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Eco-system-modelling for a German Lowland River: Input generated by an artificial flood event

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ABSTRACT: The Water Framework Directive of the European Union introduces a new approach to a most cost-effective and sustainable way of any measures to water resources and their management. The necessity of comprehending the influence of re-mobilised (contaminated) sediments on the quality of the aquatic environment increases rapidly. Data for eco-system-modelling was obtained through several field methods (topographic data, hydrologic data, and granulometrical data). An artificial flood event was initiated using an existing weir to gather suspended sediment data. A model of the Karthane reach was compared with discharge and water levels given from the controlled flood by primary numerical modelling with Hec-Ras® and SRH-1D®. To simulate the flow under steady and unsteady conditions in the investigated river reach a grid was generated. Data transfer into ETH Zurich's software Basement® leads to an eco-system-model for the German lowland river Karthane in order to get a projection not only based on specific reference conditions for categorised water bodies but to include diversified structures of the lowland river due to natural changes or renaturation measures.

Keywords: Re-mobilised Sediments, Eco-System Modelling, European Water Framework Directive, Sustainable River Basin Management

1 INTRODUCTION

The Water Framework Directive of the European Union aims to achieve a good status in all European waters using biological, physical, chemical and hydro-morphological parameters within a sustainable context in association with sediment and biota (Borja, A. et al., 2004), i.e. a new approach to a most cost-effective and sustainable way of any measures to water resources and their management is introduced by the Water Framework Directive.

With the survey of the European water bodies limitations to the ecosystems were identified and it was displayed that hydro-morphological deficits limit the aquatic ecosystem in most cases. Heavily modified water bodies are substantially changed in character due to hydro-morphological alterations and should at lest reach a good ecological potential, i.e. a ecological status should only slightly lower than the best one that could be achieved without significant adverse effects on the environment.

Since the implementation of the framework it has been discussed whether the influence of aquatic sediments are taken into account in a sufficient manner, i.e. the increasing impact of sediments as carrier and potential source of pollution is regarded adequately. Sediments are regularly discussed in respect to maintain navigability and safety against flooding, to stabilise bed and water levels, to model effects of measures and sediment management, to maintain the morphology itself and to quantify morphodynamics (Sieben, 2009). As hydraulic analysis concentrates on investigating hydrology in combination with geomorphology (sediment data) and geology (channel dimensional characteristics) to analyse features of erosion or deposition of the channel at the moment the research should be extended to gain predication about remobilised sediments in river reaches to balance the aquatic sediment as source of water pollution (Koonce, 2008).

Non-point emissions, fugitive air immersion loads or sewage disposals lead to massive entry of pollutants particularly during flood events. Cohesive sediments (also referred as suspended sediments or fine sediments) tend to adhere pollutants and to re-suspend them when transported during flood events. Deterioration of aquatic sediments results in degradation of the whole freshwater ecosystem (Owens et al., 2005). The attributes of sediments can be divided into four particular issues: memory effect, life support, secondary source and final storage.

Subsequent impacts on the ecological status of water bodies are introduced by hydro-morphological alterations. As sediments are an integral and dynamic part of water bodies' remediation methodologies as well as preceding risk assessment shall be part of a sustainable sediment management. It is, therefore, important to gain an extensive knowledge about sediment - water interactions, and cohesive sediment behaviour in particular (Förstner, 2004).

Currently there is a lack of application - orientated methods dealing with cohesive sediments and their impact on freshwater ecology. Comprehension of the dynamics, as well as predicting river evolution, is a remarkable issue in the study of water quality. Beside the analytic procedures, eco - system - modelling helps to analyse the effect to the structure of the aquatic ecological system by means of the sediments and leads to a combination of simulation technologies and measuring techniques. Although this is more or less unnoticed until now the necessity of understanding the influence of (contaminated) sediments on the quality of the aquatic environment increases rapidly.

The morphological development of aquatic ecological systems including path tracking of cohesive sediments by modelling the transport of fine sediments of a lowland river is performed to analyse alternative measures to improve the water body structure. To support the coherent implementation of the European Water Framework Directive observing and transferring the common implementation strategies agreed by the European Commission and the member states the sediment contemplation is significant for a sustainable development of water resources and the whole environment.

2 INVESTIGATED RIVER REACH

The investigation area is located in the north-western part of Brandenburg (Germany). It contains a 1.3 km long reach of the lowland river Karthane (which is an Elbe tributary). The area is predominantly used for agriculture and grassland. Therefore a multitude of barrages and drains are used for irrigation and drainage. Several fishponds and the connection to Plattenburg's moat, which is located 2.5 km upstream the studied river reaches, form a massive sediment trap. Today's appearance of the river Karthane and the lowland is the result of heavy man-made impacts.

The river Karthane identified as a heavily modified small surface water body offers trapezoidal and v-profiles with steep slopes (1:3) free of groves. The total length of the Karthane is approximately 48 km, their total drainage basin covers about $A_{Drainage\ basin} = 425\ \text{km}^2$. The largest tributary is the Cederbach, which drains a basin of $A_{Drainage\ basin} = 117\ \text{km}^2$ and reaches the Karthane about 2.1 km downstream the study reach. The studied river reach was chosen due to the existing weir (river km 0+010) representing the beginning of the investigated section.

3 HYDRLOCIGAL AND SUSPENDED SEDIMENT DATA COLLECTION

Neither continuous data collection of suspended sediment nor detailed river bed material analysis had been performed for the investigated Karthane river reach earlier. To quantify the transport of fine sediments and their influence on the morphological development a controlled flood event was initiated using an existing weir to collect suspended sediment data as well as hydrological parameters. This procedure provides the data to be sampled for a complete flood event excluding the particular - but for the lowland river Karthane in that study case about sediment remobilisation insignificant - effects by surface run-off. As particle availability is subject to seasonal dynamics with remarkable concentrations in autumn and spring (Lefrançois et al., 2007) the flood event was triggered in the European spring. 22 cross-sections were surveyed in the studied Karthane reach; river bed material was collected and inspected by granulometrical analysis.

The suspended sediment samples were taken at four specific sampling points (km 0+123, km 0+244, km 0+688 and km 1+287) along the reach (Figure 1). Two sampling spots (3 and 4) were provided with auxiliary water gauges, spot 4 was additionally used to detect flow velocities continuously during the flood event by an electromagnetic flow sensor (OTT Nautilus C2000$^{®}$) in order to calculate the discharge and to compute a hydrograph by software Q$^{®}$. Water samples were collected from 500 and 1000 ml wide-necked bottles and analysed by a Beckmann Coulter Laser Diffraction Particle Size Analyser$^{®}$ to obtain fine sediment fractions. Pre-sampling was performed to derive information about suspended sediment concentrations and particle sizes in the evolving spring flow conditions.

Figure 1. Investigated Karthane river reach

During the flooding period of 60 minutes (maximum discharge Q = 3.34 m3/s and runoff rate q = 22.2 l/km2s) flood water samples were taken at the four spots 1 to 4 (location described above) along the reach with sampling frequencies of three to five minutes. A reference measurement before flooding resulted in a discharge of Q = 1.79 m3/s. A reference rating graph for water level and discharge was given by a permanent gauging station located 7 km downstream sampling spot 4. Based on hydrological time series (1997 - 2007) of this gauging station in Bad Wilsnack, the performed flooding event relates to a mean summer flood.

4 SUSPENDED SEDIMENTS DURING FLOODING

The analysis of suspended sediment fractions results in a characteristic temporal pattern showing a shift of particle diameters with rising water level. The grain sizes distributions during the flood event conditioned by the flood wave itself and time dependencies from the beginning of flooding until the impact of the flood induced shear stresses decrease were determined. As the flooding does not imply surface run-off, a re-suspension of bottom sediment leads to a shift of the sediment mean diameter transported within the flooding. For specific particle distributions and grain size analysis refers to Koslitz & Lengricht (2008).

An average mean suspended sediment concentration (SSC) of 51 mg/l was detected between February and April 2008 and also measured directly before flooding started. The following peak of suspended sediment concentration (SSC) introduced by the increasing discharge in the river channel reached a maximum of 69 mg/l (Figure 2). The different concentrations at the sampling sites can be explained by different accumulation and erosion in the different cross sections partly due to varying grain sizes.

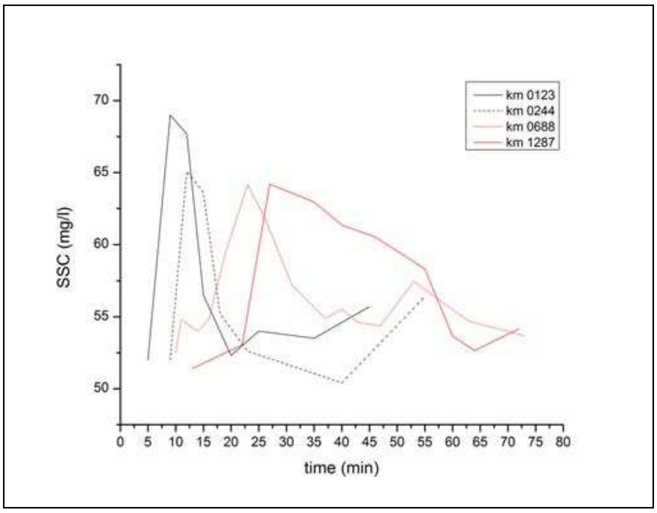


Figure 2. Suspended sediment concentration (SSC) of sampling points during flooding

The sediment distributions in the thalweg were determined for the whole investigated river reach and shown in figure 3.

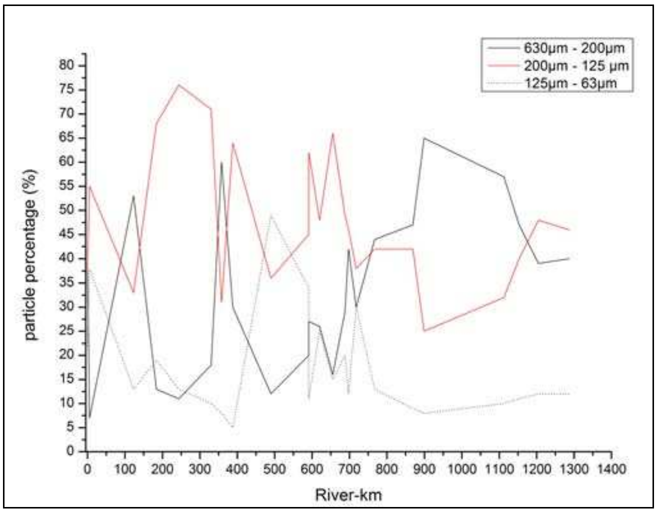


Figure 3. Sediment distribution in the thalweg, km 0+500 to 0+700

The sediment distributions in km 0+869 and in km 1+237 (refer to figures 4 and 5) indicate the particular local differences in the river reach depending on the specific location or alignment, e.g. slip-off slope, undercut slope etc..

The whole studied river reach is represented by very low rates (less than 1% by weight) of fine river bed material smaller than 63 µm (silt and clay); sandy parts dominate the river bed. The existing sand fraction appears more homogeneous upstream than downstream the weir. Finer sand fractions are more present in the Stillwater reaches than in the thalweg (particularly recorded at river reach station 0+122 km and 0+388 km as shown in table 1.

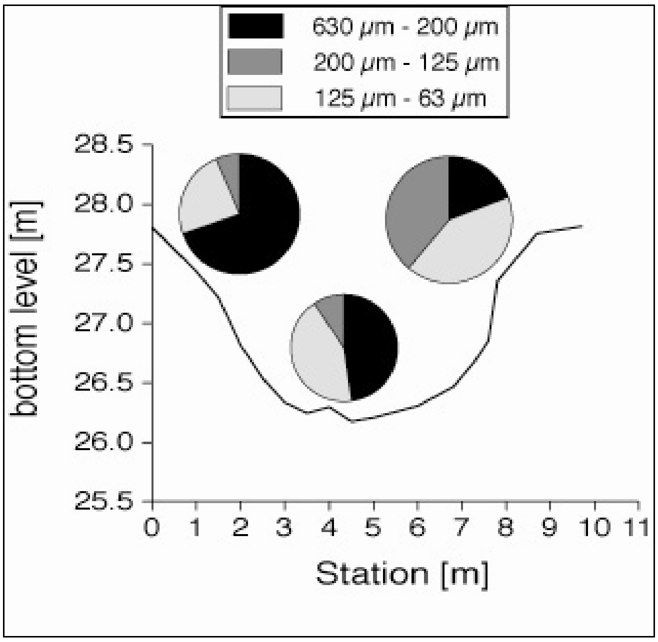


Figure 4. Sediment distribution in cross-section km 0+869

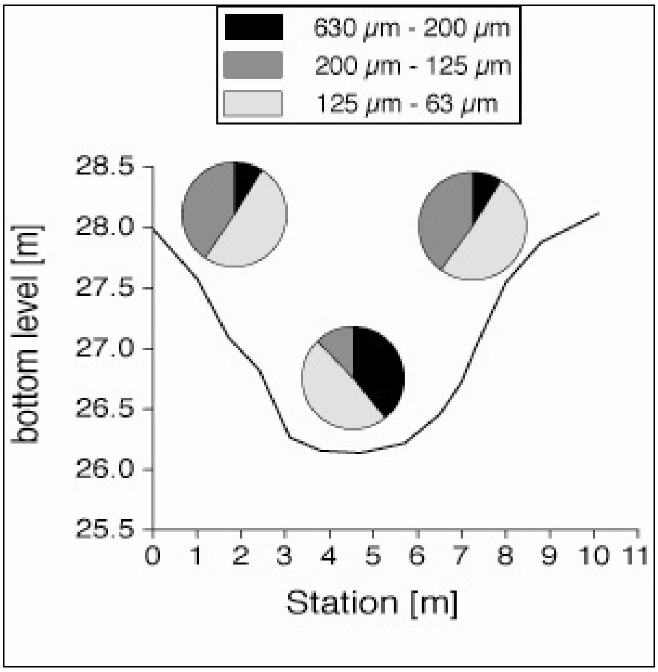
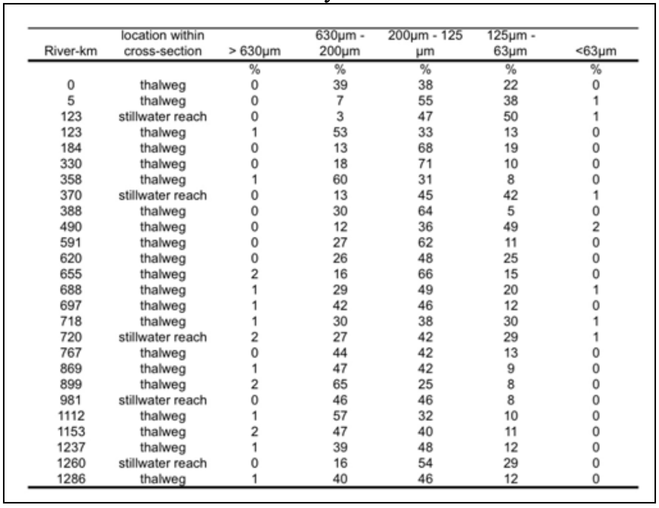


Figure 5. Sediment distribution in cross-section km 1+237

Table 1. Granulometrical analysis of river bed material



River-km	location within cross-section	> 630µm	630µm - 200µm	200µm - 125 µm	125µm - 63µm	<63µm
		%	%	%	%	%
0	thalweg	0	39	38	22	0
5	thalweg	0	7	55	38	1
123	stillwater reach	0	3	47	50	1
123	thalweg	1	53	33	13	0
184	thalweg	0	13	68	19	0
330	thalweg	0	18	71	10	0
358	thalweg	1	60	31	8	0
370	stillwater reach	0	13	45	42	1
388	thalweg	0	30	64	5	0
490	thalweg	0	12	36	49	2
591	thalweg	0	27	62	11	0
620	thalweg	0	26	48	25	0
655	thalweg	2	16	66	15	0
688	thalweg	1	29	49	20	1
697	thalweg	1	42	46	12	0
718	thalweg	1	30	38	30	1
720	stillwater reach	2	27	42	29	1
767	thalweg	0	44	42	13	0
869	thalweg	1	47	42	9	0
899	thalweg	2	65	25	8	0
981	stillwater reach	0	46	46	8	0
1112	thalweg	1	57	32	10	0
1153	thalweg	2	47	40	11	0
1237	thalweg	1	39	48	12	0
1260	stillwater reach	0	16	54	29	0
1286	thalweg	1	40	46	12	0

5 NUMERICAL SIMULATIONS

5.1 *Hec-Ras® simulation*

A Hec-Ras® simulation was performed with the topographic and geometrical data for the cross-sections delivered in the field in order to gain information about the expected hydraulic conditions in the investigated reach of the lowland river Karthane.

Figure 6 reveals the results of a Hec-Ras® simulation which fit well with the hydraulic conditions observed during the experiment of artificial flooding in terms of water levels in the single cross-sections and subcritical and critical flow states (Froude numbers) in specific locations or alignments along the investigated reach.

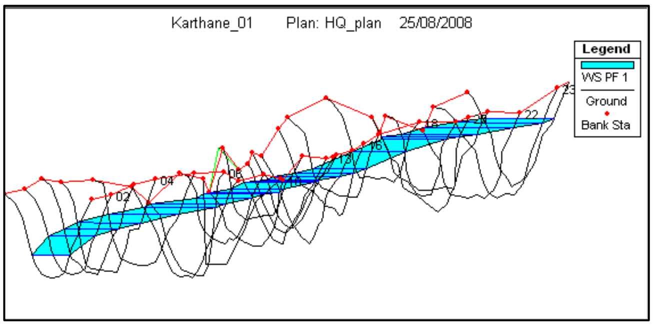


Figure 6 Hec-Ras® simulation of the investigated reach of the lowland river Karthane

5.2 *Numerical modelling the suspended sediment concentration with ETH Zurich's Basement®*

ETH Zurich's software Basement® is the first open source software which allows addressing complex problems in watercourses and river areas connecting hydraulic conditions and sediment transport. The basic 1-D element consists of two nodes with known cross-sections. At the location of the nodes all variables - velocity, flow depth and cross-section geometry - are defined by a cell-centred discretisation. The common edge of the two elements is defined by the midpoint of the connecting line between two nodes, i.e. the more nodes are known, the better the representation of the real world data, particularly at regions with strongly curved water course, is.

The required input data for simulating the Karthane river reach consists of topographic data (known through obtained cross sections), as well as hydrologic data, i.e. time series of discharge, water levels, concentration of suspended sediments, velocity profiles.

For a 2-D simulation an additional node and the ground elevation build up the discrete representation of the topography in Basement® according to Faeh et al. (2009).

Furthermore the granulometrical data given by the artificial flood event has to be embedded in the numerical model to develop an applicable routine for all hydraulic states. That explains the remarkable role of statistical treatment of the grain size distribution from the water and/or sediment samples.

The fundamental capabilities of the numerical software, the simulation of the flow under steady and unsteady conditions, the simulation of sediment transport (bed load and suspended load) under steady and unsteady conditions in channels with arbitrary geometry and the simulation of erosion are given by ETHZ's Basement®.

Within the software the one dimension numerical subsystem BASEchain was selected to perform simulation of Karthane river branch based on cross sections with respect to sediment and suspension transport. The one-dimensional model setup exists of a general input file containing control blocks geometry, hydraulics and morphology as well as specified information files. The geometry block contains information of all 22 cross-sections surveyed in the studied Karthane reach. Hydraulic boundary conditions, initial state, friction type and values and simulation duration time is given by the block hydraulics. The morphology block consists of information about bed material, bed load, suspended load and used formula.

The hydraulic boundary condition during the performed flood event is described upstream as a hydrograph with maximum discharge of 3.34 m^3/s. Boundary condition downstream is given by a relation between water surface elevation in a cross-section and corresponding discharge. As the friction type Manning-Strickler was chosen.

Based on granulometrical analysis of the studied reach (see table 1) the bed material is described through 3 grains sizes (63µm, 125µm and 200µm) and their volume fractions. Porosity is defined as 0.37 % and density as 2650 kg/m^3.

Riverbeds active layer is defined with a layer height of 0.5 m. As the bed material consists of three grain size classes transport formula of Meyer-Peter Muller Hunziker is chosen for now as the application of van Rijn formula is in progress.

Suspended load information is given through flooding event data. A suspension discharge is given describing the concentration of suspended sediment upstream in time. Advection diffusion is computed by Basements modified discontinuous profile method.

The results of the numerical simulation by ETHZ's Basement® reveal remarkable regions in terms of their morphology. The simulation duration is chosen of 90 minutes which matches flooding experiment duration. As shown in figure 7 and 8 the sediment behaviour during flooding is caused through each with three areas of deposition and erosion terms.

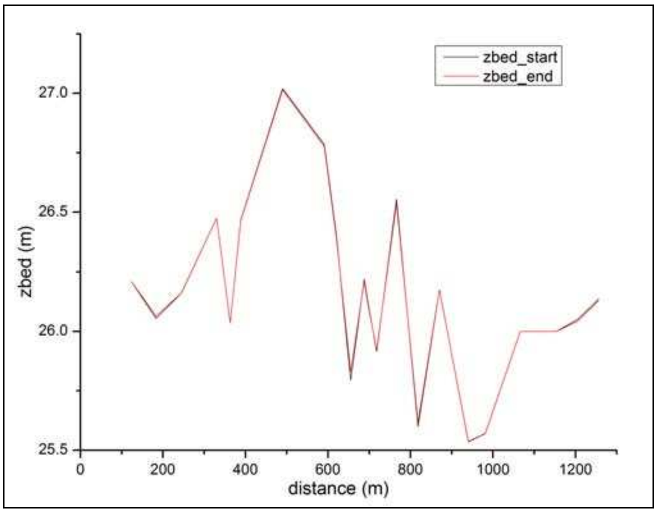


Figure 7. Longitudinal profile of mean bottom level of the start (zbed_start) and end situation (zbed_end)

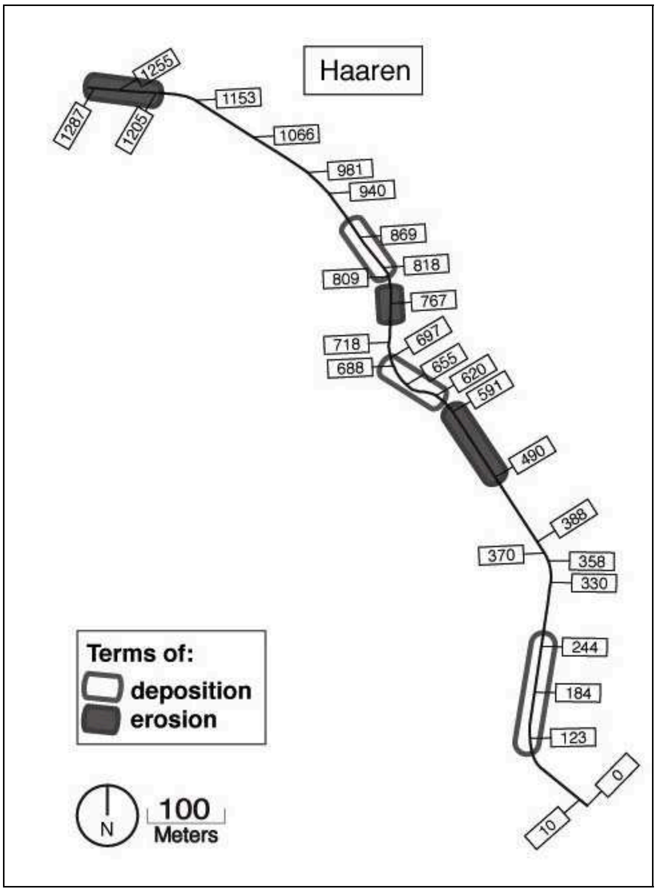


Figure 8. Survey of morphological alterations of simulated River reach

Here the most intense area is formed between km 0+591 and km 0+655. The simulation results enable slightly statements about riverbed evolution in this area. The morphological alterations in the cross-sections are shown in Figure 9, 10 and 11.

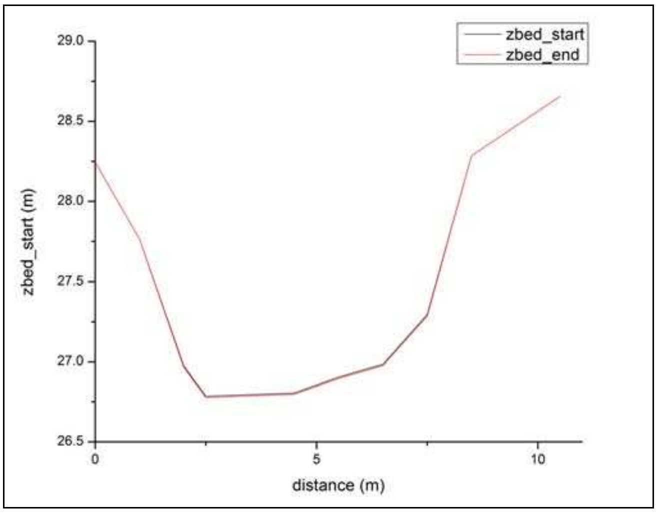


Figure 9. Notably morphological bottom alterations river km 0+591

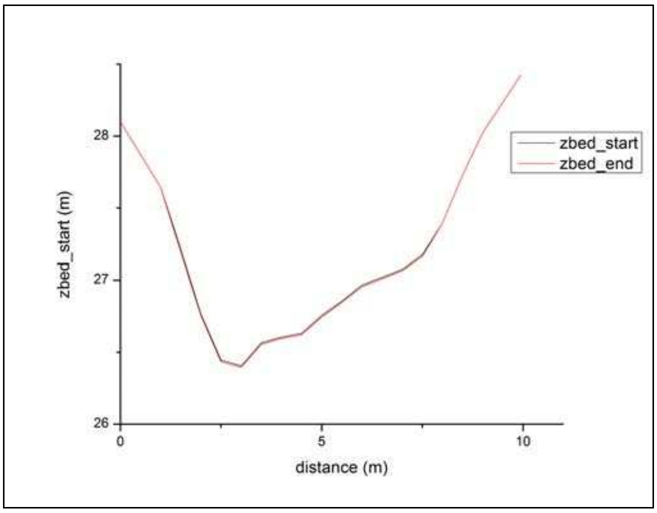


Figure 10. Notably morphological bottom alterations river km 0+620

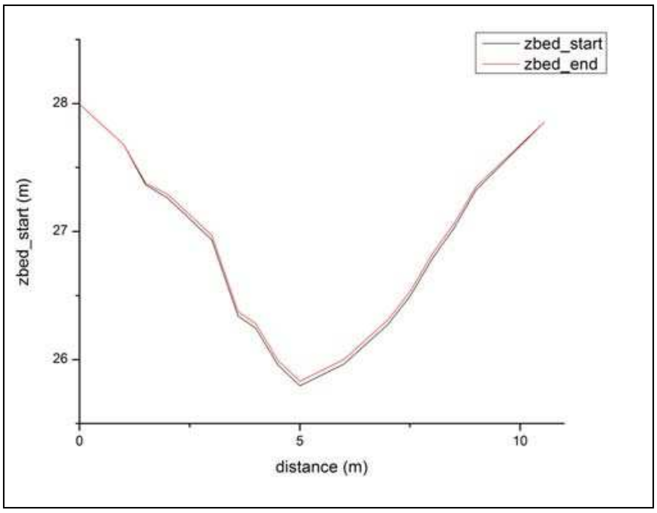


Figure 11. Notably morphological bottom alterations river km 0+655

Results of hydraulic simulations fit the field observations of the artificial flooding.

As the flooding does not imply surface run-off a re-suspension of bottom sediment is expected and supported through granulometrical analysis of sampled data. As discharged induced shear stresses mean increased re-suspension of bottom fine sediment, the temporal development of the suspended sediment is closely related to water level elevations induced by flooding. Due to this suspended sediment concentration (SSC) relates closely to terms of erosion and deposition as these areas exhibit sediment supply. This clearly relation could be validated through the simulation and is illustrated figure 12 which reveal modelled SSC during modelling time steps in minutes. As shown SSC decreases from high concentration at beginning (due to existing weir at km 0+010) till river km 0+388. Now Karthane River flows through morphologic main active region between km 0+388 and 0+591. Erosive terms lead to re-suspension of bottom fine material and increases SSC till river km 0+600 (see fig. 12). Similar patterns also exist in morphologic important regions between km 0+600 and 0+800 as well as around km 1+000. The SSC peak concentration is reached within simulation duration from 20 till 35 minutes.

Based on simulation results Karthane River reach between 0+400 and 0+800 seems to be the most morphologic active area with regard to river bed alteration and SSC. Hence ongoing analysis concerning WFD river basin management suggestions focuses on that reach.

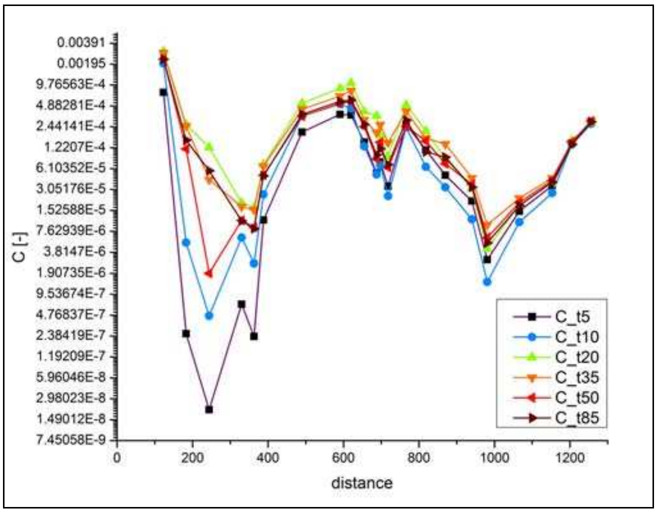


Figure 12. Temporal development of the suspended sediment concentration during simulation

6 CONCLUSION AND OUTLOOK

To support the coherent implementation of the European Water Framework Directive, to observe and to transfer the common implementation strategies agreed by the European Commission and the member states, the sediment contemplation is significant for a sustainable development of water resources and the whole environment. Ecosystem modelling requires detailed sampling data and hydrologic parameters.

Beside the analytic procedures, eco-system-modelling helps to analyze the effect to the structure of the aquatic ecological system by means of the sediments and leads to a combination of simulation technologies and measuring techniques. Although this is more or less unnoticed until now the necessity of understanding the influence of (contaminated) sediments on the quality of the aquatic environment increases rapidly.

Eco-system-modelling was performed with detailed sampling data and hydrologic parameters. The required data was obtained through several field methods (topographic data, hydrologic data, and granulometrical data). Additionally a controlled flood event was initiated and triggered using an existing weir to gather suspended sediment data. A model of the Karthane reach was compared with discharge and water levels given from the controlled flood by primary numerical modelling with Hec-Ras®. To simulate the flow under steady and unsteady conditions in the investigated river reach a model was built up performing an eco-system-modelling with ETH Zurich's software Basement®. The analysis of fine sediment fractions have resulted in a characteristic temporal pattern, which shows a shifting of particle diameter with rising water level, i.e. the rising water level, the grain sizes distributions during the flood event conditioned by the flood wave itself and time dependencies from the beginning of flooding until the impact of the flood induced shear stresses decrease. Modelling results validating this and reveal morphologic active river zones. At the present stage simulations dealing with common river restoration methods are being performed to obtain WRRL respective improvements.

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