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ODRA 1997 FLOOD EFFECTS ON SOIL PROPERTIES OF CULTIVATED AREAS IN GERMANY

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Abstract. During the 1997 summer flood of the river Odra, a small cultivated area of 50 km^2 was flooded in the German part of the catchment. The flood completely killed the vegetations stands on the fields. Afterwards, the effects of the flood on the ecological properties of the soils and on the conditions for agricultural production had to be evaluated. A study was conducted to estimate the flood effects on heavy metal concentrations and on the nutrient status of the soils.

The sediment layer left from the flood had a thickness of less than 3 mm. The heavy metal concentrations within this layer were below legal limits valid in Germany. Thus, no restriction had to be announced for food production purposes. Regarding the nutrient status of the flooded soils, only the mineral nitrogen content was substantially reduced when compared to not flooded soils. This effect could most probably be related to denitrification processes as a result of anaerobic conditions during the flood. Despite the nitrogen losses, the effects of the flood on agricultural management conditons were minor. However, hydrological and land use management concepts have to be developed that help to reduce the probability of such flood events in future.

Keywords: flood effects, heavy metal concentration, soil fertility, denitrification

INTRODUCTION

The 1997 summer flood of the river Odra was the highest flood ever measured for the 854 km long river. Two consecutive rainstorm fields, one of about 460 - 513 mm rainfall amount during 5 days covering the upper part of the catchment, and a second one of about 90 mm amount during 4 days covering almost the entire catchment led to runoff responses that flooded almost 10 % of the total area of Poland [2].

About 5 % of the 118 000 km^2 catchment area is located in the north-east part of the state of Brandenburg, Germany. During the 18th and 19th century this area was damned for cultivation purposes of the lowland soils which are the most fertile in the state of Brandenburg. Following a major flood in 1947 the dam was reconstructed and enlarged. However, immense human and technical activities were required during the 1997 flood to support the dam structures and to prevent the lowland areas from being flooded. Dam failures only occurred at two adjacent dam locations leading to flooding of an 50 km^2 isolated area, the so called „Ziltendorfer Niederung". The flood in this cultivated area lasted for about 7 weeks with a water table of about 1.5 m maximum height. Due to water logging, the vegetation stands on the cultivated fields were completely killed.

The consequences of the flood for the farmers consisted of harvest losses and the destruction of agricultural infrastructure. Additionally, long term effects on the cultivation conditions of the soils were expected that could result from soil pollution due to sedimentation of pollutant enriched material and from changes of the nutrient status of the soil. These effects had to be estimated within a short time span, since they might have affected decision making concerning the management practices for the subsequent vegetation period. The objective of our study was therefore to determine the impact of the flood on the fertility and the ecological properties of the flooded soils in order to provide a quick estimate of flood effects on the conditions for agricultural production in the flooded area. We focused on two effects: (i) the possible enrichment of the soils with heavy metals following the sedimentation of polluted material, and (ii) the changes of the nutrient status of the soils due to leaching effects on the one hand and sorption or biologic transformation during anaerobic conditions on the other hand.

MATERIALS AND METHODS

Site characteristics

The 50 km^2 area of the „Ziltendorfer Niederung" is located in the German part of the lowlands of the River Odra south of the city of Frankfurt/Oder with an average height of 23 - 26 m above sea level. Dam constructions in the 18th and 19th century allowed for the cultivation of a previously periodically flooded area. The average height of the area is now about 2 m below the mean water level of the river. Drainage systems keep the ground water level deeper than 0.8 m below the surface.

The floodplain soils are characterised by layered horizons being a consequence of the periodic flooding with consecutive sedimentation of material. Soil texture ranges from sand to loamy clay with a pronounced short range vertical and horizontal variability. Most of the soils have hydromorphic properties.

The main crops of the cultivated area are grain crops, canola, and corn. The flood occurred in July shortly before the harvest of most crops. Therefore, the vegetation stands were high on most of the fields. The flood lasted for about 7 weeks with a water table of about 1.5 m maximum height that completely killed the vegetation stands.

Sampling design and measurement methods

Two major effects of the flood on the soil properties were expected: (i) an increase in the heavy metal content as a result of the sedimentation of heavy metal enriched material, and (ii) a change in the nutrient status of the soils as the result of sorption and desorption on the one hand, and biologic transformation, i.e., denitrification due to anaerobic conditions on the other hand.

Since the objective of the study was to provide results the farmers could use for decision making concerning the forthcoming management activities, the time span for conducting the study was short and the number of samples that could be analysed was restricted. We therefore decided for a screening type study involving two steps: 1st a field survey that gave us an overall estimate of the spatial variability of sediment deposition and physical status of the soil, and 2nd soil sampling for further analysis at those locations that were found to be of interest during the field survey.

To determine the risk of heavy metal enrichment, the heavy metal concentration of the sediment layer resulting from the flood was measured. The concentration of heavy metals in the solid soil phase was determined in an aqua regia solution. The nutrient status of the soils was determined by taking samples in 0 - 30 cm depth. For these samples, the pH-values (in $CaCl_2$-solution), cation exchange capacity (CEC), plant-available phosphorus, potassium, and magnesium (all double-lactate method) as well as the mineral nitrogen content (Nmin, photometric determination in $CaCl_2$-solution) was measured. Nmin measurements were also conducted in 30 - 60 cm soil depth. The number of samples taken for each measurement are listed in Table 1. Each sample consisted of a mixture of 15 subsamples from a 40 m^2 area within the field.

A problem evolved due to the fact that for estimating the flood related changes of the soil properties, reference measurements of not flooded conditions were required. Naturally, no samples were taken immediately prior to the

Table 1. Description of the sampling design to determine the heavy metal concentration and the nutritient status of the soils after the flood

Parameter analysed	Sampling depth	Number and location of samples taken from flooded areas	Number and location of reference samples
Elements: As, Se, Mo, Cr, Zn, Pb, Co, Cd, Ni, Cu, Al, Sr	Sediment layer 0 - 3 mm	3 samples from flooded fields	1 sample from a continuosly flooded field
pH, K, P, Mg	0 - 30 cm	98 samples from 11 flooded fields	98 samples from the same 11 fields; but sampled in October 1996
Cation exchange capacity (CEC)	0 - 30 cm	42 samples from 4 flooded fields	5 samples from 1 not flooded field
Mineral nitrogen content (Nmin)	0 - 30 cm 30 -60 cm	24 samples from 10 flooded fields taken for each depth	4 samples from 2 not flooded fields taken for each depth

flood, since the event was not expected. We solved the problem by either taking reference samples from locations not flooded but having soil properties comparable to those that were flooded, or by comparing the measurements with results derived from sampling the soil at the same locations one year earlier. The method used for comparing the measurements is also summarised in Table 1.

RESULTS AND DISCUSSION

Heavy metal concentration

According to the field survey, the sediment layer derived from the flood in the 50 km^2 area had a maximum depth of 3 mm. The concentration of selected heavy metals and other elements analysed from 3 sediment samples is listed in Table 2. As a reference, the element concentration of a sediment sample taken from a regularly flooded area outside the dam as well as the legal limits for heavy metal concentrations valid in Germany are listed in Table 2.

Results of the sediment analysis show that the concentrations of the elements cadmium, molybdenum, and selenium were below the limit that could be detected with the method applied. None of the elements had a concentration that exceeded the legal limits according to the sludge disposal legacy for cultivated soils (AbfKlärV, 1992). This legacy is used in Germany to determine the threshold values of heavy metal concentrations in soils above which the application of waste water sludge as a fertiliser is not permitted. The results of heavy metal concentration analysis in general coincide with those derived from flooded areas in Poland. Karczewska [7] and Weber *et al.*, [10] reported heavy metal concentrations of the sediment from flooded areas that also were below critical values. However, in those regions the sediment layer was up to 10 mm and was therefore higher than in our study area [7].

The comparably low heavy metal concentrations of the sediment samples and the very thin depth of the sediment layer (< 3 mm) lead to the conclusion that in terms of heavy metal pollution no risk must be expected for agricultural production in the flooded area. However, the very limited number of samples analysed implies a factor of uncertainty and warrants further investigation, which is currently underway.

In Table 2 is listed, as a reference, the heavy metal concentration of a sediment sample taken outside the dam at a location that is regularly flooded. In this case, most of the elements had much higher concentrations than those measured within the dam. The concentration values measured for cadmium, copper, and zinc exceeded the legal limits (AbfKlärV, 1992). High

Table 2. Concentration of some heavy metals in 3 sediment layer samples and in 1 reference sample

Element	Element concentration (mg/kg)					
	Samples of 3 mm sediment layer				Reference sample*	Legal limit**
	# 1	# 2	# 3	Mean		
As	6.9	6.8	7.4	7.0	18.4	*20*
Cd	< 0.5	< 0.5	< 0.5	< 0.5	1.8	1
Co	6.9	8.6	7.0	7.5	10.8	*50*
Cr	32.2	35.8	35.7	34.6	44.7	100
Cu	15.3	14.1	13.6	14.3	66.0	60
Mo	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	*5*
Ni	18.1	19.4	18.4	18.6	21.5	50
Pb	25.5	21.2	22.4	23.0	72.6	100
Se	< 3	< 3	< 3	< 3	< 3	*10*
Zn	76.6	69.7	63.3	69.9	446.9	200
Sr	39.3	35.1	34.5	36.3	29.6	-
Al	20691	22196	23216	22034	10255	-
Mn	730.3	764.5	542.1	679.0	1407.7	-

* reference sample from a regularly flooded area

** legal limit according to the German slugde disposal legacy (AbfKlärV, 1992) or (in Italic) according to the "Kloke-list" (GABl, 1980), respectively.

concentration of heavy metals in the sediment of European rivers have often been measured and is a subject of environmental concern.

Nutrient status of the soils, pH values, and cation exchange capacity (CEC)

The results from soil analysis in terms of the plant-available potassium, phosphorus, and magnesium content and the pH-values for 10 fields are listed in Table 3. In these cases, the measured values from the flooded fields could be compared with measurements conducted on the same fields, one year earlier. To isolate the effect of the sampling date (1996 vs. 1997) on the soil properties, one not flooded field was also sampled and analysed. All numbers are mean values derived from 6 to 11 replications for each field according to the respective field size.

Results show that in most cases the amount of plant-available phosphorus and magnesium was decreased on the flooded fields. The decrease was not pronounced and was within the yearly variation caused by fertiliser application and plant uptake. However, contrary to the results derived from the flooded fields, the values of phosphorus and magnesium had increased on the non flooded field number 1.

The amount of plant available potassium was increased after the flood in most of the fields. When related to the soil volume of the Ap-horizon, the increase in the potassium content from an average value of 11.7 mg / 100 g soil in 1996 to an average value of 15.5 mg / 100 g soil in 1997 would be equal to an additional value of about 200 kg potassium per ha. Two explanations for the increase of the potassium content might be possible: (i) the saturation of the soil might have resulted in the widening of smectitic clay minerals and thus release of previously fixed K, and (ii) according to the farmers reports large fertiliser storage buildings have been flooded resulting in the dissolution of the stored fertilisers within the flood water. The latter might also be the reason for the increase in the phosphorus and magnesium content on some of the fields. However, the measured changes in the potassium content were also within the range of yearly variation due to fertilisation. None of the changes were significant at the 5 % confidence level. Therefore, the conclusion is drawn that in terms of the plant available contents of phosphorus, magnesium and potassium, the flood did not have a pronounced effect on the nutrient status of the soils and on the management conditions for the fields.

Table 3. PH - values, plant available phosphorus, potassium and magnesium (mg/100 g dry soil) measured for 10 fields in 1996 (before the flood) and in 1997 (after the flood)

Field #	pH		P		K		Mg	
	1996	1997	1996	1997	1996	1997	1996	1997
1*	6.5	6.3	8.2	11.4	11.1	32.6	9.7	12.0
2	6.7	5.8	7.8	6.3	10.3	14.8	10.7	12.7
3	6.2	6.0	6.6	6.5	10.1	16.1	16.9	14.1
4	6.4	6.1	6.3	5.0	8.1	12.8	14.8	14.0
5	6.3	6.0	6.7	4.5	7.3	15.0	20.0	18.1
6	6.3	6.3	8.0	4.6	29.4	22.6	19.3	18.2
7	5.8	6.0	6.1	6.4	7.7	6.9	10.0	10.1
8	5.7	5.8	6.7	7.6	14.9	18.1	9.7	7.2
9	6.1	5.8	6.6	4.1	8.3	17.5	19.6	18.6
10	6.4	5.8	5.7	3.5	9.6	15.4	12.7	13.0
Mean**	**6.2**	**5.9**	**6.7**	**5.4**	**11.7**	**15.5**	**14.8**	**14.0**

* field # 1 was not flooded in 1997
** mean values of field # 2 to # 10.

The pH-values were decreased on most of the fields after the flood when compared to the conditions before the flood (Table 3). The same trend was measured for the other set of samples listed in Table 4. This table also contains the mean values of the cation exchange capacity as well as the relative contribution of several cations to the CEC measured for 42 flooded and for 5 not flooded soil samples. The CEC of the flooded soil samples was 6 mval /100 g higher in average than that of the not flooded samples, respectively. However, due to the pronounced variation of the clay content in the different soil samples the CEC values were within a wide range varying between 9 and 38 mval /100 g soil (not shown in the table). The relative contribution of the different cations to the CEC might therefore be a better basis for comparing the situation of the flooded and not flooded soils. Although the differences of the relative cation contributions to the CEC were not significant at the 5 % level, clear trends could be detected. Monovalent and divalent cations contributed to a higher degree and the contribution of protons was lower in the flooded soils when compared to the not flooded soils, respectively. The displacement of protons into the solution was in agreement with the results from pH measurements which also showed lower pH-values on the flooded soils. One reason for the decreased pH-values in the flooded soils might have been anaerobic fermentation processes that took place during water logging conditions. The increase of the relative contribution of cations to the CEC might be explained with the same factors already stated above: (i) the displacement of protons by cations, mainly K^+, that were released from clay minerals due to widening during saturated conditions, and (ii) the increased cation availability as a consequence of the flooding of the fertiliser storage. Therefore, the results derived from pH and CEC measurements and the direct measurement of plant available nutrients are in general coincidence.

Table 4. Cation Exchange Capacity (CEC) and relative contribution of the elements K, Na, Ca, Mg, H^+ to the CEC

Number of samples	CEC (mval /100g dry soil)	Relative contribution to the CEC (%)					pH
		K	Na	Ca	Mg	H^+	
5 not flooded	18.0	1.5	1.5	80.0	6.1	10.8	6.4
42 flooded	24.0	2.5	3.0	81.6	7.7	2.9	6.1

But the measured differences between the flooded fields and the not flooded fields or between the two sampling data were low. The conclusion is therefore drawn that no appreciable effects of the flood on the fertility conditions of the soils were detected.

Mineral nitrogen content (Nmin)

The mineral nitrogen content Nmin had been measured for 24 samples from flooded fields and for 4 reference samples from not flooded fields. The nitrate contents derived for the 2 different soil depths are listed in Table 5. The nitrate content expressed in kg / ha was calculated from the measured values assuming a soil density of 1.5 g/cm. The ammonium content was below the value of 0.05 mg /100 g dry soil for all samples.

In most of the samples derived from flooded fields, the nitrogen content was appreciably lower than that in the not flooded fields. This result was more pronounced in the 0-30 cm soil layer than in the subsoil layer. Two explanations might be given for the nitrate loss due to the flood event: (i) the dissolution of nitrate in the flood water and the removal with the flood wave, and (ii) the denitrification of nitrate due to anaerobic conditions during the flood. The first explanation might not have accounted for a major amount of nitrogen removal, since nitrogen concentrations in surface runoff are usually found to be appreciably lower than in subsurface soil water [8]. Given the vegetation and weather conditions during the flood, the second explanation might be more reasonable: the air temperature was above 20°C, and the high vegetation stands on the fields being killed due to water logging provided a source of easily decomposable carbon. This together with the anaerobic conditions during the flood might have triggered the denitrification process [4]. Similar effects have frequently been observed for other areas as a result of flood events or water saturation due to high intensity irrigation [3,6,9]. The denitrification process might have been less pronounced in the subsoil because of the lower availability of decomposable carbon in this soil volume.

A conservative estimate accounting for the uncertainties resulting from the limited number of samples and the high variability of the measured values would give an average value of about 30 - 50 kg NO_3^--N per ha lost as a result of the flood. These nitrate losses the farmers had to take into consideration for the planning of the coming up management activities.

Table 5. Mineral nitrogen content of flooded and not flooded soils

Field number #	NO_3^- - N (mg / 100g dry soil)		NO_3^- - N (kg / ha)	
	0 - 30 cm	30 - 60 cm	0 - 30 cm	30 - 60 cm
1 not flooded	2.94	2.32	132	104
2 not flooded	2.08	0.85	94	38
1 flooded	0.35	0.34	16	15
2 flooded	1.52	1.02	68	46
3 flooded	1.75	1.25	79	56
4 flooded	0.70	0.76	31	34
5 flooded	2.31	1.36	104	61
6 flooded	2.23	1.57	100	71
7 flooded	1.04	0.58	47	26
8 flooded	1.62	0.80	73	36
9 flooded	2.83	1.13	127	51
10 flooded	0.42	n.d.	19	n.d.
Mean flooded	**1.48**	**0.98**	**66**	**44**

n.d. - not determined

SUMMARY AND CONCLUSIONS

The objective of our study was to determine the impact of the flood on chemical properties of the flooded soils in order to provide a quick estimate of flood effects on the conditions for agricultural production in the flooded area. We focused on two possible effects: (i) heavy metal enrichment in the sediment, and (ii) the changes of the nutrient status of the soils.

The sediment layer left from the flood was less than 3 mm thick in most of the area. The concentration of heavy metals within this layer was below legal limits for heavy metal concentrations valid in Germany.

Concerning the nutrient status of the soils, reduced phosphorus and magnesium contents and increased potassium contents were measured in the soils of the flooded areas. The pH-values as well as the relative contribution of protons to the CEC were also reduced. Although these results could be explained with flood related processes such as anaerobic fermentation, release of cations out of swollen smectitic clay minerals, enrichment of fertilisers due to flooded fertiliser storage, the changes of the nutrient status were within the range of yearly variations.

The mineral nitrogen content was appreciably reduced in the soils of the flooded areas. This effect could most probably be related to denitrification processes as a result of anaerobic conditions during the flood. The nitrate losses were estimated to be about 30 kg N/ha on average, a number the farmers had to consider in the fertilisation planning for the following crops.

The conclusion is drawn that the effects of the recent flood on the conditions for agricultural production in the 50 km^2 area „Ziltendorfer Niederung" were minor. For the farmers, the most detrimental effects of the flood were the direct harvest losses and the destruction of agricultural infrastructure. Despite that, the farmers could proceed with the usual management activities. However, given the major damage and social costs the flood caused in the entire catchment, measures are urgently needed that help to reduce the probability of such flood events in future. The development of sustainable solutions aiming not only at reducing the effects of the flood, but aiming predominantly at reducing the probability of flood events requires a better understanding of the physical nature of rainfall - runoff relationships as well as of the effects of land use systems on the hydrologic response of the catchment as a whole and in its parts. Then, the political conditions for public incentive programs to support land use changes that reduce runoff production have to be evaluated. Multinational co-operation and mutual research activities are of paramount importance for success in this research field.

REFERENCES

1. AbfKlärV - Klärschlammverordnung. Bundesgesetzblatt, Jahrgang 1992, Teil I, S. 912 - 934, 1992.
2. **Dubicki A.:** Flood in the basin of upper and middle part of Odra river. In International Seminar: Alleviating the needs of specific rural area damaged by the summer floods 1997. Lublin and Wroclaw 24-29.03, 1998.
3. **Engler R.M., Patrick W.H.:** Nitrate removal from floodwater overlying flooded soils and sediments. J. Environ. Qual., 3: 409-413, 1974.
4. **Frede H.G., Gebhardt H. ,Meyer B.:** Größe, Ursachen und Bedingungen von Boden- und Dünger-N-Verlusten durch Denitrifikation aus dem Ap-Horizont einer Acker-Parabraunerde aus Löß. Göttinger Bodenkundliche Berichte, 34, 69-213, 1975.
5. GABI: Kloke-Liste. Erlaß des Ministeriums für Ernährung, Landwirtschaft und Forsten, Baden-Würtemberg über Schwermetallbelastungen von Böden. AZ 24-2310 /3, 1980 .
6. **Humphreys E., Melhuis F.M., Xi Z.B., White R.J.G., Muirhead W.A.:** Flood irrigation of wheat on a transitional red-brown earth. II. Effect of duration of ponding on availability of soil and fertiliser nitrogen. Austr. J. Agric. Res., 42: 1037-1051, 1991.
7. **Karczewska A.:** Effects of the flood in July 1997 on the soils of Lower Silesian arable lands and allotment gardens. In International Seminar: Alleviating the needs of specific rural area damaged by the summer floods 1997. Lublin and Wroclaw 24-29.03, 1998.
8. **Lowrance R.:** Nitrogen outputs from a field-size agricultural watershed. J. Environ. Qual. 21: 602-607, 1992.
9. **Schnabel R.R., Stout W.L.:** Denitrification loss from Pennsylvania floodplain soils. J. Environ. Qual., 23: 344-348, 1994.
10. **Weber J., Drozd J., Licznar M.:** Characteristics of soils subjected to flood in July 1997 at the region of Lubsza comunnity - situation after 5 months. Int. Agrophysics, 12, 249-257, 1998.