg^{-1}$).

TOLERABLE OUTPUT OF HEAVY METALS BY LEACHING

The tolerable leaching flux of heavy metals can be calculated according to the equation:

$$HM_{le(crit)} = Q * c_{(crit)} \qquad \text{(Eq.5)}$$

where:

Q = the flux of leaching water ($m.yr^{-1}$).

$c_{(crit)}$ = the critical limit for the total concentration of heavy metal in the percolating soil solution ($mg.kg^{-1}$).

According the recommendation of the Ad Hoc International Expert Group on Critical Limits (CURLIK et al. 2000), the total heavy metal concentration of the soil solution is the most appropriate value to calculate the tolerable leaching flux. In this term both free metal ions and metals bound in dissolved complexes are included. Both parts are relevant to the leaching process. The most biological effects of metals in soils are more closely related to the soil solution concentration, or free ion activity of the metal in soil solution than to total soil content. This is in accordance with the pore-water hypothesis (CROMMENTUIJN et al. 1997).

In this investigation for critical limits was used the concentration in soil solution according recommendations of Workshop in Bratislava (2000). For calculation critical soil solution concentration was used the transformation function (SCHÜTZE and NAGEL 2000) which involves soil properties. For solid concentration was used the determined concentration in the investigated profile.

According SCHÜTZE and NAGEL (2000) the lowest concentration of a heavy metal in the soil solution, calculated with transformation functions from effect based Critical Limits (total concentrations in the soil), should be used. The idea behind this is: If effects have been found at a certain total concentration in the soil and there is no clear relationship to soluble concentrations in dependence of soil characteristics, it were assumed that effects can occur even at very low soil solution concentrations. Beside this effects can exist at this total concentration in the soil, which are independent of the soil solution concentration.

The critical limits of the soil solution concentrations derived with such transformation function is actually effected based only with respect to those organisms, which are exposed mainly via pore water. Beside this, it may occur that background concentrations in the soil solution in soils of ecosystems with naturally acid soils are higher than the critical limits. For these ecosystems other biocenoses may be more typical than those for more neutral soils.

For calculation of critical soil solution concentration were used following transformation functions after LIEBE (1999):

Pb

$\log Pb(NH_4NO_3)[mg.kg^{-1}]=0.760 \log Pb(\text{aqua regia})[mg.kg^{-1}]–0.614\ pH+1.03$ r=0.82***

$\log Pb(BSE)[\mu g.l^{-1}]=0.5 \log Pb(NH_4NO_3)[\mu g.kg^{-1}+0.27$ (DIN 19735-draft)

Cd

$\log Cd(NH_4NO_3)[mg.kg^{-1}]=0.943 \log Cd(\text{aqua regia})[mg.kg^{-1}]–0.466\ pH+0.99$ r=0.82**

$\log Cd(BSE)[\mu g.l^{-1}]=0.68 \log Cd(NH_4NO_3)[\mu g.kg^{-1}] - 0.6$ (DIN 19735-draft)

Calculated soil solution concentrations are presented in Table 6.6.

Tab. 6.6: Calculated values for critical soil solution concentration using transformation function (SCHÜTZE and NAGEL 2000)

Soil profile	pH ($CaCl_2$)	Total content of the element(mg.kg^{-1}) determined with extraction with aqua regia		Critical soil solution concentration (µg.l^{-1})	
		Cd	Pb	Cd	Pb
1	4.81	2.5	80	5.34	14.84
2	3.91	2.5	80	10.31	28.04
3	6.36	2.5	80	1.72	4.96
4	4.56	2.5	80	6.41	17.71
5	4.26	2.5	80	7.98	21.90

According to DE VRIES et al. (1998) the use of critical metal concentrations in the soil solution caused higher critical loads for Pb and Cd as compared to the soil criterium. With using the soil solution criterium resulted in only small differences between the different soil groups. This can be expected since adsorption and complexation descriptions are not needed when using critical dissolved metal concentrations, which implies that the critical load mainly depends on the precipitation excess.

CRITICAL LOAD

Calculated values for metal removal by biomass, release by weathering, output by leaching, and critical load for lead and cadmium are presented in Tables 6.7. and 6.8.

Tab. 6.7: Calculated values for critical load for cadmium in investigated profiles

Soil Profile	Land use	Cd_U (mg.m^{-2}.yr^{-1})	Cd_{we} (mg.m^{-2}.yr^{-1})	$Cd_{le(crit)}$ (µg.m^{-2}.yr^{-1})	Cd_{CL} (mg.m^{-2}.yr^{-1})
1	Arable land	0.64	0.11	1.34	1.86
2	Arable land	0.64	0.09	2.58	3.12
3	Arable land	0.88	0.02	0.14	1.00
4	Coniferous forest	1.25	0.04	3.69	4.89
5	Coniferous forest	1.25	0.04	4.59	5.80

Tab. 6.8: Calculated values for critical load for lead in investigated profiles

Soil Profile	Land use	Pb_U (mg.m^{-2}.yr^{-1})	Pb_{we} (mg.m^{-2}.yr^{-1})	$Pb_{le(crit)}$ (µg.m^{-2}.yr^{-1})	Pb_{CL} (mg.m^{-2}.yr^{-1})
1	Arable land	4.35	1.06	3.71	7.00
2	Arable land	4.35	0.97	7.01	10.39
3	Arable land	9.53	0.67	0.35	9.21
4	Coniferous forest	7.25	1.73	10.18	15.70
5	Coniferous forest	7.25	1.45	12.59	18.39

Calculated critical loads for lead and cadmium on a regional scale for both types of land use vary as follows:

Cadmium: 1.0 – 3.12 mg.m^{-2}.yr^{-1} for arable lands and 4.89 – 5.80 mg.m^{-2}.yr^{-1} for forest soils.

Lead: 7.0 – 10.39 mg.m^{-2}.yr^{-1} for arable lands and 15.7 – 18.4 mg.m^{-2}.yr^{-1} for forest soils.

It is estimated that critical loads for Cd and Pb vary depending mainly on land use type. The values of calculated loads for both elements increased from arable to forest soil. The reason is that forest ecosystems had bigger filtering capability and also precipitation rate in studied region is high, that helps for deposition of pollutants on the forest floor.

Comparison between estimated values and those calculated for German soils, shows, that calculated critical load for Cd is higher than those calculated for Germany (FEDERAL SOIL PROTECTION LAW 1998). It can be concluded that the calculated values for Cd and Pb give a good initial indication of the spatial variability of ecosystem sensitivity to heavy metal pollution in Bulgaria.