Interpretation of spatial distribution of sediment toxicity data

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Abstract

Sediment plays a central role in ecosystem processes. Contaminated sediment may pose a serious risk, affecting ecosystem health in many ways, seriously damaging restoration and rehabilitation measures. A wide variety of methods are available by which sediment contamination can be assessed, in most cases chemical and biological methods are combined. While chemical analysis is focusing on the potential exposure, ecotoxicity testing and biological survey are estimating the potential and actual ecological effects. None of these methods alone are able to provide a firm basis for environmental decision making. In this study the potential of spatial analysis of environmental data to characterize contamination distribution, to identify hot spots and to link toxicity data to contamination concentration/sources is illustrated. For demonstration we have selected two case studies, both are of practical importance.

Keywords: sediment contamination, toxicity assessment, ToxAlert, risk mapping

1. INTRODUCTION

Sediment is a key structural and functional component of any aquatic ecosystem. Toxics in the sediment play a secondary source of contamination, posing risk to aquatic biota long after the primer source had disappeared. Toxic contaminants can be present in the sediment in many forms: they can be bound to the sediment particles and can be dissolved in the so-called pore water. Therefore, biotic components of the ecosystem can be affected in a different way. Firstly, sediment-dwelling organisms can be exposed to toxics directly, in other word, they are in direct contact with contaminants. Some sediment-dwelling taxa play an important role in keeping the ecosystem healthy: for example, larvae of midges (family Chironomidae) live in the sediment, and when they emerge they remove all the nutrients from the lake they have built in. Fish feeding on

such organisms might be exposed both directly and indirectly. Indirect exposure means consuming contaminated organisms. Plants rooting in contaminated sediment might accumulate toxics, contributing to exposure pathways. Toxics being present in the pore water might escape to the water, posing risk to not only those organisms which are in contact with the sediment but for all elements of the ecosystem.

It seems obvious that mapping sediment contamination is a very important tool either for assessing environmental health or for establishing remediation measures. Environmental authorities might need to rank contaminated sites and to establish target remediation objectives for dredged material.

Standard analytical methods are available to provide an accurate measurement on the concentration of a given contaminant (exposure assessment). On the other hand, toxicity tests are focusing on the potential effect of the contaminant or of the contaminated medium. However, either analytical tools or toxicity tests alone might fail to accurately determine ecosystem health: analytical measurements do not give any information on the bioavailability of the contaminant in question while toxicity testing gives an overall measure of the ecotoxicity of the medium, not distinguishing natural and anthropogenic factors. In general, if toxicity is occurring, measured values should be related to exposure or to some indicative measure of exposure (e.g. MacDonald and Ingersoll, 2002). Seemingly, the simplest way of doing that is to calculate correlation between contaminant concentrations and toxicity. An alternative approach can be to determine the relationship between the occurrence of toxicity (e.g. toxicity measured is well above levels considered significant) and sources of contaminants (such as effluents, spills, etc.) (Suter, 1996).

In the decision making process communication of the results is of crucial importance. Risk is most often reported as a single value, neglecting the spatial nature of risk. Risk assessment must deal with a diverse set of data, including multiple contaminants sampled from multiple locations at different intervals. However, it is very difficult to summarise and interpret these data in a format applicable for decision-makers. Communication may be enhanced by spatial analysis and visualization (Bertazzon et al., 2000). In this study the potential of spatial analysis of environmental data to characterize contamination distribution, to identify hot spots and to link toxicity data to contamination concentration/sources is illustrated. For demonstration we have selected two case studies, both are of practical importance.

2. TOXICITY ASSESSMENT IN THE SÓS-TÓ OF SZÉKESFEHÉRVÁR AS A PRE-RECONSTRUCTION TOOL

Sós-tó (the name means Salt Lake) is a degraded wetland in Székesfehérvár. Its degradation has been partly caused by drying out, partly by uncontrolled sewage load which had been piped till March 2000. Due to the sewage effluent significant sediment disposal had occurred and presence of diverse pollutants can be expected. On behalf of the Major's Office of Székesfehérvár considerable efforts have been made to take rehabilitation measures. 4 alternative concepts have been elaborated for the complex restoration of the area, partly to restore its wetland functions and partly to ensure its wise use (ForEnviron, 2002). The common element of all concepts is to raise water level by using external water supply, restoring a wetland with open water. As sediment contamination might damage the success of the rehabilitation, our basic aim was to make an ecological risk assessment to get a complex view about what risk sediment

contamination might pose to the success of any future rehabilitation work, using different parameters to characterise contamination level.

2.1 Analysis of the sediment samples

Sediment samples were collected in two series. The first series was collected on 30th September, 2003, at this time the lake was completely dry (Fig. 1.). The second series was collected on 7th April, 2004, after a rainy winter and spring period the lake was under water (Fig.2.). GPS coordinate were recorded on the field using an e-trex Vista GPS.

Fig.1. The Salt Lake in autumn 2003 ….

Fig.2. … and in spring 2004.

The first series was collected for screening purposes, and only toxicity was measured. In spring 2004 a more comprehensive study was initiated, and besides

toxicity, other environmental parameters were measured such as BOD, COD, TOC, TSS and NO_3^--N.

Toxicity of the sediment samples was measured using ToxAlert®100 luminometer. The test uses bacterial bioluminescence which is a rapid indicator of the metabolic status and of the viability of the cell. The enzyme involved in the process is bacterial luciferase. A toxic substance will cause changes in some cellular structures or functions such as the electron transport system, cytoplasmic constituents or the cell membrane, which are directly reflected in a decrease in bioluminescence.

During the test luminescent organisms are exposed to aqueous samples, and the light output of the luminescent bacteria is measured before and after they have been challenged by a sample. A difference in light output between the sample and the control is attributed to the toxicity of the sample on the organisms. The ToxAlert®100 luminometer calculates the inhibition effect (H_t) of the samples automatically in % values.

Although some authors question the relevance of the test organism, being a marine bacterium, sensitivity and applicability to test sediment toxicity is widely demonstrated and accepted (e.g. Guzzella et al., 1993, Burton et al., 2001a). However, as it is the case with all ecotoxicological tests, sensitivity varies according to the contaminant. It is partly due to the acute nature of the test: short term assays may not be able to detect the toxicity of high K_{ow} compounds as they are more slowly desorbed (Burton et al., 2001b). The test is more often recommended for screening purposes (e.g. Bennett and Cubbage, 1992).

BOD, COD, TOC, TSS and NO_3^--N were measured by a *Secomam* Pastel-UV which is a portable UV analyser for water quality. It is a rapid, multiparametric measuring set. The traceability of the measured components is based on the analysis of UV absorption spectra of the samples.

For toxicity assessment and for BOD, COD, TOC, TSS and NO_3^--N analyses aquaeous solutions had to be used. Elutriates were prepared by Hungarian Standard MSZ 21470/2-81:1982.

2.2 Results of sediment contamination assessment

Toxicity of the first series of sediment samples collected in autumn 2003 is shown in Table 1.

Table 1: Toxicity measured in autumn, 2003.

Number of sediment sample	Inhibition %		Number of sediment sample	Inhibition %	
	15 min	*30 min*		*15 min*	*30 min*
1	9.20	22.25	7	2.05	7.15
2	8.80	10.45	8	-0.20	3.85
3	-13.35	-9.20	9	-1.75	-6.50
4	6.70	5.75	10	4.50	6.25
5	-3.30	-0.70	11	11.05	13.95
6	7.70	12.90	12	1.20	2.90

Table 2 gives an overview of sediment samples collected in spring 2004, indicating all environmental parameters measured.

Table 2: Contamination of sediment samples collected in spring, 2004.

Number of sediment sample	Inhibition %	NO_3^-- N	TSS	COD	BOD_5	TOC
	30 min	*mg/l*				
E1	60.55	49	430	650	250	190
E2	54.85	46	460	560	130	100
E3	58.20	52	470	670	230	180
E4	61.15	50	950	2100	1200	950
E5	57.05	53	630	830	240	180
E6	61.50	48	500	610	140	100
E7	59.75	48	520	670	180	140
E8	59.40	48	550	750	250	190
E9	55.00	48	500	620	150	110
E10	60.40	47	590	870	310	240
E11	58.90	52	260	700	460	380
E12	56.00	47	580	1000	470	370
E13	60.90	51	450	650	220	170
E14	51.65	48	470	670	230	180
D1	40.30	46	310	380	90	100
D2	48.80	48	770	1080	360	280
D3	47.90	48	460	570	130	100
D4	51.85	50	230	390	170	140
D5	41.10	43	190	230	50	100
D6	46.35	42	380	470	110	100
D7	53.75	25	510	630	160	110
D8	23.65	28	250	310	70	100
D9	40.30	24	570	930	410	320
D10	45.75	24	400	480	11	100
D11	45.60	23	330	480	170	130
D12	46.80	24	380	460	100	100
D13	58.70	25	1700	3850	2250	1800
D14	45.20	77	210	1580	1160	94

Toxicologists generally call a sample toxic when the bioluminescence inhibition exceeds 20%. The data below 0 means the sample had stimulating effect on the test organisms.

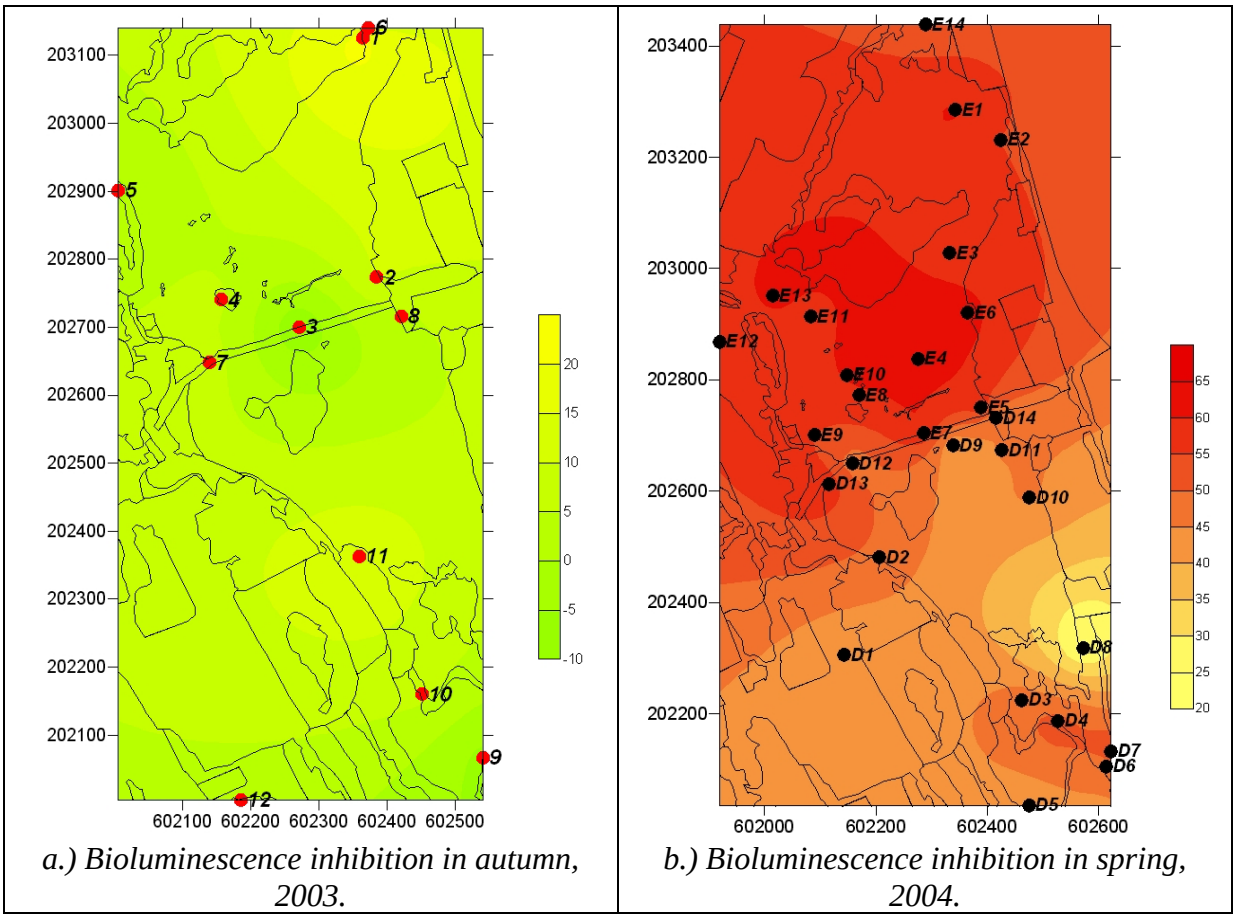
2.3 Interpretation of temporal distribution of data measured

There are striking differences between the two series of measurement. As it was mentioned already, in autumn 2003 the area was completely dry, but in spring 2004 it was under water. The fact that practically no toxicity was detected during the first measurement and in contrary, during the second measurement bioluminescence inhibition was well above 20% may be explained by a shift towards anaerobic conditions. It is also a possible explanation that toxic compounds had been dissolved.

2.4 Interpretation of spatial distribution of data measured

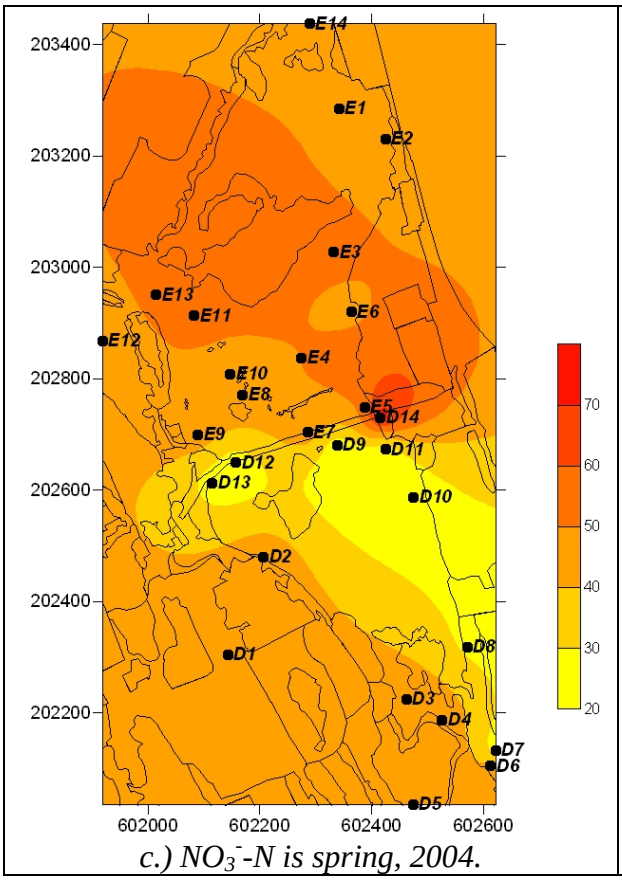
The measured data were pictured by Surfer8. It's a very user-friendly contouring and 3D surface mapping program by *Golden Software*. Isocline maps produced are shown in Fig. 3.

Fig.3(a) shows the result of 2003 autumn assessment, when sampling was made under dry conditions. The 2004 spring assessment simulates post-restoration conditions much better, thus we make our conclusion on the basis of the second series of measurements. At the first glance effect (toxicity) and exposure (BOD_5, COD, TOC, TSS, NO_3^--N) do not show a clear correlation. Toxicity reflected as bioluminescence inhibition shows a rather uniform spatial distribution in the northern part of the lake (Fig.3(b)). However, toxicity itself is an aggregate parameter, reflecting the so-called matrix effect (Overton et al., 1997). Natural processes might also be responsible for the presence of toxic agents. For example, sulphur, which is produced during the microbial oxidation of sulphide, can be found in anaerobic sediments (Jacobs et al., 1992). On the other hand, most of the analytically derived values of contaminants (BOD_5, COD, TOC, TSS) are in good correlation with each other, delineating the most polluted zones as can be seen in Fig.3(d), (e), (f) and (g). Creating a map where information regarding both exposure and effect is visualised, overlapping zones will clearly identify hot spots. Such a map can be seen in Fig.3(h). This map was created by aggregating exposure and effect data. Considering the history of the area, hot spots are probable sinks of organic pollution, posing risk to the area even after sewage effluent was terminated.

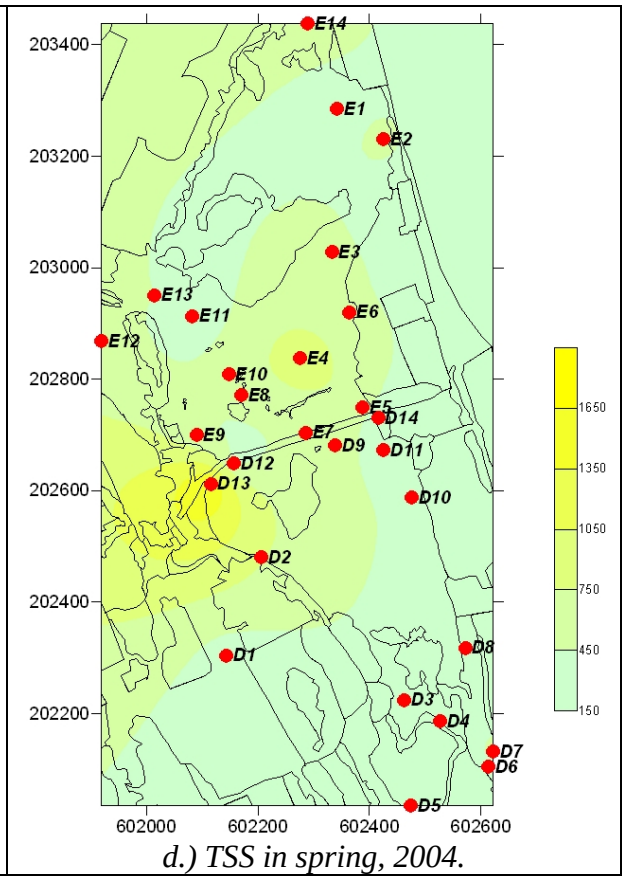


a.) Bioluminescence inhibition in autumn, 2003.

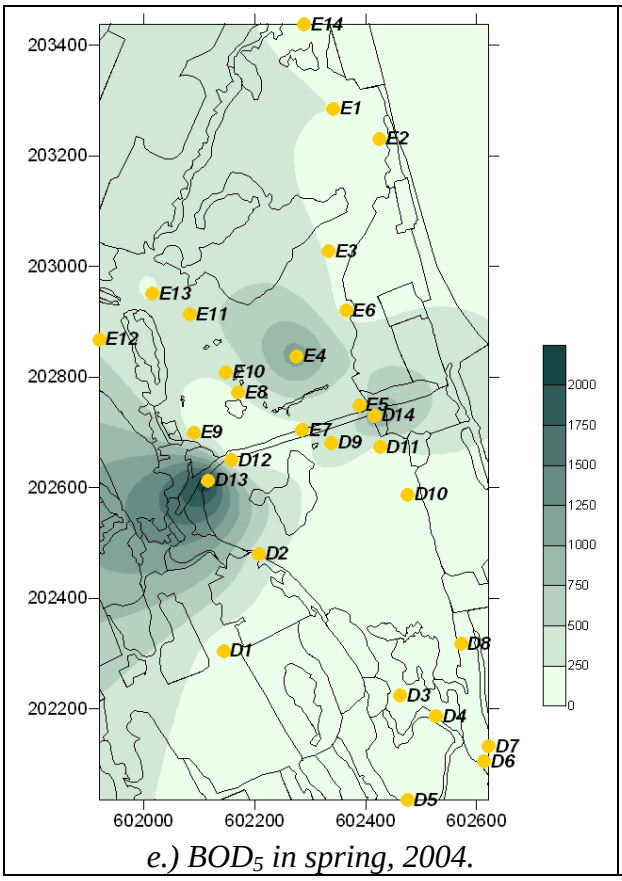
b.) Bioluminescence inhibition in spring, 2004.



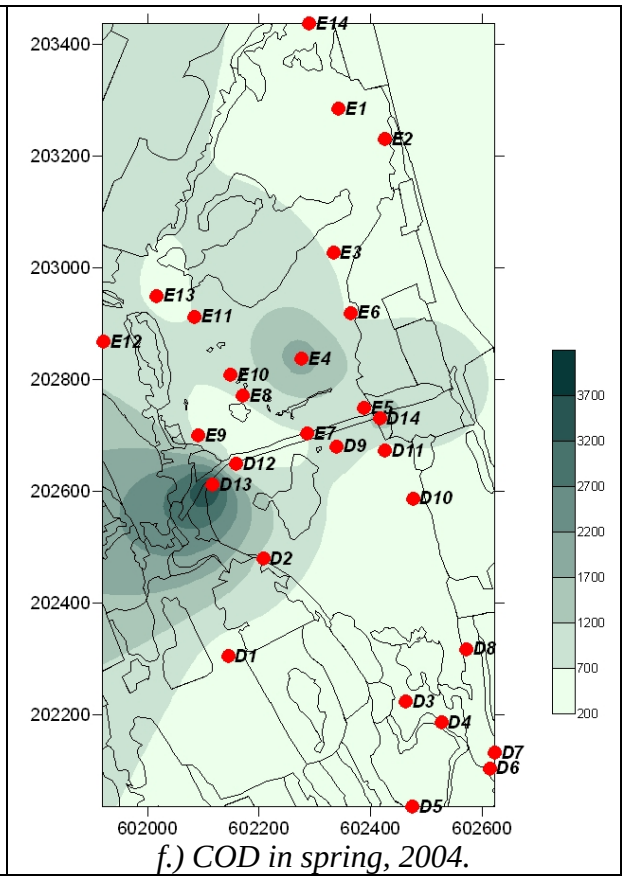
c.) NO_3^--N is spring, 2004.



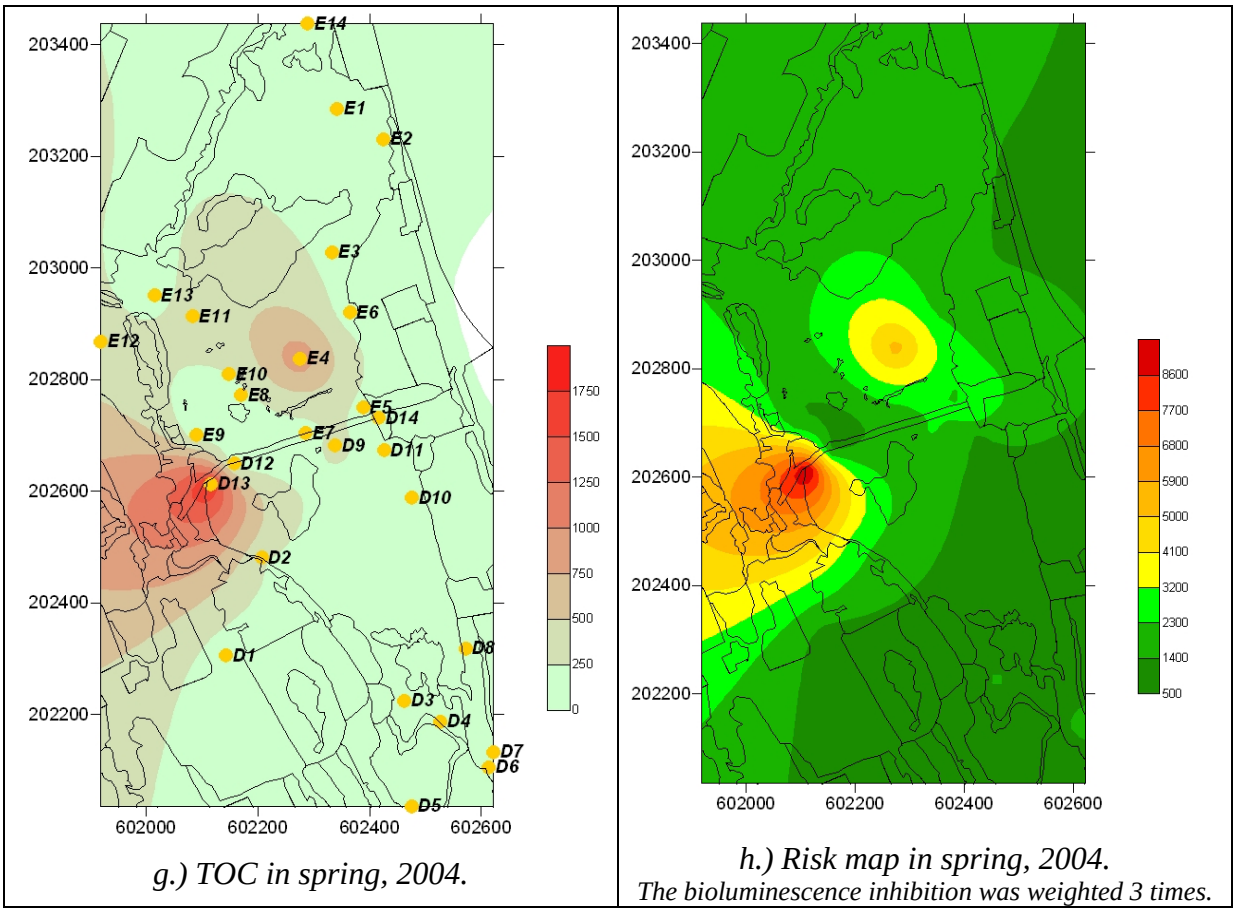
d.) TSS in spring, 2004.



e.) BOD_5 in spring, 2004.



f.) COD in spring, 2004.



g.) TOC in spring, 2004.

h.) Risk map in spring, 2004.
The bioluminescence inhibition was weighted 3 times.

Fig. 3. Contour maps

The difference between the nitrate-nitrogen and the other maps can be explained by the adsorption range of the Pastel-UV.

3. MAPPING TOXICITY IN THE KIS-BALATON WATER PROTECTION SYSTEM

Lake Balaton and the Kis-Balaton Water Protection System are situated in the western part of Hungary (Fig. 4.). Main function of the system is the protection of the water quality of Lake Balaton, by retenting most of the nutrients and suspended solids carried by River Zala and other, small watercourses. The system is in fact made up of two reservoirs. The first part, the Hídvégi Pond was completed in 1985. The second part, the Fenéki Pond has been partially operating since 1992.

Between 1986 and 1997 the first reservoir, Hídvégi Pond retained app. 78 000t of suspended solids, 290 t of TP, in which 250 t of phosphate and 800 t of TN (Tátrai et al., 2000). The second reservoir, Fenéki Pond retains app. 75% of suspended solids coming from the first reservoir. However, these figures were calculated on the basis of input carried by River Zala regarded as a point pollution source. Load carried by small watercourses and other, mostly non-point sources such as agricultural runoff were not taken into consideration.

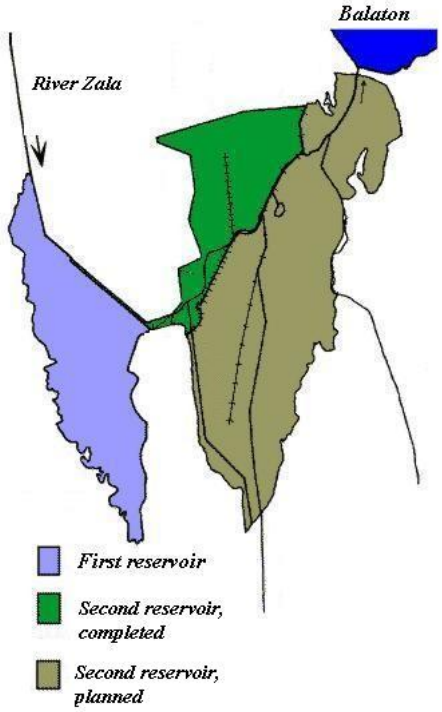


Fig.4. Location of Lake Balaton and the Kis-Balaton Water Protection System.

3.1 Analysis of the sediment samples

Fig.5 shows the sampling spots in the second reservoir. As a baseline map we used the digital ortophoto provided by the West Transdanubian Water Authority, Dept. Kis-Balaton. The infrared imagery reflects vegetation conditions: the more intense the red colour is, the more intense photosynthetic activity is attributed.

Toxicity of the samples was determined using ToxAlert as described above. Bioluminescence inhibition values measured are given in Table 3.

Table 3: Toxicity of sediment samples collected in the Kis-Balaton Water Protection System.

Number of sediment sample	Inhibition %	
	15 min	*30 min*
1	75.05	72.63
2	59.05	54.90
3	37.15	34.35
4	45.25	69.70
5	71.78	65.37

3.2 Spatial distribution of toxicity data measured

Toxicity values are also indicated in Fig.5. In the case of sampling spots 1-2, 4-5, in order to characterise a bigger area, several samples were taken, in the map average of these subsamples is shown. It is clearly visible that in River Zala (1) bioluminescence inhibition is very high, 72.63%. Toxicity is somewhat reduced (54.9%) at the point where the river reaches the second reservoir (2) and goes under further reduction (3). Sampling spot 4 shows high toxicity again, 69.7% and no toxicity reduction is experienced after that point (5).

One possible explanation is that agents causing sediment toxicity are mostly carried by watercourses. Contamination carried by River Zala is retained within the second reservoir, as the trend 1 → 3 shows. However, small watercourses might also pose serious risk to the system; one of them is the Hévíz-Páhoki Canal (4) and high toxicity experienced afterwards (5) can be attributed to this extra load. However, we cannot neglect the occurrence of background toxicants, so-called biochemicals, extracted from the marsh biomass (Overton et al., 1997).

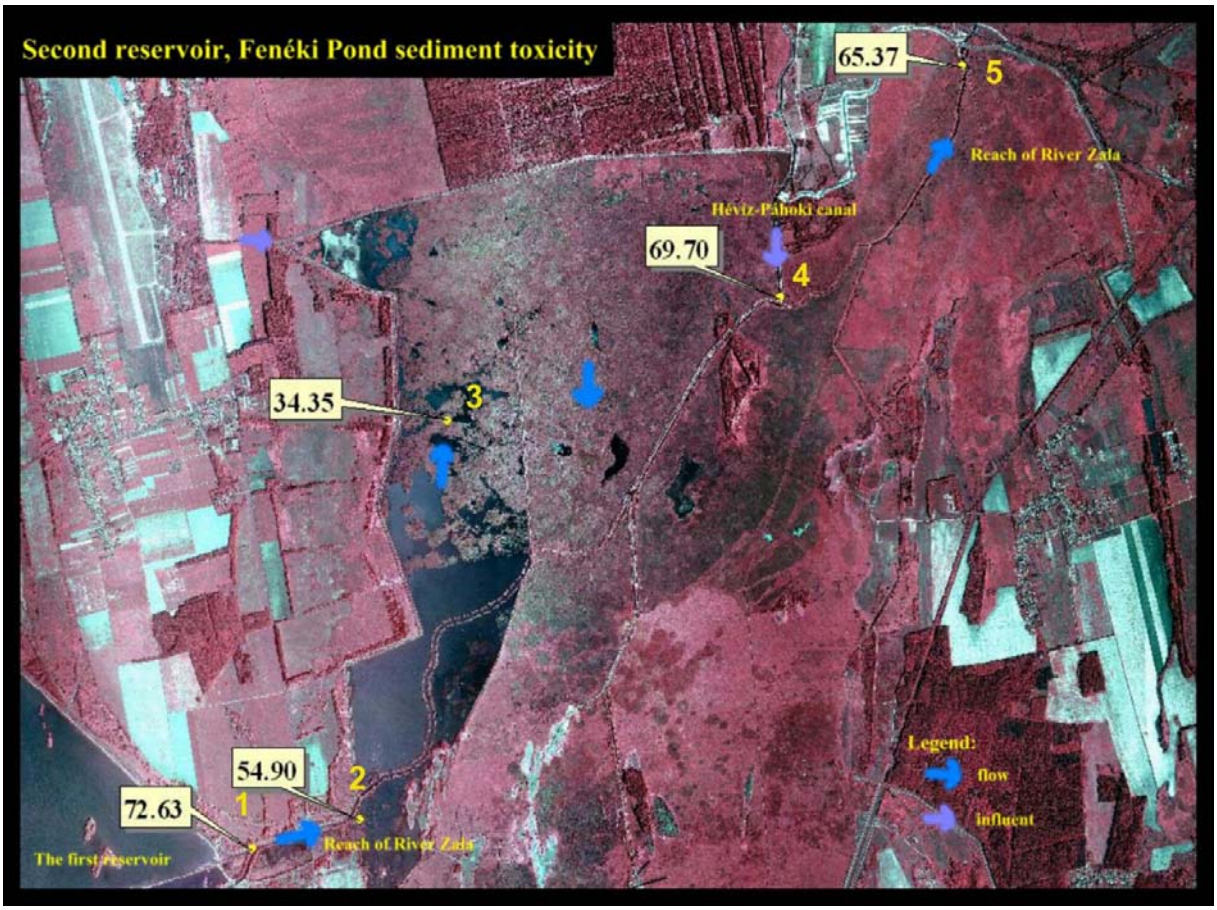


Fig.5. Sampling spots in the Kis-Balaton Water Protection System, indicating sediment toxicity measured.

4. FINAL CONCLUSIONS

Ecotoxicological tests involve several uncertainty factors (e.g. Cairns, 1993). The aim of this paper is not to discuss the inherent uncertainty of toxicity testing, rather to give guidance how to interpret toxicity values. As it was mentioned already in the introduction, establishing causality is a must if we wish to incorporate toxicity assessment in the decision making process.

The outcome of the Sós-tó case study is a risk map where both exposure and effect (toxicity) data are aggregated. Such a map is a ready-to-use tool for decision makers: not only hot spots can be identified requiring direct management measures to be taken but also, relative risk zones can be delineated.

In the case of Kis-Balaton Water Protection System, spatial distribution of toxicity data is linked to the supposed contamination sources and to the direction of contamination dilution. In this later case it is strongly emphasized that sampling and analysis should be done in an iterative manner, to distinguish background toxicity from ecological risk posed by inflow waters.

5. REFERENCES

Bennett, J., Cubbage, J. (1992). Review and Evaluation of Microtox® Test for Freshwater Sediments. Environmental Assessment Program Report, 92-e04

Bertazzon, S., Carlon, C., Critto, A., Marcomini, A., Zanetto, G. (2000). Integration of spatial analysis and ecological risk assessment in a GIS environment. The case study of the Venetian lagoon contaminated sediments. 4th International Conference on Integrating GIS and Environmental Modeling (GIS/EM4): Problems, Prospects and Research Needs. Banff, Alberta, Canada, September 2 - 8, 2000.

Burton, G. A. Jr. (1991). Assessing freshwater sediment toxicity. *Environ. Toxicol. Chem.,* **Vol. 10:** 1585-1627 pp.

Burton, G.A. Jr. (1992). Sediment Toxicity Assessment. Lewis Publishers. Boca Raton, 457 pp.

Burton, G. A. Jr., Baudo, R., Beltrami, M. and Rowland, C. (2001a). Assessing sediment contamination using six toxicity assays. *J. Limnol*., **60 (2):** 263-267 pp.

Burton, G. A. Jr., Pitt, R. & Clark, S. (2001b). The Role of Traditional and Novel Toxicity Test Methods in Assessing Stormwater and Sediment Contamination. *Critical Reviews in Environmental Science and Technology,* **Vol. 30 (4)**

Cairns, J. (1983). Are single species toxicity tests alone adequate for estimating environmental hazard? *Hydrobiologia,* **100:** 47-57 pp.

ForEnviron Környezetvédelmi és Mérnöki Szolgáltató Kft. (2002). Koncepcióterv a székesfehérvári Sós-tó rehabilitációjához. Budapest.

Guzzella, L., Ross, P., Bartone, C. and Baudo, R. (1993). Toxicity identification evaluation of Lake Orta sediments. I SETAC World Congr. Ecotoxicology and Environmental Chemistry – a Global Perspective. Lisbon, Portugal, March 28-31, 1993. Abstract Book: abstr. 108.

Jacobs, M.W., Delfino, J.J., and Bitton, G. (1992). The Toxicity of Sulphur to Microtox® from Acetonitrile Extracts of Contaminated Sediments. *Environ. Toxicol. Chem.,* **Vol. 11:** 1137-1143 pp.

MacDonald, D. D., Ingersoll, C. G. (2002). A Guidance Manual to Support the Assessment of Contaminated Sediments in Freshwater Ecosystems. USEPA, Great Lakes National Program Office EPA-905-B02-001-C, Chicago, Illinois

Overton, E. B. Jr., Henry, C. B., Mendelssohn, I. (1997). Application of Microtox® assay to establish and evaluate the efficacy of *in situ* burning of oiled marshes. Louisiana Applied Oil Spill Research and Development Program, OSRADP Technical Report Series 96-009.

Suter, G. W. (1996). Risk Characterization for Ecological Risk Assessment of Contaminated Sites. Prepared by the Environmental Restoration Risk Assessment Program, Lockheed Martin Energy Systems, Inc., Oak Ridge, Tennessee, ES/ER/TM-200

Tátrai, I., Mátyás, K., Korponai, J., Paulovits, G., Pomogyi, P. (2000). The role of the Kis-Balaton Water Protection System in the control of water quality of Lake Balaton. *Ecological Engineering* **16:** 73-78 pp.