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Environmental Risk Management of diffuse pollution of mining origin

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MOKKA context

http://mokkka.hu

ENVIRONMENTAL RISK MANAGEMENT

ENVIRONMENTAL RISK MANAGEMENT OF CONTAMINATED SITES

ENVIRONMENTAL RISK MANAGEMENT OF CONTAMINATED MINING SITES

ENVIRONMENTAL RISK MANAGEMENT OF DIFFUSE POLLUTION FROM MINING

Risk Assessment → **Risk reduction**

DIFFUSE POLLUTION

Definition: non-point source pollution arising from various dispersed, often individually minor point sources.

Characteristics of diffuse sources of pollution

- individually minor, but collectively significant
- cannot be managed as point sources
- difficult or impossible to monitor at the point of origin
- high surface/volume ratio
- the extent and significance relates to:
  - climatic and geographical conditions
- Risk Reduction by in situ treatment

Approach:

- catchment or regional scale, GIS (Geographical Information System) based

DIFFUSE POLLUTION FROM MINING

Typical diffuse pollution from mining

acid mine drainage,
acid rock drainage from mine waste dumps,
wind and runoff water transported solid waste
polluted sediment
polluted soil etc.

OBJECTIVE

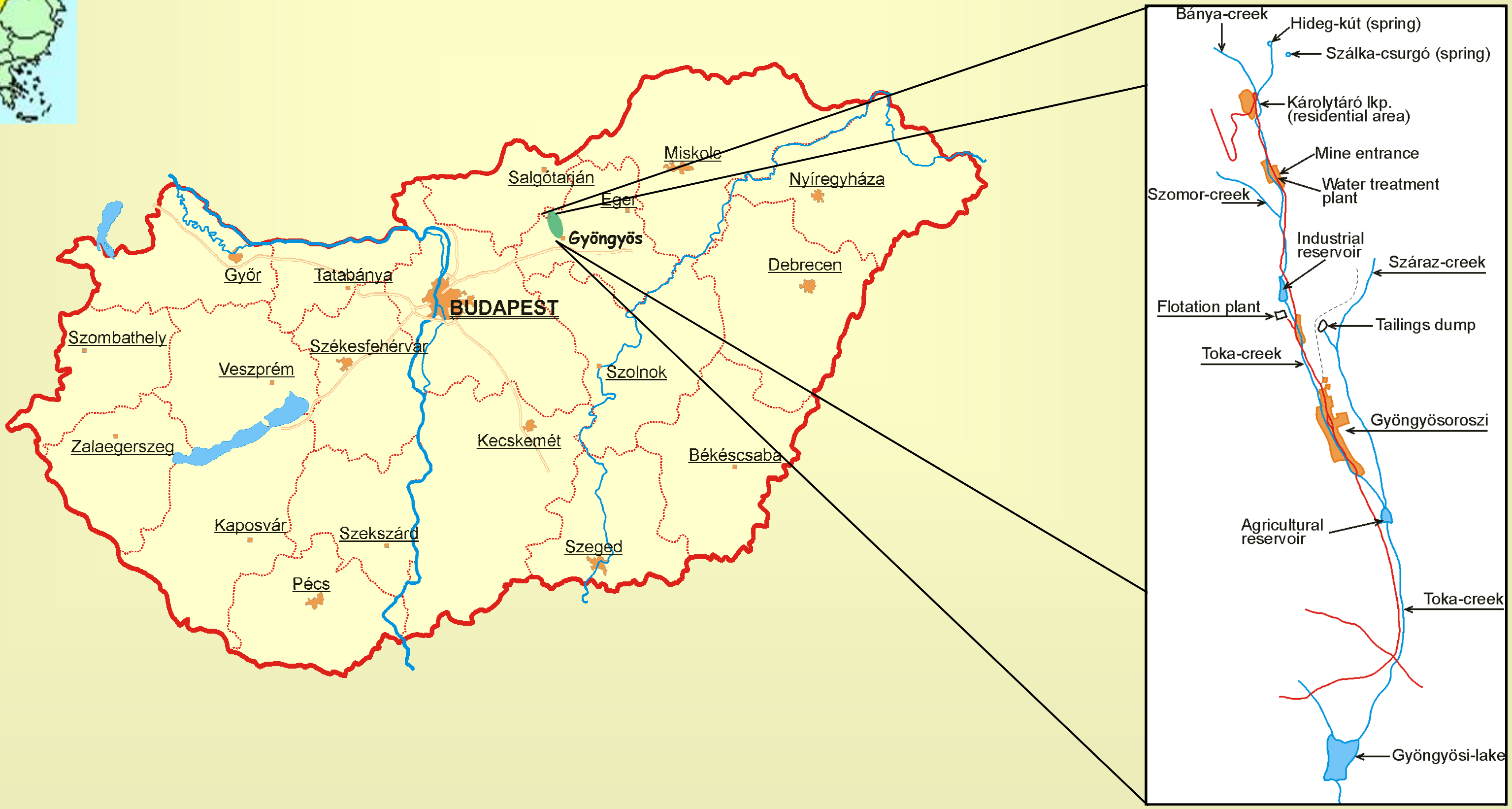
To develop

a GIS (Geographical Information System) based Environmental Risk Management (ERM) methodology in support of risk based remediation of diffuse pollution sources originating from mining

LOCATION OF THE STUDIED SITE

Northern Toka catchment area: 10 km^2

Total Toka catchment area: 25 km^2



SITE DESCRIPTION (1)

STATUS:	Mining ceased in 1985, mine closure and remediation started in 2005
POLLUTION SOURCES:	Pyrite (FeS_2) containing point and diffuse (mine waste dumps)
POLLUTANTS:	As, Cd, Cu, Pb, Zn, from exploited base metal sulphide ore veins of hydrothermal origin
HOST ROCK:	Pyroxene andesites of Miocene age
TYPICAL PROCESSES:	Erosion, weathering, acidification, mobilisation of metals, leaching, partition and infiltration

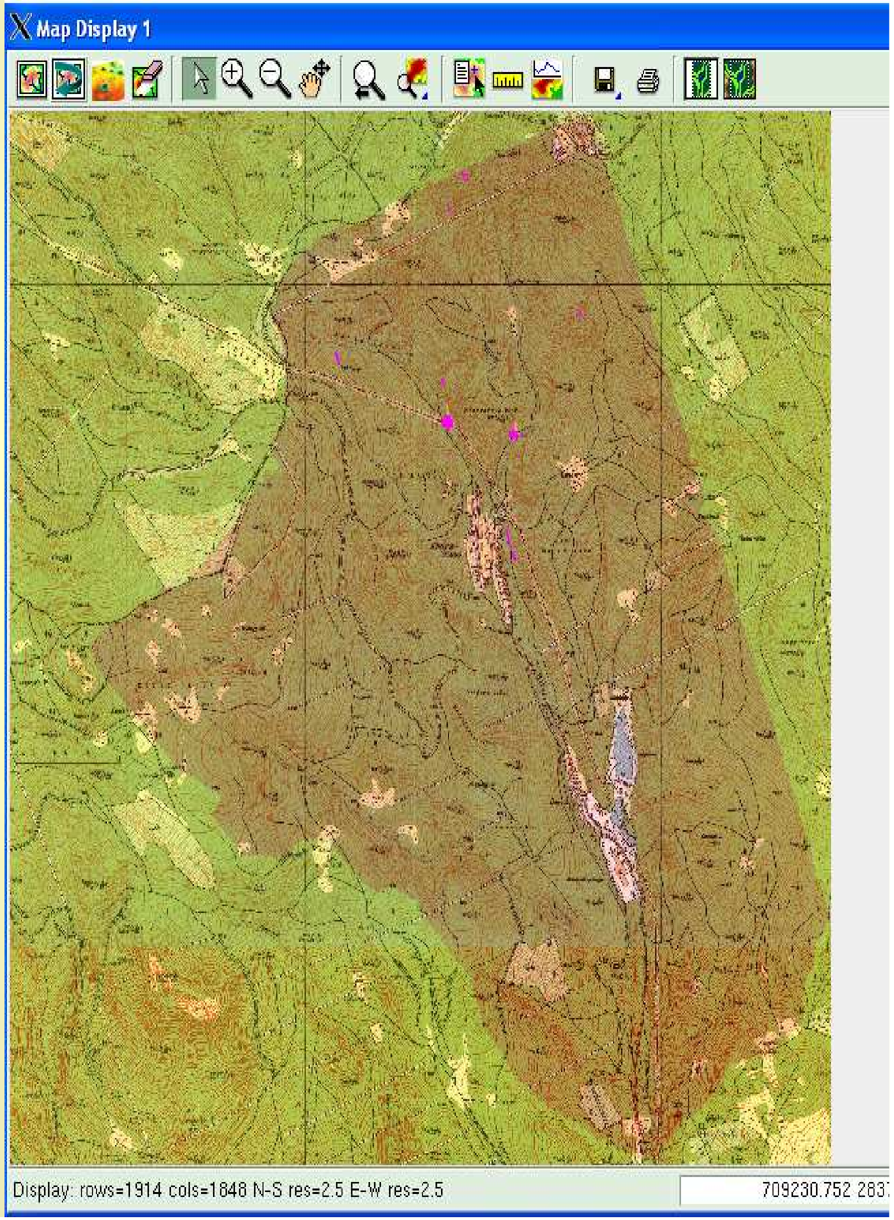
SITE DESCRIPTION (2)

STUDIED AREA: 10 km^2

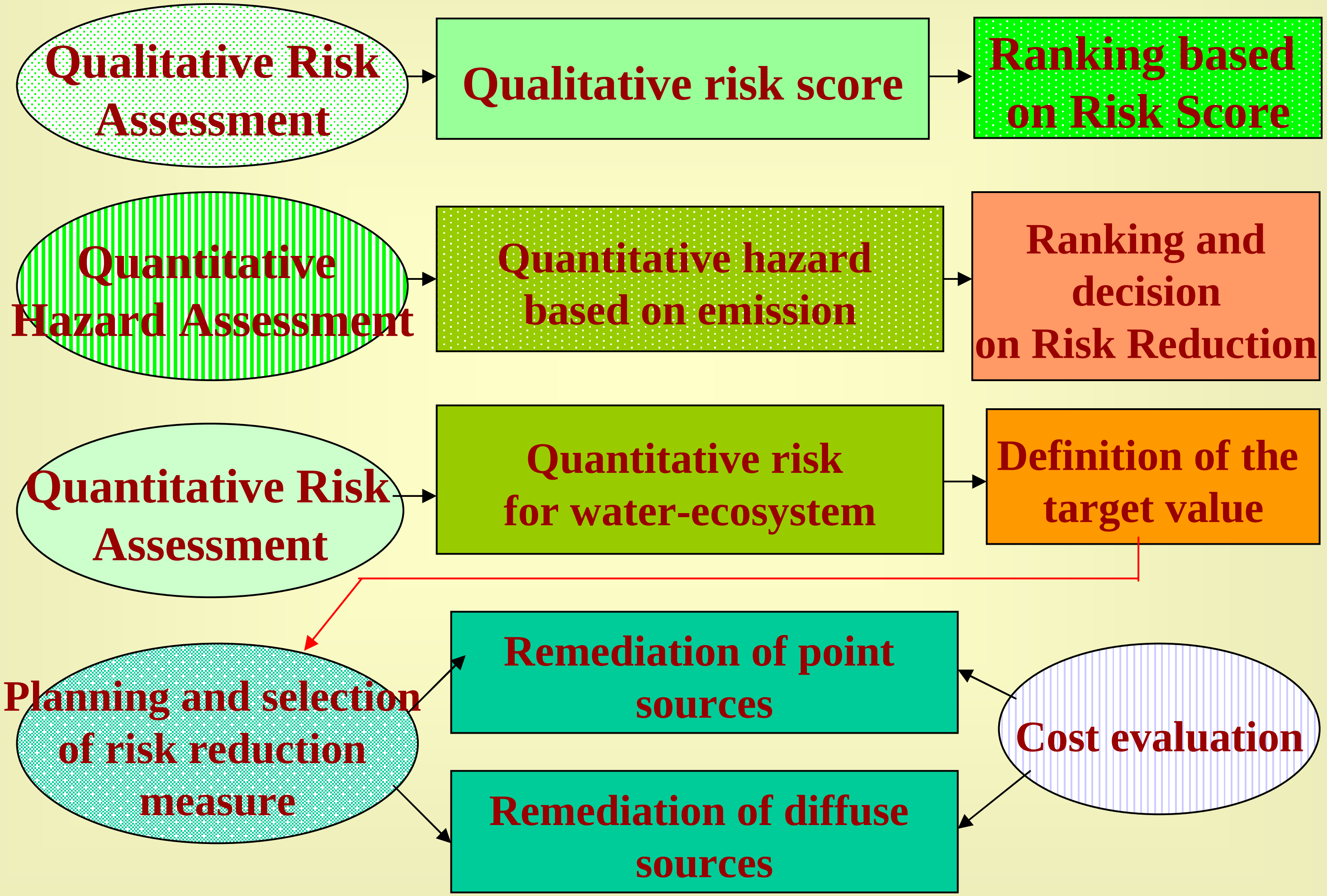
AVERAGE ANNUAL PRECIPITATION: 756 mm/year

RUNOFF FROM ANNUAL RAIN: 375 mm/year

Pollution sources



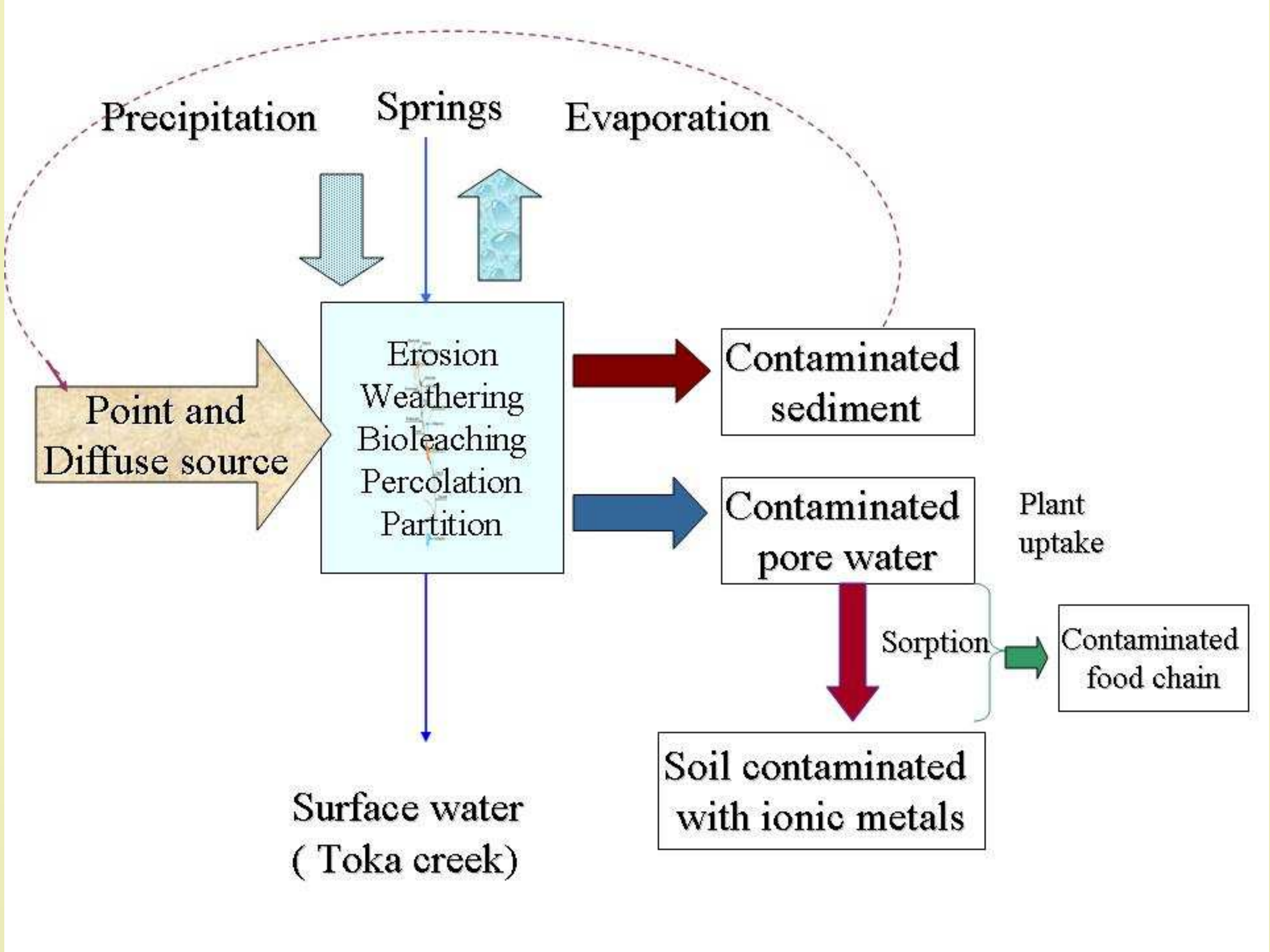
MAIN COMPONENTS OF THE ERM METHODOLOGY



Engineering tools supporting the ERM work: conceptual risk model of the site, GIS modelling, microcosm testing

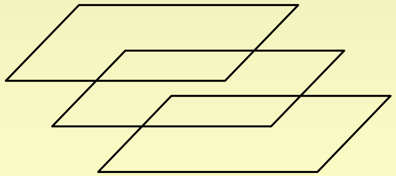
CONCEPTUAL RISK MODEL

The conceptual risk model includes the point and diffuse sources (primary & secondary), the transport routes and the land-use specific exposure routes and receptors.

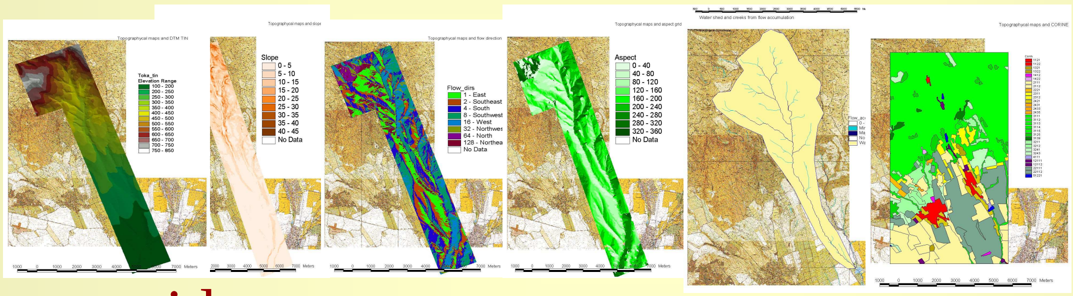


GIS MODELLING

Layers integrating local input parameters



Digital Terrain Model, Slope angles, Azimuth of flow directions, Watershed-waterflows, CORINE 2003 Land Cover, Site investigation data



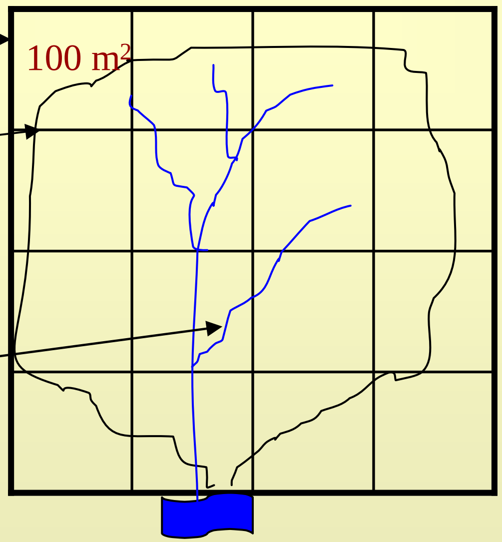
Local parameters

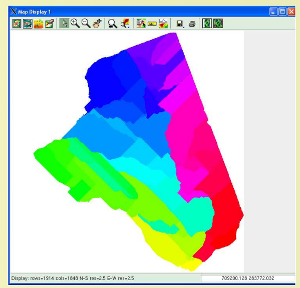
100 m^2 square grids

10 m

Catchment border

Water collection network





Integration of the local parameters at catchment scale

THREE TIERED ITERATIVE RISK ASSESSMENT

Risk score for all point and diffuse sources: questionnaire

Total risk score = sum of sub-scores relevant

- to the source (max. 33 points)
- to the transport routes (max. 33 points)
- to the receptors (max. 33 points)

Scoring: based on quantitative, qualitative categories, topography, geology, hydrogeology, climatic conditions, land use data

Score ranges:	**Risk:**	**Preliminary recommendation:**
❑70–100:	very high risk	removal or complete isolation
❑50–70:	high risk	combined chemical- and phytostabilisation
❑< 50:	slight risk	revegetation

THREE TIERED ITERATIVE RISK ASSESSMENT

Qualitative Risk Assessment Results

Pollution source	Risk score	Tons	Recommendation
Flotation tailings dump	99	4 000 000	complete isolation
Ore transportation line	92	30 000	to be removed
Main adit dump, mine waste	84.5	1 100 000	in situ remediation
Surface water, sediments	81–93	215 000	to be removed
5 point sources (mine waste dumps)	73–81	45 900	to be removed
14 different diffuse waste dumps	55–70	10 000	in situ remediation
15 different diffuse waste dumps	>50	10 000	revegetation

THREE TIERED ITERATIVE RISK ASSESSMENT

GIS-based Quantitative Hazard Assessment → Quantitative Hazard based on emission

GIS BASED MODELLING OF THE RUNOFF FLUX

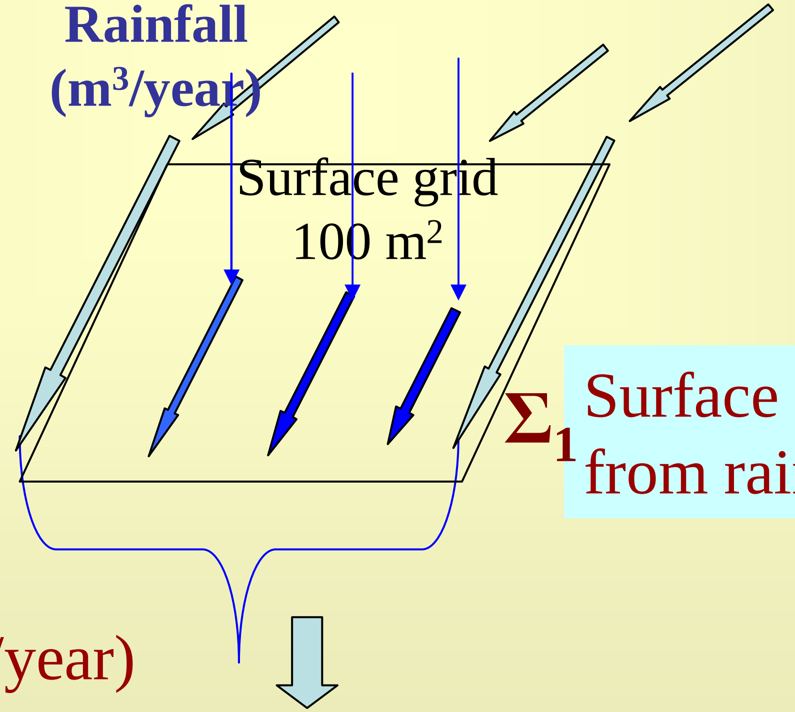
(ArcView3.1 3D Analyst)

Spatial scale:

- **catchment**
- **subcatchment**
- **$100 m^2$ grid**

Average annual rainfall: 756 mm/year

Σ_2 Surface and subsurface runoff flux from upstream (m^3/year)



Σ_1 Surface runoff flux from rainfall (m^3/year)

$\Sigma_{1,2}$ (m^3/year)

Runoff flux downstream (m^3/year)

THREE TIERED ITERATIVE RISK ASSESSMENT

GIS based Quantitative Hazard Assessment

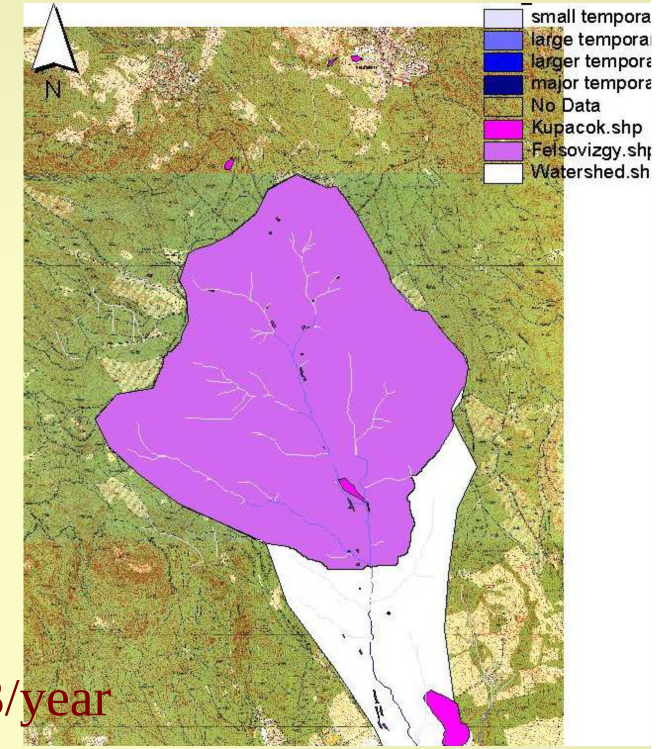
Runoff flux from various diffuse pollution sources

Waste dump	**Surface runoff (Σ_1)**	**Run-through watershed (Σ_2)**	**Total runoff flux ($\Sigma_{1,2}$)**
	m^3/year	m^3/year	m^3/year
Residual diffuse from removed point sources	22 000	203 000	223 000
Sum of 14 diffuse sources to be remediated	1 600	52 000	53 600
Sum of 15 diffuse sources to be revegetated	6 300	58 680	64 980

Total runoff flux through Northern watershed: 341 580 m^3/year

THREE TIERED ITERATIVE RISK ASSESSMENT

GIS based Quantitative Hazard Assessment



RUNOFF DELIVERED DISSOLVED METAL EMISSION FROM DIFFUSE SOURCES

Total runoff flux:

Total runoff flux through Northern watershed: 341 580 m3/year

Total metal flux:

Total metal flux$_{min}$ (kg/year): As: 64 Cd: 57 Pb: 36 Zn: 10 107

Total metal flux$_{max}$ (kg/year): As: 136 Cd: 224 Pb: 619 Zn: 30 502

THREE TIERED ITERATIVE RISK ASSESSMENT

GIS based Quantitative Hazard Assessment

SOLID FLUX BY EROSION (t/year)

Potential erosion in the Northern catchment of the Toka creek was modelled by GRASS 5.4 GIS.

Revised Universal Soil Loss Equation (RUSLE)

$$A = R*K*L*S*C*P$$

(A) annual solid material loss (tonnes/ha/year), (R) rain erosivity, (K) erodibility, (LS) slope factor, (C) cover management factor, (P) soil protection factor

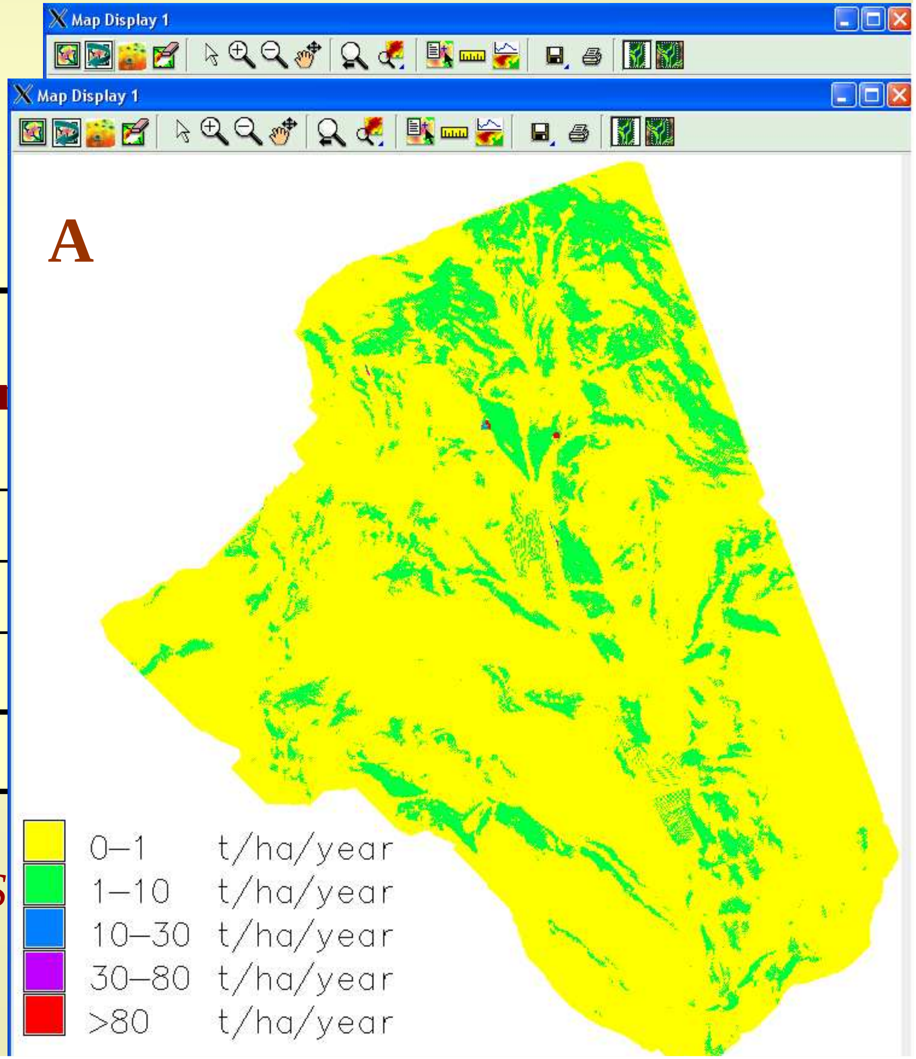
Rain intensity	Annual average rain [mm/year]	24 hours rainfall recurrence 2 years [cm/24 hours]	1 hours rainfall recurrence 2 years [cm/hour]	Soil erodibility K [–]
A (average)	756	7.4	0.18	0.12 and 0.23
B (high)	756	10.5	0.53	0.12 and 0.23

The average annual solid loss results were classified ⇨ Erosion map

THREE TIERED ITERATIVE RISK ASSESSMENT

GIS based Quantitative Hazard Assessment

Erosion map of the N. Toka watershed



Erosion of the mine waste dumps compared to the total N. Toka watershed : (A) and (B) cases

Case „A" average and „B" heavy rain	**Total Northern watershed**	**Mine waste dumps**
Cell number	169 8763	773
Area ha	1 062	0.5
Total erosion A t/year	337	47
Total erosion B t/year	1053	147

See poster: *K.Gruiz, E.Vaszita, P.Zaletnyik, Z. S*
of toxic metal transport by erosion

THREE TIERED ITERATIVE RISK ASSESSMENT

GIS based Quantitative Hazard Assessment

EROSION RELATED METAL EMISSION OF MINIMUM CONCENTRATION MINE WASTE

A: average rain B: heavy rain	Erosion t/year	Metal emission kg/year				
		As	**Cd**	**Cu**	**Pb**	**Zn**
A watershed (forest) (1061.5 ha)	296	18	0.3	24	59	59
A mine waste dump (0.5 ha)	**47**	**11**	**0.2**	**6**	**24**	**24**
A total watershed (1062 ha)	**337**	**29**	**0.5**	**30**	**83**	**83**
B watershed (forest) (1061.5 ha)	906	54	0.9	72	181	181
B mine waste dump (0.5 ha)	**147**	**35**	**0.7**	**18**	**74**	**74**
B total watershed (1062 ha)	**1053**	**89**	**1.6**	**90**	**225**	**225**

THREE TIERED ITERATIVE RISK ASSESSMENT

Quantitative Risk Assessment

Characterisation of the Quantitative Risk:

$$RQ = PEC/PNEC$$

Actual Risk related to Toka creek water	Actual metal concentration in the Toka creek	Effect-based Quality Criteria for ecological water use

where:

RQ: Risk Quotient

PEC: Predicted Environmental Concentration

PNEC: Predicted No Effect Environmental Concentration

Target of risk reduction: RQ≤1

THREE TIERED ITERATIVE RISK ASSESSMENT

Quantitative Risk Assessment

Toka creek actual concentration (PEC)

As: 50 µg/l Cd: 2 µg/l
Pb: 30 µg/l Zn: 800 µg/l

RQ = PEC/PNEC

Risk reduction $RQ \leq 1$

RQ_{As}: 5 RQ_{Cd} : 2 RQ_{Pb} : 3 RQ_{Zn} : 8

combined chemical and phyto-remediation of **diffuse & residual sources**

Targeted Effect-based Quality Criteria ($EBQC_{max}$)(PNEC)

As: 10 µg/l Cd: 1 µg/l
Pb: 10 µg/l Zn: 100 µg/l

RISK REDUCTION PLANNING (1)

Natural Risk Reduction Capacity of the site

Waste dump

Estimated emitted concentration from the diffuse sources of the Northern catchment

minimum **As: 150 µg/l Cd: 100 µg/l**
Pb: 100 µg/l Zn: 25 000 µg/l

Natural Risk Reduction Capacity of the site ($NRRC_{min}$)

As: 3.0 (66%) Cd: 50 (98%)
Pb: 3.4 (70%) Zn: 30 (97%)

Toka creek outflow of the N. catchment

Toka PEC

As: 50 µg/l Cd: 2 µg/l
Pb: 30 µg/l Zn: 800 µg/l

RISK REDUCTION PLANNING (2)

Water phase related Maximum Permissible Emission from diffuse sources (Backwards mode Risk Assessment)

Waste Dump

Calculated Maximum Permissible Emission (**MPE**) from the pollution sources to satisfy the EBQC levels in the Toka creek

As:	**30 µg/l**	**Cd:**	**50 µg/l**
Pb:	**34 µg/l**	**Zn:**	**3 000 µg/l**

Natural Risk Reduction Capacity of the site ($NRRC_{min}$)

As:	3.0 (66%)	Cd:	50 (98%)
Pb:	3.4 (70%)	Zn:	30 (97%)

Toka creek

EBQC Toka (PNEC)

As:	10 µg/l	Cd:	1 µg/l
Pb:	10 µg/l	Zn:	100 µg/l

RISK REDUCTION PLANNING (3)

Solid phase related targeted erosion of diffuse sources (forest value)

Target: Erosion of the mine waste dumps to be mitigated to the GIS modelled erosion level of the local forest area

Cases	**Erosion t/year**	**Metal emission kg/year**				
		As	**Cd**	**Cu**	**Pb**	**Zn**
Before phytostabilisation						
A waste dumps (0.5 ha)	47	11	0.2	6	24	24
B waste dumps (0.5 ha)	147	36	0.7	18	74	74
After phytostabilisation (forest value)						
A waste dumps (0.5 ha)	0.139	0.033	0.0007	0.017	0.069	0.069
B waste dumps (0.5 ha)	0.426	0.102	0.002	0.051	0.213	0.213
Emission mitigation (%): 99.7						

VALIDATION OF THE GIS-BASED RISK REDUCTION PLAN

Leachate (untreated plot)

As: 26 µg/l   Cd: 441 µg/l   Pb: 17 µg/l   Zn: 89 079 µg/l

Microcosm

Efficiency of ZVI

As: 98%

Reduced As emission by ZVI addition

As: 0.52 µg/l

Field experiment

Efficiency (compared to the untreated plot)

Cd: 99,5%   Pb: 88%   Zn: 99,7%

Reduced emission by chemical & phytostabilisation

Cd: 2 µg/l   Pb: 2 µg/l   Zn: 226 µg/l

Maximum Permissible emission from diffuse sources for non-sensitive# and sensitive## water use in the Toka catchment

 # As: 30 µg/l   Cd: 50 µg/l   Pb: 33 µg/l   Zn: 3 000 µg/l

As: 9 µg/l   Cd: 15 µg/l   Pb: 6.8 µg/l   Zn: 600 µg/l

CONCLUSIVE REMARKS (1)

- Environmental Risk Management of diffuse pollution requires a complex and interdisciplinary approach;
- GIS-based risk assessment and risk reduction planning was demonstrated on an actual diffusely contaminated former mining site in the Toka catchment area;
- Risk Assessment is iterative, pessimistic, tiered and GIS-based;
- Qualitative Risk Assessment results preliminary ranking of the pollution sources (both point and diffuse source) and enables setting of remediation priorities;
- Quantitative Hazard Assessment gives the GIS based emission from diffuse sources and its results refine preliminary ranking of pollution sources;

CONCLUSIVE REMARKS (2)

- The GIS model forecasted remediation target values were validated by the results of the planned and field tested remediation technology;
- The selected risk reduction measure, combined chemical and phytostabilisation is an innovative remediation technology, able to reduce water dissolved and eroded solid related metal emission from diffuse sources (poster: *V. Feigl, A. Anton, F. Fekete, K. Gruiz: Combined chemical and phytostabilisation of metal polluted soils – From microcosms to field experiments)*;

THANK YOU FOR YOUR ATTENTION!

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