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The long term fate and environmental significance of contaminant metals released by the January and March 2000 mining tailings dam failures in Maramureş County, upper Tisa Basin, Romania

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Abstract

In January and March 2000 two tailings dam failures in Maramureş County, northwest Romania, resulted in the release of 200,000 m^3 of contaminated water and 40,000 tonnes of tailings into tributaries of the Tisa River, a major tributary of the Danube. The high concentrations of cyanide and contaminant metals released by these dam failures resulted in pollution and fish deaths not only in Romania, but also downstream in the Tisa and Danube rivers within Hungary, Serbia and Bulgaria. Following these accidents, a research programme was initiated in northwest Romania to establish metal levels in rivers affected by the tailings dam failures and to compare these to metal values in river systems contaminated by historic mining and industrial activity. In July 2000, 65 surface water, 65 river sediment and 45 floodplain sediment samples were collected from trunk streams and principal tributaries of the Lapuş/Someş rivers (affected by the January 2000 spill) and the Vişeu/Tisa rivers (affected by the March 2000 Novat spill) down to the Hungarian and Ukrainian borders, respectively. Sample analyses for Pb, Zn Cu and Cd show that metal contamination in surface water and river sediment decreases rapidly downstream away from presently active mines and tailings ponds. Concentrations of heavy metals in water and sediment leaving Romania, and entering Hungary and the Ukraine, generally fall below EC imperative and Dutch intervention values, respectively. However, Zn, Cu and Cd concentrations in river sediments approach or exceed intervention values at the Romanian border. The results of this survey are compared with earlier surveys to ascertain the long-term fate and environmental significance of contaminant metals released by mine tailings dam failures in Maramureş County.

1. Introduction

Since 1970 there have been 35 reported major mine tailings dam failures around the world resulting in significant river pollution and the loss of more than 500 lives (Diehl, 2001). Indeed, in 2000 alone there were a total of 5 reported accidents (in China, Romania, Sweden and in the USA) and there is growing pressure on mining companies to find alternative, safer ways of storing mine waste, particularly in environments prone to earthquakes or high rates of erosion. What distinguishes river pollution arising from catastrophic tailings dam failures from inadvertent or controlled industrial or

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municipal inputs, is the huge volumes of contaminated liquid and slurry normally involved, and the rapidity at which waste is discharged into river systems. For instance, in the case of the April 1998 Aznalcóllar accident, southwest Spain, the channels and floodplains of the lower Agrio and the middle / lower Guadiamar rivers were completely overwhelmed by 4×10^6 m^3 of acidic water and 2 million m^3 of toxic mud containing large amounts of heavy metals (Grimalt et al., 1999). Subsequent clean-up operations removed waste, sediment and vegetation from the channels and valley floor creating a highly unstable river system (Macklin et al., 1999; Benito et al., 2001). By contrast, the smaller (400,000 m^3) August 1996 El Porco spill, Bolivia, although polluting up to 300 km of the Pilaya River, was not of sufficient size to significantly affect longer term erosion and sedimentation patterns within this much larger drainage basin (Hudson-Edwards et al., 2001).

The tailings dam failures that occurred in January and March 2000 in the upper Tisa basin, Maramureş County, northwest Romania, were of a similar scale to those in the Pilaya in terms of the spectrum of mining impacted river basins described above. The Tisa is a major tributary of the River Danube and, largely because the spill resulted in pollution and fish deaths downstream in Hungary, Serbia and Bulgaria, it attracted enormous media interest and prompted a number of investigations coordinated by the United Nations Environmental Programme (UNEP) and the EU Baia Mare Task Force.

These studies monitored the immediate aftermath of the spills up to the end of March 2000. However, because of the continued uncertainty and concern of the long term effects of heavy metal pollution, a larger scale and more intensive survey of surface water, river and floodplain sediment in the Vişeu/Tisa and Lapuş/Someş river basins, Maramureş County, was carried out in July 2000. The results of this survey are reported in this paper and are compared with earlier surveys to ascertain the long-term fate and environmental significance of contaminant metals released by mine tailings dam failures in Maramureş County.

2. Study area

Maramureş County has a very long history of metal mining that is documented back to the 14th century, and is generally believed to have started in the Roman period. Mining in the region today currently exploits both base (Cu, Pb, Zn) and precious metals (Ag, Au) from Neogene age hydrothermal vein mineralisation deposits. At present there are 19 flotation plants and 215 disused and functioning mine tailings ponds, in addition to a number of Cu and Pb smelters, including the famous 351.5 m high S/C Phoenix stack. The most recent phase of mining activity commenced in May 1999 when S.C. Aural S.A. began processing old tailings pond material just outside the city of Baia Mare using cyanide to recover Ag and Au. A new tailings storage pond was constructed near the village of Bozanta Mare, 6 km west of Baia Mare, to store waste from this new venture (Fig. 1). As a result of very high snowfall, followed by rapid thawing and heavy rainfall, the tailings dam wall was breached on the 30 January 2000 at 10.00 p.m., releasing nearly 100,000 m^3 of waste water and sediment containing high concentrations of cyanide and contaminant metals into the Lapuş and Someş rivers.

The second recent major tailings pond failure in the Novat valley, 10 km north of Baia Borsa (Fig. 1) occurred 2 months later on the 20 March at 10.30 a.m. Similar to the earlier spill, the Novat tailings dam wall was breached following rapid snowmelt and heavy rain, discharging around 100,000 m^3 of contaminated water and 40,000 tonnes of solid waste into the Vaser and Vişeu rivers, the latter joining the River Tisa at the Ukrainian border.

The Lapuş and Vişeu rivers both have mountain headwaters rising up to 1840 m and 2305 m, respectively. Upstream of Tirgu-Lapuoş, the Lapuş is a laterally active, single thread gravel bed river of relatively low sinuosity. Immediately downstream of Tirgu-Lapuş it enters an inaccessible narrow gorge that extends almost to its confluence with the River Cavnic. In its lower reaches channel sinuosity increases and it has a well-developed floodplain. The Lapuş flows into the Someş, which is a similar high sinuosity, low gradient channel with extensive flood embankments, particularly where it flows through major urban areas such as Satu Mare. The River Vişeu, by contrast, down to its confluence with the River Tisa, is a steeper gradient, lower sinuosity gravel bed river. It is actively reworking its valley floor and in some reaches has a near braided channel pattern.

Mine tailings in both affected river systems were dispersed under very high flow conditions, during which sediment-associated metals were deposited in both within-channel and overbank environments. The volume of solid waste in relation to the size of both drainage basins was, however, relatively small, and as a consequence it did not disrupt river dynamics except immediately downstream of the dam failure sites.

3. Field sampling and laboratory metal analysis

To establish partitioning of contaminant metals between their dissolved and particulate phases, a total of 65 surface water and 65 fine-grained (<2 mm) river sediment samples were collected from the Vişeu/Tisa and Lapuş/Someş rivers (down to the Ukrainian and

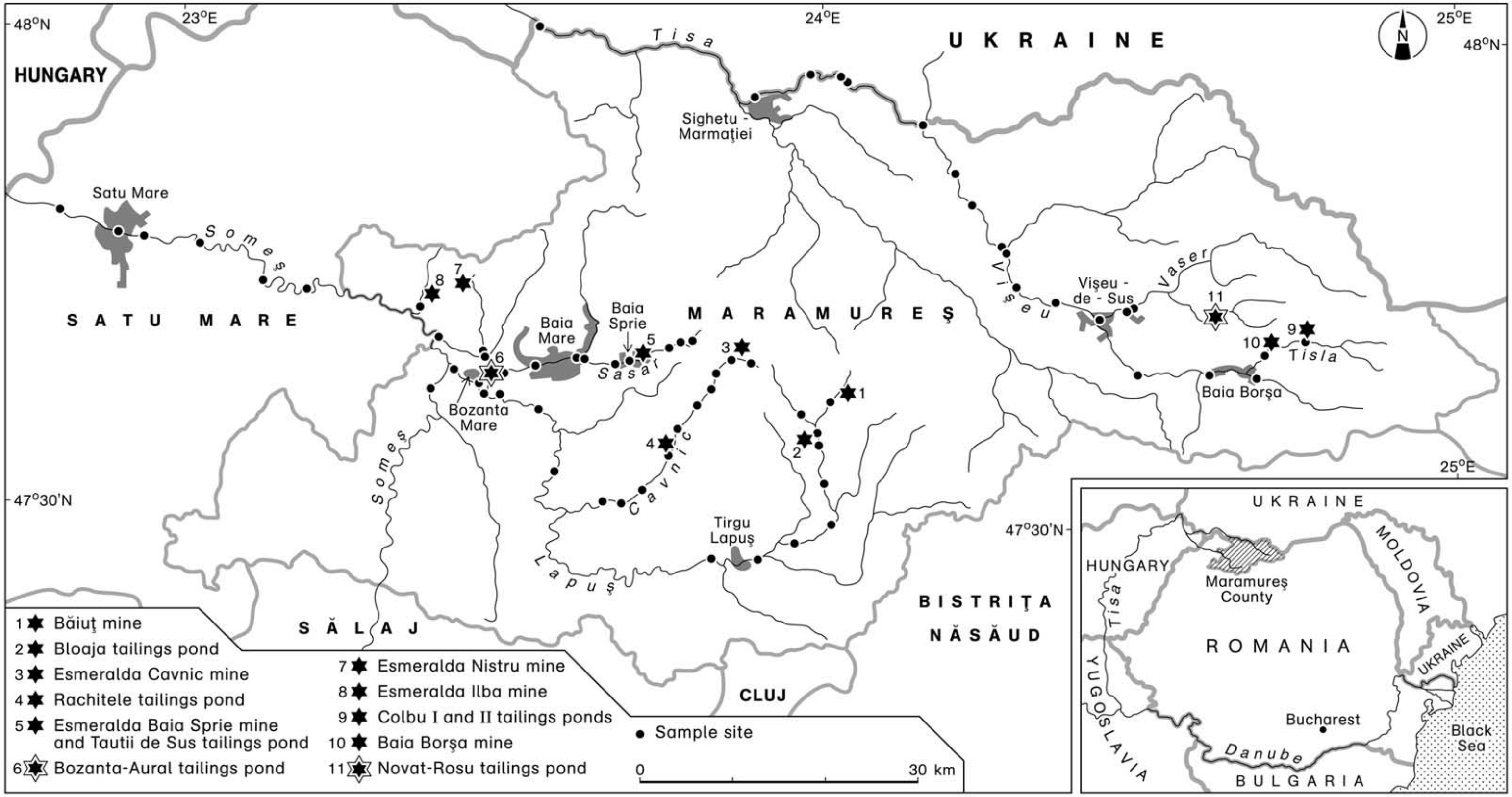

Fig. 1. Maramureş County showing the principal study rivers, towns, tailings dam accident sites and the water/sediment sample site locations.

Hungarian borders, respectively), as well as from their principal tributaries (Cavnic, Sasar, Tisla and Vaser) affected by industrial, mining and urban metal pollution (Fig. 1). Sampling was carried out between 7th and 14th July 2000 during a very dry period with river levels at their lowest for 50 years. Water samples were filtered through 0.45 μm filter papers and stored in 60 ml sterilized plastic bottles. All samples were acidified with three drops of 50% nitric acid. River sediment samples were collected using a stainless steel trowel from bar surfaces above low flow river levels with 10 spot samples taken within a 10 m radius, which were then aggregated to form a sample of 100–150 g wet weight. To evaluate the long-term storage, and potential remobilization, of sediment borne contaminant metals in the river valleys, floodplain material was also sampled at depths of between 10 and 60 cm below ground level (45 samples).

Metal concentrations (Pb, Zn, Cu and Cd) in surface water samples were measured using an ICP-MS (VG Elemental Plasma Quad II+) and metal levels are presented in μg/L. River and floodplain sediments were sieved through a 2 mm plastic mesh, digested in HNO_3 and metal levels determined using AAS (Perkin-Elmer 2380). To check the precision of the technique an extra 10% of the total number of samples analysed were inserted as 'blind duplicates'. Analytical accuracy of the digestion procedure was checked by using a reference sediment standard (GBW07311) from the Office of the Government Chemist, UK. Both precision and accuracy of the results were found to be within 10%.

Metal concentrations in surface water are assessed against those in EC directive (75/440/EEC) required of surface water intended to be used for the abstraction of drinking water (Table 1), and metal levels in river and floodplain sediment are compared with the latest (4 February 2000) Dutch target and soil remediation intervention values (Table 2).

4. Results

4.1. Surface water

Lead, Zn, Cu and Cd concentrations in surface waters for all river basins are plotted in the form of proportional circles on a series of drainage network maps (Fig. 2); the larger circles show higher metal concentrations. Black circles denote where metal concentrations exceed imperative levels (Pb 50 μg/L; Zn 3,000 μg/L; Cu 50 μg/L; Cd 5 μg/L), grey circles denote where metal concentrations exceed target values (Zn 500 μg/L; Cu 20 μg/L Cd; 1 μg/L) and open circles show where metal values comply with the EC water quality directive. In addition, for the main channel of the Tisla, Vişeu and Tisa rivers, and the Lapuş and Someş rivers, metal concentrations are plotted on a downstream basis from the source of the Tisla and Lapuş, respectively (Fig. 3). To evaluate whether metal concentrations in river water exceeded levels considered to be unsafe, proportional areas have been coded to show where values fall above or below target values, or where they exceed imperative metal concentrations required for the abstraction of drinking water (75/440/EEC). In the case of downstream plots, dashed and solid horizontal lines show target and imperative metal values, respectively.

In the Vişeu/Tisa catchment only 2 sample sites in the River Tisla, immediately downstream of Colbu 1 and 2 tailings ponds, exceed imperative Cd and Cu concentrations (Figs. 2 and 3). Indeed, in the Vişeu only Cd values exceed guideline levels but by river km 50 they decrease and remain low, falling to within acceptable levels. Metal concentrations in the surface water of the Vişeu/Tisa system, with the exception of the River Tisla, would appear at present not to be of potential concern to public health.

The tributaries of the Someş close to Baia Mare including the Cavnic, Sasar and headwaters of the Lapuş are polluted, particularly by Cd, Cu and Zn. In the Lapuş, surface water metal concentrations exceed or are close to imperative drinking water abstraction quality values up to 10 km downstream of the Băiut mine and Bloaja tailings pond. It is interesting to note that high metal concentrations from the Bozanta-Aural mining operations are also found in the lower part of the Lapuş immediately downstream of its confluence with the Sasar. The Cavnic and Sasar, both in terms of river length and metal levels, are the most seriously

Table 1
EC directive concerning the quality required of surface water for the abstraction for drinking (75/440/EEC)

	Target value (μg/L)	Imperative value (μg/L)
Pb	–	50
Zn	500	3000
Cu	20	50
Cd	1	5

Table 2
Target values and soil remediation intervention values for selected metals in soils from the Dutch Ministry of Housing, Spatial Planning and Environment (VROM, 2001).

	Target value (mg/kg)	Intervention value (mg/kg)
Pb	85	530
Zn	140	720
Cu	36	190
Cd	0.8	12

Values have been expressed as the concentration in a standard soil (10% organic matter, 25% clay)

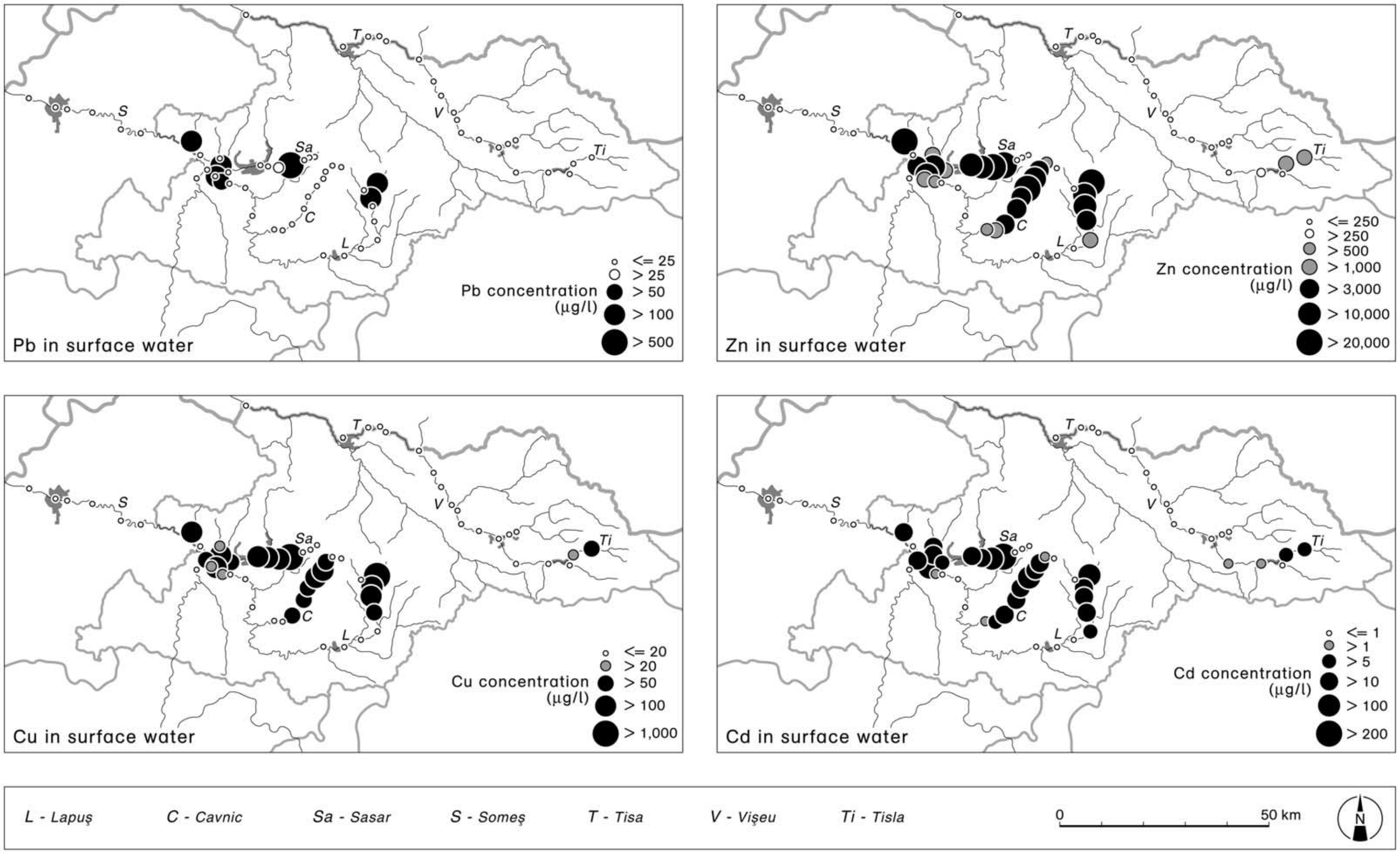

Fig. 2. Surface river water concentrations of Pb, Zn, Cu and Cd in Maramureş County. Shaded proportional circles show where concentrations fall either below (white) or above (grey) EC target values, or where they exceed (black) EC imperative values for drinking water abstraction.

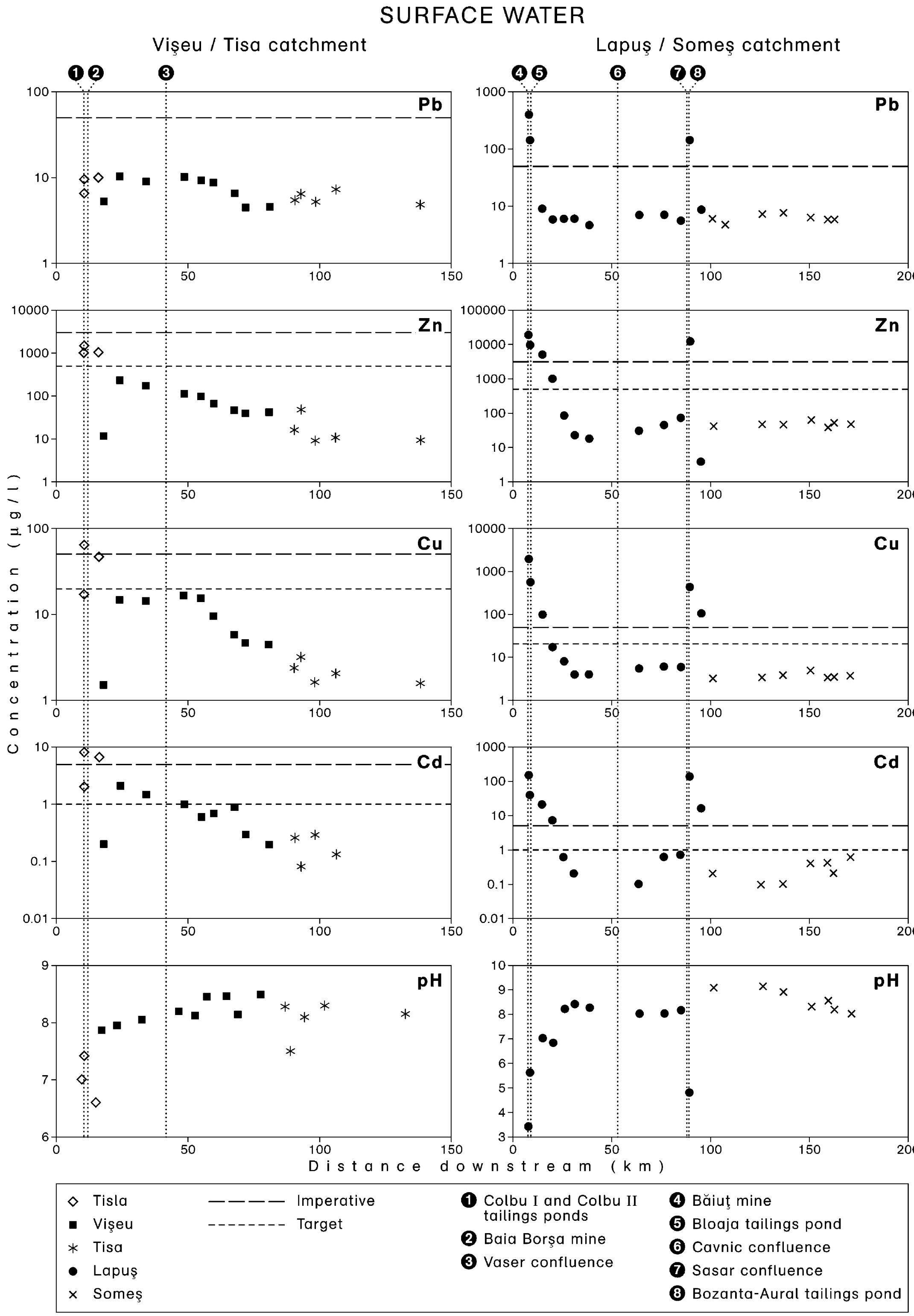

Fig. 3. Downstream changes in surface river water metal concentration and pH values in the Vişeu/Tisa and Lapuş/Someş catchments.

polluted basins. The Cavnic is polluted downstream of Esmeralda Cavnic mine and Rachitele tailings pond although by the time it joins the Lapuş, metal concentrations are approaching guideline levels. Metal values in the upper Sasar are relatively low but rise sharply downstream of the Esmeralda Baia Sprie mine with further contaminant metal inputs from municipal wastewater and mining industry at Baia Mare.

In the lower Someş, however, downstream of its confluence with the Lapuş, values for all the principal contaminant metals fall within EC guidelines for drinking water abstraction purposes. Cd concentrations, although relatively low, do slightly increase downstream of Satu Mare.

Surface water metal levels in the Vişeu, Tisa (within Romania), and Someş (downstream of the Lapuş confluence) rivers comply with the EC water quality directive, and at least during the period of sampling, downstream water quality in both Hungary and Ukraine did not appear to be unduly affected by mining, industrial and urban metal waste from this part of Romania. The upper parts of the Tisla, Lapuş and Cavnic basins, and the middle reach of the Sasar, however, mainly as the result of present and past mining operations, are severely polluted. Metal concentrations in surface water at some sites within all of these catchments represent a potentially serious hazard to human health.

4.2. River and floodplain sediments

Unlike metal concentrations in surface water where there are clear and unambiguous EC guidelines, there are no agreed European standards of metal levels in river or floodplain sediment. We have chosen to use the latest (4 February 2000) Dutch Ministry of Housing, Spatial Planning and Environment target and intervention values for soil remediation (Table 2) on the basis that this is a long established (first introduced in the early 1980s), tried and tested scheme where the intervention values are based on extensive studies of both human and eco-toxicological effects of soil contaminants. Although it is one of the most stringent set of guidelines for the assessment of soil/sediment contamination, it does not take into consideration the current or intended use for the land after restoration. Nevertheless, they do assist in the assessment of contaminated soils/sediments and sites that pose potential concern, as well as means for screening out those soils that do not warrant additional attention.

The Dutch intervention values for soil/sediment remediation are considered to be numeric manifestations of the concentrations above which there can be said to be a case of serious contamination. These values indicate the concentration levels of metals above which the functionality of the soil for human, plant, and/or animal life may be seriously compromised or impaired. Target values indicate the level at which there is a sustainable soil quality and gives an indication of the benchmark for environmental quality in the long term on the assumption of negligible risk to the ecosystem.

In the upper Vişeu catchment, metal concentrations in river sediments are elevated (most notably Cu and Zn) up to 60 km downstream of Baia Borsa mine, and Colbu tailings ponds (Figs. 4 and 5). Metal values in the Vişeu decrease downstream until its confluence with the Vaser where concentrations rise as a result of metal inputs from both municipal wastewater at Vişeu de Sus and the Novat-Rosu tailings pond. In the lower Vişeu and in the Tisa, contemporary river sediment metal concentrations do not exceed intervention values at any of the sample sites. Indeed, all Pb levels in the Tisa fall at, or slightly below, Dutch target values and can, therefore, be considered to be uncontaminated.

River sediment metal concentrations are higher in the Lapuş / Someş catchment than in the Viseu / upper Tisa basin (Figs. 4 and 5). The principal tributaries of the Lapuş, the Cavnic and Sasar are very contaminated along their entire lengths with only headwater sites upstream of the main mining and industrial areas having river sediment metal levels below intervention values. The upper reaches of the Lapuş are similarly contaminated though by 35 km downstream of the Bloaja tailings pond metal concentrations are very close to or, in the case of Pb, below target values. Metal values again rise in the Lapuş downstream of both the Cavnic and Sasar, and for Cu and especially Zn, concentrations exceed intervention values. In the Someş, river sediment Pb concentrations remain low and, for all but one sample site, Pb levels are at or even below target values down to the Hungarian border. Copper, Cd and particularly Zn concentrations, however, remain relatively high as a result of municipal wastewater inputs from Satu Mare and the Esmeralda Ilba and Nistru mining sites.

Floodplain sediment metal concentrations in the Vişeu/Tisa and Lapuş/Someş catchments (Figs. 6 and 7) are generally lower than those found in contemporary river sediments. In the Lapuş and Someş catchment, floodplain and river sediment metal concentrations generally parallel each other, although floodplain metal levels decrease more rapidly downstream and at none of the Someş sites do metal concentrations exceed intervention values. Nevertheless, in the Cavnic and Sasar, and in the upper Lapuş, floodplain sediments do appear to be significantly contaminated. Floodplain Cu and Zn concentrations are high in all three of these systems with Pb values elevated in both the Cavnic and Sasar basins, and Cd levels consistently exceed intervention values in the Cavnic valley. There is, however, a very different relationship between metal concentrations in contemporary river and floodplain sediment in the Vişeu

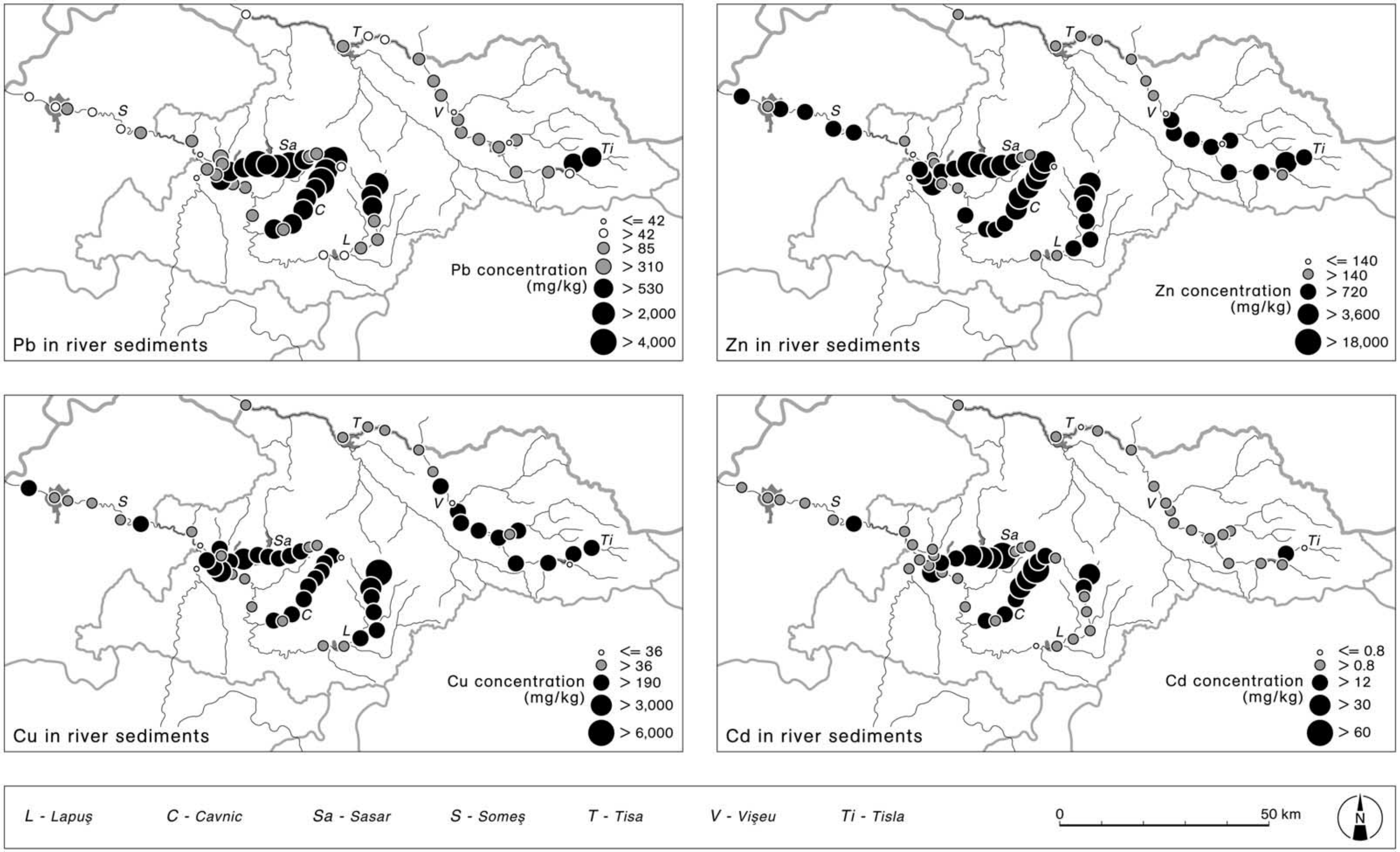

Fig. 4. River sediment concentrations of Pb, Zn, Cu and Cd in Maramureş County. Shaded proportional circles show where concentrations fall either below (white) or above (grey) Dutch target values, or where they exceed (black) Dutch intervention values for soil remediation.

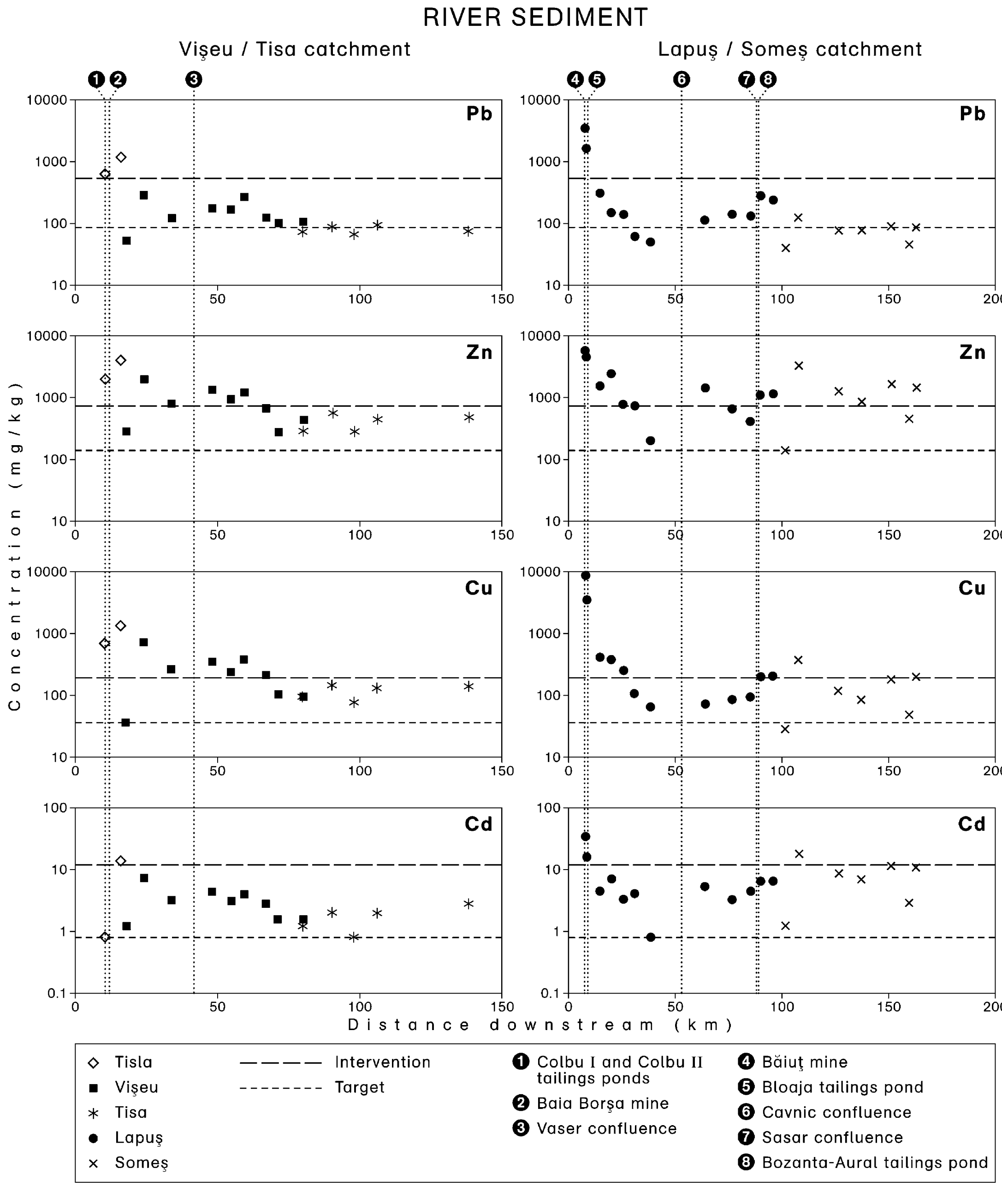

Fig. 5. Downstream changes in river sediment metal concentration in the Vişeu/Tisa and Lapuş/Someş catchments.

and Tisa catchments. Modern river sediment metal values progressively decrease from 60 km downstream and remain generally low to the Ukrainian border. Floodplain metal concentrations, however, increase at this point and progressively rise in the lower part of the Vişeu valley until declining downstream of the confluence with the River Tisa (river km 80). It is not clear what the source of the pollution is but it certainly predates the March 2000 Novat-Rosu mine tailings pond spill. With up to 33 and 47% of the floodplain sites sampled in the Vişeu/Tisa and Lapuş/Someş catchments, respectively, having metal levels exceeding intervention values (Table 3), it is highly likely that contaminated floodplain material is a major secondary source of contaminant metals. This may occur when floodplain soils are disturbed or contaminated sediment is re-introduced back into the river channel by bank erosion.

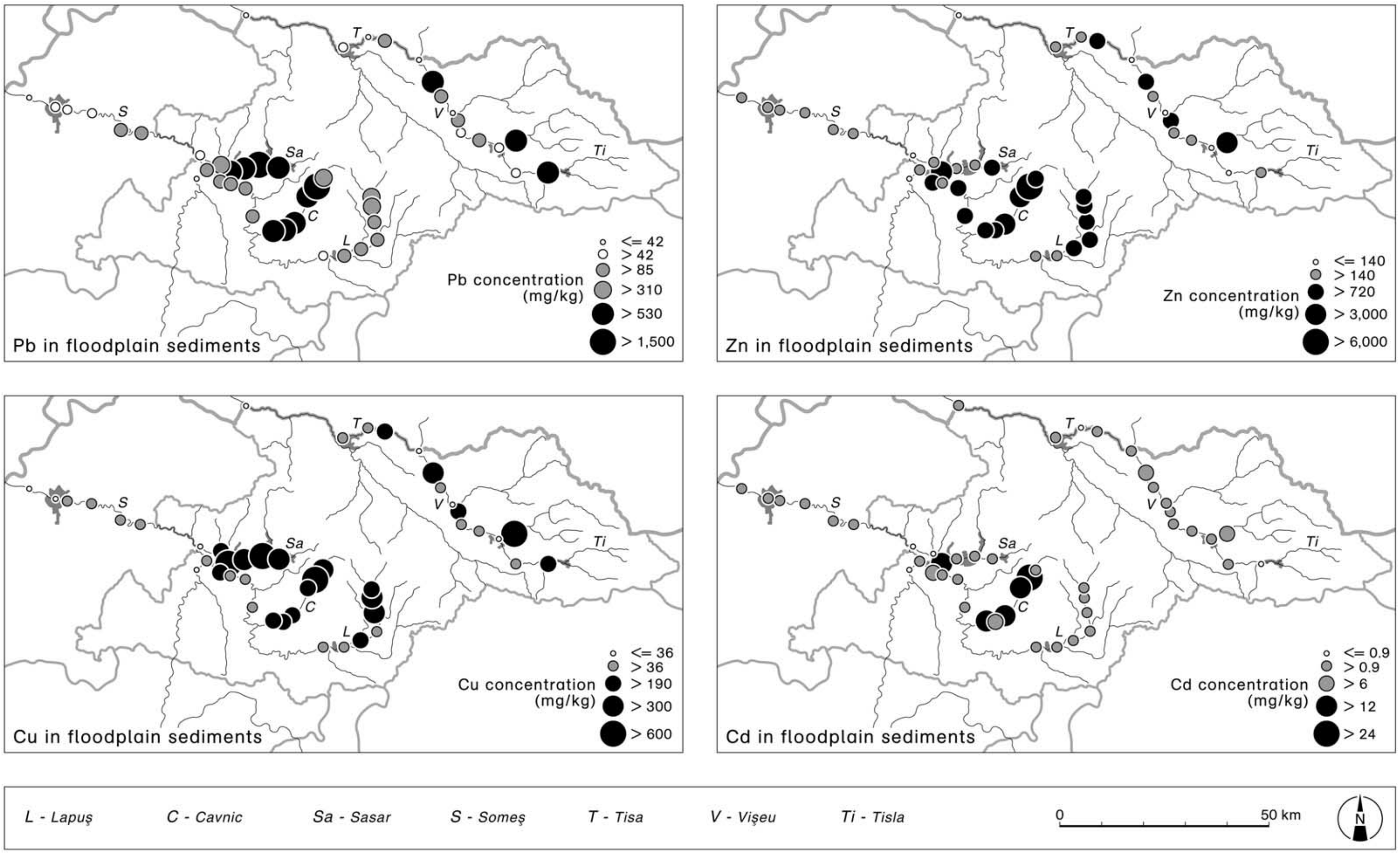

Fig. 6. Floodplain sediment concentrations of Pb, Zn, Cu and Cd in Maramureş County. Shaded proportional circles show where concentrations fall either below (white) or above (grey) Dutch target values, or where they exceed (black) Dutch intervention values for soil remediation.

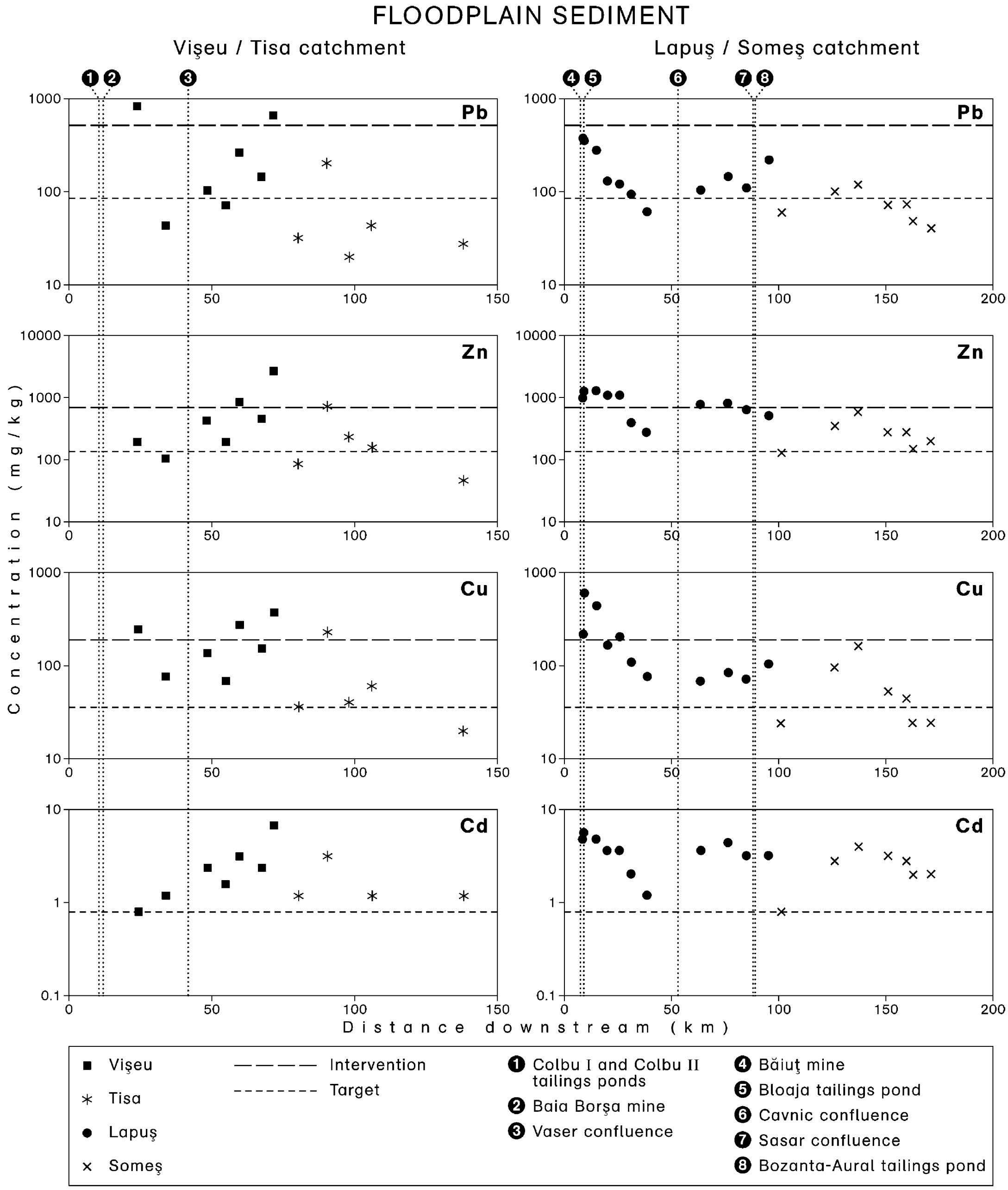

Fig. 7. Downstream changes in floodplain sediment metal concentration in the Vişeu/Tisa and Lapuş/Someş catchments. Distances from the source of the Tisla and Lapuş, respectively.

4.3. Comparison of river water and sediment metal levels in July 2000 with previous surveys

Data on surface water metal levels in the Lapuş, Someş and Tisa rivers were recorded in 1992 (by UNEP) and on nine subsequent occasions between January 2000 and March 2000 following the Aural tailings dam failure but before the Novat accident. These are plotted in Fig. 8 along with surface water metal concentrations in July 2000.

There is an overall downstream decline in concentration of all metals. This is particularly marked for Pb, Zn and Cd which, in the most downstream sample sites, fall below target values and meet the EC Directive 75/440/EEC on surface water quality. In July 2000, metal concentrations at all sites are generally much lower than

Table 3
Percentage of surface river water samples, river sediment samples, and floodplain sediment samples exceeding heavy metal imperative/intervention values.

	Catchment	No. of samples	Pb	Zn	Cu	Cd
Surface water						
	Tisa	6	0	0	0	0
	Vişeu	9	0	0	0	0
	Tisla	3	0	0	33	67
	Vaser	2	0	0	0	0
	Combined catchment	22	0	0	5	9
	Someş	8	0	0	0	0
	Lapuş	12	25	33	42	50
	Cavnic	9	0	44	56	67
	Sasar	10	10	40	60	60
	Combined catchment	43	14	33	42	49
	All catchments	65	9	22	29	35
River sediment						
	Tisa	6	0	0	0	0
	Vişeu	9	0	56	67	0
	Tisla	2	100	100	100	50
	Vaser	2	0	100	100	0
	Combined catchment	20	10	45	50	5
	Someş	8	0	63	25	13
	Lapuş	12	17	67	58	17
	Cavnic	10	70	90	70	80
	Sasar	11	73	73	73	64
	Combined catchment	45	38	67	56	40
	All catchments	65	29	60	54	29
Floodplain sediment						
	Tisa	5	0	20	20	0
	Vişeu	7	29	29	43	0
	Tisla	0	n.d.[a]	n.d.	n.d.	n.d.
	Vaser	2	50	50	50	0
	Combined catchment	15	20	27	33	0
	Someş	8	0	0	0	0
	Lapuş	11	0	64	36	0
	Cavnic	6	83	100	100	67
	Sasar	4	100	50	100	25
	Combined catchment	30	30	50	47	17
	All catchments	45	27	42	42	11

NB combined catchment data includes samples taken from tributaries that are not individually listed

earlier measurements and show that water quality has improved significantly, particularly downstream of the Aural tailings dam failure. For example, Cu concentrations at Cicârlău on the Someş (river km 101) decreased by 4 orders of magnitude (10,500 μh/L in January 2000 to 3.4 μh/L in July 2000) in 6 months. What is particularly interesting, however, is that concentrations of Pb, Zn, and Cd measured by UNEP in 1992 were actually higher than those recorded in January 2000 immediately after the Aural spill. This suggests that in the early 1990s, and probably today, continuous but lower level waste discharges from industry and urban areas constitutes the principal source of contaminant metals to the river systems of Maramureş County.

Fig. 9 plots data from UNEP, RIZA and this study on post-spill river sediment metal levels in the Lapuş, Someş and Tisa rivers from February to July 2000. There is an overall downstream decline in concentration of all metals, with metal concentrations exceeding intervention values in the headwaters of the Lapuş (downstream of Băiut mine) but falling below intervention values, and occasionally target values, in the Danube. Immediately downstream of the Aural tailings dam failure site, however, concentrations of all metals increase by an order of magnitude, but then rapidly decline downstream. Unlike the pattern in surface waters discussed above, in July 2000 metal concentrations in river sediments were not significantly lower than measurements taken by UNEP and RIZA earlier in the year (Fig. 9). This suggests that since February 2000 there has either been little downstream movement of contaminated sediment, and/or that metal levels in this reach are being augmented by local industrial and urban sources.

4.4. Summary of principal findings

1. Metal concentrations at 9 and 49% (Table 3) of the sites sampled in the Vişeu/Tisa and Lapuş/Someş catchments, respectively, do not meet EC Directive 75/440/EEC for surface water intended for the abstraction of drinking water. The rivers Cavnic, Sasar and Tisla that drain the major industrial, mining and urban centers are the most severely polluted.
2. Surface water metal concentrations in both the lower Someş and Vişeu catchments are lower and generally meet the EC Directive 75/440/EEC on surface water quality. At the time of the July 2000 survey there was little evidence to suggest that dissolved metals in the River Someş entering Hungary and River Tisa entering the Ukraine, were being greatly elevated by industrial, mining or waste inputs from Maramureş County.

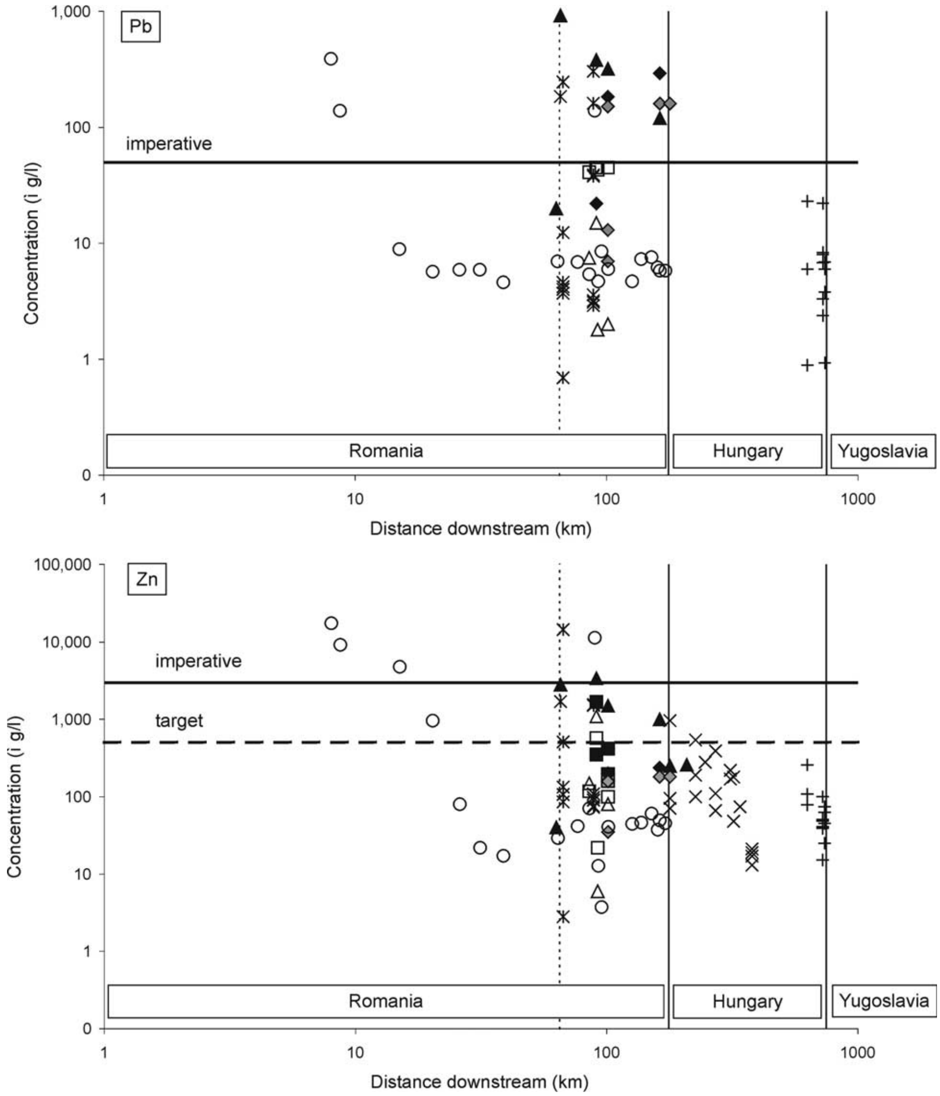

Fig. 8. Downstream changes in surface river water metal concentration for Pb, Zn, Cu and Cd from the source of the Lapuş in Romania to Moldova Veche (Yugoslavian/Romanian border) on the Danube. RIZA and Apele Romane data from Knijff et al. (2000), UNEP 1992 data from UNEP (2000), Hungarian Government data from Hungarian Government (2000), Romanian Government data from Romanian Government (2000).

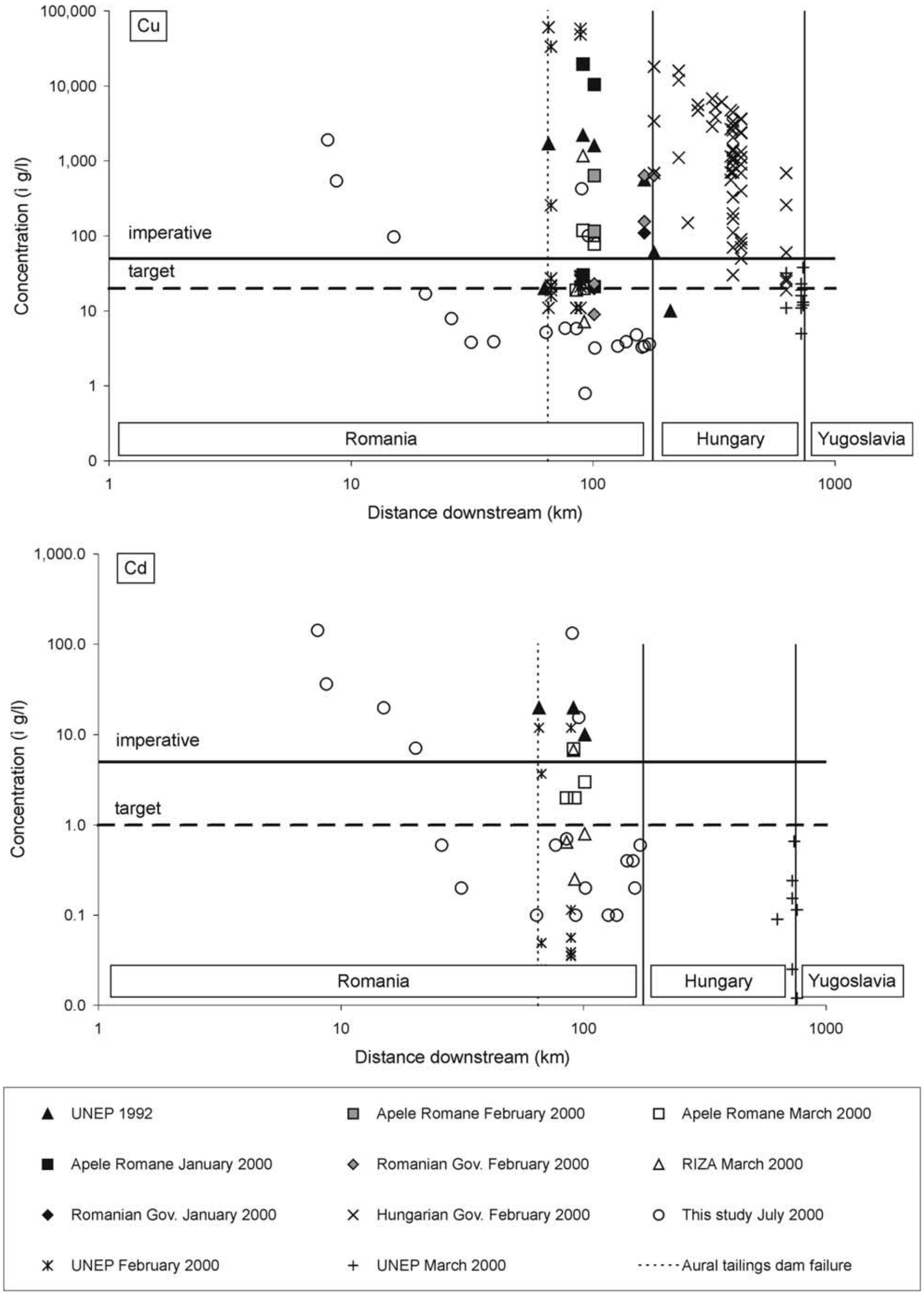

Fig. 8 (*continued*)

3. River sediment metal concentrations at 50 and 67% (Table 3) of the sites sampled in the Vişeu/Tisa and Lapuş/Someş catchments, respectively, exceed Dutch intervention values for soil remediation. Cu and Zn concentrations are high, particularly in the Cavnic, upper Lapuş, Sasar, and Tisla catchments. Elevated levels of both Cu and Zn are also found in the River Someş (down to the Hungarian border) and in the lower Vişeu, indicating that sediment-associated metals are currently being dispersed away from main mining areas.
4. Floodplain metal concentrations at 33 and 50% (Table 3) of the sites sampled in the Vişeu/Tisa and Lapuş/Someş catchments, respectively, exceed Dutch intervention values for soil remediation.

Similar to river sediment, Cu and Zn concentrations would appear to pose the greatest hazard especially in the mining-affected Cavnic, upper Lapuş and Sasar valleys. In the middle and lower parts of the Vişeu valley, down to its confluence with the River Tisa, metal values in floodplain soils exceed those in river sediment.

5. Surface water and river sediment metal concentrations in the lower Someş and Tisa rivers generally fall below imperative/intervention and occasionally fall below target values. The exception to this is Cu concentration in surface water measured in February 2000 that exceeded imperative values at river km 738 (Fig. 8). It is likely that these elevated Cu levels were a direct result of the Aural tailings dam failure, since in July 2000 Cu concentrations in surface water fell below the target value downstream of the tailings dam.

5. Conclusions and future research priorities

The long-term environmental impact of the Bozanta–Aural and Novat–Rosu mine tailings pond failures is at present still difficult to quantify, primarily because of the multiple extant and past sources of contaminant metals into the region's rivers. Although river and floodplain sediment (and surface water in the case of Bozanta-Aural) metal concentrations are significantly

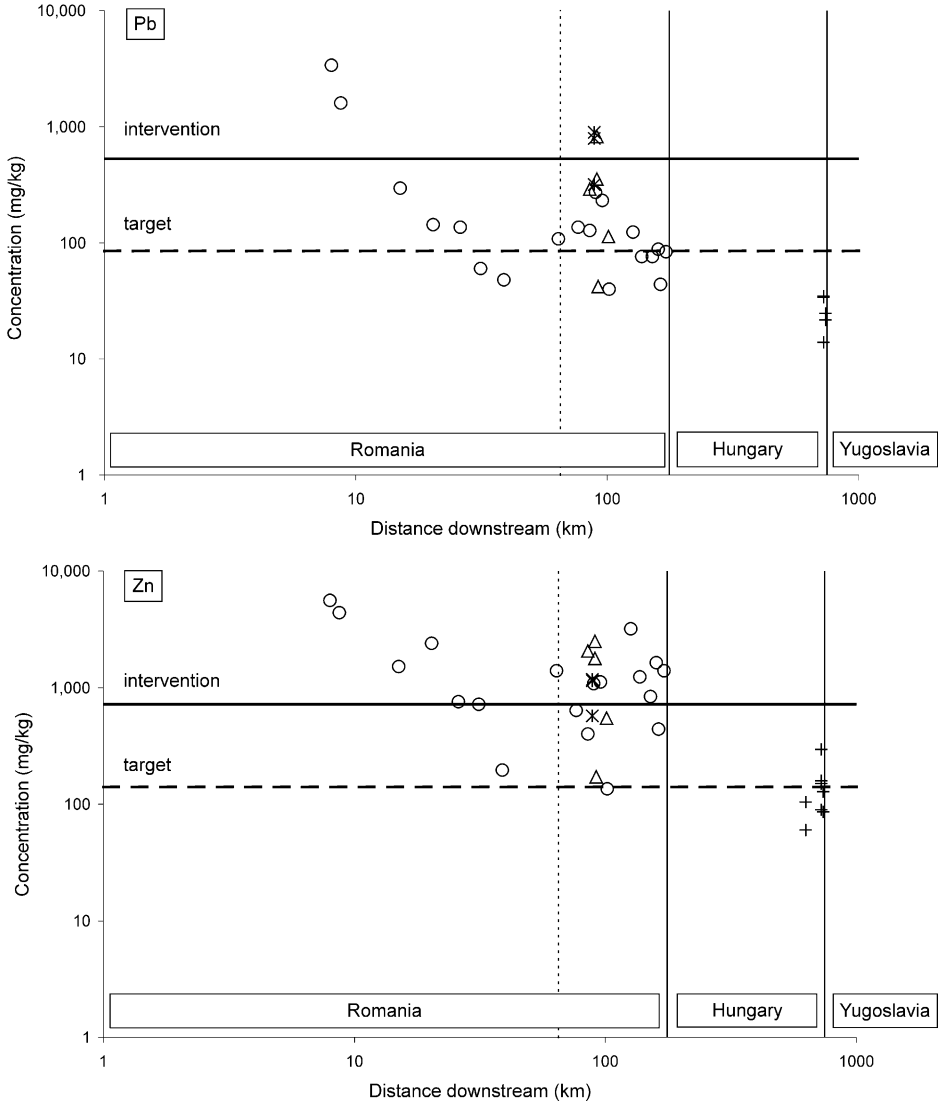

Fig. 9. Downstream changes in river sediment metal concentration for Pb, Zn, Cu and Cd from the source of the Lapuş in Romania to Moldova Veche (Yugoslavian/Romanian border) on the Danube. RIZA data from Knijff et al. (2000).

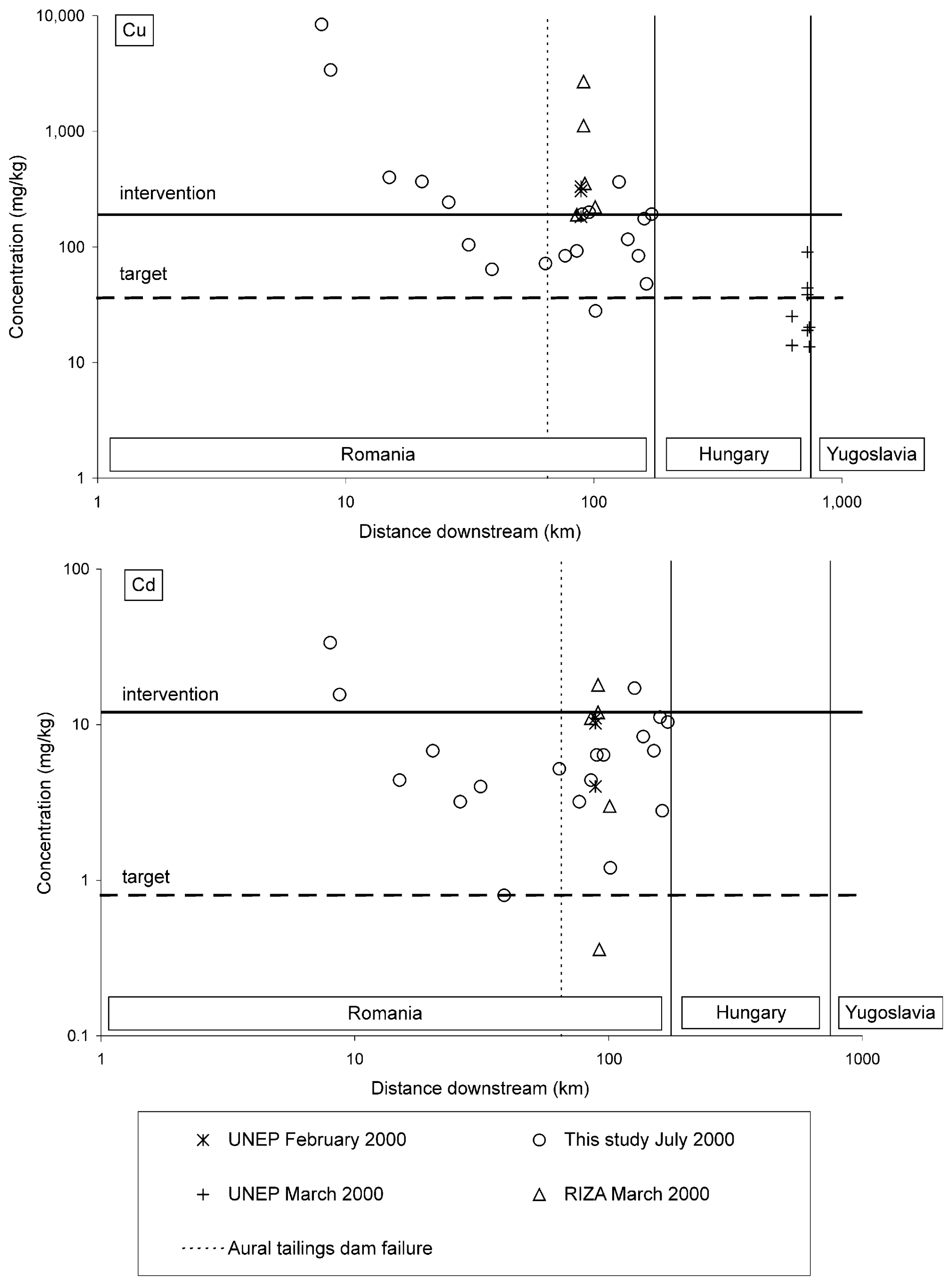

Fig. 9 (*continued*)

elevated immediately downstream of the spill sites, within less than 10 km metal values fall appreciably. Indeed, more widespread contamination is clearly arising from ongoing mining activity in the Cavnic, upper Lapuş, Sasar and Tisla catchments. While not downplaying the short term ecological effects of the spills, they should be seen more as compounding much longer term problems associated with many decades of poorly regulated, and largely untreated, industrial, mining and urban discharges into local rivers.

An ecologically robust and cost effective remediation program is urgently needed for Maramureş County to ensure that a balance is achieved between environmental protection and sustainable economic development. We are beginning a three year research project to address this which will involve first, identifying the precise sources of sediment-associated metals within the Lapuş/Someş and Vişeu/Tisa catchments, using geochemical, mineralogical and isotope finger-printing techniques, and second, mapping the surface and subsurface distribution, and storage, of contaminant metals in river valley floors and floodplains. We anticipate that these data can then be used in numerical models to simulate sediment-associated metal contaminant transport and to forecast downstream heavy metal dispersal rates and patterns arising from historical mining activity and recent tailings dam failures in northwest Romania.

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