Evaluating Functionality and Sustainability of River widenings at the Kamp River/Austria concerning to flood protection and aquatic ecology including a numerical sensitivity test

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ABSTRACT

The catastrophic flood events of the years 2002 and 2005 in Central Europe showed clearly the necessity to act in terms of flood protection. The meaning of floodplain areas and the errors in land use management of the past became obvious by the occurred extraordinary discharges. Unfortunately a high use pressure exists in the surrounding of rivers and the important floodplain areas are blocked in most European countries. Within this work the results of a study of an Austrian River are presented, which exactly exhibits the described problems. In August 2002 a thousand-year flood occurred at the Lower Austria Kamp River. The flood wave damaged 2304 building in the catchment area and caused huge sociologic and economic losses. The destruction on building, road- and railway dams was estimated with 145 Mil. € for this Danube River tributary. Based on the specific geomorphic situation (narrow valley) with average overbank width of 125 m only few flood protection and river restoration concepts were possible. Apart from the construction of flood protection dams, river widenings were seen as possible measures and were established in some reaches of the Kamp River in 2003. This work presents the results of a hydraulic- and morphological monitoring of one of these river widenings (village Kammern) from 2003 – 2005. It was possible, combined with meso-habitat modelling, to evaluate the measure concerning to flood protection and ecological demands of the European Water Framework Directive (WFD). This integrated approach allows to define decisive parameters (Q_{bf}, shear stress, d_m, WUAs) for a sustainable management of river widenings.

Further a hydrodynamic – numerical sensitive analysis was implemented in this work for Cross section enlargement in different reaches of the Kamp River. The modelling of statistical defined flood events (HQ_{200} – HQ_1) showed that the maximum reduction of the water surface level was the highest in the upper reaches (bed slope=0.006). This improvement for flood protection occurred only within the range of the measure. Contrary to these results river widening in the lowland reach (bed slope = 0.0007) exhibited a smaller reduction of water surface elevation, but the effects of the measure were found 3 times longer than the widening length in upstream direction. Based on the monitored aggradation processes of Kammern between 2003 and 2005 different scenarios of bed level rising were developed and included in the numerical sensitive analysis. As example for 500 case studies the results for a one-hundred year flood are presented in this paper showing the effects of aggradation on v_m and τ. In summary it can be said, that this complex matrix of different “widening” szenarios concerning to different river morphologies with the implementation of aggradation processes can be seen as useful tool for sustainable river restoration.

Keywords: river widening, flood protection, meso-habitat modelling

1 INTRODUCTION

Currently, a shift from classical flood protection as engineering task towards integrated flood risk management concepts can be observed (Buchele et al., 2006). During the last 200 years, many rivers industrialized countries have been modified by canalization. In the last two decades, the philosophy of river management has changed considerably, and restoration of ecological integrity has become an important management goal. One appealing restoration approach is to create “river widenings” that permit braiding within a limited area (Rhode, 2004). In the study of Downs (1994) it was documented that the increasing involvement of fluvial geomorphology in river channel management has highlighted the desirability of being able to predict spatially differentiated river channel adjustment in relation to prevailing drainage basins characteristics. Whereby river restoration aims to re-establish the ecological integrity of a river ecosystem (Rhode et al., 2006). Restoration measures in form of cross section enlargement were used to arrest the degradation of Rivers, which has caused technical (instability of bank protection measures) and ecological (loss of dynamic river reaches with alternate bars) problems (Habersack & Nachtnebel, 1995). The human role in changing river channels is explained in Gregory (2006), where he described that specific terns have become associated with changing river channels including enlargement, shrinkage and metamorphosis. The level of public concern regarding the Maaswerken project suggests that overall level of stakeholder involvement may have been insufficient, even though it complied with pertinent environmental and planning legislation (Van der Meulen et al., 2006). Those who are involved in floodplain restoration have cope with historical conflicts between human and ecosystem needs. The topic is of high importance in Europe due to the European Water Framework Directive that requires restoration and/or maintenance of a “good ecological status of aquatic ecosystems” (Pahl-Wostl, 2006).

Therefore the study highlights the need of an integrative analysis in terms of river widening presenting a concept of sustainable flood protection and restoration management.

2 STUDY REACH

The study reach is situated in the northern part of Lower Austria (Gauss Krüger – 900220.94/ 5390369.93 // -42888.59/5367503.33; national grid Austria). The origin of the Kamp River is near the village Karlstift (920 m.a.sl.). Its 160 km long course discharges into the Danube River (182 m.a.sl.) at Altenwörth. The total catchment area is defined with 1.753 km² (Fig. 1). In the past (1950 – 1957) three large power plants were build. The reservoirs of Ottenstein, Dobra and Thurnberg influenced the sediment transport and the hydrological regime drastically. The whole part of the Kamp River from river station 73+500 km to the Danube River can be described as a residual flow zone with no sediment input from upstream and reduced input from tributaries since that time. The release of the near bottom water into the Kamp River with 10 degrees temperature (Frangez et al., 2006) by the three power plants causes a reduction of maximum water temperature (Stoiss, 1992). Therefore the fish region changed from epipotamal to meta – hyporhithral (Wiesbauer, 1999).

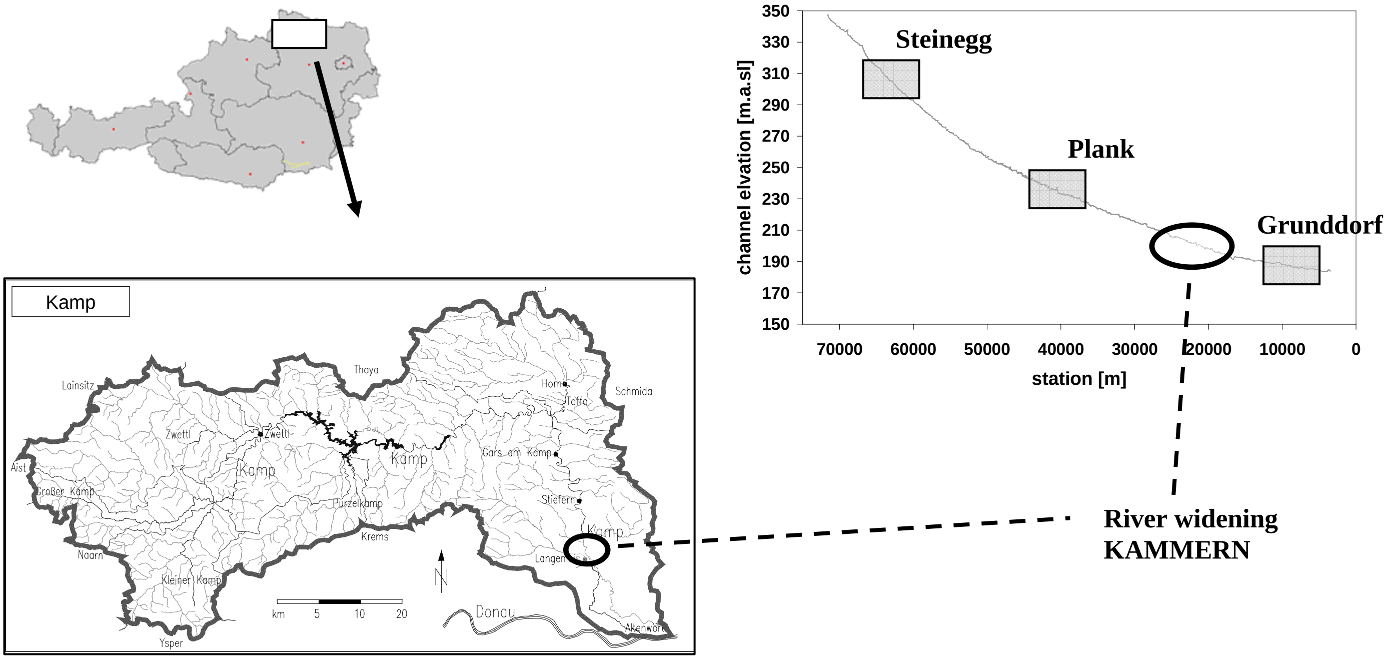

Figure1: Catchment area of the Kamp River in Lower Austria; Longitudinal profile of the Kamp River between Thurnberg and the mouth into the Danube River containing the river widening of KAMMERN and the modeling reaches for the sensitive analysis.

3 METHODS

In this paper an integrative analysis and definition of river widening is presented, including hydrodynamic-numerical modelling, habitat modelling and sensitive analysis of cross sectional enlargement in different reaches of the Kamp River.

3.1 Terrestrial survey and hydrodynamic-numerical modelling

The geometric boundary conditions of the River widening section KAMMERN were obtained by terrestrial survey (total station TC805) based on a three year morphological monitoring (2003 – 2005). Cross sectional data (n = 11) were surveyed each year and taken as geometric input data for one dimensional hydrodynamic-numerical modelling. To obtain two-dimensional velocity distribution from the average value in the Cross section, the model uses following formula (F1).

$$v_m = \frac{1}{\sqrt{\lambda}} \cdot \sqrt{8 \cdot g \cdot R_{hy} \cdot I_E} \qquad (1)$$

A possibility of using this equation for the description of local currents consists of dividing the wetted area into strips (F2).

$$v_i = \frac{1}{\sqrt{\lambda_i}} \cdot \sqrt{8 \cdot g \cdot h_i \cdot \mathrm{I}_E} \qquad (2)$$

where: v_m = average velocity (m s^{-1}), λ = resistance coefficient of Darcy-Weisbach (-),
g = gravity force (9.81 m s^{-2}), R_{hy} = hydraulic radius (m), I_E = energy slope (m);

3.2 Mesohabitat Modelling

Mesohabitats are often described by predefined classes of velocity and water depth (Egger et al., 2005). Further some methods of meso-habitat analyses are using the Froude Number (Jowett, 1993) or include bottom shear stress (Hauer et al., 2006c). In this study a method of multiplying weighted mesohabitat parameters (velocity and depth) was applied (formula 3). This method is similar to the PHABSIM approach for weighted usable areas (Bovee, 1986), but only usable for riffle- and shallow water habitat definition by numerical modelling. Further classifications (pools, runs, fast runs) by numerical models must include additional parameters like it is presented in Hauer et al., (2006c).

$$WC_{ges} = WC_d \cdot WC_v \quad \longrightarrow \quad MHA = WC_{ges} \cdot A_i \tag{3}$$

where: WC=weighted class; d=depth (m), v=velocity (ms^{-1}), MHA=Mesohabitat area (m^2), A_i=area of single modelling grid (m^2);

Table 1: Weighted classes of riffle- and shallow water habitats related to velocity and water depth.

WC	(1.0 – 0.8)	(0.8 – 0.5)	(0.5 – 0.2)	(0)
riffle depth [cm]	0–30	30–45	45–90	> 90
riffle velocity [cm/s]	100–110	80-100/110–120	70–80/130-140	<70, >140
shallow w. depth [cm]	0–30	30–60	60–120	> 120
shallow w. velocity [cm/s]	0–5	10–15	20–35	> 35

shallow w. = shallow water;

3.3 Sensitivity test

A sensitive test of river widenings in different reaches of the Kamp River was applied in this work to define the effects of Cross section enlargement concerning to different bed slope, bankfull discharge and flood plain width at the Kamp River. To generalize river geometric for a better comparison between the river reaches, regular trapezoid cross sections were developed based on bankfull discharge (Q_{bf}), bankfull width (w_{bf}), bankfull depth (d_{bf}), the flood plain width (fp_w) and the local bed slope (S_f) (Fig. 3). Most of these parameters were calculated by one-dimensional numerical modelling of the 78 kilometres river reach between the reservoir of Thurnberg and the mouth into the Danube River. The floodplain width was defined by aerial photographs. As geometric input data for the one-dimensional model the results of an Airborne Laserscan (LiDAR) (1 m * 1 m accuracy) were taken to build up the high quality digital terrain model (DTM) (389.000 points) where the modelling Cross sections were cut out.

4 RESULTS

In most river engineering projects, which include Cross section enlargement, flood protection and the stabilization of river bed degradation were defined as the main targets. Based on these experiences of hydraulic engineering from the past and new targets for the future (European Water Framework Directive) a classification of river widening was developed in this study and is presented in Table 1. Based on different time scales, possible functionalities are found to be realistic. Beginning with river widenings as initial measures (Preis et al., 2005), which are only temporary until other flood protection concepts (dams) are realized, different decisive parameters are described. The increase of bankfull discharge (Q_{bf}) by cross section enlargement can be seen as the main target and most important parameter in all terms of river widening. Based on the time scale factor and the existing morphologic and sedimentologic regime, changes (aggradations/degradations) of the artificial river geometry can be expected. This must be considered if the increasing discharge capacity should function as a permanent measure. Concerning to the Water Framework Directive and the improvement of physical habitat quality a mid- to long term monitoring was found to be necessary. Additionally habitat modelling on the micro- and meso scale allows evaluating these morphologic changes including suitability- or preference data of the main fish species. A sensitive test of flood protection for a specific longitudinal river profile makes it possible to define in which river reaches Cross section enlargements are meaningful and will bring the desired effect.

Table 1. Overview of river widenings and their functionality related to time scale effectiveness and the main parameters for successful application.

Time scale	**Functionality**	**parameters**
< 0.5 years	River widening as inital measure for flood protection	$discharge_{bf}$
< 10 years*	River widening as permanent measure for flood protection	$discharge_{bf}$ shear stress/d_m aggradation/degradation
< 30 years	Sustainable River widening as permanent measure for flood protection and improvement for aquatic ecology	$discharge_{bf}$ shear stress/d_m aggradation/degradation habitatmodelling monitoring sensitivity test for sustainability

*…depending on River Type;

Exemplary for the sustainable river widening concept as permanent measure for flood protection and aquatic ecology the monitoring and modelling results of Cross section enlargement in KAMMERN are presented describing all the decisive steps of Table 1.

4.1 Hydrodynamic numerical modelling

The effects of the cross sectional enlargement of 2003 to the water surface levels were between -0.43 m (HQ_1) and -0.08 m (HQ_{200}). It was obvious, that the lowering of the water levels was clearly found at discharges beneath bankfull (< 190 m^3s^{-1}). At discharges with recurrence intervals > 10 years the positive effect for flood protection can be neglected (reduction < 0.1 m). Beside the local effects of riverbed widenings, the influence of theses artificial measures is found additionally in upstream direction. The increase of the conveyance through the cross sectional enlargement is documented up to 300 m upstream for discharges around 50 m^3s^{-1}.

4.2 Mesohabitats

Changes in bottom shear stress by 30% Cross section enlargement in 2003, combined with three one-year floods (HQ_1) during the monitoring time, brought significant changes of the longitudinal profile within the river reach of Kammern. In general, river widening decreases the transport capacity of a river and causes retention of sediment within the widening so that the mean bed level rises. At the same time river widening allow river braiding which increases the variability of flow patterns and the diversity of in-stream habitats (Rhode, 2004). The homogenous river bed (2003) of the Kamp River was eroded and exhibited 2005 a more heterogeneous characteristic than in 2003, which can be seen in the increase of riffles (Figure 2a).

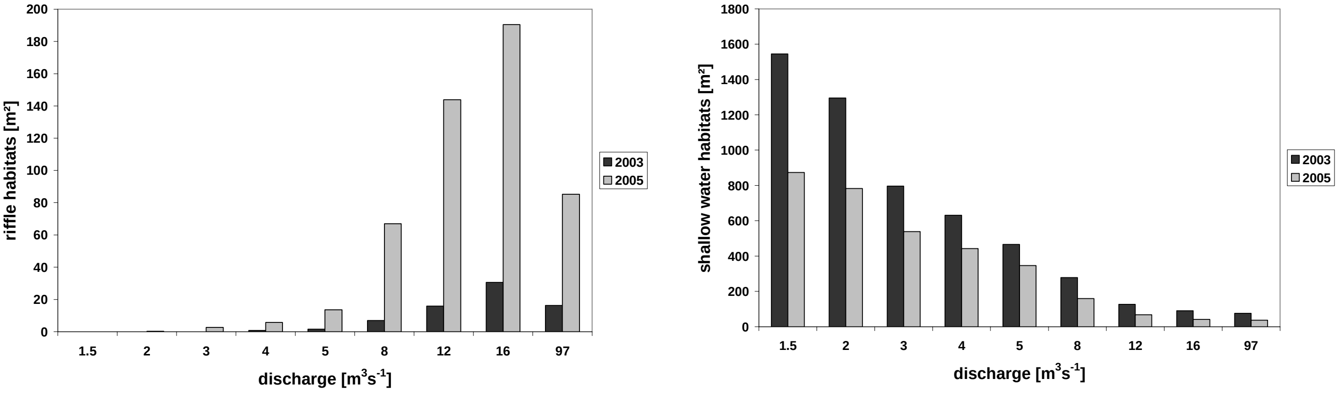

Figure 2. Quantitative development of riffle- (a) and shallow water habitats (b) over the monitoring period (2003 – 2005).

These riffles are suitable as spawning grounds for rheophilic cyprinids (main fish species at Kammern); the use of riffles as reproduction areas has further been described in other studies (Keckeis, 1992; Maier et al., 1992). Contrary to the increase of riffles, shallow water habitats exhibit a quantitative reduction (Fig. 2b). This is caused by the fact that aggradating material (mainly suspended load) is found in low-flow velocity areas of the widening sections. The aggradations in this important habitat types were between 4 cm (Cross section 3) and 23 cm (Cross section 5) during the monitoring period 2003 – 2005. Based on these morphologcial developments the shallow water habitats were reduced, especially for low- and mean flow, with nearly 50 percent (1.5 m^3s^{-1}) (Fig. 2b) compared to the artificial widening of 2003.

4.3 Sensitive test

Based on river morphologic- and hydraulic parameters of the Kamp River trapezoid formed Cross sections were developed for the upper-, central- and lowland reaches which are presented in Figure 3.

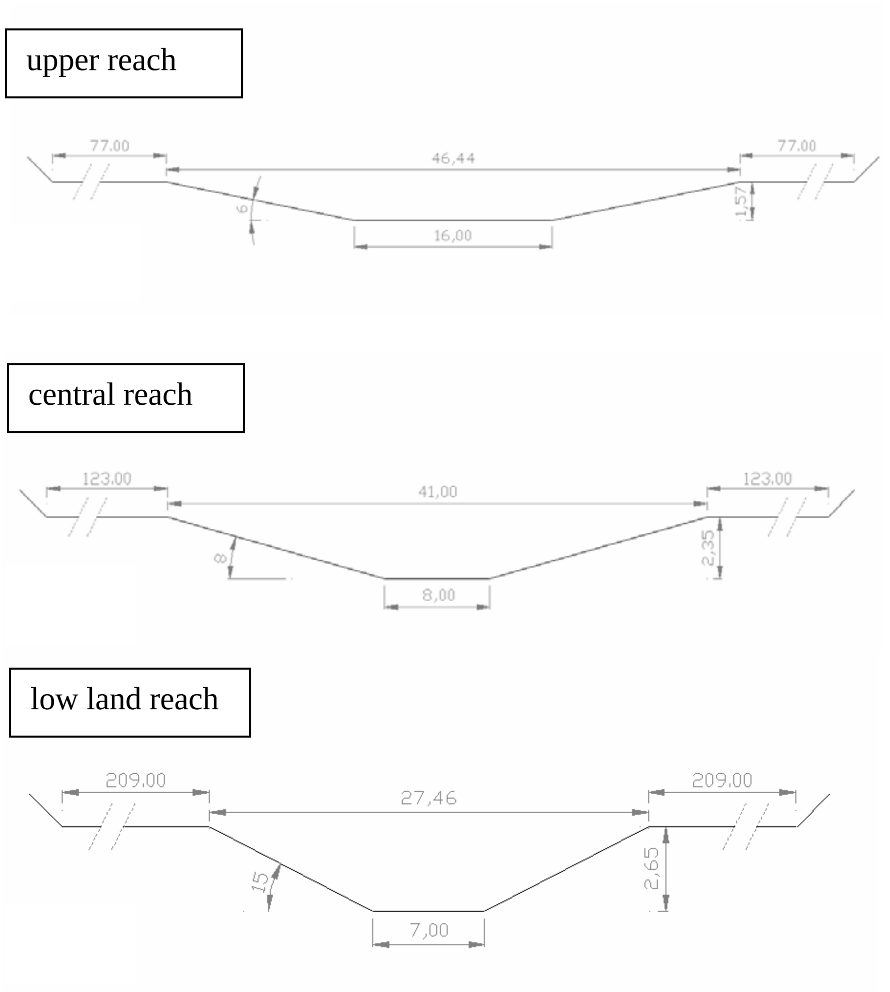

Figure 3. Artificial Cross sections based on field measurements in three different reaches of the Kamp River (a) Steinegg, (b) Plank, (c) Grunddorf.

The modelling results of artificial river widenings in three different reaches are presented in Figure 4. Those trapezoid Cross sections, which are presented in Figure 3, were enlarged by 2 m, 4 m and 6 m at each bank on a total length of 400 m. The effects of river widening by the maximum reduction of water surface elevation and the maximum range of the lowering are presented for a ten year flood (HQ_{10}) (Fig. 4). Grunddorf, which is representing the lowland river reach, exhibits a maximum reduction of the water surface elevation of only 0.1 m with a recognizable influence of 1800 m in upstream direction. For the modelling section of Plank the simulations brought 0.25 m/reduction and 1300 m/range as maximum values. Finally in the investigation area with the highest bed slope (0.006) the influence of the river widenings showed its minimum range with 650 m in upstream direction but the most effective reduction on water surface elevation (0.28 m) (results were modelled for 6 m widening / 400m length). Additionally a comparison of river bed widening in the upper-, central- and lowland-river reach was done for a hundred-year flood (HQ_{100}). While Cross section enlargement in the lowland reach of the Kamp River become now apparent with a reduction ranges (1500 m) but small lowering depths (0.11 m), river widening in the upper reach exhibits larger lowering depths but however a smaller range of the water surface reduction in upstream direction (750 m). This can be explained by the energy slope, which is clearly higher in the upper river reach of Steinegg (0.006 m m^{-1}) compared to the lowland river reach (0.0007 m m^{-1}). Based on the monitored aggradation processes of Kammern, different scenarios of bed level rising were included in the numerical sensitive analysis (Table 2).

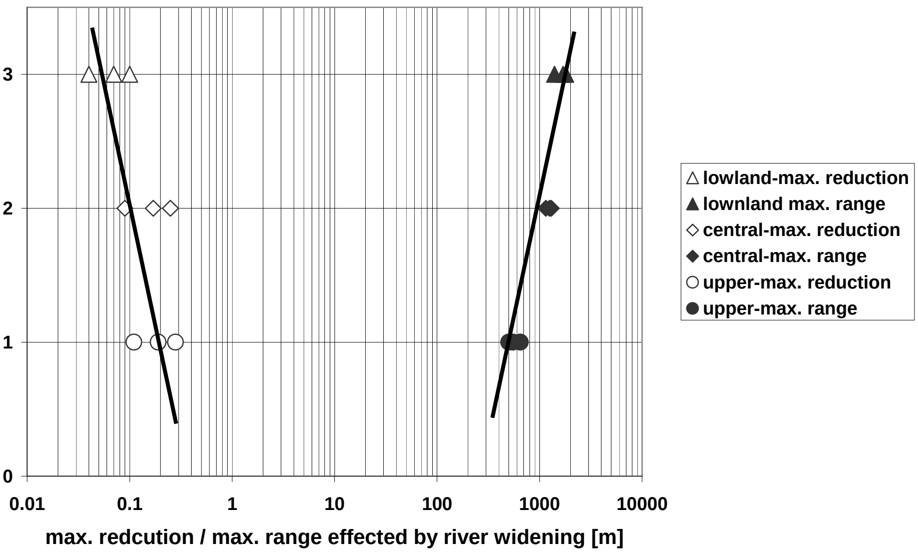

Figure 4. Effects of river widening in different river reaches on maximum reduction of water surface elevation and the maximum range of improvement to flood protection for a ten year flood (HQ_{10}).

Table 2: Effects of different aggradation scenarios in areas of 6 m river widening on each bank on a total length of 400m presented for a hundred-year flood (HQ_{100}).

	widening/length	2/100		2/400		6/100		6/400	
	aggradation [m]	Δv_m [ms^{-1}]	$\Delta\tau$ [Nm^{-2}]	Δv_m [ms^{-1}]	$\Delta\tau$ [Nm^{-2}]	Δv_m [ms^{-1}]	$\Delta\tau$ [Nm^{-2}]	Δv_m [ms^{-1}]	$\Delta\tau$ [Nm^{-2}]
*	+0.1	-0.01	-0.04/0.05	-0.01	-0.12/0.05	-0.01	-0.05/0.13	-0.01	-0.16/0.13
	+0.2	-0.01	-0.08/0.09	-0.01	-0.24/0.09	-0.01	-0.10/0.26	-0.01	-0.32/0.26
	+0.3	-0.01	-0.13/0.12	-0.02	-0.37/0.12	-0.01	-0.16/0.38	-0.02	-0.48/0.38
	+0.4	-0.02	-0.19/0.13	-0.02	-0.51/0.13	-0.01	-0.21/0.49	-0.02	-0.64/0.49
	+0.5	-0.02	-0.24/0.14	-0.03	-0.64/0.14	-0.01	-0.27/0.60	-0.02	-0.80/0.60
	+1.0	-0.05	-0.53/-0.01	-0.07	-1.32/-0.01	-0.02	-0.62/0.95	0.13	-2.04/0.95
**	+0.1	-0.01	-0.49/0.75	-0.02	-1.09/0.75	-0.01	-0.55/0.80	-0.03	-1.61/0.80
	+0.2	-0.02	-0.97/1.50	-0.02	-2.17/1.50	-0.02	-1.10/1.62	-0.06	-3.51/1.62
	+0.3	-0.03	-1.46/2.24	-0.06	-3.20/2.24	-0.03	-1.65/2.44	-0.09	-4.65/2.44
	+0.4	-0.04	-1.92/3.00	-0.08	-4.18/3.00	-0.05	-2.19/3.29	-0.12	-6.10/3.29
	+0.5	-0.05	-2.41/3.73	-0.09	-5.18/3.73	-0.06	-2.75/4.14	-0.15	-7.51/4.14
	+1.0	-0.11	-4.92/7.12	-0.20	-9.74/7.12	-0.12	-5.60/8.39	-0.28	-13.81/8.39
***	+0.1	-0.06	-4.26/3.62	-0.02	-5.94/3.62	-0.08	-6.52/3.03	-0.14	-12.27/3.03
	+0.2	-0.11	-8.15/7.48	-0.06	-11.10/7.48	-0.16	-12.47/6.26	-0.27	-22.28/6.26
	+0.3	-0.17	-11.97/11.51	-0.22	-15.79/11.51	-0.23	-17.87/9.74	-0.37	-30.65/9.74
	+0.4	-0.22	-15.61/15.73	-0.29	-20.03/15.73	-0.30	-22.84/13.45	-0.47	-37.82/13.45
	+0.5	-0.28	-19.22/20.02	-0.35	-23.90/20.02	-0.36	-27.42/17.41	-0.56	-44.03/17.41
	+1.0	-0.51	-33.71/41.27	-0.60	-39.02/41.21	-0.66	-46.45/40.65	-0.91	-66.30/40.65

* = Grunddorf; ** = Plank; ***= Steinegg;

During the sensitivity test of the different scenarios (upper-, cental- and lowland) it was obvious that river widening measures showed the highest effects for smaller flood events (HQ_1; HQ_5). With increasing discharges the positive effects of lowering water surface levels can be neglected. As it was proofed in Kammern, river widenings cause aggradation of bed material and an increase of river bed elevation. Aggradation within the widening sections exhibited only in the upper river reach of Steinegg a significant change on velocity and bottom shear stress (Table 2). In the central- and lowland modelling section the effects of bed level rising up to 1m were not so significant.

5 DISCUSSION

In Austria and all over Europe rivers face progressive river bed erosion due to river training and the lack of sediment input from the catchment areas (Habersack, 1996). Traditionally, sills, chutes or block ramps were installed to stabilize the river bed (Rhode, 2004). But these measures disrupt the river continuum and impair species movement. An alternative option is the construction of river widenings. Until a new equilibrium bed slope and bed level becomes established material deposit will reduced the discharge capacity progressively. This should be considered if river widenings are used for flood protection. Caused by the fact, that the effectiveness of river widenings is limited to bankfull discharge capacity. The reduced efficiency of river widening at the Kamp River with increasing discharge was also proofed in Hauer et al., (2006a). It was exhibited that the lowering of water levels was clearly found at discharges beneath bankfull (<190 m^3s^{-1}). At discharges with recurrence intervals < 10 years the positive effect for flood protection can be neglected (reduction < 0.1 m). This study further exhibited the possibility of an integrative river restoration concept including flood protection and habitat improvements for main fish species. A strategy which must be included in hydraulic engineering protects in future concerning to the demands of the European Water Framework Directive.

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