Quantitative Risk Assessment as part of the GIS based Environmental Risk Management of diffuse pollution of mining origin

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ABSTRACT : The Toka catchment area, a former base metal mining site in Gyöngyösoroszi, Hungary, was selected to demonstrate the adaptation potential of the Difpolmine approach applied to diffuse pollution of mining origin at the Salsigne (France) site. The postmining activities at the Hungarian site require the management of both the point and diffuse sources. The mobile Cd and Zn content of the mine waste, soil, sediment and water pose the highest environmental risk in the area. A complete Environmental Risk Management methodology was worked out. The approach is „GIS based" and „catchment scale", using a three tiered, iterative Environmental Risk Assessment methodology. The risk reduction concept aims at reducing the runoff water quantity and contamination by removal of the point sources and chemical & phytostabilisation of the residual and diffuse pollution. This paper focusses on the Quantitative Risk Assessment methodology.

1. INTRODUCTION

The management of point and diffuse pollution of mining origin is a timely issue in Europe. Considerable effort is being invested to develop a common management methodology that could handle the exisiting situation, assess and compare potential problems on a multinational and catchment basis. An Environmental Risk Management approach focussed on the risk of the metal content of the surface water has been worked out to the Toka catchment in Gyöngyösoroszi (Gruiz et al., 2005), a former Pb and Zn sulphide ore mining area in Hungary, the Hungarian demonstration site of the Difpolmine EU Life Project (http://www.difpolmine.org). In the Toka catchment area the main environmental pressures are related to the mobile Cd and Zn content of the mine wastes, surrounding soils and transported sediments (Bekõ et al, 1992; ELTE, 1991; Horváth and Gruiz, 1996; Gruiz et al., 1997). The toxic metals originate from the exploited sulphide ore veins hosted in andesite rocks. 1–3 pH leachate is being produced around the waste rock heaps due to the complex chemical and biological oxidation of the pyrite containing material in contact with the rainwater and runoff. The mine had been abandoned for 20 years, mine closure and remediation activities started in 2005.

2. OBJECTIVE

The overall objective was to work out a risk based management concept for point and diffuse pollution, which substantiates a risk based remediation approach.

The GIS based Quantitative Risk Assessment applied to the Toka catchment aimed at providing the PEC/PNEC based quantitative risk for calculation of the target emission of the point and diffuse sources after remediation (Gruiz et al 2005). In our assessment the extent of the necessary risk reduction is function of the effect based quality criteria for surface waters and the emission of the sources. The Natural Risk Reduction Capacity (NRRC) of the site between the source and the ouflow of the catchment was taken into account as well as the efficiency of the integrated chemical and phyto-stabilisation remediation technology.

3. CONCEPT AND THE COMPONENTS OF THE ENVIRON-MENTAL RISK MANAGEMENT METHODOLOGY

The Environmental Risk Management methodology is based on an integrated conceptual risk model (Gruiz et al., 2000) , including the point and diffuse sources, the transport routes and the land-use specific exposure routes and the receptors.

The risk management concept is focused on the dominant risk. According to our conceptual model the dominant risk is the metal content of the sources. The dominant transport route is the runoff and the surface water system, therefore the most exposed receptors are the members of the water-ecosystem.

The main components of the methodology are: the conceptual model at catchment scale and pollution source basis, GIS database with the inventory of pollution sources using historical documents and site assessment data, three tiered iterative risk assessment, planning risk reduction using the quantitative risk model and focusing on fulfillment of the effect based quality criteria values targeted for the surface water ecosystem.

The three tiered, catchment scale risk assessment methodology (Gruiz et al, 2005) is applied to both point and diffuse pollution sources:

1 Qualitative Risk Assessment, resulting in inventory and relative ranking of the pollution sources. 2. Hazard assessment, based on the emission from the sources. 3. Assessment of the quantitative risk to give the target value for remediation and risk reduction planning.

4. QUANTITATIVE RISK ASSESSMENT

The quantitative risk of the ecosystem is characterised by the Risk Quotient (RQ), which is the ratio of the Predicted Environmental Concentration (PEC) and the Predicted No Effect Concentration (PNEC) (Gruiz et al, 2000). The PEC is given by the measured metal concentrations of the Toka creek water and sediment. The PNEC is defined based on effect based quality criteria obtained from literature and regulatory data (BKH, 1995; Swartjes, 1999). According to the site specific Quantitative Risk Assessment of the Toka catchment area the risk quotient (RQ=PEC/PNEC) is higher than 1 (RQ>1). The target risk value is RQ =1. The aim is to reduce PEC to the PNEC value. Having the target concentration in the Toka creek (PNEC) and the Natural Risk Reduction Capacity of the site the maximum permitted emission from the point and diffuse sources able to ensure the PNEC value in the Toka creek is calculated.

4.1 Parameters and processes influencing the Predicted Environmental Concentration (PEC) and supporting the Quantitative Risk Assessment

Quantitative Risk Assessment utilised site-specific data and parameters taking into account the: Water Balance Sheet of the area (OMSZ, 2002), geological data (Gruiz et al, 2005), results of the microcosm leaching experiment (Gruiz et al., 2006), natural risk reduction capacity of the site, results of the chemical stabilisation microcosm experiment (Feigl, 2005). The site-specific processes were modelled in soil microcosm experiments. To produce the Water Balance the main pollution pathways were identified and the Conceptual model (Figure 1.) was developed. The runoff water was considered to be the main pollution pathway in the model, given the topography (steep slopes), hydrogeology (high infiltration rate) and geology of the area and the site specific processes due to the mineralogical composition of the ore, mine waste material and country rock (leaching, bioleaching, partition). The conceptual model shows, that the risk posed by the contaminants leached out from the pollution sources is distributed amongst the surface waters, subsurface waters (Gruiz et al., 2001) and plant uptake (Sipter et al., 2005). The solid transport by erosion is included in the conceptual model. However the Quantitative Risk Assessment at this stage was not focussed on the solid phase (sediment) transport by runoff, like it did in case of the Salsigne site (Pottecher, 2002), but more on the mobile metal transport by surface water.

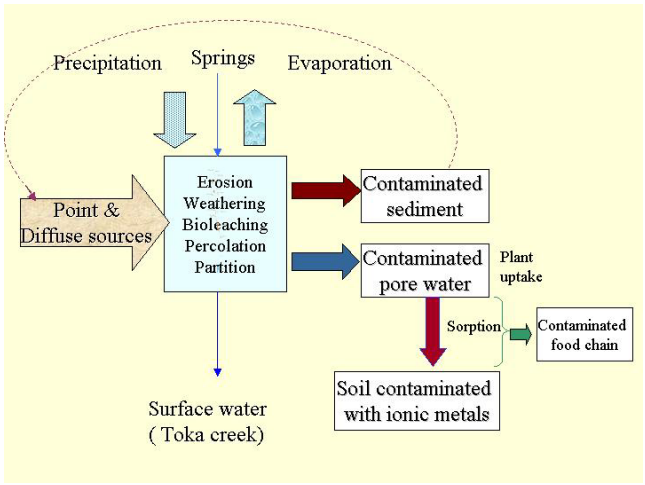

Figure 1. Conceptual Transport model of the Toka catchment

4.1.1 Water Balance and Flow Accumulation

The first step in calculating the distribution of the risk was to estimate the distribution of the precipitation in the area (Water Balance). The Water Balance (Figure 2) was prepared for the Northern catchment of the Toka creek using the same distribution ratios (%) for the total water catchment of Toka.
The Quantitative Water Balance was the basis for the quantification of the Flux of Pollutants, estimation of the Quantitative Hazard, using the GIS Flow Accumulation Model (ESRI Arcview Arcgis 9 software), historical data, on site measurement data, test data. The Water Balance Sheet was used to calibrate the GIS Flow Accumulation.

The GIS Flow Accumulation and the leaching parameters of the microcosm experiment resulted the GIS based Pollution Transport Model enabling calculation of the flux of pollution from the identified point and diffuse pollution sources. The time factor was not considered in the model. The emission from the pollution sources calculated by the Pollution Transport Model gives a realistic view on the emitted metal amount, enabling ranking of the pollution sources according to their emission, which is the aim of the Quantitative Hazard Assessment (Gruiz et al., 2005)

Water Balance and Pollution Transport

In-coming water	Type of incoming water	% of total incoming	Amount of incoming water type	Water form and components
	Precipitation	100%	20 712 m³/ day/10 km²	Rain, snow
	Infiltrated water	43%	8 972 m³/ day/10 km²	Pore water, soil moisture
	Subsurface runoff	16%	3 248 m³/ day/10 km²	Runoff water
	Surface runoff	16%	3 241 m³/ day/10 km²	Runoff water
	Water in biomass	4%	767 m³/ day/10 km²	Plant water
	Vapour	10%	2 451 m³/ day/10 km²	Evapo transpiration
	Outflow from the water zone	12%	2 451 m³/ day/10 km²	Toka creek
TOTAL		100%	20 718 m³/ day/10 km²	

Figure 2. Water Balance of the Toka catchment

The risk of the pollution sources depends not only on the metal concentration, tonnage and surface area of the mine waste dumps but also on the precipitation and the running through water amount. The running through water is function of the size of the waste dump watershed, resulted from the Flow Accumulation Model.

The GIS approach allows estimation of every pollution source (mine waste dump) as an individual water catchment. The surface area of the waste dump and the topography around the pollution source determine the size of the watershed of every individual waste dump, and therefore the water volume likely to run through it from upstream (indirect flow) and directly on its surface (direct precipitation). The resulted water volume is the basis of the Quantitative Hazard Assessment.

To estimate the metal amount transported yearly by the runoff water generated by the annual rain per polluted area the metal concentration of the leachate resulted from the microcosm experiment was used (Gruiz et al., 2006). The GIS approach enabled calculation of the pollution flux of every individual source using the runoff volume derived from the Flow Accumulation (function of the watershed size and annual precipitation) and the metal concentration of the leachate from the complex microcosm leaching test.

4.1.2 Chemical and biological leaching

To model the site specific processes microcosm experiments were run. Leaching of metals from pollution sources and the characteristic parameters of the process were given based on a complex (physical-chemical-biological) leaching test using the most polluted mine waste material in the area. Weathering of the sulphide ore containing waste rock and leaching coupled with microbiological sulphide oxidation, natural decontamination of the leachate by high sorption capacity forest soil was simulated in microcosms. The quantity and quality (pH, As, Cd, Cu, Pb, Zn content) of the leachate was measured at regular time intervals. The key parameters of environmental risk assessment: the rate of acidification and metal mobilisation, metal concentration of the emitted leachate were determined.

Three mine waste qualities were used in the bioleaching micro-cosm experiment (Table 1.) (minimum, medium and maximum grade) to simulate the minimum, medium and maximum emission (Table 2.) (Gruiz et al., 2006).

Table 1. Total metal concentration of the typical mine wastes used in the bioleaching microcosm test

Metals	Total metal* concentration (minimum) mg/kg	Total metal* concentration (medium) mg/kg	Total metal* concentration (maximum) mg/kg
As	44	100	216
Cd	1	3	12
Cu	25	50	107
Pb	295	600	13 100
Zn	370	800	2 155

* aqua regia extract ICP-MS

Table 2. Metal concentration of the microcosm leachates giving the estimated metal emission of the waste sources

Metals	Minimum emission •g/lit	Average emission •g/lit	Maximum emission •g/lit
As	150	340	700
Cd	100	300	1 200
Cu	400	800	4 710
Pb	100	203	3 600
Zn	25 000	54 135	163 000

In light of a conservative approach the average and maximum concentration values were used to give the average and maximum emission/year (Table 3, Table 4) whereas the minimum leachate concentration values were used to generate the Natural Risk Reduction Capacity (Table 5.) of the site (NRRC).

The Tables 3. and 4. below show the calculated yearly emission of various sources (point, diffuse, residual from point sources handled as diffuse) using the runoff water volume from precipitation and indirect flow and the metal concentration of the emitted microcosm leachate.

Table 3. Yearly emission from average and maximum metal concentration sources by runoff water from yearly precipitation

Pollution sources	Emitted metal with precipitation kg				
	As	Cd	Cu	Pb	Zn
Sum of 15 point sources	22–45	19–77	51–301	13–230	3464–10432
Sum of 14 +15 diffuse sources	3–6	2–10	6–38	2–29	433–1304
15 Residual of the point sources	7–10	7–26	18–103	4–479	1190–3597

Table 4. Yearly emission from average and maximum metal concentration sources by runoff water from yearly indirect flow

Pollution sources	Emitted metal with indirect flow kg				
	As	Cd	Cu	Pb	Zn
Sum of 15 point sources	46–100	41–162	108–637	27–483	7308–22 077
Sum of 14+15 diffuse sources	12–26	11–42	28–165	7–125	1894–5723
Residual diffuse 15	35–75	30–122	61–87	20–313	5495–16579

The calculated emitted metal amount is the basis for determining the contribution to the total risk of each point and diffuse pollution source. The calculated emission is used as a semi-quantitative relative value for differentiation between the sources on hazard basis.

4.1.3. Natural Risk Reduction Capacity (NRRC) of the site

Having the pollutant emission from the source and the actual measured concentration in the recipient Toka creek the natural risk reduction capacity of the site was introduced as a generic parameter along the transport pathway from the source to the recipient. The Natural Risk Reduction Capacity of the site incorporates the following site specific parameters: soil sorption, partition between phases, changes in the chemical form and as a consequence changes in the mobility of the metals, bioaccumulation, etc. The generated Natural Risk Reduction Capacity of the site is a calculated parameter obtained by comparing the emitted metal content of the leachate (based on the results of the bioleaching microcosm experiments) with the actual metal concentration measured in the surface water (Toka creek). When calculating the NRRC of the site the minimum concentration waste was considered (Table 5).

Table 5. Calculation of the Natural Risk Reduction Capacity (NRRC) of the Toka catchment based on the minimum concentration leachate

Waste emitted minimum leachate conc. (•g/lit)				Toka creek measured, average conc. (•g/lit)				Risk Reduction Capacity (NRRC) of the Toka box decrease ratio and %			
As	Cd	Pb	Zn	As	Cd	Pb	Zn	As	Cd	Pb	Zn
150	100	100	25 000	100	2	30	800	3.0 (66%)	50 (98%)	3.3 (70%)	30 (97%)

The NRRC is a calculated parameter used as a tool:

- to estimate the Maximum Permitted Emission from the sources if only the NRRC works (MPE),
- to estimate the targeted Risk Reduction Efficiency (TRRE) by combined chemical and phytoremediation to reach the MPE.
- to plan the removal of the sources, if target concentration in the Toka river is known (EBQC).

4.2. Defining the Predicted No Effect Environmental Concentration

The PNEC is defined according to the future water-use, considering the requirement of the surface water ecosystem. Ecooxicity data and effect based quality criteria were used for the creation of the target concentration of the Toka-creek water, the outflow of the catchment (http://www.sitespollues.ecologie.gouv.fr BKH, 1995; Swartjes, 1999).

4.2.1. Setting the Effect based Environmental Quality Criteria

Given that the work focussed on the risk of toxic metals on the surface water, the target metal concentration in the Toka creek was set by using effect based water quality criteria given by expert studies on the area, taking into account the different effect based quality criteria in various countries (BKH, 1995; Swartjes, 1999). The set criteria are based on environmental toxicity data. Risk levels and environmental quality objectives in some countries are or will be considered tools in the execution of environmental policy. Due to the scientific deduction methods and the consequences associated with chosen risk levels the comparability of the environmental quality criteria in the various countries is poor (BKH, 1995). The necessity of setting the Effect Based Quality Criteria (EBQC) for the Hungarian demonstration site occurred for three reasons: 1. Lack of Hungarian quality criteria/limit values on surface water. The water quality is regulated and inspected based on standards imposed on the discharge/emission from various industries. 2. Location of the Hungarian demonstration site in the vicinity of the Mátra Natural Reservation classifies the area in the sensitive water usage category, for which reason the minimum EBQC values ($EBQC_{min}$) were generated. 3. Due to the geological setting and former mining activity the background concentration values in some sub-areas are higher. It was taken into consideration.

Table 6. Effect based quality criteria (EBQC) (BKH, 1995; Swartjes, 1999; http://www.sitespollues.ecologie.gouv.fr/).)

Effect based Environmental Quality Criteria	As	Cd	Pb	Zn
Surface Water	•g/l	•g/l	•g/l	•g/l
HU standard for underground water	25	5	10	200
Holland	8.6	0.35	10	6
Canada	50	0.01–0.06	1–7	30
US-EPA	190	1.1	3.2	110
Swedish	0.45	0.045–0.09	0.6–1.2	4.5–9
Danish	4–9	2.5	5.9–9.2	86–110
French	10	5	25	3 000
UK	50		4–20	8–50
$EBQC_{min}$	3	0.3	2	20
$EBQC_{max}$	10	1	10	100

Having the target EBQC of the Toka creek (set by expert studies) and the effect of natural risk reduction (calculated), the maximum permitted emission (MPE) from the diffuse and residual sources in the Toka catchment was calculated, using $NRRE_{min}$ from Table 6.

4.3. Estimation of the Maximum Permitted Emission (MPE)

The Maximum Permitted Emission (MPE) is a calculated key parameter to plan risk reduction. The MPE has been defined function of the Natural Risk Reduction Capacity of the site (NRRC), the Effect Based Quality Criteria and based on the actual emission.

Table 7. Maximum Permitted Emission (MPE) based on minimum and maximum EBQC of Toka creek if only NRRC works

Target EBQC of Toka creek $EBQC_{min}$, $EBQC_{max}$				Natural Risk Reduction Efficiency ($NRRC_{min}$)				Maximum permitted emission if only NRRE works (MPE)			
As	Cd	Pb	Zn	As	Cd	Pb	Zn	As	Cd	Pb	Zn
•g/l	•g/l	•g/l	•g/l					•g/l	•g/l	•g/l	•g/l
3	0.3	2	20	1.5	50	3.4	30	4.5	15	14	600
10	1	10	100	1.5	50	3.4	30	15	50	34	3000

The target emission (MPE) is dependent on the required surface water quality (EBQC) and on the natural risk reduction potential (NRRC) of the site. The scheme of calculating the NRRC and the Maximum Permitted Emission (MPE) of the site based on the max. EBQC for non-sensitive water usage is shown in Figure 4.

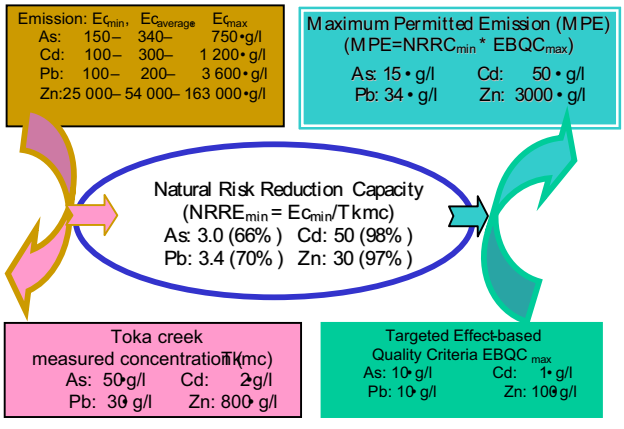

Figure 4. Scheme of calculating NRRE and MPE to reach target $EBQC_{max}$

Legend to Figure 4.
Ec_{min}, $Ec_{average}$, Ec_{max}: Emissions from minimum, average and maximum concentration point and diffuse pollution sources, calculated from the bioleaching microcosm test.
Tkmc: Measured concentration in the Toka creek before removal of point sources.
$NRRC_{min}$: Natural Risk Reduction Capacity of the site based on the minimum emission Ecmin (calculated).
MPE: Maximum Permitted Emission of the site to reach target concentration in the Toka creek if only $NRRC_{min}$ works (calculated).
$EBQC_{max}$: Effect-based Quality Criteria for non sensitive land usage (target concentration in the Toka creek, set by expert studies).

The NRRC alone cannot lower the pollutant load transported from the diffuse and residual pollution sources towards the watershed and cannot fulfill the required Environmental Quality Criteria in the Toka creek. Further decrease of the pollutant flux could be achieved by chemical stabilisation of the pollutants in the diffuse waste and soil, to prevent the transport via runoff and by phytostabilisation to prevent transport through solid erosion.

4.4. Estimation of the Targeted Risk Reduction Efficiency (TRRE)

The risk reduction requirements of the site will be controlled by the Targeted Risk Reduction Efficiency (%), which includes both the efficiency of chemical and phytostabilisation. The targeted Risk Reduction Efficiency (TRRE) of combined chemical + phytoremediation was calculated taking into account the maximum permitted emission (MPE) to reach EBQC and the concentration of the emitted leachate from a maximum concentration source (Table 8). Having a targeted Risk Reduction Efficiency (TRRE) and the efficiency of chemical stabilisation, the required maximum efficiency of phytostabilisation can be estimated. Revegetation will decrease erosion and improve quality of the leachate emitted from the polluted area.

Figure 5. shows the scheme of calculating the Targeted Risk Reduction Efficiency (TRRE) in case of a highly polluted site (maximum emission) complying with the requirement on non-sensitive water usage after remediation ($TEBQC_{max}$).

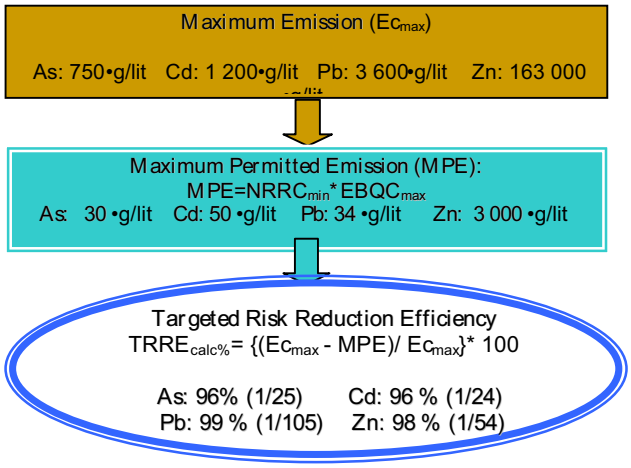

Figure 5. Scheme of calculating the Targeted Risk Reduction scale

Legend to Figure 5.
Ecmax (measured): Emission from maximum concentration point and diffuse pollution sources, based on the bioleaching microcosm test
TRRE: Targeted Risk Reduction Efficiency to reach maximum permitted emission of the sources after removal of point sources (% of the requried concentration reduction to reach
MPE (calculated)
MPE: Maximum Permitted Emission of the sources if only the Natura Risk Reduction Capacity (NRRCmin) calculated with the minimum emission works
EBQCmax: Effect based Quality Criteria set for the Toka creek considering non-sensitive land use

4.5 Estimation of the effect of chemical stabilization based on the chemical stabilisation microcosm experiments

Immobilisation / stabilisation of contaminants in soil was modeled in microcosms to determine the most efficient amendment to be added to the soil (Vangronsveld, 1995; Feigl, 2005).

The contaminated soil from the mining site (Gy) was treated with 1w%, 2w% and 5w% flyash (PA) in microcosms. The efficiency of the stabilisation process was characterised by the mobile metal content of the water- and different acidic extracts of the treated soil (Feigl, 2005). The results of the water extracts are shown in Table 8. and 9. The mobility of the metals decreased during 1 year.

Table 8. Toxic metal concentrations in the water extract of the treated soil after 3 weeks

Treated material	MU	As	Cd	Cu	Pb	Zn
Gyo soil initial	mg/kg	ND	1.00	0.66	ND	171.0
PA flyash	mg/kg	ND	ND	ND	0.09	0.43
GYPA1 theoretical (mixture of soil and 1% flyash)	mg/kg	ND	0.99	0.65	ND	169.26
GYPA2 theoretical (mixture of soil and 2% flyash)	mg/kg	ND	0.98	0.65	ND	167.59
GYPA5 theoretical (mixture of soil and 5% flyash)	mg/kg	ND	0.95	0.63	ND	162.47
GYPA1 measured concentration after treatment	mg/kg	ND	0.34	0.35	ND	39.86
GYPA2 measured concentration after treatment	mg/kg	ND	0.15	0.31	ND	10.91
GYPA5 measured concentration after treatment	mg/kg	ND	0.01	0.41	0.03	0.55
GYPA concentration decrease compared to the theoretical concentration of the mixture (mg/kg)						
GYPA1 theoretical–GYPA1 measured	mg/kg	ND	0.65	0.30	ND	129.43
GYPA2 theoretical–GYPA2 measured	mg/kg	ND	0.83	0.34	ND	156.68
GYPA5 theoretical–GYPA5 measured	mg/kg	ND	0.94	0.22	ND	161.92
GYPA concentration decrease compared to the theoretical concentration of the mixture (%)						
GYPA1 theoretical–GYPA1 measured		ND	66	46	ND	76
GYPA2 theoretical–GYPA2 measured		ND	85	52	ND	99
GYPA5 theoretical–GYPA5 measured		ND	99	36	ND	100

Table 9. Toxic metal concentration decrease in the water extract of the treated soil after 4 month

Treated material	MU	As	Cd	Cu	Pb	Zn
GYPA concentration decrease compared to the theoretical concentration of the mixture (%)						
GYPA 1 theoretical –GYPA 1 measured		ND	90	ND	ND	74
GYPA 2 theoretical –GYPA 2 measured		ND	94	ND	ND	97
GYPA 5 theoretical –GYPA 5 measured		ND	>99	ND	ND	100

The microcosm experiments on chemical stabilisation demonstrated that 2% and 5% fly ash addition to the polluted soil resulted 66 to 100% reduction in the dissolvable Zn and Cd content of the soil after 3 weeks and 94–100% after 4 months.

The effect of chemical stabilisation was calculated for maximum emission values (Figure 6.) based on the efficiencies resulted from the microcosm test.

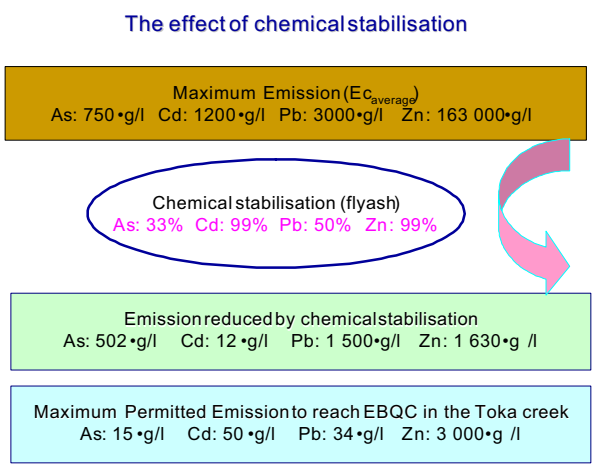

Figure 6. Scheme of estimating the effect of chemical stabilisation

Figure 6. shows that in case of maximum emission (pessimistic approach) from the diffuse and residual pollution sources the effect of chemical stabilisation is enough to reduce mobile metal emission (Cd and Zn) to satisfy the EBQC set for the Toka creek. The estimated 12 •g/l Cd emission is below the Maximum Permitted 50 •g/l Cd emission for non-sensitive water usage (Table 6.) and the estimated Zn = 1 630 •g/l is below the Maximum Permitted 3 000 •g/ Zn Emission set for non-sensitive water usage. Pb and As are still above the targeted MPE values in case of a maximum emission scenario. As and Pb are transported mainly with the solid phase (Auerbach, 2003), so the prevention of solid erosion by phytostabilisation will further reduce the concentration of these two metals in the Toka creek water.

4.6 Estimation of the required emission reduction by phytostabilisation to satisfy the targeted Risk Reduction Efficiency

The Targeted Risk Reduction Efficiency (TRRE) that incorporates the effect of Chemical Stabilsiation plus Phytostabilsation was calculated in paragraph 4.4. The Efficiency of the chemical stabilisation resulted from the microcosm experiment (Paragraph 4.5). Cd and Zn can be stabilised by chemical stabilisation such as to comply with the MPE requirement for nonsensitive water use. Phytostabilisation has to reduce solid transport by erosion from the diffuse pollution sources such as the As and Pb emission is also reduced to the required MPE levels. The required Reduction % by phytostabilisation is shown in Figure 7.

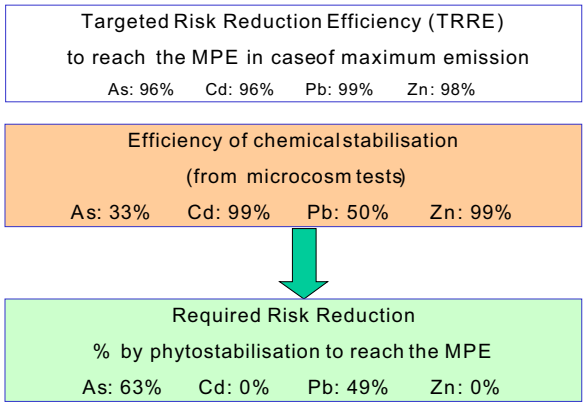

Figure 7. Required Risk reduction % by phytostabilisation

5. CONCLUSIONS

The introduced Quantitative Risk Assessment methodology is tiered, iterative and PEC/PNEC based and can be used also in case of missing data. The methodology fully fits into the generally applicable qualitative and semi-quantitative risk assessment schemes used for preliminary screening of pollution sources. The concept enabled calculation not only of the relative and absolute risk values but also forecasting the results of the selected risk reduction measure. The methodology allows estimation of the effect of the removal of point sources and the emission reduction of diffuse sources, consequently estimation of the target remediation value. The model can be further refined with additional data input, assuming various water uses. The scale can vary from the point through diffuse sources to water catchment or regional scale.

ACKNOWLEDGEMENT

The work was performed with the financial support of the "DIFPOLMINE" EU Life 02 ENV/F000291 Demonstration Project and the "BANYAREM" Hungarian GVOP 3.1.1-2004-05-0261/3.0-R&D Project (http://www.eugris.info/Projects)

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