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MODELLING CONCEPTS AND DECISION SUPPORT IN ENVIRONMENTTAL SYSTEMS

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The purpose of the present publication is to popularize information tools and applications of informatics in environmental engineering and environment protection that have been investigated and developed in Poland and Germany for the last few years. The papers published in this book were presented during the workshop organized by the Leibniz-Institute of Freshwater Ecology and Inland Fisheries in Berlin in February 2006. The problems described in the papers concern the mathematical modeling, development and application of computer aided decision making systems in such environmental areas as groundwater and soils, rivers and lakes, water management and regional pollution. The editors of the book hope that it will support the closer research cooperation between Poland and Germany and when this intend succeeds then also next publications of the similar kind will be published.

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CHAPTER 2

Rivers / Lakes

ARTIFICIAL VS NATURAL FLOODING REGIME OF A POLDER IN THE LOWER ODRA VALLEY: SEDIMENTS AND LOADS

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Abstract: *Floodplains act as a „natural trap" for suspended sediment and particle associated substances (i.e heavy metals) carried by a river. Investigating polders – areas separarated by dikes from the river and inundated in a controlled way through inlet and outlet locks – one has the opportunity to determine qualitatively the retention ability of a floodplain area. The effect of floodplains on the selfpurification of a river catchment area can thus be assessed. We investigated the effect of the hydrological flood-regime on particle retention in a periodically inundated polder of the Lower Odra Valley. The flood-regime is characterized by time and duration of inundation. The retention of suspended matter is determined by discharge and load of the inflowing water as well as by sedimentation and transformation processes (basic properties of the flowing particles like settling velocity, density, loss on ignition etc. change on their way through the polder area). A simple input-output model was developed here to assess the sedimentation losses during an inundation period. The model uses (i) data offered by water administration agencies (i.e. daily discharges of the Odra River at polder inflow gauging stations and sediment concentrations of inflowing water) and (ii) data obtained in field experiments (flow velocities and suspended particulate matter (SPM) concentrations at the polder input and output). The retention of particulate matter of the River Odra by flooded areas calculated by the model was verified by sedimentation losses measured in field. For this purpose we used traps which were distributed over the polder area during an inundation period. The settled material from traps was retrievd and subsequently analysed. With the help of the model the impact of a hypothetical natural inundation regime regarding the additional sedimentation and heavy metal load could be assessed.*

Keywords: floodplain, natural inundation regime, Odra River, polder, heavy metal load, sediments.

1. Introduction

In the early 20th century, river-training measures in the Lower Odra Valley resulted in the separation of riparian floodplains from the main river channel. Now dikes surround the prevailing part of the floodplains of the lower Odra River and the areas contained by them, the so-called polders (the inundation of which is regulated by locks) can be used as active flood mitigation reservoirs during high flow. A mancontrolled, artificial inundation regime was installed and the administrative flooding instructions for the German flooding polders („Polizeiverordnung zur Regelung der Wasserwirtschaft im Gebiet der unteren Oder (Wässerordnung)", 1931) have remained unchanged to date. They require open locks between November and April (winter flooding). Additionally, in case of peak river discharge, water is temporarily stored in the embanked polders (summer flooding). During flooding periods, water from the Odra River passes the open locks upstream (polder inlet), and flows through the polder area to the downstream locks (polder outlet) to confluence with the mainstream. In contrast to the artificial flooding regime for the German polders, the Polish polders on the right bank of the Odra River have a natural flooding regime with permanently open locks since the end of World War II.

After the founding of a National Park in the Lower Odra Valley in 1995, the question arises of a change in the traditionally established German flooding regime, which exhibits substantial disadvantages: (i) expensive technical maintenance, (ii) high pumping costs to facilitate agricultural use, and (iii), ecologically damaging, the interruption of meadow bird breeding in the spring through the pumping dry of inundated polder meadows. A flooding regime which avoids seasonal closing of locks and in which the polder inundation depends only on the gauge of the Odra River would be without these harmful side-effects. Nevertheless, it remains unclear which undesirable effects on the polder environment this more natural flooding regime may have. Because the suspended sediments behave differently on the slow-flow area of a flooded polder than on the river main channel, there is a matter retention inside the polder area. Thus, expanded flooding times will cause enlarged sedimentation of suspended particles and the particle-bound substances carried with the flow. The question as to which extent this additional sedimentation can endanger the ecological status of the Lower Odra polders could not be answered until now. Here we attempt to bring forward quantitative arguments, predicting the heavy metal retention inside a Lower Odra flooding polder under "natural" flooding conditions with the help of a model evaluated by extensive field measurements.

Generally, the self-purification process of a river is significantly determined by physical, chemical and biological aspects of matter transport inside regions with low flow velocity (Johnston, 1991). Besides permanently flooded in-channel areas (backwaters and oxbow lakes), seasonal inundated floodplains contribute substantially to suspended matter sedimentation (Nicolas, 2003). Here, the knowledge of the spatial and temporal variability of inundation (Hamilton et al. 2004) as well as the knowledge of sediment characteristics provides a foundation for the management of natural resources. Even in artificial floodplains like polders there is rarely sufficient information about inundation characteristics. In spite of the importance of polder areas, only a few field studies (Engelhardt & Krüger, 1997; Dybkowska-Stefek, 1998; Engelhardt et al., 1999) have quantified their contribution to matter retention in lowland rivers. Being separated by dikes, polders have the adventage of well-defined conditions at the inlet and outlet locks. This was exploited by Engelhardt et al. (1999) when providing an input-output balance of nutrients and plankton in the

Lower Odra in Polder A/B. Collecting water and suspended matter samples at the inlet and the outlet of the investigated polder offered the opportunity to balance the matter retention inside the floodplain. It was shown that between 33% and 70% of the suspended particulate matter (SPM) carried by the inflowing river water was trapped in the polder. Basic properties of the flowing particle ensemble like settling velocity, density, loss on ignition etc. change on their way through the polder area (Engelhardt et al., 1999).

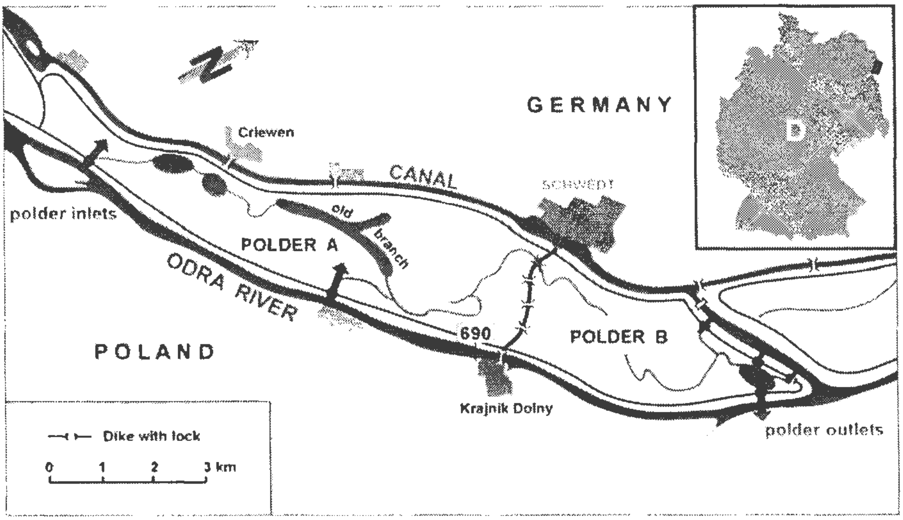

Figure 1. Polder A/B in the Lower Odra Valley National Park.

Here the authors aim at quantifying the sedimentation effect inside Polder A/B of the Lower Odra National Park (figure 1) after the hypothetical implementation of a natural inundation regime. To succeed in assessing this effect of additional flooding,

- firstly, a simple analytical model (CASPRO) to assess sedimentation rates in the polder area was developed, based on existing daily data of water level and suspended sediment concentration of the Odra River water;
- secondly, field measurements for model calibration were performed and implement in the developed CASPRO model (i) to quantify polder inflow/outflow rates depending on Odra gauges, (ii) to measure sedimentation rates for a flooding period, and (iii) to find a correlation between Odra gauge and the flooded area;
- thirdly, measurements of the amount of material sedimented during an inundation period were performed in the field with the help of sediment traps and compared with the calculated sedimentation;
- and fourthly, the percentage of sedimentation growth for a natural inundation regime scenario was computed with the help of the CASPRO model.

2. The CASPRO Model

To assess the amount of suspended particulate matter which settles during a certain time interval inside the inundated polder area, one has to determine the mean discharge of water flowing through the polder and the sedimentation losses between the inflow and outflow. The polder discharge is an (a priori unknown) function of Odra river gauge. The daily values of Odra gauge are available from the local authorities; Waterways and Shipping Administration (WSA Eberswalde).

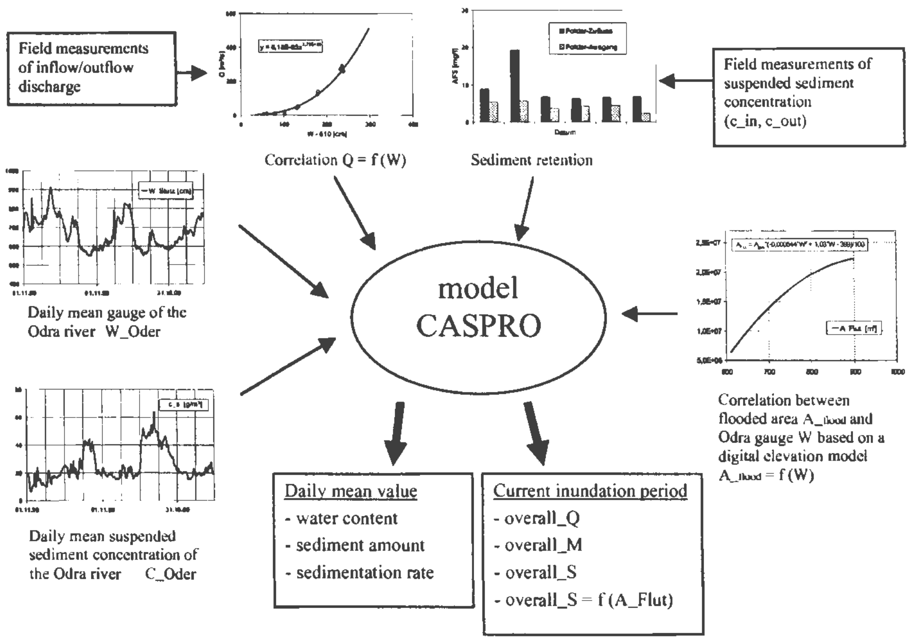

Figure 2. Input and Output parameters included in the CASPRO model.

Whereas water quality data of the Odra River at the polder inlet are available, usually nothing is known about the sediment concentration and the heavy metal load attached to the suspended particles at the polder outlet. If the time of interest spans a whole inundation period (e.g. winter flooding) one cannot assume the inundated area constant over the flooding period because of the changing water gauge (and the polder topography). The CASPRO model (figure 2) consists of different modules which provide the input data (needed for the sedimentation calculation) from data available from common sources. The first module supplies a correlation between Odra gauge and polder discharge which was possible to establish after comprehensive field measurements of flow at polder inlets and outlets. A second module computes the sedimentation losses during the water transit through the polder, also based on field investigations (Engelhardt et al. 1999). A third module determines the correlation between Odra gauge and the inundated area using a digital elevation model of the polder area. CASPRO delivers the daily polder discharge and the daily amount of settled material and provides a time-integration for an arbitrary inundation period.

3. Model correlations

Polder discharge

To obtain the polder discharge as a function of the river water level, measurements of flow velocity and hydraulic radius at each of the polder inlets and outlets (see figure 1) are required for a representative set of Odra water levels. During the inundation periods 1999/2000, 2000/2001 and 2001/2002 vertical profiles of the mean flow velocity were measured at the inlets and outlets of the polder A/B with an inductive current meter. The resulting dependency (figure 3) was used in the in the CASPRO model.

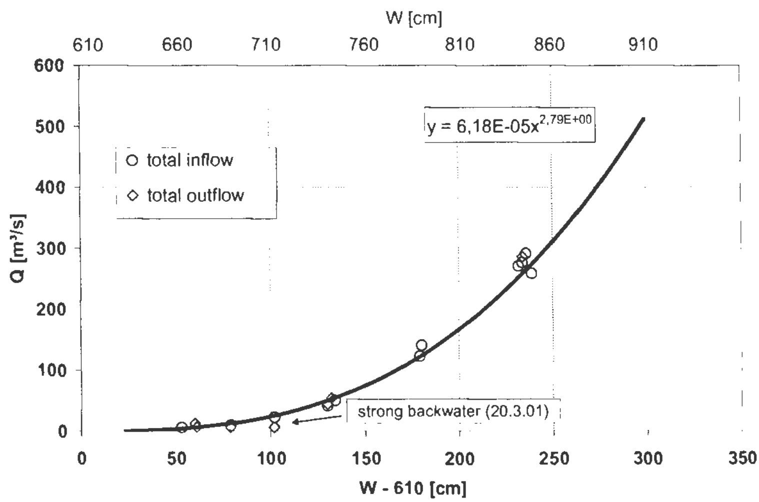

Figure 3. Correlation between measured polder discharge and Odra river water level at inlet gauging station

Sediment budget

Estimates of sediment and heavy metal loads in water masses before and after passing the polder area are required in order to determine the retention capacity of the investigated polder. Thus, at the polder inlet and outlet, samples of water and suspended matter had to be taken considering their residence time in the polder area of about 27 km^2. Whereas inflow characteristics are provided by local authorities (e.g. figure 4; data source: German Federal Institute of Hydrology (BfG)) nothing was known about the loads at polder outflow.

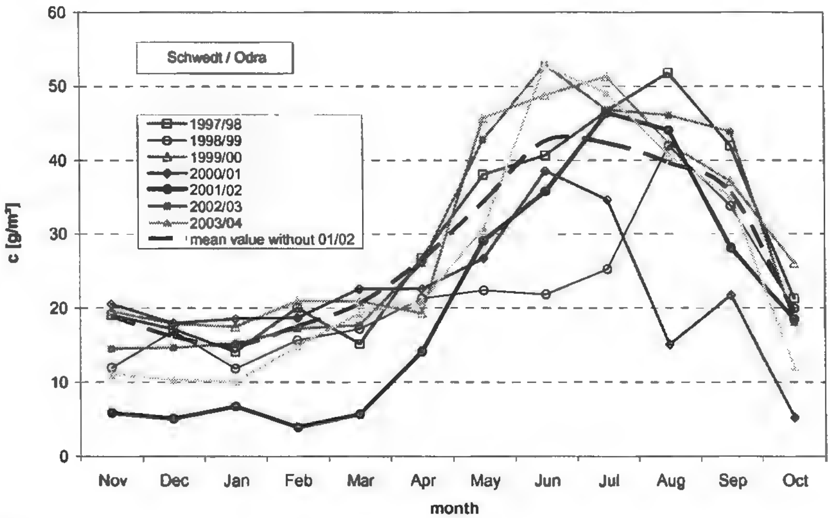

Figure 4. Concentration of suspended sediments (dry weight) in the Lower Odra River at polder inflow. Dotted line shows a mean value of all indicated years except the year 2001/2002 with an outstanding low sediment concentration (thick line).

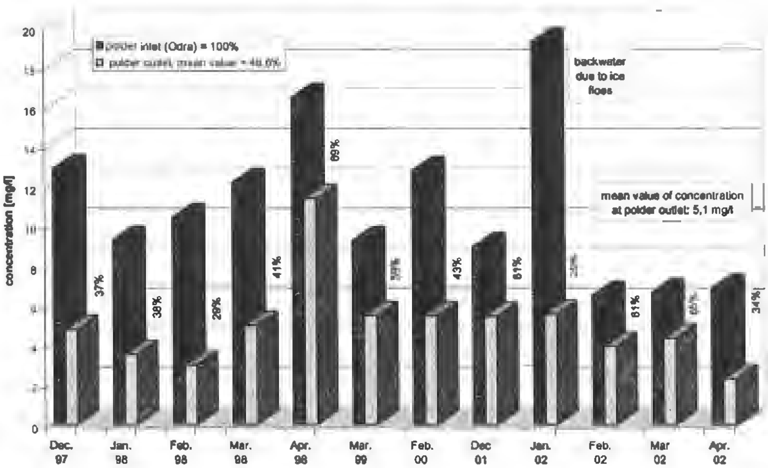

Figure 5. Measured suspended particulate matter concentrations at polder inlet (dark columns) and outlet (light columns).

Here the mean sediment retention of 51% found for the years 1997-2002 (figure 5) was used to recalculate the suspended particulate matter (SPM) concentration at the polder outlet in the frame of the CASPRO model. Methodological details are given by Engelhardt et al. (1999).

Inundated polder area

Polder flooding occurs when two preconditions are fulfilled: firstly, water level in the main channel of the Odra exceeds the base of the inlet locks (e.g. 6.10 m altitude threshold in figure 6) and, secondly, when the polder inlets are opened either because of administrated winter inundation, or when storm-induced, dangerously high water level is reached upstream. In the case of polder flooding, the inflowing river water raises permanently the level of the old branches, oxbow lakes and ponds inside the polder area (see aerial photography below, figure 7) until it overflows adjacent land. The value of the inundated polder area depends on its morphology and should be approximated to be used in the model. Often remote sensing technologies (optical or microwave scanning) were used (Hammilton et al. 2004) to estimate the size of inundation patterns in natural floodplains of large rivers. For the polder investigated here, a digital elevation model was available (Brandenburg Office for the Environment (LUA)) and this comfortable (in comparison with analysis of aerial photography or satellite scanning) tool could be used. The specific correlation between Odra River water level and the inundated area of the investigated polder A/B was chosen (figure 6) using the absolute altitude data at a 5 m x 5 m grid with regard to the digital elevation model. CASPRO calculates the inundation area in correspondence with the shown dependence (figure 6).

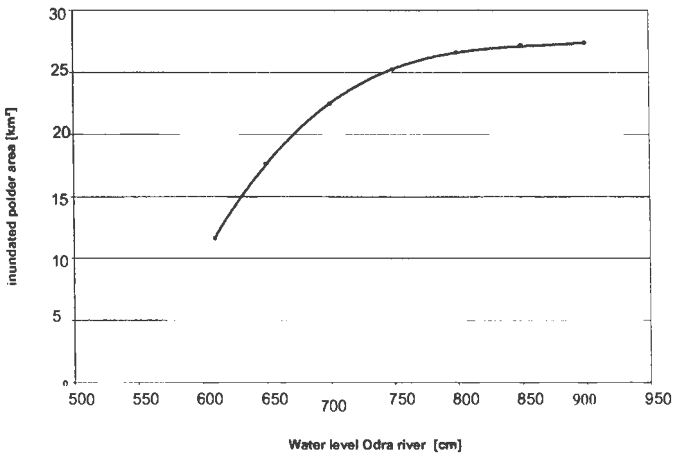

Figure 6. Correlation between flooded polder area and Odra gauge based on a digital elevation model

4. Trap measurements and model calculations

Field measurement during four winter flooding periods (years 1998/99 – 2001/02) were performed in order to compare the sedimentation rate computed by CASPRO with data from sediment traps which were located in up to 17 places (figure 7) at several altitudes inside the polder area before flooding (beginning of November) and retrieved after flooding (mid-May).

Figure 7. Location (dots) of the sediment traps in polder A/B.

The particulate matter which settled during the whole period of winter flooding was collected, dried, weighed and finally analysed in accordance with DIN 38414 S7 (1983). The trapped amount of particulate matter per area was compared with calculated sedimentation rates (figure 8). The latter take into consideration the daily polder discharges and the mean sediment retention in the polder over a decade (figure 5).

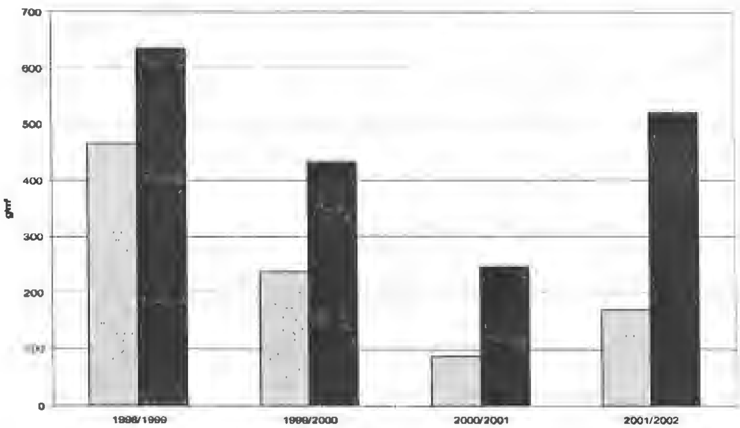

Figure 8. Particulate suspended matter (dry weight per square unit) settled during a winter flooding period in accordance to CASPRO calculation (light columns) and field measurements (dark columns).

Although the general discharge pattern (figure 9) - a decrease for the first three flooding periods and a following rise (2001/2002 period) - trace the sedimentation pattern (figure 8) of the four flooding periods under investigation, it is remarkable that the polder discharge for the flooding period 2001/2002 is the highest, whereas the calculated sedimentation is the second lowest between the four periods. This can be explained by the outstanding low sediment concentration of Odra water between July 2001 and April 2002 (figure 4) which led to sedimentation losses in the polder probably distinct from the mean value (51%) presumed in the CASPRO model. Thus it is clear that the model calculation underestimates the sedimentation rate in 2001/2002, but the unambiguously moderate (in comparison with discharge) sedimentation during this flooding period was confirmed by the results of sediment trapping (last columns in figure 8). When discussing the differences between measured and calculated sedimentation values which 100% exceed in two of the cases, one should keep in mind that the trap measurements only approximate the real net sedimentation values. The sedimentation traps are far from being a precision instrument. Moreover, the amount of trapped suspended matter depends on the number of traps as well as on their positioning. Nevertheless, the study shows that the modelled sedimentation predicts (at least) the scale of the sedimentation process. Thus, this tool will be used to assess the consequences of a natural flooding regime for the Polder A/B.

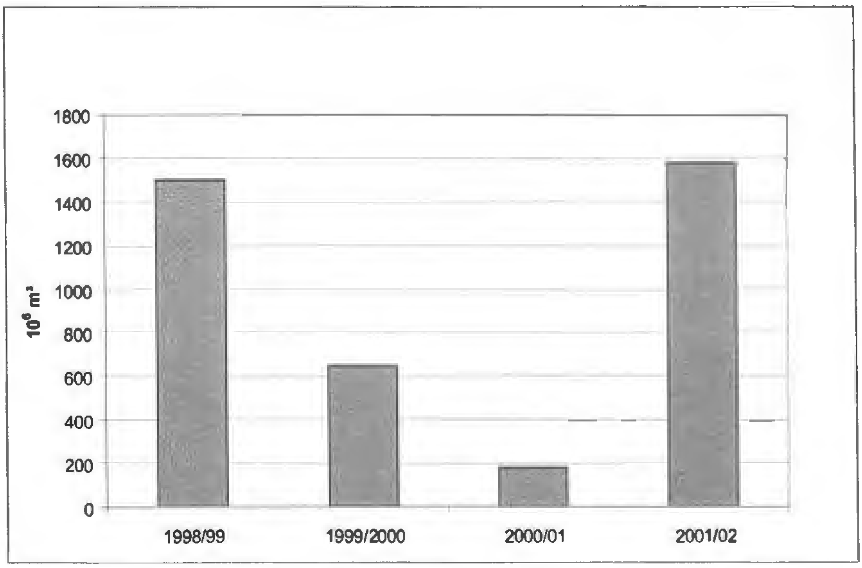

Figure 9. Water volume flowing through Polder A/B during winter flooding periods.

5. A natural inundation regime scenario

The natural flooding regime of a polder is defined by constantly open inlets and outlets, meaning that the inundation dynamics depend solely on the water gauge in the main river channel.

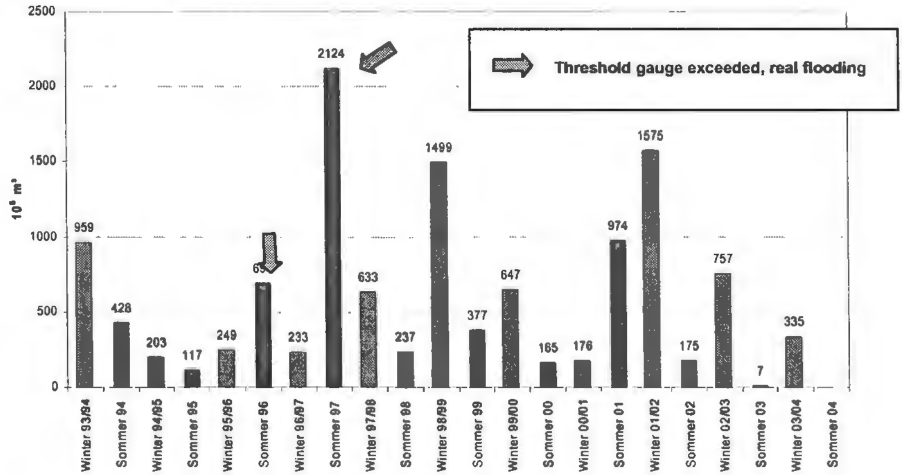

Figure 10. Water volume flowing through Polder A/B during the course of a decade. Winter flooding: November – April; (hypothetical/real) Summer flooding: April – November.

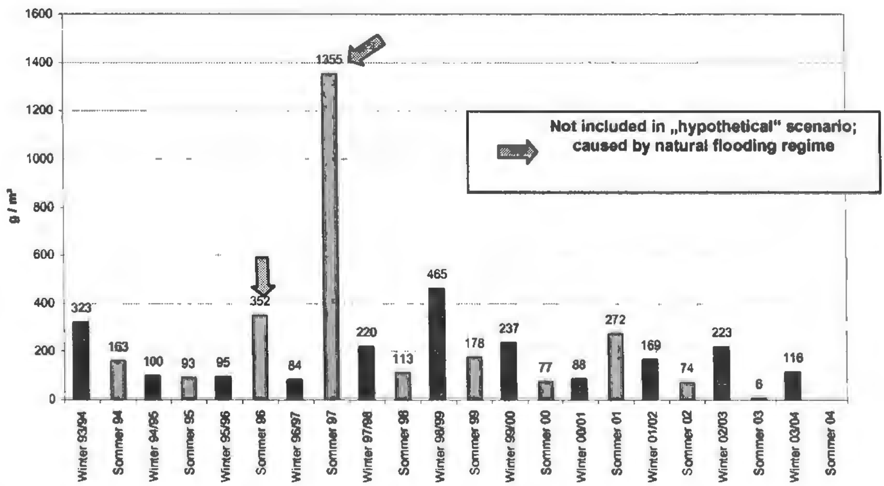

Figure 11. Polder sedimentation rate during the course of a decade. Winter flooding: November – April; (hypothetical/real) Summer flooding: April – November.

To quantify the difference between the existing artificial and a hypothetical natural inundation regime it is necessary to predict sedimentation for time periods during which the locks are closed according to the still existing rules. To realise that, data collected between winter 1993/1994 and 2003/2004 were used to calculate the polder discharge (figure 10) and sedimentation (figure 11) for the whole decade with the CASPRO model. The additional effect of a natural inundation regime is given by the summer columns except those indicated by arrows in figures 10 and 11. In these cases the exceeded threshold level in the Odra River postulates open locks already in compliance with the "Wässerordnung"of 1931

Thus, in the case of a natural inundation regime the total amount of particulate matter settled in polder A/B between 1993-2003 results in 123 kt, whereas sedimented matter equals only 99 kt when the existing artificial inundation regime is assumed. The modelled difference of approximately 2500 t sediment per year is an additional exposure affecting the polder ecosystem because of the suspended sediment`s anthropogenic load. Especially the heavy metal content of the suspended particulate mater input from the Odra River could be dangerous for the agricultural activities in the polder area (Höhn et al., 2000). To answer the question how harmful the additional sediment exposure is, the heavy metal load of sediments captured in the sediment traps between 1998 and 2002 was measured according to DIN 38414 S7 (1983) and compared to threshold values for floodplain soils and sewage sludge (table 1).

Table 1. Mean load for selected heavy metals of sedimented matter trapped in Polder A/B during four flooding periods (see figure 7).

	Hg µg/g	Cd µg/g	Pb µg/g	As µg/g	Cu µg/g	Zn µg/g
Mean concentration	0.76	2.43	65.12	22.03	47.03	550.5
Limit soil*	1	6	500	20	500	2000
Limit sludge *	6	10	1000	-	800	2200

*Berliner Liste, Richtwerte für Böden Kat. II, Urstromtal

6. Conclusions and outlook

A natural inundation regime would cause approximately 20% enlarged sedimentation inside the investigated polder A/B (in average over the last decade). At the same time the sediment load of the Odra River (and thus the input into the Baltic system) would be reduced by about 2.5 kt suspended sediments per year. The deposited river sediments do not exceed the German limits for heavy metal concentrations in soil and even sewage sludge, which can be used for agricultural fertilization. Nevertheless, it is bioavailability that counts, not concentration, when the heavy metal effect should be assessed. Bioavailability differs between different organisms, depending on feeding groups and life strategy, thus this topic needs further research. Direct comparison of the heavy metal content in plants from the Polish and the German polder areas after more than 60 years of different flooding regimes would answer the question of harmfulness of a natural flooding regime.

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Jan Studzinski, Olgierd Hryniewicz (Editors)

MODELLING CONCEPTS AND DECISION SUPPORT IN ENYIRONMENTAL SYSTEMS

This book presents the papers that describe the most interesting results of the research that have been obtained during the last few years in the area of environmental engineering and environment protection at the Systems Research Institute of the Polish Academy of Sciences in Warsaw and the Leibniz-Institute of Freshwater Ecology and Inland Fisheries in Berlin (IGB). The papers were presented during the First Joint Workshop organized at the IGB in February 2006. They deal with mathematical modeling, development and application of computer aided decision making systems in the areas of the environmental engineering concerning groundwater and soil, rivers and lakes, water management and regional pollution.

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