# Tiered risk assessment of diffuse pollution of mining origin

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**Abstract** The complex risk management of diffuse pollution by mining waste at a former mining site is introduced in this presentation. The risk management methodology is based on an integrated conceptual risk model, a tiered GIS-based risk assessment and on risk reduction by combined chemical- and phytostabilisation.
Risk characterisation includes three levels of assessment:

1. Qualitative risk assessment for initial hazard identification and rough ranking
2. GIS-based Quantitative Hazard (Generic Risk) Assessment for refined ranking and risk characterisation
3. Site specific Risk Assessment

Risk reduction is planned on the basis of the site specific, risk based target value and selected according to the result of laboratory and field experiments.
**Keywords** toxic metals, mine waste, GIS-modelling, risk assessment, soil, chemical and phytostabilisation

## THE SITE

The former Zn and Pb mining area is situated in the Toka-valley, North-East from Budapest, near to the town of Gyöngyös, close to the Mátra Natural Park (Mátra Mountains) in Hungary, where operation of the former Pb, Zn underground mine including relevant infrastructure, flotation plant and tailings dam ceased 20 years ago. The Toka valley has been the subject of many studies done by BME starting with 1991, especially following the major floods that occurred in the area in 1991 and 1996 (Bekõ et al., 1992; Gruiz, 1994; Horváth et al., 1996 and 1997; Auerbach, 2003; Sipter et al., 2005; Gruiz et al., 2005).

Historical mining for gold started in the area already in the Middle Ages and the underground mining of the lead and zinc bearing vein type mineralisation intensified during the last century and was suspended in 1986. The mined base metal ore was milled and processed in the local flotation plant. The flotation tailings were discharged into a tailings dam from 1955. The acid mine water exiting via the main adit was treated and is being treated by lime from 1985, the sludge is settled in 3 storage ponds and the treated water is discharged into the Toka river. Final closure of the mine and remediation of the site has not been carried out yet.

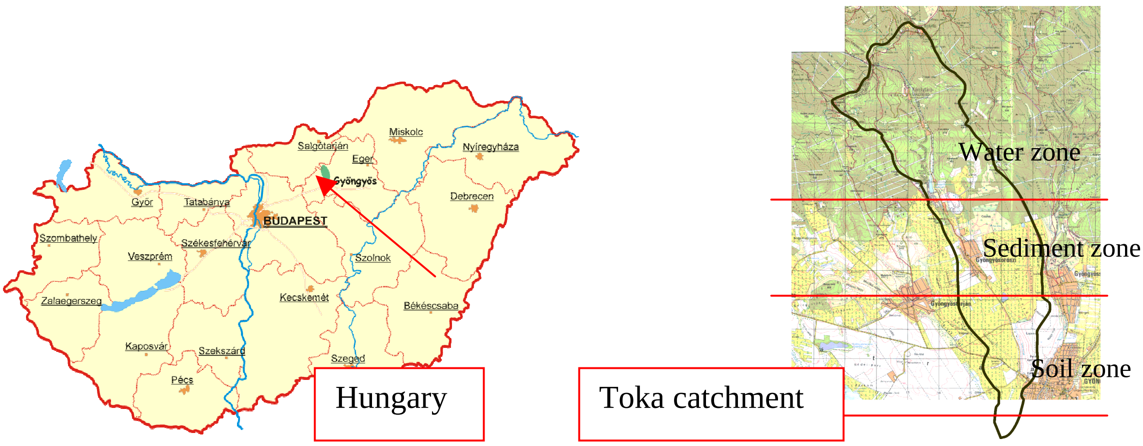


**Figure 1.** The former Pb and Zn mine along the Toka valley, in Northern Hungary

The Toka catchment covers 25 km$^2$ from the emerging springs area (altitude 750 m) to the inflow into the Gyöngyös lake (150 m). The relatively small catchment is much diversified. For the purpose of risk management the Toka catchment was divided in three zones based on topographical, meteorological and environmental characteristics and the type of pollution and land uses.

The Northern catchment ("water zone") of the Toka creek extends on 10 $km^2$ (altitude 750–450 m), starting from the emerging springs area down to the Flotation Tailings Dam. There are springs and many temporary water flows in this area. It is a typical steep mountain area with relatively low temperatures and a lot of precipitation. The average slope is 13 %, the maximum slope is 43 %. The site is close to a natural park, land use is typically natural and recreational.

The middle section of the Toka river course is the "sediment zone". The village of Gyöngyösoroszi is situated at this area. This area overlaps the "soil zone", the lower section of the Toka creek with typical topography for plains covering the hobby garden area, where the pollution of soil by floods is the most risky process. This area continues along a narrow line down to the inflow of the creek into the Gyöngyös lake. Land use is residential and agricultural.

The pollution sources are of several categories: underground mine wastes, flotation tailings and lime precipitate from mine-water treatment. The secondary sources are: sediments of reservoirs (originating from flotation tailings, lime precipitate, eroded rocks and ores), and contaminated soil. Most of the mine waste is dumped in the water zone and is transported by runoff water. A typical situation is shown in Figure 3. The recipient of the polluted runoff is the Toka creek itself as the outflow of the water zone. This is shown in the conceptual model of the water zone, Figure 4.

The toxic metals Cd, Zn, Cu, Pb, As cause the pollution. The Cd and Zn exist mainly in dissolved and ionic form contaminating surface waters, leachates, sediments and soils, while Pb and As are dominantly bound to solid phase elements, like soil and sediment. The Gyöngyösoroszi site is sensitive to the pH, because of the sulphide-content of the rock and the dominant biological acidification. Table 1. shows the contamination of the water of the Toka creek at the upper catchment and at the outflow point from the water zone (ELTE, 1991; Bekõ et al., 1992; Gruiz et al., 2005). The metal content of the Toka water depends on meteorological and climatic parameters, it is changing in a wide range. Table 2. shows the metal content of a regularly flooded garden soil. A clear decreasing gradient can be measured with the growing distance. This fact serves as evidence on the origin of the pollution: Toka creek sediment and the floods.

**Table 1.** Toxic metal content and pH of the Toka creek water

| Location<br>Year<br>Metal | MU | Upper Toka creek 2004 | Toka creek: border of the water zone | | | | |
|---|---|---|---|---|---|---|---|
| | | | 1991 | 1992 | 2004 | 2005 | Weighted average for calculations |
| As | • g/lit | 2.9 | 10 | nd | 2–112 | 7–50 | 50 |
| Cd | • g/lit | 0.5 | 30–50 | 5–16 | 1–5 | 0.5–4 | 2 |
| Cu | • g/lit | 50.0 | 20–40 | nd | 3–90 | nd | – |
| Pb | • g/lit | 28.0 | 30 | 6–55 | 1–120 | 4–105 | 30 |
| Zn | • g/lit | 1 620 | 9000–14 000 | 500–6000 | 100–1600 | 300–1650 | 800 |
| pH | – | 4.4 | 2.0–5.0 | 2.6–5.0 | 5.0 | 5.0 | |

**Table 2.** Metal content of a flooded hobby garden soil (Gruiz and Vodicska, 1992)

| Soil | Distance from Toka | As mg/kg | Cd mg/kg | Cu mg/kg | Pb mg/kg | Zn mg/kg |
|---|---|---|---|---|---|---|
| Hobby garden | 5 m | 110 | 7.5 | 210 | 462 | 1685 |
| Hobby garden | 15 m | 63 | 1.0 | 127 | 248 | 998 |
| Hobby garden | 30 m | 31 | 0.6 | 200 | 120 | 520 |
| Hobby garden | 50 m | – | 0.6 | 131 | 63 | 208 |

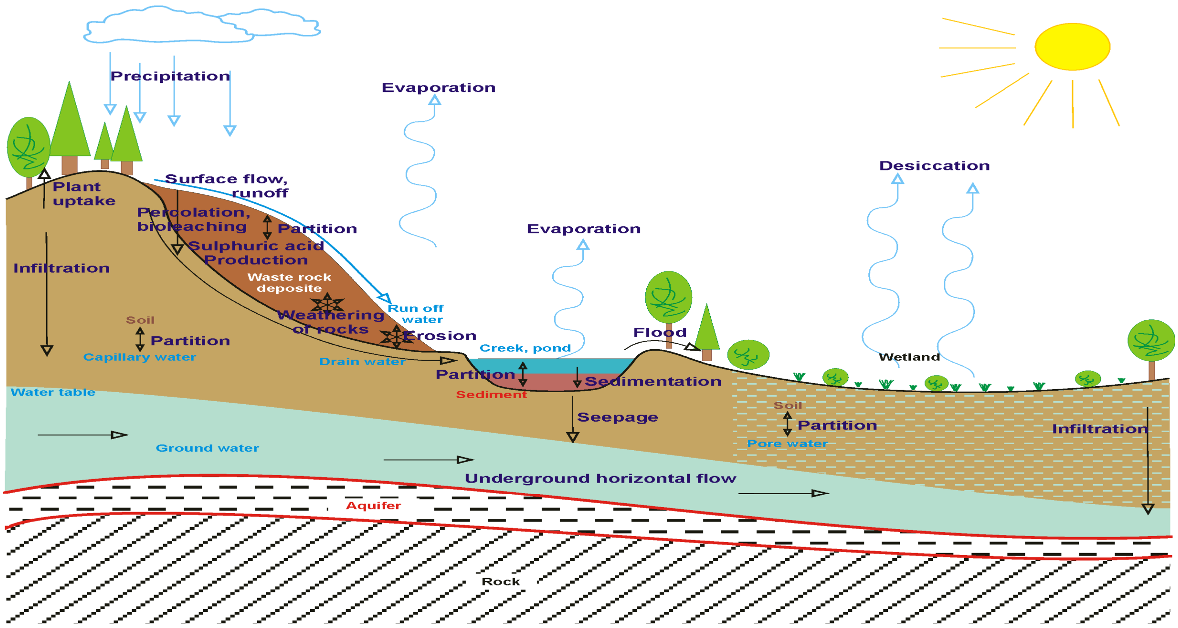


**Figure 2.** Typical situation at the catchment area: mining waste disposal and transport routes

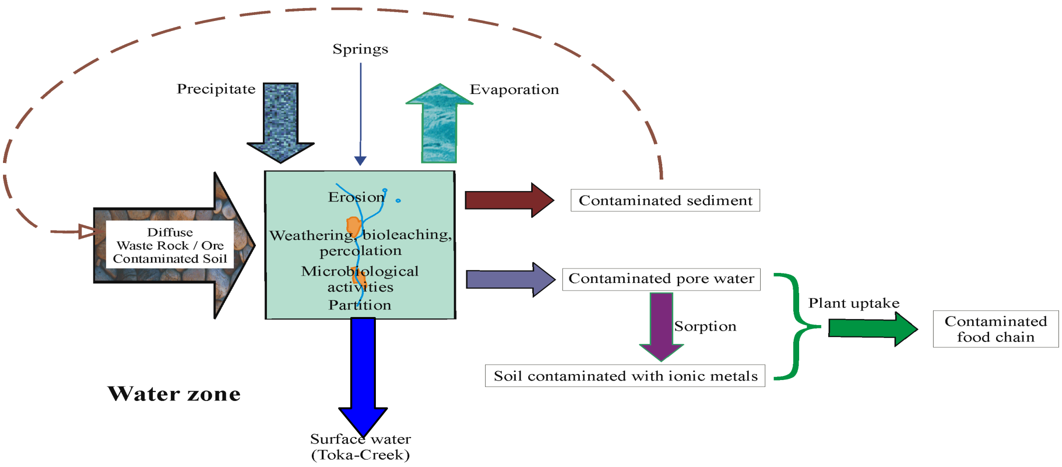


**Figure 3.** Conceptual risk model of the watershed

The site specific conceptual model was created after complete survey of the site. The main water and pollutant forms are shown in the conceptual model of the Northern catchment, the water zone, where the water is the main transport-medium.

## METHODOLOGY AND CONCEPT

The complex risk management of diffuse pollution by mining waste at a former mining site is introduced in this presentation. The risk management methodology is based on an integrated conceptual risk model, a tiered GIS-based risk assessment and on risk reduction by combined chemical- and phytostabilisation (Vangronsveld et al., 1995).
Risk characterisation includes three levels of assessment:

- Qualitative risk assessment for initial hazard identification and rough ranking
- GIS-based Quantitative Hazard (Generic Risk) Assessment for refined ranking and risk characterisation
- Site specific Risk Assessment

Risk reduction is planned on the basis of the site specific, risk based target value and selected after the result of laboratory and field experiments.

The conceptual model (Pottecher et al., 2002) of the water transport was created on the basis of hydrogeological and meteorological data and own assessments. The GIS flow accumulation model was derived from the digital terrain model and was calibrated by the water mass balance of the catchment. For pollution mapping and the delineation of the point and diffuse sources historical data, *in situ* XRF measurements and laboratory analytical data were used. Some transport parameters, like the scale of metal leaching from mine waste and the partition of the pollutants were determined in microcosm tests. The risk reduction effect of immobilising agents was also measured in soil microcosms. The stabilisation microcosm tests were followed by chemical analytical and biological (toxicological) methods, to get direct evidence on risk reduction.

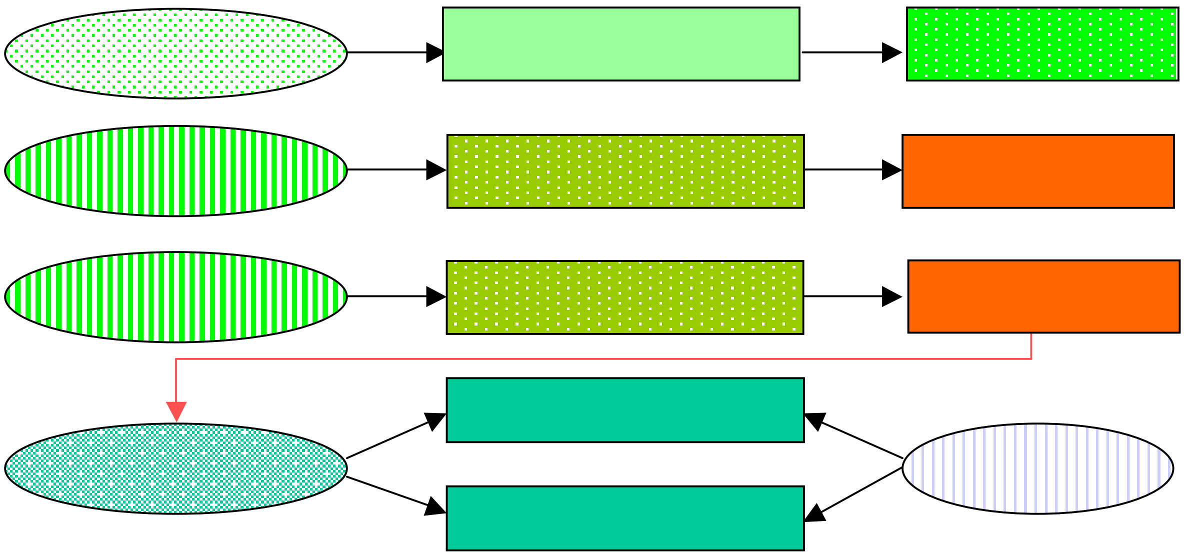

**Figure 4.** Scheme of the Risk Assessment and Risk Reduction methodology

Both the qualitative and the quantitative risk assessments are site specific and based on the integrated risk model, which integrates the transport and the exposure model (Figure 5.) of the site, identifying the pollutant transport pathways from the source and the exposure of the receptors relevant to land uses. The width of the arrows is proportional with the transported pollutant.

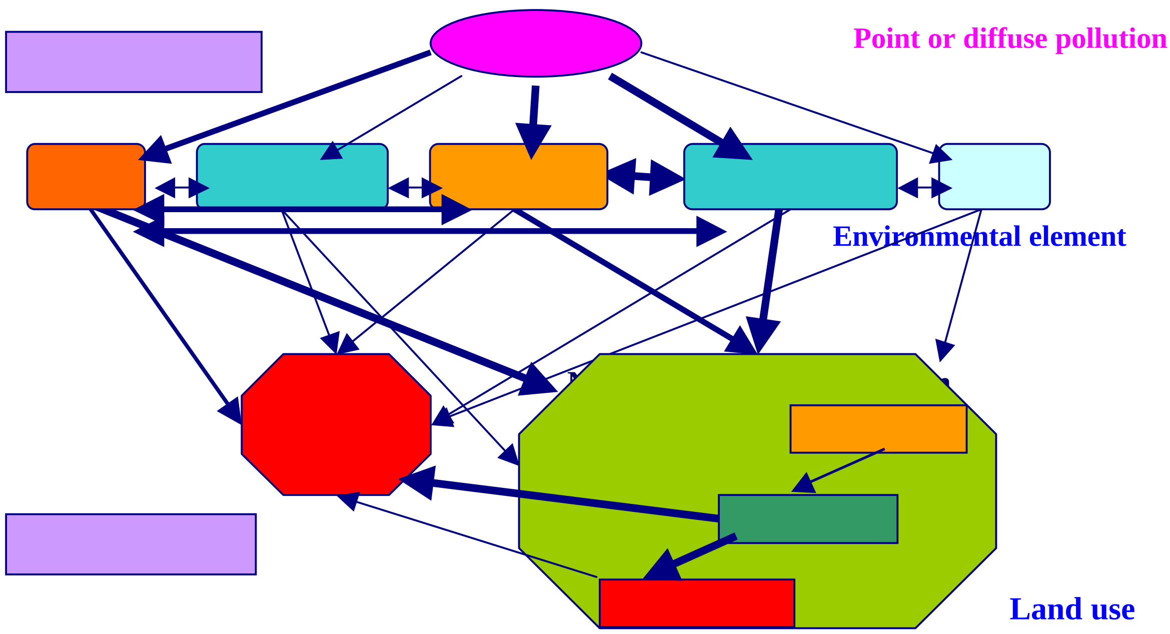


**Figure 5**. The integrated risk model of the Toka catchment

***Qualitative Risk Assessment*** was based on a site-specific score system, resulting in a relative risk value used for priority setting and preliminary ranking of pollution sources, including waste dumps and diffuse sources. The risk score is calculated from the input data of a questionnaire. The score is summarised from three sub-scores given to the source (max. 33 points), the transport routes (max. 33 points) and the receptors (max. 33 points). The evaluation is based on quantitative categories: waste mass, contaminant content, soil characteristics, etc. Evaluation proceeds on two alternative ways: if the pollution and its consequences are proven, the risk score is maximal, if not, the detailed site specific assessment is prepared. The scores between 0 and 100 indicate three risk categories: 70–100: removal or complete isolation of point sources; 50–70: *in situ* remediation of the point or diffuse sources by combined chemical- and phytostabilisation; under 50: revegetation.

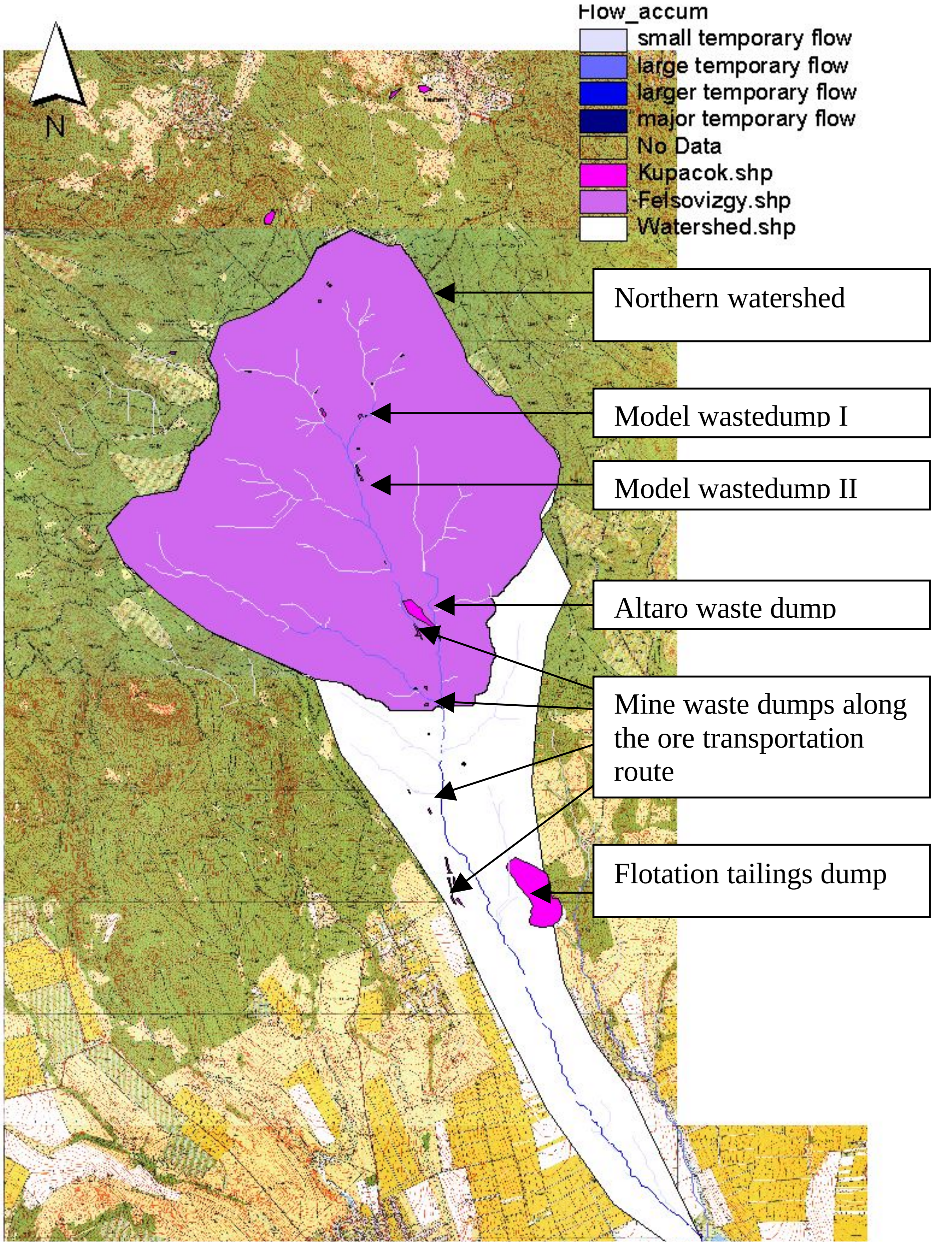


**Figure 6.** GIS based flow accumulation: temporary creeks in the Toka watershed

***The Quantitative Hazard Assessment*** of point and diffuse sources was done by the GIS-based calculation of the metal emission from disposal sites of various size, sub-areas of diffuse sources and the total catchment area. The quantitative emission data for sub-sites or any selected area were used for more precise ranking, for differentiation between point and diffuse sources and also for the estimation of the metal load on the watershed. The GIS based emission was calculated from the accumulated flow of rain water, which includes the rain water coming directly on the surface of a certain area and the subsurface runoff running through the same area. From the water emission of these smaller or larger catchments of the water zone the metal amount leached out and transported from the pollution source is calculated on the basis of the results of leaching experiments. At the end, the metal emission of each source is obtained and used for ranking and decision making on the best intervention.

The transport is followed on the topographic map with the help of the GIS-based Flow Accumulation and Transport model shown on Figure 6. The flow accumulation model shows the relative flow rate of the catchment, the colour of the water flows depends on the flow rate, symbolized on the map by gradually deeper blue colour.

For the ***Quantitative Risk Assessment*** the GIS-based transport model was calibrated with the water-balance of the catchment (Figure 7.), which was prepared using ecological, hydrogeological and meteorological data (Heinrich and Hergt, 1995; OMSZ, 2002).

Other pollution transport pathway features, like the efficiency of bioleaching, partition of metals between water and solid phase of the soil, the natural risk reduction efficiency of the site, were calculated using model-parameters, based on microcosm experiments or field-measurements.

| **In-coming water** | **Type of incom-ing water** | **% of total incoming** | **Amount of incoming water type** | **Water form and components** |
|---|---|---|---|---|
| | Precipitation | 100% | 20 712 $m^3$/ day/10 $km^2$ | Rain, snow |
| | Infiltrated water | 42% | 8 972 $m^3$/ day/10 $km^2$ | Pore water, soil moisture |
| | Subsurface runoff | 16% | 3 248 $m^3$/ day/10 $km^2$ | Runoff water |
| | Surface runoff | 16% | 3 241 $m^3$/ day/10 $km^2$ | Runoff water |
| | Water in biomass | 4% | 767 $m^3$/ day/10 $km^2$ | Plant water |
| | Vapour | 10% | 2 451 $m^3$/ day/10 $km^2$ | Evapo transpiration |
| | Outflow from the water zone | 12% | 2 451 $m^3$/ day/10 $km^2$ | Toka creek |
| **TOTAL** | | 100% | 20 718 $m^3$/ day/10 $km^2$ | |

**Figure 7.** Water Balance in the Northern catchment of the Toka creek

The quantitative risk of the ecosystem is characterised by the Risk Quotient (RQ), the ratio of the Predicted Environmental Concentration (PEC) and the Predicted No Effect Concentration (PNEC). The RQ value is calculated stepwise, iteratively, starting with a minimal data-set, using conservative (pessimistic) estimation. This enables the exclusion of the negative cases if highly justified.

The endpoint of the emitted toxic metals transport is the Toka creek. The necessary risk reduction scale is planned based on the target water quality of the creek and the targeted reduced emission of the point sources and the diffusely polluted area. To set the necessary emission control the efficiency of chemical stabilisation and phytostabilisation is taken into consideration.

After having the targeted emission of the sources, the technology for the reduction of the emission from the sources can be selected, considering remediation efficiency and costs.

## RESULTS

***Target of the research*** was to work out a risk based management concept, which substantiates a risk based remediation approach for both of point and diffuse sources. The catchment scale Environmental Risk Management methodology focuses on the risk of the pollutants posed on the surface water.

***Steps of the work*** were 1. Creating the integrated risk model (Figures 3, 4, 5) for the catchment with the pollution sources, the transport routes, the land-use specific exposure routes and the receptors. 2. Preparation of the GIS-based inventory of pollution sources on the basis of historical documents and site assessment. 3. Application of the developed tiered site-specific risk assessment methodology on catchment scale for priority setting, for differentiation between point and diffuse/remaining sources. 4. Calculation of the scale of the necessary risk reduction using the site specific target value and the Natural Risk reduction Efficiency of the site.

In the following we show some of the results of GIS-based pollution mapping, the tiers of the risk assessment, the microcosm tests and the use of these data for the calculation of the NRRE and for the planning of the Risk Reduction measure and its scale

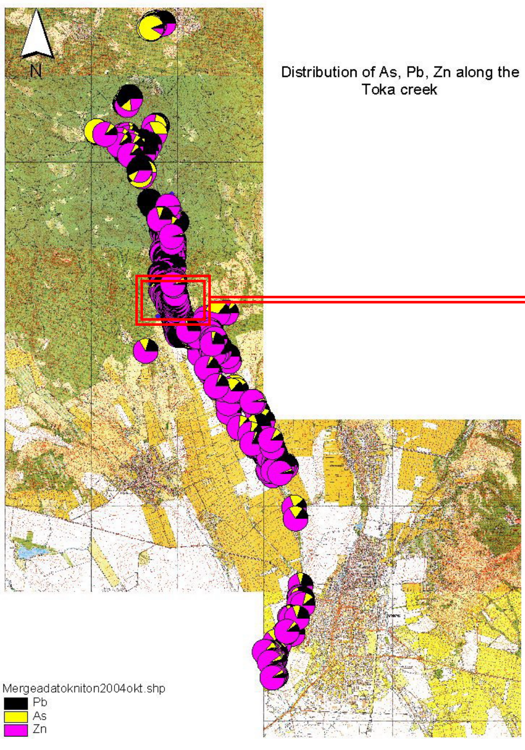


**Figure 8.** Distribution of As, Pb, Zn in soil along the Toka creek. General view

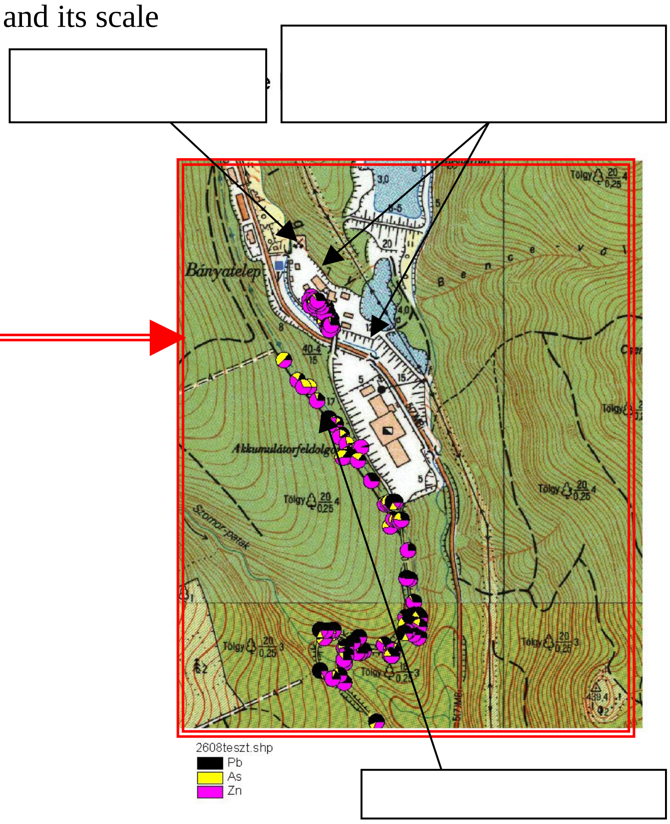


**Figure 9.** Distribution of As, Pb, Zn. Detailed view of Northern catchment

The GIS based pollution maps (Figure 8. and 9.) showed some trends: the distribution map (relative percentage) of As, Pb, and Zn shows that upstream of the adit arsenic is dominant, close to the adit and on the transportation line Pb is much higher, than before and going to South from original sources the relative amount of the most mobile Zn is higher and higher.

After the assessment of the pollution, identification and delineation and the waste sources the preliminary ranking was prepared, as you can see in Table 3.

**Table 3**. Inventory and risk score of the pollution sources and the tonnage of the waste material

| Pollution source | Risk score | Tons | Runoff $m^3$ | Recommendation |
|---|---|---|---|---|
| Tailing dump, flotation tailings | 99 | 4 000 000 | 184 000 | complete isolation |
| 14 sites along the ore transportation route | 92 | 30 000 | 16 500 | to remove |
| Altáró waste dump, mine waste | 84,5 | 1 100 000 | 11 880 | in situ remediation |
| Model waste dump II, mine waste | 81,5 | 16 000 | 3 324 | to remove |
| Új Károly-gallery, model waste I. | 79,5 | 8 000 | 1 160 | to remove |
| Új Károly-gallery, mine waste | 79,5 | 800 | | to remove |
| Péter-Pál shaft, mine waste | 75,5 | 16 100 | 2 640 | to remove |
| Katalin gallery, mine waste | 73,5 | 5 000 | 62 500 | to remove |
| 14 different diffuse waste dumps | 55–70 | 10 000 | 43 000 | in situ remediation |
| 15 different diffuse waste dumps | >50 | 10 000 | 35 000 | revegetation |

Legend: mine waste, sediment, lime precipitate, various wastes diffuse pollution for remediation, diffuse pollution

A refined ranking was done after hazard assessment, based on the emitted amount of metal from the point and diffuse waste sources. To estimate the metal content of the leachates the complex leaching process was studied in long term (three years) laboratory microcosm experiments, simulating the weathering and leaching of the mine waste material, disposed in the water zone of the Toka catchment. The leaching parameters were used for the model calculations in the quantitative hazard and risk assessment.

**Table 4.** Total metal concentration of typical mine wastes and their leachate from the microcosms

| Metals | Total metal* (minimum) mg/kg | Minimum emission • g/lit | Total metal* (medium) mg/kg | Average emission • g/lit | Total metal* (maximum) mg/kg | Maximum emission • g/lit |
|---|---|---|---|---|---|---|
| As | 44 | 150 | 100 | 340 | 216 | 700 |
| Cd | 1 | 100 | 3 | 300 | 12 | 1 200 |
| Cu | 25 | 400 | 50 | 800 | 107 | 4 710 |
| Pb | 295 | 100 | 600 | 203 | 13 100 | 3 600 |
| Zn | 370 | 25 000 | 800 | 54 135 | 2 155 | 163 000 |

*Aqua regia extract, ICP MS)

After calculating the emission of the documented sources hazard assessment and the refined ranking was prepared. The summarised results are shown in Table 5.

**Table 5.** Summary report on point and diffuse sources and their min. and max. metal emission

| Sources | | Sum of 15 point sources | 15 diffuse to remediate | 14 diffuse to revegetate | Diffuse residual from removed point |
|---|---|---|---|---|---|
| Surface area ($m^2$) | | 192 000 | 5 000 | 19 000 | 68 000 |
| Watershed area ($m^2$) | | 664 000 | 160 000 | 180 000 | 622 000 |
| Runoff from precipitation ($m^3/y$) | | 63 000 | 1 600 | 6 300 | 22 000 |
| Runoff from indirect flow ($m^3/y$) | | 216 000 | 52 000 | 58 680 | 203 000 |
| Emitted metal with precipitation (kg) | As | 21–44 | 0.5–1 | 2–4 | 7–15 |
| | Cd | 19–76 | 0.5–2 | 2–8 | 7–26 |
| | Cu | 50–297 | 1–7 | 5–30 | 18–103 |
| | Pb | 13–227 | 0.3–6 | 1–23 | 4–79 |
| | Zn | 3 411–10 269 | 87–260 | 340–1 027 | 1 190–3 586 |
| Emitted metal with indirect flow (kg) | As | 37–80 | 9–19 | 10–22 | 35–75 |
| | Cd | 32–130 | 8–31 | 9–35 | 30–122 |
| | Cu | 86–510 | 21–122 | 23–138 | 81–479 |
| | Pb | 22–387 | 5–93 | 6–105 | 20–313 |
| | Zn | 5 847–17 662 | 1 407–4 252 | 1 588–4 798 | 5 495–16 579 |

The emitted metal amount was calculated based on the GIS Transport Model, using the runoff volume resulted from the sum of the direct and indirect rain (runoff from the surface and runoff through the mine waste dump.) and on the concentration of the leachate, measured in the microcosm test (Gruiz et al, 2005; Gruiz et al, 2006). It is a range between the estimated minimum and maximum emissions based on the minimum and maximum pollution of the wastes in the group.
***Assessment of the Quantitative Risk:*** the PEC is calculated from the GIS based Flow Accumulation Model, the PNEC from the land-use dependent target concentration. As the leachate from the sources does not reach the Toka creek directly, the Natural Risk Reduction Efficiency (NRRE) of the Toka-box, the area between the source and the Toka water plays a risk reducing role by immobilising (sorption, chemical modification, etc) the water soluble metals. We calculated the NRRE for the catchment and applied it in the Risk Assessment and Risk Reduction estimations. For conservative estimations of NRRE, the minimum emitted metal concentration was used.

**Table 6.** Calculation of the NRRE of the Toka box based on the minimum concentration leachate

| Waste dumps emitted minimum leachate concentration | | | | Toka creek (weighted average concentration in water) | | | | Risk Reduction Efficiency (NRRE) of the Toka box | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| As | Cd | Pb | Zn | As | Cd | Pb | Zn | As | Cd | Pb | Zn |
| • g/lit | • g/lit | • g/lit | • g/lit | • g/lit | • g/lit | • g/lit | • g/lit | | | | |
| 150 | 100 | 100 | 25 000 | 100 | 2 | 30 | 800 | **3.0 (66%)** | **50 (98%)** | **3.3 (70%)** | **30 (97%)** |

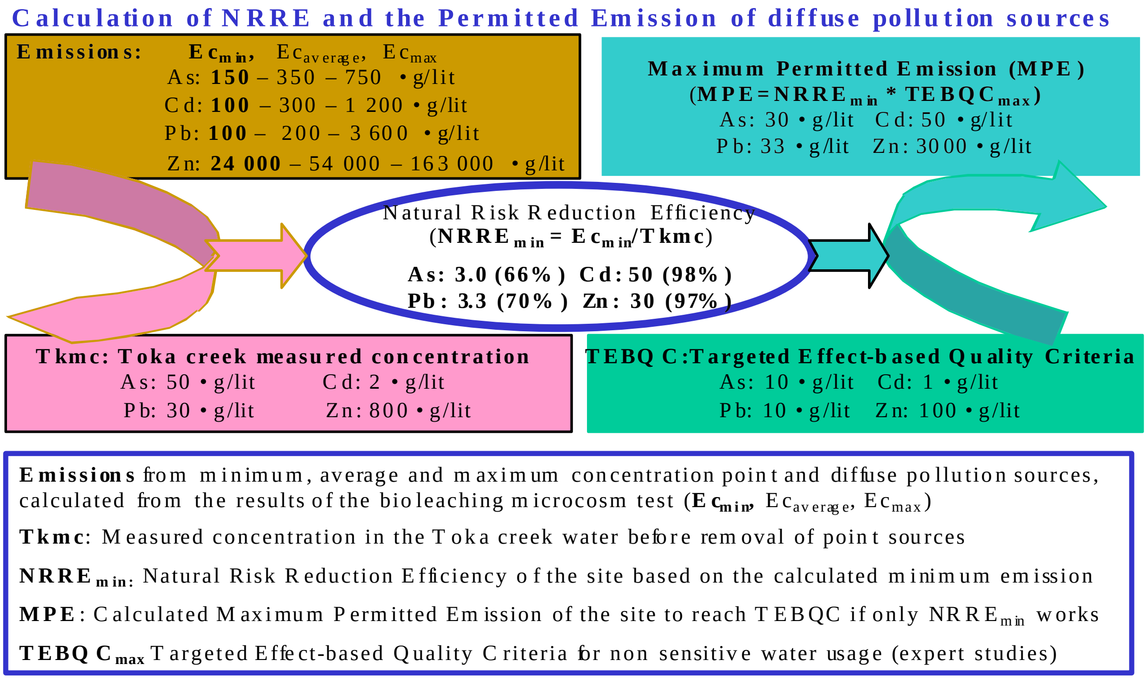


**Figure 10.** Scheme of the calculation of the NRRE and its use for the determination of the Maximum Permitted Emission from the pollution sources

If only NREE works for the lowering of the risk, the MPE cannot be reached: As:150 instead of 30, Cd: 100 instead of 50 Pb: 100 instead of 33 and Zn: 25 000 instead of 3 000 • g/lit (Table 4.) Calculating the same for a more sensitive surface water use (Table 7. second row) the Maximum Permitted Emission from the residual sources is much lower, and NREE alone cannot solve the problem.

Knowing the target EBQC of the Toka creek set by expert studies (BKH, 1995; Swartjes, 1999) 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 the $NRRE_{min}$ based on the minimum emitted metal concentration from Table 7. and Figure 10.

**Table 7.** Maximum Permitted Emission (MPE) in case of sensitive and less sensitive EBQC

| **Target EBQC of Toka creek** Sensitive / less sensitive water use | | | | Natural Risk Reduction Efficiency of the Toka box ($NRRE_{min}$) | | | | Maximum permitted emission from sources if only NRRE works | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| As | Cd | Pb | Zn | As | Cd | Pb | Zn | As | Cd | Pb | Zn |
| • g/lit | • g/lit | • g/lit | • g/lit | | | | | • g/lit | • g/lit | • g/lit | • g/lit |
| **3.0** | **0.3** | **2.0** | **20** | 3.0 | 50 | 3.3 | 30 | **9.0** | **15** | **6.6** | **600** |
| **10** | **1.0** | **10** | **100** | 3.0 | 50 | 3.3 | 30 | **30** | **50** | **33** | **3000** |

The permitted emission values will be used as target concentrations for diffuse site remediation. The target emission (MPE) is dependent on the predicted surface water quality (TEBQC) and on the natural risk reduction potential (NRRE) of the site. The scheme of calculating the NRRE and the Maximum Permitted Emission (MPE) of the site based on the maximum TEBQC is shown in Figure 10. NRRE alone cannot lower the transport from the diffuse and residual pollution sources towards the watershed and fulfil the required Target Quality Criteria in the Toka creek.

How could further decrease in the risk be reached? We have three complementary possibilities: 1. the NRRE, 2. the chemical stabilisation of the pollutants in the diffuse waste and soil, to prevent the transport with runoff and 3. phytostabilisation to prevent transport with solid erosion.

We tested the efficiency of several chemical stabilisers in microcosm tests. 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). We show the results of the water extracts in Table 8. The mobility of the metals had decreased further, for 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 |

ND: not detectable

**Table 9.** Toxic metal concentrations 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 (%) | | | | | | |
| GYPA1 theoretical -GYPA1 measured | | ND | 90 | ND | ND | 74 |
| GYPA2 theoretical –GYPA2 measured | | ND | 94 | ND | ND | 97 |
| GYPA5 theoretical –GYPA5 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 average emission values (Figure 11.) based on the efficiencies resulted from the microcosm test. The scheme of estimating the effect of chemical stabilisation applied to an area with average emission is shown in Figure 11.

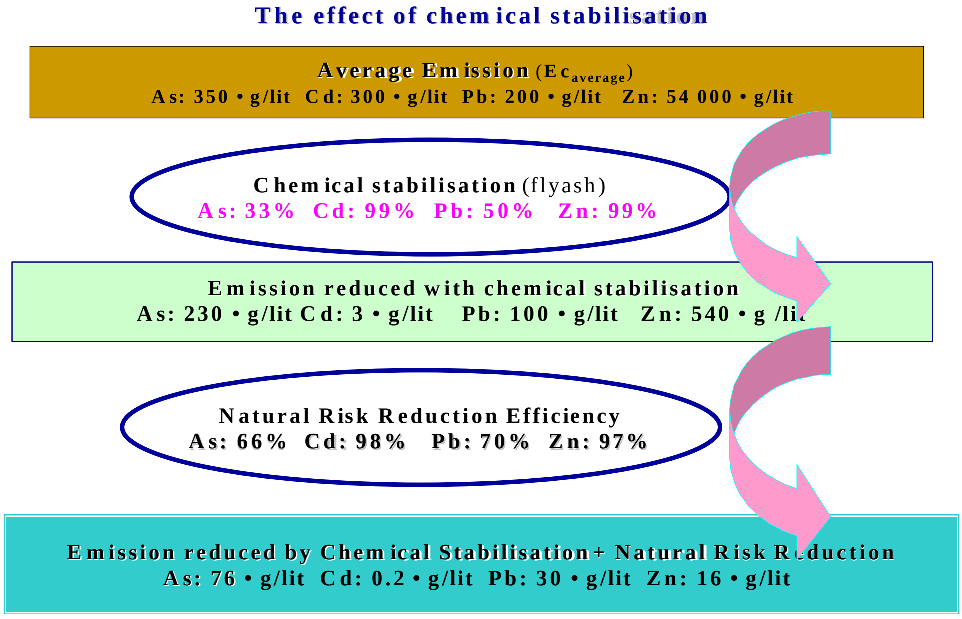


**Figure 11.** Risk reduction of diffuse pollution by Chemical Stabilisation

From the data of Figure 11. we can see, that Chemical Stabilisation of the diffuse and residual sources is able to reduce mobile metal (Cd and Zn) transport into the Toka creek. The estimated concentration in the Toka water –as a result of the treatment of diffuse pollution –is much lower, than the target concentration in case of sensitive water use (EBQC in Table 7.). Pb reduction fulfils the requirement of the “less sensitive” scenario, As is twice as much as the requirement. As and Pb are transported mainly with the solid phase, so the prevention of solid erosion by phytostabilisation will reduce the concentration of these two metals to the 1/10 based on our estimation.

## SUMMARY

A tiered Risk Assessment methodology was established to assess the environmental risk of diffuse pollution at catchment scale. We developed a qualitative method, with site specific risk score for initial ranking of the sources. The Quantitative Hazard Assessment methodology is based on a GIS transport model, using the GIS pollution map and the GIS flow accumulation model. Every diffuse and residual source is treated as a mini-watershed. The emitted water and the emitted metal amount is calculated. The metal emission of the sources is the basis of the Quantitative Hazard Assessment and the final ranking of the sources. The same approach is applied for the whole catchment or any sub-area of the catchment.

Instead of the complete transport modelling we used the Toka-box approach, where the emission from all sources was compared to the actual quality of the Toka creek, the outflow of the catchment. The reduction in the metal content is due to the so-called Natural Risk Reduction Efficiency (NRRE) of the catchment. This parameter was used for all of the calculation, independent of the length of the transport routes. With the help of the NRRE the target concentration in the Toka creeek water and the emission of the diffuse sources get into direct relation. The NRRE helps the planning of Risk Reduction by mitigating the emission from the sources.

The GIS based Quantitative Risk Assessment enables the calculation of the expected result of the risk reduction measure, the effects of the removal or non- removal of any point or diffuse source and the necessary reduction of the pollutant concentration relevant to the target risk value.

After removal of point sources and mitigation of emission from the residual pollution sources the actual toxic metal concentration in the Toka creek could be reduced by the calculated efficiency of the "risk reduction box" and the remediation measures, as chemical and phytostabilisation.

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