THE INFLUENCE OF RIPARIAN VEGETATION COVER ON DIFFUSE LATERAL SEDIMENT CONNECTIVITY AND BIOGEOMORPHIC PROCESSES IN A MEDIUM-SIZED AGRICULTURAL CATCHMENT, AUSTRIA

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Poeppl, R.E., Keiler, M., von Elverfeldt, K., Zweimueller, I. and Glade, T., 2012. The influence of riparian vegetation cover on lateral sediment connectivity and biogeomorphic processes in a medium-sized agricultural catchment. *Geografiska Annaler: Series A, Physical Geography*, ••, ••-••. DOI:10.1111/j.1468-0459.2012.00476.x

ABSTRACT. Connectivity concepts are often used to describe the linkages between sediment sources and sinks within a catchment. Vegetation plays an important role as it influences surface roughness and the local capacity to store sediments and water. However, knowledge about the effects of riparian vegetation on lateral sediment connectivity as well as on the processes and factors that govern them is rare and presents an important research gap. This paper assesses the influence of riparian vegetation cover type on diffuse lateral sediment connectivity on valley floors and investigates biogeomorphic processes acting in forested riparian zones of a medium-sized agricultural catchment. Governing processes and factors are assessed using GIS-based overland flow pathway modelling and geomorphic field surveys together with multivariate statistics (principal component analysis, logistic regression modelling). The results reveal that diffuse lateral sediment connectivity is highly influenced by the respective type of riparian vegetation cover. Forested riparian zones significantly reduce sediment inputs and act as strong disconnectors between the catchment area and the river channel. Topographical features called root dams emerge from biogeomorphic processes in forested riparian zones and act as buffers that limit the connectivity between landscape compartments.

Key words: biogeomorphic processes, land use, lateral sediment connectivity, riparian vegetation, root dams

Introduction

Concepts of connectivity are often used to describe the linkages between the sediment source areas and the corresponding sinks within a catchment (Croke *et al*. 2005). The term sediment connectivity is defined by Hooke (2003) as the 'transfer of sediment from one zone or location to another and the potential for a specific particle to move through the system'. Sediment connectivity occurs at a range of spatial scales and can be connected (coupled) or disconnected (decoupled) over differing timescales (Harvey 2002). Generally, connectivity operates within longitudinal, lateral and vertical dimensions (Ward 1989; Fryirs *et al*. 2007a). According to Brierley *et al*. (2006), longitudinal linkages are defined as upstream–downstream and tributary–main stem relationships, which drive the transfer of flow and sediments through the catchment. Lateral linkages, such as channel–floodplain and slope–channel relationships, govern the supply of materials to the channels. Vertical linkages refer to surface–subsurface interactions of water, sediment and nutrients.

Connectivity assessment is an important tool to estimate sediment conveyance and propagation through a system. Croke *et al*. (2005) distinguish between two types of connectivity: direct connectivity via new channels and diffuse connectivity where surface runoff and transported sediments reach the stream network via overland flow pathways. Sediment connectivity is further governed by frequency and magnitude characteristics (Wolman and Miller 1960) of sediment transport processes and the temporal evolution of vegetation, land use and management (Borselli *et al*. 2008). A greater understanding of the connectivity relationships between landscape compartments is crucial as it leads to an understanding of how (i.e. how fast and if at all) the observed systems react to external forcing (e.g. human interference). Nowadays, almost every catchment is affected by human interventions, such as land clearance and different types of agricultural practices. Deforestation, followed by agricultural land use, for example, generally leads to sediment mobilization as a result of increased soil erosion rates and increased transfer rates from sediment source areas to the river channel networks (e.g. Van Rompaey *et al.* 2002). In general, vegetation cover is most susceptible to human alterations (Brooks and Brierley 1997) and is one of the primary internal factors that determine the magnitude of erosion and sediment delivery to a river. Furthermore, vegetation plays an important role in governing lateral sediment connectivity as it influences surface roughness and the local capacity to store sediments and water (Puigdefabregas *et al.* 1999).

Large quantities of mobilized sediment may be deposited prior to reaching the stream channels. The specific sediment yield of a discrete catchment can therefore be significantly less than the rates of soil loss (Slattery *et al.* 2002; Raclot *et al.* 2009). Increased travel distances generally increase the opportunity for sediment deposition and lead to decreasing sediment delivery ratios with increasing catchment area (e.g. Boyce 1975; Williams 1977; Walling and Webb 1996; Lane and Richards 1997; Walling 1999). In some basins, the correlation of sediment yield and catchment area is even inverse or complex, since topographic thresholds play an important role for the initiation of different erosion processes (de Vente *et al.* 2007). A general decrease of sediment delivery with increasing catchment size is often related to the presence of sediment stores and sinks along the sediment transport pathways, which reduce sediment connectivity between landscape compartments (refer to Brunsden and Thornes 1979; Phillips 1992; Harvey 2002; Michaelides and Wainwright 2002; Hooke 2003). Topographical features, such as buffers, barriers and blankets act as landscape impediments, that is, stores and sinks which potentially limit the connectivity as they hinder the sediment transport between landscape compartments (Fryirs *et al.* 2007a). Since increased travel distances generally increase the opportunity for sediment deposition (de Vente *et al.* 2007), agricultural areas that lie adjacent to the riparian zones are often considered the main sources of fine sediment input to the river channel due to soil erosion processes. De Vente and Poesen (2005) state that with increasing catchment size, floodplains tend to substitute slopes as the direct source of sediment to the channels. Hence, agricultural source areas on valley floors should receive specific attention in terms of a lateral sediment connectivity assessment.

Disconnection effects are further caused by different types of vegetation cover, as they increase the hydraulic roughness and infiltration rates (from plot to catchment scale: e.g. Le Bissonnais *et al.* 2004; on plot to mesoscale: e.g. Borin *et al.* 2005; Deletic 2006). This leads to sediment deposition as a result of reduced transport capacity (Wu *et al.* 1999; Wilson *et al.* 2005) and sediment trapping processes (Dabney *et al.* 1995; Meyer *et al.* 1995; Keesstra 2007; Leguédois *et al.* 2008; Keesstra *et al.* 2009). Tree belts, for example, induce the development of micro-terraces due to sedimentation processes as well as sediment trapping in backwater deposits (e.g. Leguédois *et al.* 2008). These features emerge from biogeomorphic processes and can further act as disconnectors between the different landscape compartments, especially in low-relief areas like floodplains including the riparian zones. Riparian zones are described by Green and Haney (2011) as transitional boundaries between the stream and the terrestrial catchment. The capability of a riparian zone to buffer the sediment flux from agricultural areas to the channel network highly depends on its vegetation cover. Especially in small to medium-sized streams, forested riparian zones can significantly reduce sediment inputs (Osborne and Kovacic 1993). Hence, they potentially act as strong disconnectors between the river channel and the adjacent catchment areas. Nevertheless, in the field of geomorphology, preceding studies mainly dealt with catchment sediment fluxes and the importance of sediment connectivity in general, whilst the role of riparian vegetation was not assessed. Knowledge about the effects of riparian vegetation on lateral sediment connectivity as well as on the processes and factors that govern them is rare and presents an important research gap.

The spectrum of methods used to assess sediment connectivity ranges from field-based empirical techniques to GIS and numerical modelling approaches. In addition, connectivity can be quantified by using statistical connectivity functions (e.g. Western *et al.* 2001) and connectivity indices (e.g. Borselli *et al.* 2008). Potential effects of different types of land use and vegetation cover on sediment conveyance have already been considered in some empirical and experimental studies by Hayes *et al*. (1984), Cooper *et al*. (1987), Dillaha *et al*. (1988, 1989), Dabney *et al*. (1995), Daniels and Gilliam (1996), Mankin *et al*. (2007) and Leguédois *et al*. (2008). Numerical models for vegetated filter effects such as GRASSF, VSMOD, TRAVA have been developed (see Gumiere *et al*. (2011) for an overview) and catchment-scale erosion models for predicting area-specific sediment yield including the mitigating effects of vegetation cover on sediment transport such as EUROSEM, EMSS, WEPP, LISEM, SEMMED, LASCAM are used (cf. Gumiere *et al*. 2011). Few studies have, however, combined GIS and field approaches in order to assess sediment connectivity and less have included the factor of vegetation cover (e.g. Borselli *et al*. 2008; Sandercock and Hooke 2011).

Based on the previous considerations and the detected research gaps, the main objectives of this paper are (i) to assess the influence riparian vegetation cover type on diffuse lateral sediment connectivity on valley floors, and (ii) to investigate biogeomorphic processes acting in forested riparian zones of a medium-sized agricultural catchment. In order to survey the governing processes and factors as well as the interrelated effects, GIS analyses and geomorphic field surveys were combined with multivariate statistics.

As described in the next section, the Fugnitz River catchment, like many river catchments of Austrian lowlands, is highly affected by agricultural land use. However, the upper and middle reaches of the Fugnitz River are lined with different types of riparian vegetation cover adjacent to agricultural areas. These features of the selected study area allow a comprehensive investigation of the effects of different types of riparian vegetation cover on lateral sediment connectivity as well as to assess the role of biogeomorphic processes. A detailed outline of the conceptual background is given and the underlying assumptions and hypotheses for each of the study′s objectives are presented.

Study area

The Fugnitz catchment is located in the eastern part of the Bohemian Massif in Austria (Fig. 1). It is characterized by a humid temperate climate with a mean annual temperature of 8.5°C and annual precipitation ranging from 500 to 600 mm with maxima between April and September. The Fugnitz River is a 29.7 km long, mixed-load, single-thread perennial stream draining a watershed with a total area of 138.4 km^2. The maximum catchment elevation reaches 540.5 m a.s.l. and the outlet is at 286.4 m a.s.l. The drainage basin is characterized by a rather smooth topography with an average slope angle of 2.6° and maximum slope angles up to 32° (computed from a *digital elevation model* (*DEM*) with 10 × 10 m; data source: provincial state government of Lower Austria 2009). The bedrock mainly consists of crystalline mica granite and mica shale, which are largely overlain by Quaternary Pleistocene loess layers (silt, fine sand) and, in some places, by Tertiary silts, clays and sands (brackish-maritime) (Roetzel *et al*. 2008). Prevalent soil types are Cambisols (IUSS Working Group WRB 2007). The land use/vegetation cover is very heterogeneous, exhibiting the following land use classes: agricultural land (56%), forests and woodland (34%), grassland (7%) and built-up areas (3%) (see also Fig. 1).

The maximum slope angle occurring in agricultural land is 31%, with tillage practices dominated by autumn ploughing, exhibiting bare ground during late autumn and early winter. Unfortunately, neither detailed data on the proportions of those agricultural areas that are subject to tillage, nor data on the proportions of bare ground during autumn/early winter are available. The main crops are cereals (summer barley, winter wheat, winter rye and corn), rape, lucerne, milk thistle and oil squash (data source: AMA Austria 2010). The riparian zones along the upper and middle reaches of the main river channel, which are adjacent to agricultural areas, are mainly covered by managed grassland and/or by discontinuous forests and woodland. The predominant tree species occurring in these riparian biotope types are *Salix fragilis*, *Alnus glutinosa*, *Salix cinerea* and *Fraxinus excelsior* (UBA 1989).

Conceptual background

Study area zonation

To assess the influence of riparian vegetation cover type on diffuse lateral sediment connectivity on the valley floor (objective i), a medium-sized agricultural catchment was conceptually subdivided into different zones: upland area and hillslope, valley floor, riparian and streambed (Fig. 2). This was done, firstly, to define criteria for delimiting the modelled overland flow pathways to the area of main research interest (i.e. valley floors), and sec-

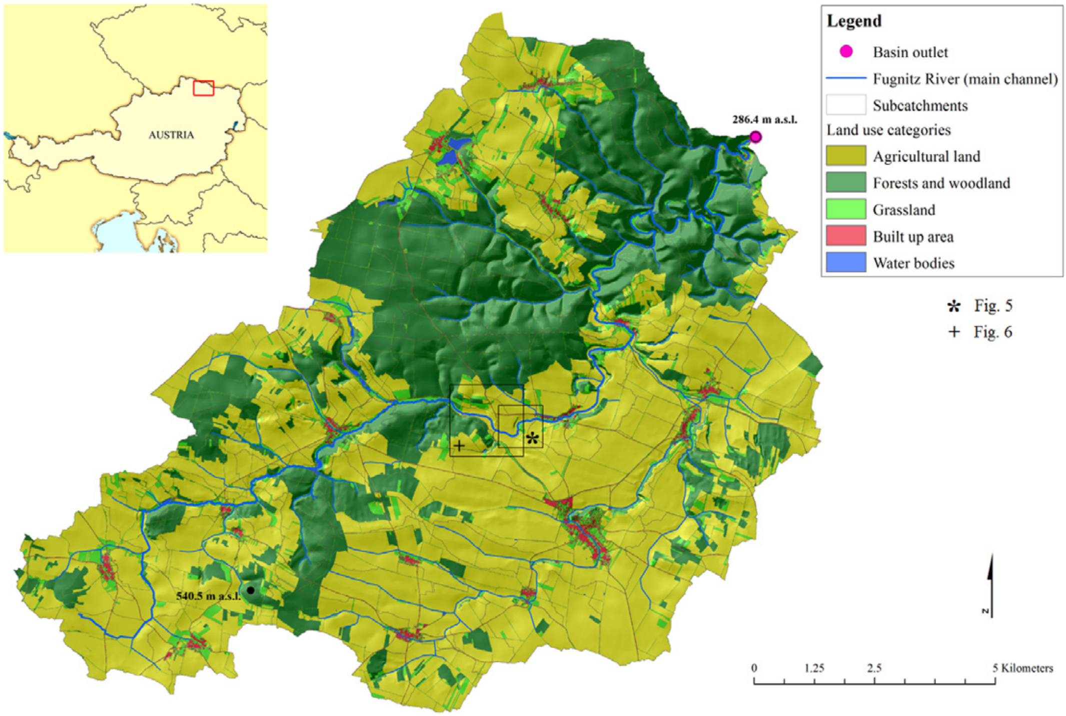

Fig. 1. Location and land use of the study area. Land use data have been derived by applying aerial photograph interpretations (data source: provincial state government of Lower Austria 2009). Catchment areas were delineated with Arc Hydro Tools 1.4 in ArcGIS 9.3 using a LiDAR-DTM with 1 m × 1 m resolution (data source: provincial state government of Lower Austria 2009). The course of the main river channel was digitized with a manual mapping procedure that interprets a DTM-derived hillshade.

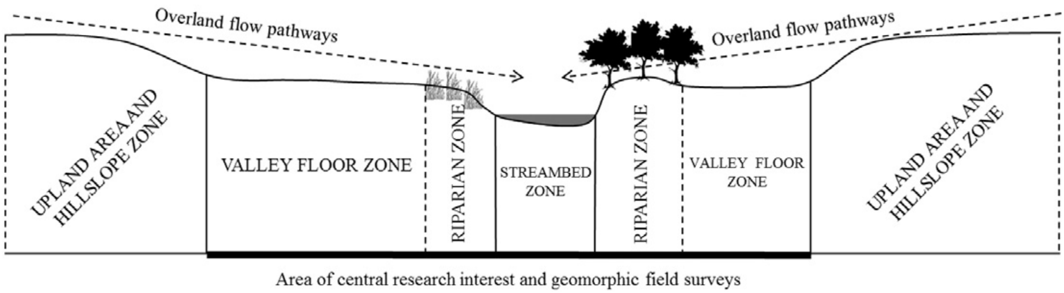

Fig. 2. Zonation of the study area. Dashed arrows indicate overland flow pathways that potentially connect the different study area zones. The area of central research interest and geomorphic field surveys is shown by the bold black line. Root dams are present in the forested riparian zones (see section 'Biogeomorphic processes').

ondly, for further analyses of the pathways within the valley floor zone (see 'Lateral sediment connectivity'). The zonation of the catchment is based on the following general criteria: slope angle thresholds related to surface morphology breaklines, and changes in land use and vegetation cover.

The valley floor zone includes those catchment areas that are located between the upland area/hillslope zones and the streambed zone. The valley floor zone was delimited from the upland area/hillslope zone by a slope angle threshold of 2°. According to Fryirs *et al*. (2007b), who also used slope threshold analysis in GIS to analyse landscape (dis)connectivity in a similar environment, this value represents conditions under which off-slope sediment transport is likely to be

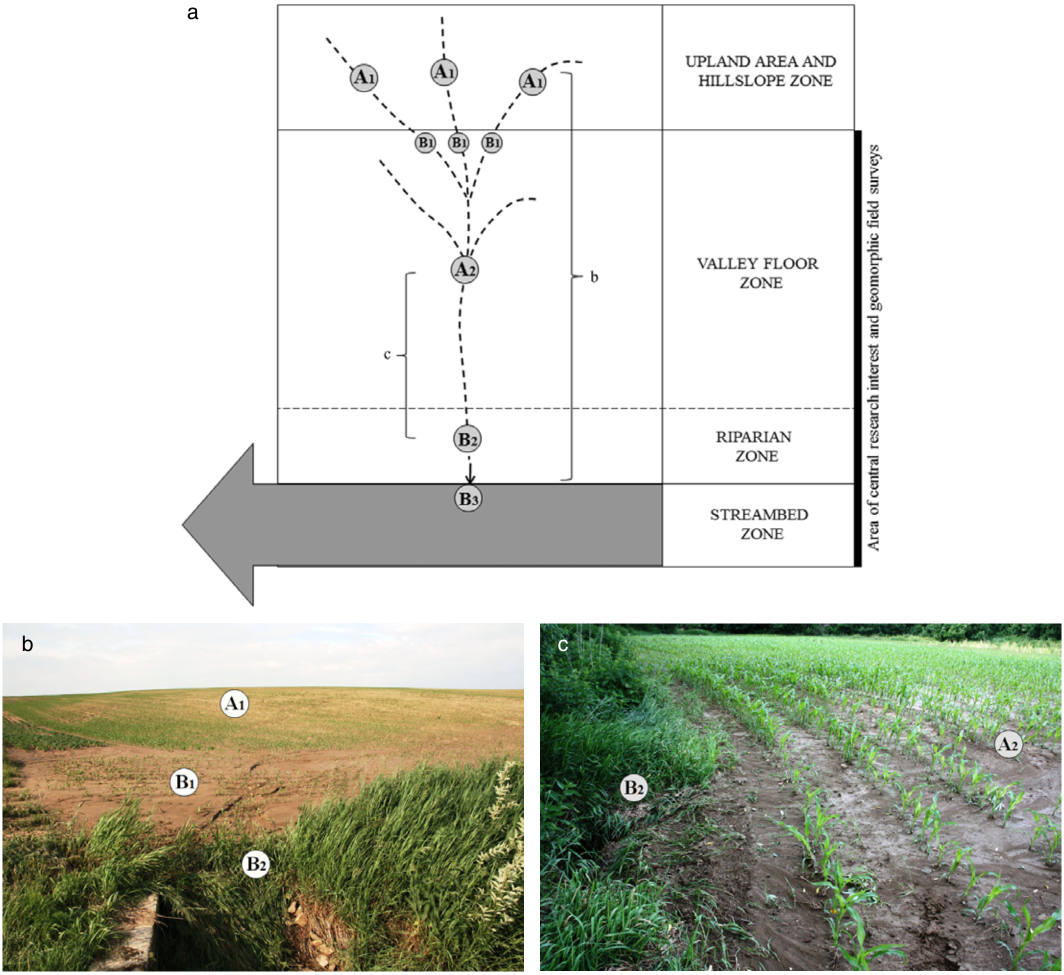

Fig. 3. (a) Conceptual model of sediment entrainment, transport and accumulation. Dashed arrows show potential overland flow pathways. The grey shaded arrow symbolizes the river channel. A1 and A2 in grey shaded circles show locations of potential sediment mobilization due to soil erosion processes, whereas B1, B2, and B3 indicate potential locations of sediment deposition or remobilization. Curly brackets localise the areas of extent of (b) and (c) which show real-life events from the study area. The bold black line at the bottom right hand side of (a) indicates the area of central research interest and geomorphic field surveys.

promoted. The occurrence of river banks is again assumed to be related to slope angles greater than 2°. At locations where slope angles are below a threshold of 2° (i.e. the base of the river banks), the streambed zone was delimited from the valley floor zone. The riparian zone, which is the transitional zone between the streambed zone and its catchment, was distinguished from the valley floor zone by a change in vegetation cover (i.e. from agricultural land use to the presence of trees/shrubs and/or grasses). Information on land use and vegetation cover was obtained in the course of the land use mapping procedure (see below).

Lateral sediment connectivity

Hydrologic overland flow connectivity is the basic requirement for sediment connectivity between the different zones of the study area (see Fig. 3a). If sediment particles are mobilized within the upland area/hillslope zone at location A1, they are potentially routed via overland flow pathways to location B1 in the valley floor zone. Here, sediment particles can be deposited if the transport capacity changes abruptly, for example, due to the presence of a surface morphology breakline and a related decrease of slope angle. If overland flow is sufficient to overcome these breaklines, sediment can be routed further along the overland flow pathways within the valley floor zone or sediments will accumulate. Sediments can be remobilized and transported further in the course of a later overland flow event until they meet the streambed zone. If sediment is mobilized at location A2 within the valley floor zone, the sediment is transported until transport capacity declines due to resisting forces. The material is then either deposited at location B2 (riparian zone), or transported further until it reaches the river streambed zone, where the material is temporally stored or transported downstream (location B3).

As illustrated above, erosivity, transport capacity of overland flow and erodibility determine the type of process (erosion, transport, accumulation) as well as the location of appearance. In order to assess the sediment connectivity between the agricultural source areas and the river channel, a range of factors that potentially govern sediment generation and sediment transport processes need to be considered.

Sediment source areas. In an arable field, soil erosion rates mainly depend on rainfall pattern, soil type, topography, crop system and management practices. These factors can be identified by using specialized models for soil erosion, such as USLE and RUSLE (Wischmeier and Smith 1978; USDA-SCS 1986). Additionally, soil erosion processes may be directly observed by using geomorphic field survey methods, which also can be used to validate the results of soil erosion models (ground truthing). Initially, all agricultural areas within the valley floor zone of the study area are considered as potential sediment source areas, since in these areas increased erodibility due to open soil conditions is assumed. In contrast, erodibility of grassland and forest-covered areas is expected to be comparatively low and hence soil erosion to be negligible.

Sediment transport. In addition to sediment mobilization, the second basic requirement for potential sediment transport by water is the presence of overland flow pathways. Generally, sediment transport capacity depends on slope angle, surface roughness and the availability/amount of water. Water can be generated on the spot itself (valley floor zone) and/or upslope (upland area/hillslope zone) (Borselli *et al.* 2008). Transport capacity generally increases with slope angle and flow accumulation. Local flow accumulation, in turn, strongly depends on the rainfall intensity and the spatial distribution of rainfall events in a catchment. Slope profile curvature which displays the change of the gradient is another important factor which also has to be considered in the course of assessing potential water flow and sediment transport processes (e.g. Moore *et al.* 1993). Furthermore, sediment transport capacity of water is influenced by surface roughness and soil infiltration capacity, since physically and biologically controlled thresholds have to be exceeded (Puigdefabregas *et al.* 1999; Cammeraat 2002; Croke *et al.* 2005).

The potential for sediment transport is expected to be reduced by the respective types of land use and vegetation cover along the overland flow pathways within the riparian zone since infiltration rates and/or hydraulic roughness increase which results in sediment deposition. A further decrease in sediment transport capacity can also be expected due to sediment trapping in the backwater reaches of tree roots and trunks, and due to the establishment of root dams in forested riparian zones (see below). Based on these assumptions, sediment connectivity is hypothesized to be lower in forested areas than in agricultural and grassland areas. It is therefore assumed that, if flow accumulation and slope angle remain constant, sediment connectivity in forested and grassland areas declines with the length of the overland flow due to cumulative disconnecting effects of vegetation cover.

Apart from disconnecting effects of vegetation cover, the local surface morphology breaklines depict azonal occurrence patterns (e.g. related to field boundaries or building structures, such as farm tracks) that affect transport capacity within the valley floor zone as these features can lead to abrupt changes in transport capacity and hence sediment connectivity. These features are therefore also included in the present connectivity assessment, again by applying a slope threshold of 2°.

The following forms are assumed to be indicators of overland flow connectivity between the agricultural source areas and the river channel network. They are therefore used as indicators for sediment connectivity:

- Continuous rills (vegetated or non-vegetated) (see also Fig. 3b).

- Continuous indications of overland flow processes (sheet flow or concentrated flow): plants oriented in flow direction, siltation marks on vegetation (see also Fig. 3c).

Biogeomorphic processes

Dam-like geomorphic features called *root dams* potentially form parallel to the stream channel. It is hypothesized that these features emerge from biogeomorphic processes polygenetically (see also Fig. 2) based on the following considerations.

Surface roots of trees and shrubs have a soil-binding function (Rawnsley 1991), and protect the underlying soil from potential soil erosion processes. In contrast, those areas within the valley floor zone without or with less surface roots exhibit a higher potential for soil loss. This leads to elevation differences between protected and unprotected surfaces.

It is assumed that the formation of natural levees preferably occurs in forested riparian zones, as the presence of trees leads to higher a reduction of transport capacity and thus sediment deposition during flood events.

The establishment of root dams may be caused by the presence of surface tree roots, trunks of trees and shrubs. These act as natural obstacles to overland flow and transported sediment arriving from adjacent agricultural areas. Surface tree roots and trunks cause backwater areas and flow separation, thus altering the hydraulic conditions and consequently the sediment transport capacity of overland flow. Furthermore, infiltration rates of forest soils are comparatively high due to soil loosening caused by root action (e.g. Carmean 1957).

These factors lead to a reduction of sediment transport capacity, especially in flat areas such as floodplains and sediment accumulation occurs in front of obstacles at location A (stage 1, see Fig. 4a). Hypothetically, dense treelines lead to synergistic flow and sedimentation processes between close tree roots and trunks. In a following flow event, sediments that reach location A are diverted by the previously accumulated forms at location A (stage 2, see Fig. 4b) and further routed to neighbouring tree roots (see Fig. 4b, locations B), where accumulation takes place. Accumulation is also said to occur adjacent to the accumulation forms at location A (Fig. 4). This is expected to be caused by a reduction of transport capacity in the lateral reaches of the overland flow pathways when the water level drops. When root dams have fully established they are hypothesized to act as local natural barriers to sediment flow as they hinder subsequently arriving sediments to enter the streambed zone (stage 3, see Fig. 4c).

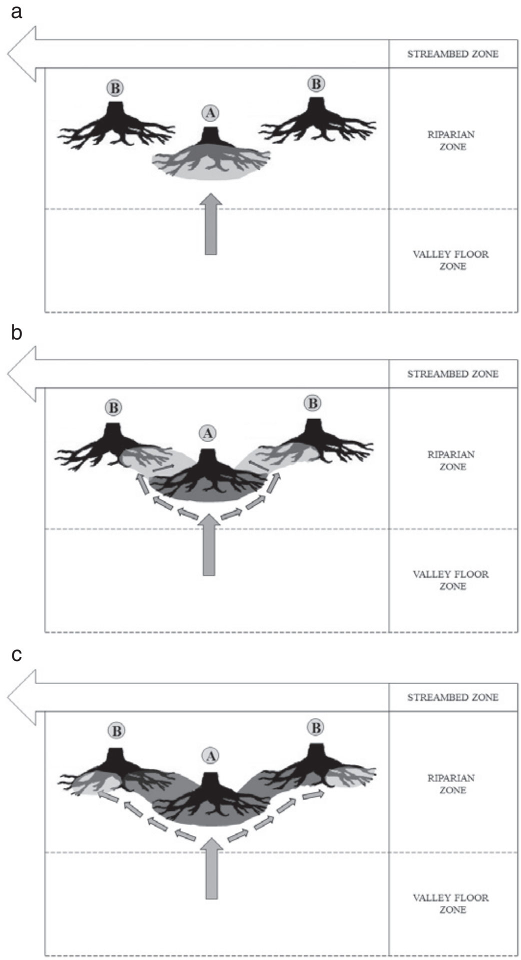

Fig. 4. (a)–(c) Conceptual model showing the influence of damming processes along overland flow pathways on the establishment of root dams (angled view). Black shapes symbolize roots and trunks of trees which are protruding above the soil surface (subsurface roots are not shown here). Grey shaded arrows indicate the routing of oncoming sediment via overland flow pathways. Locations where accumulation processes occur are indicated by letters A and B. Light grey shaded shapes delineate newly deposited material, whereas dark grey shaded areas symbolize sediments which have been accumulated during a preceding event. For specific study area location, see Fig. 1.

Methods

Lateral sediment connectivity

To assess the lateral sediment connectivity within the catchment, two key processes have to be assessed: sediment mobilization in source areas and sediment transport along the flow routes. Source areas are delineated using land use mapping, while sediment transport is assessed applying GIS analyses, geomorphic field surveys and statistical analyses. These methods are presented in detail below.

Land use mapping – potential sediment source areas. Land use mapping was conducted by using recent orthorectified aerial photographs with 25 × 25 cm resolution within ArcGIS (data source: provincial state government of Lower Austria 2009). The following land use classes were outlined for the whole catchment: agricultural land, grassland, forests and woodland (incl. shrubland) and built-up areas. Land use mapping was verified using field surveys conducted during the geomorphic field survey (see below). To estimate the land use conditions of the valley floor zone, percentages of each land use class within a bilateral streamside buffer range of 100 m were calculated in ArcGIS for areas exhibiting slope angles below 2° (see also criteria for valley floor subdivision above). For this, raster data containing information on land use were clipped on the extent of a bilateral streamside buffer range of 100 m. The same was done with a slope raster dataset which was calculated with Spatial Analysts Tool in ArcGIS using a DTM with 1 × 1 m resolution. The clipped slope raster data were then reclassified by assigning pixels with slope angles >2° the value '0' and pixels with slope angles <2° the value '1'. Subsequently, both datasets were multiplied by each other which resulted in a raster dataset only containing land use information for pixels with slope angles <2° within a bilateral buffer range of 100 m.

Overland flow pathway modelling – sediment transport. The aim of these GIS analyses is to obtain a simple model of sediment routing within the valley floor zone based on the criteria for study area zonation. The modelled flow routes (represented as polylines) were required to exhibit the following characteristics, i.e. they have to:

- originate in agricultural areas of the valley floor zone (see Fig. 5c);
- end in front of surface morphology breaklines (see Fig. 5d);
- end at the border of the streambed zone (see Fig. 5e);
- consist of a single line per vegetation cover type, including information on segment length (measured in metres) (see Fig. 5e).

The analyses are conducted in ArcGIS 9.3 using a LiDAR-DTM with 1 × 1 m resolution. The river channel network of the study area is integrated into the calculation process by burning the river channel network into the DTM by subtracting 10 m from the filled DTM along the river channel network. This was done to prevent misroutings during the overland flow pathway modelling (see below) that can result from errors in the DTM along the channel network. The river channel network itself is digitized with a manual mapping procedure that interprets a DTM-derived hillshade. The result is corrected according to aerial photograph interpretations and field surveys.

In order to model *overland flow pathways*, the flow accumulation is calculated (Fig. 5a). The GIS command 'Flow Accumulation' creates a raster grid of accumulated flow into each cell. It is considered to be a proxy for the potential amount of water for each grid cell within the catchment. A hydrological 'correction' was required for processing. Single cells of the DTM surrounded by higher elevation cells were therefore filled using the 'Fill Sinks' tool, while 'real' depressions (sinks) were assumed to stay mainly unmodified. When the modelled flow reaches sediment sinks, the flow routing will stop after entering the sink area.

To drop cells with low flow accumulation values, the modelled Flow Accumulation grid is reclassified to a grid that only contains values above the mean. The output raster grid was then converted into polyline format (Fig. 5b). In order to extract the overland flow pathways, the longest line features crossing the last agricultural area within the valley floor zone was extracted and merged manually. All other segments were deleted, which resulted in a single line segment from the last agricultural area to the main river channel crossing the riparian zone (Fig. 5c). Finally, line segments were cut according to the criteria described above. Information on slope thresholds was obtained by calculating a slope derivate of the DTM and by reclassifying the resulting raster grid. This reclassification is again based on a 2° slope threshold, and all values beneath/above this threshold were set to 0 and 1, respectively. When a line segment crosses a slope threshold of 2°, the respective upline segment was manually cut and deleted (Fig. 5d). Where a change in vegetation cover

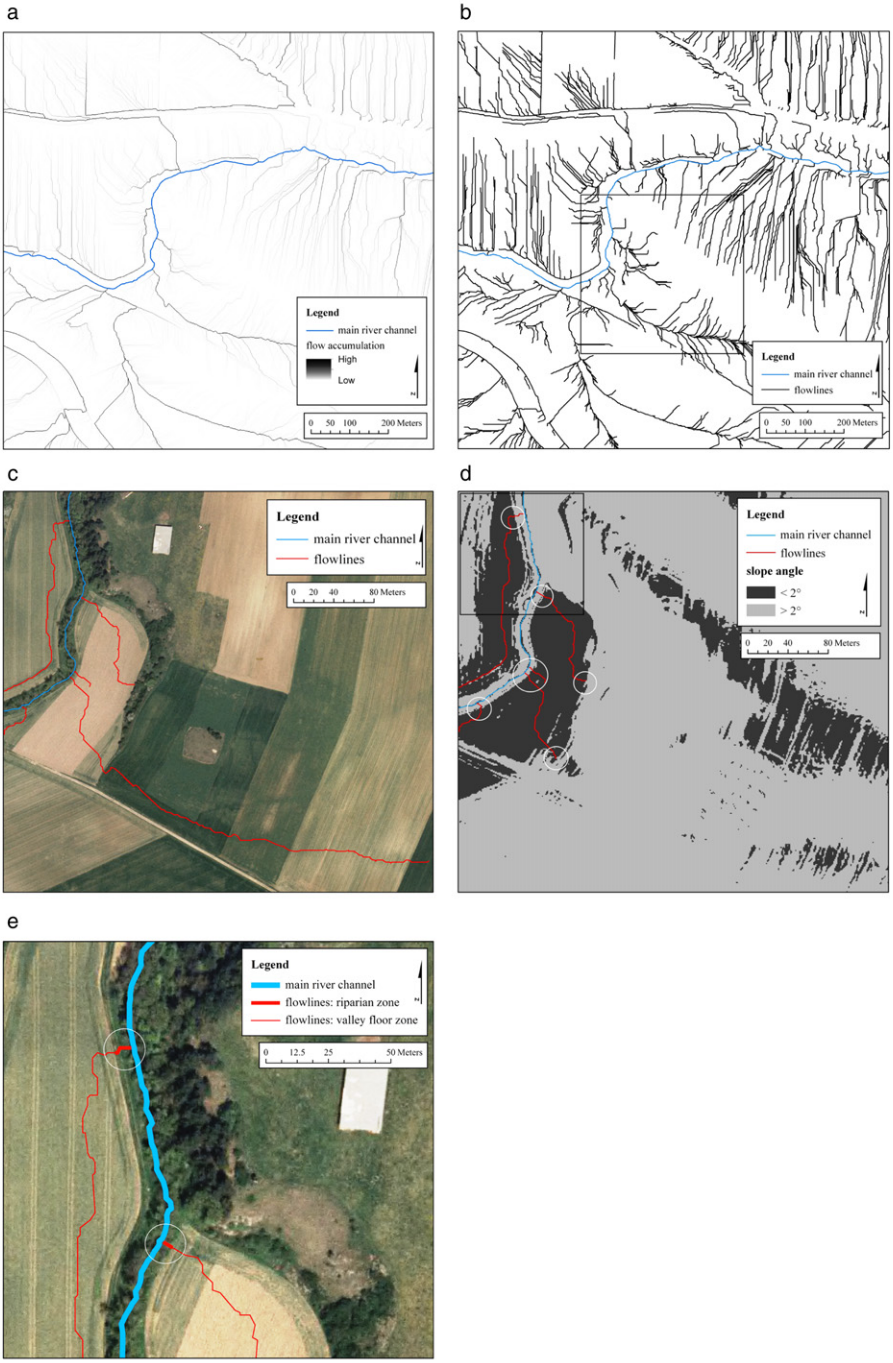

Fig. 5. Delineation of overland flow pathways with ArcGIS. (a) Calculation of flow accumulation. (b) Conversion of flow accumulation raster grid into polyline format. (c) Extraction of the longest flowlines that cross the last agricultural area within the valley floor zone before they confluence the main river channel. All other segments were deleted, resulting in a single line segment from the last agricultural area to the main river channel, also crossing the riparian zone. (d) Cutting of line segments crossing a slope threshold of 2°: the respective upline segment was cut and deleted (locations are indicated by white circles). (e) Cutting of line segments according to changes in vegetation cover (locations are indicated by white circles). For specific study area location, see Fig. 1.

along a line segment occurs, the line segment was cut. This led to the conversion of a single line to a polyline feature (Fig. 5e). Furthermore, for each line segment the segment length was calculated.

To obtain information on the factors that potentially influence lateral sediment connectivity, the 'Line Raster Intersection Statistics Tool' provided by Hawth's Analysis Tools for ArcGIS (Beyer, http://www.spatialecology.com/htools, 18-Jul-12) was used. This application calculates the length of each line that falls within a raster cell and a statistical summary is created based on these segments (i.e. length weighted mean, minimum values, maximum values, standard deviation). It is assumed that the following factors influence sediment transport and thus sediment connectivity: slope angle in degrees; profile curvature; and flow accumulation. Consequently, these factors were created as raster layers for the whole catchment and used for this statistical analysis. After processing, the values were stored in the attribute table of the polyline layer for further statistical analyses.

Table 1. Geomorphic field survey check list.

Location No.	Survey date
Modelled overland flow pathway? ☐ Yes ☐ No	
RIPARIAN ZONE	
Overland flow pathways	**☐ No overland flow pathways**
☐ Rill	
☐ Marks of overland flow processes	
☐ Root damming	
Vegetation cover	
Vegetation Type	*Segment length in m*
☐ Grassland (GL)	
☐ Forested land and/or shrubland (FL)	
VALLEY FLOOR ZONE	
Overland flow pathways	**☐ No overland flow pathways**
☐ Rill	
☐ Indications of overland flow processes	
Plough Direction ☐ parallel ☐ perpendicular	
☐ Presence of farm tracks	

Geomorphic field surveys – sediment transport. To assess overland flow pathways and to validate the model performance (ground truthing), geomorphic field surveys were applied. The geomorphic field surveys were conducted after a daily rainfall event of 37 mm which occurred in autumn 2010 and constituted approximately 7% of the annual precipitation. This rainfall event occurred during a time of sparse crop cover in agricultural areas due to preceding harvesting which was expected to promote overland flow processes. Surveys were carried out along both sides of the river channel within the valley floor zone at locations where overland flow pathways were modelled. Locations with contradictory results were also recorded, that is, where indicators for overland flow processes were observed in the field, but where no flow pathways have been modelled. The lengths of overland flow pathway per vegetation cover within the riparian zone were measured with a measuring tape. Plough direction and root damming were included in the geomorphic field survey process, since they are assumed to influence lateral sediment connectivity. Plough lines running perpendicular to the flow direction of the main river channel are expected to enhance sediment connectivity, whereas contour ploughing lines are assumed to have the opposite effect. Root dams were surveyed, since they are regarded as major disconnecting features due to related damming processes. The presence of farm tracks running parallel to the river channel were also considered as they are assumed to lower sediment transport capacity due to damming effects or surface flattening. Table 1 shows the detailed check list for the geomorphic field survey procedure:

For very short segment lengths (e.g. 1 m) with more than one type of vegetation (i.e. grassland (GL) and forested land (including shrubland, FL) observed in riparian zones, the values for riparian overland flow pathways segments from Line Raster Intersection Statistics (i.e. information on slope angle, profile curvature, flow accumulation) were not differentiated further. In such cases, it was assumed that consistent conditions for the whole segment within the riparian zone occurred while assigning the values of the whole segment to each single segment per vegetation cover. Nevertheless, information on segment lengths per vegetation cover was considered in the course of the statistical analyses (logistic regression) (see next section).

Statistical analyses – sediment transport. To investigate the influence of riparian vegetation cover type on sediment connectivity, as well as to examine the explanatory power of the potential factors of influence, logistic regression modelling was applied. Logistic regression allows the prediction of the probability of an event to occur (p). In our case probabilities higher than 0.5 are taken as an indicator for sediment connectivity; probabili-

Table 2. Explanatory variables for PCA analysis and logistic regression modelling, including abbreviations and type of input data. All numerical values were $\log_2$ transformed. According to the type of land use and vegetation cover along each line segment, abbreviations were extended by adding 'AL' for agricultural land, 'GL' for grassland, and 'FL' for forested land including shrubland.

Explanatory variable	Abbreviation	Type of input data
Percentage of riparian vegetation (GL/FL)	Per	Numerical
Cumulative flow length for all segments within the riparian zone (m)	CumLen	Numerical
Flow length (m) (AL)	Len	Numerical
Slope angle (°) (mean)	Slo	Numerical
Profile curvature (mean)	Cur	Numerical
Flow accumulation (mean)	Flo	Numerical
Difference in slope angle, profile curvature and flow accumulation between valley floor zone and riparian zone (= mean of valley floor zone – mean of riparian zone, 3 variables), see also scenario 1	Dif_Slo, Dif_Cur, Dif_Flo	Numerical
Root dams: 0 (no root dam present), 1 (root dam present)	Rod	Binary
Plough direction: 0 (parallel to the flow direction of the main river channel), 1 (perpendicular to the flow direction of the main river channel)	Plo	Binary
Farm tracks: 0 (no farm tracks present), 1 (farm tracks present)	Fat	Binary

ties below 0.5 indicate the contrary. The dependent variable (in our case the lateral sediment connectivity) is binary (yes = 1, no = 0).

Binary and numerical parameters for each line segment which had been examined in the course of GIS analyses and/or geomorphic field surveys were chosen as explanatory variables. Table 2 presents a list of the explanatory variables which were used for logistic regression modelling, introduces their abbreviations and provides information on type of input data.

A *principal component analysis* (*PCA*) was performed as some of the explanatory variables were highly correlated. This was done to avoid collinearity problems and PCA components were used as uncorrelated explanatory variables for the logistic regression model. The scree-criterion was used to select the number of PCA factors extracted and a varimax rotation was applied to ensure easy interpretation of the factors.

To determine the variables with the highest explanatory power for sediment connectivity, logistic regression (dependent variable = presence of sediment connectivity), backward elimination of explanatory variables was applied and all explanatory variables were initially included. Subsequently, the variable that contributes the least to explain the response variable is removed at each step (= 'backward elimination'). Positive regression coefficients indicate a predicted increase in probability for sediment connectivity if the explanatory variable increases. The opposite holds true for negative regression coefficients.

As 37 of 91 observations of overland flow pathways were not modelled and only examined in the field, they lacked information on slope angle, slope profile curvature, flow accumulation and flow length along agricultural areas adjacent to the riparian zone. Nevertheless, data on 'Per', 'CumLen', 'Rod', 'Plo' and 'Fat' for segments within the riparian zone were available because these features had been examined during the geomorphic field surveys. Thus, two different logistic modelling scenarios were calculated followed by a comparison of the results aiming to perform a statistically representative analysis for each explanatory variable.

Scenario 1: the five axes from the PCA and the three binary variables 'Plo', 'Fat' and 'Rod' were used as explanatory variables. Observations without numerical information on explanatory variables (i.e. observations of overland flow pathways, which had not been modelled, but examined in the field) were excluded from the analysis.

Scenario 2: all observations with explanatory variables, which had been examined in the field, were integrated into the logistic regression model (i.e. 'Per', 'CumLen', 'Rod', 'Plo' and 'Fat').

Biogeomorphic processes. During geomorphic field surveys (see Table 1), root dams were examined in the field. The survey was carried out along the modelled overland flow pathways within forested areas of the riparian zone. The delineation of root dams was conducted in the field based on the following criteria: presence of overland flow pathways within the valley floor zone; absence of overland flow pathways within the riparian zone; riparian zone lies higher than the adjacent areas of the valley floor zone. Differences in elevation

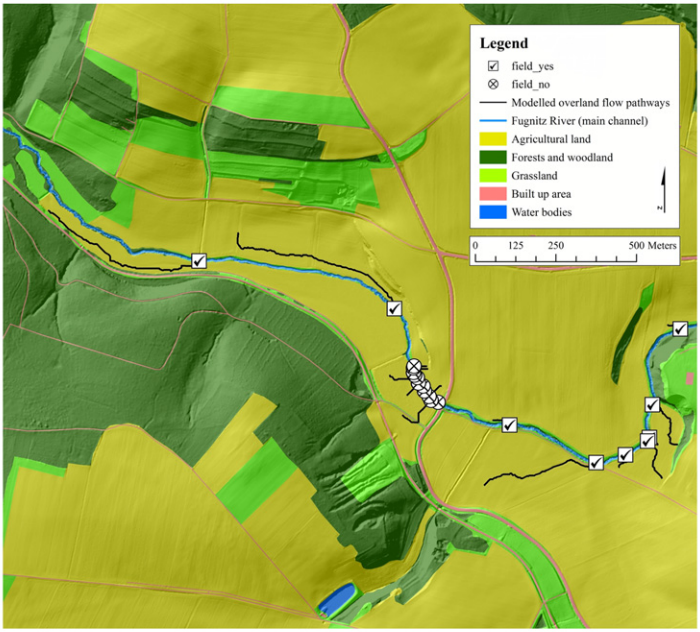

Fig. 6. Overland flow pathway modelling output; field-verified modelled overland flow pathways are indicated by 'field_yes'; modelled overland flow pathways where no related features had been observed in the field are designated by 'field_no'.

between the riparian zone and the adjacent areas within the valley floor zone were examined visually and by walking in the field. To visualize root dams, valley floor cross sections have been drawn using the 3D Analyst Tool in ArcGIS 9.3 using a DTM with 1 × 1 m resolution. For this procedure, a non-filled DTM was used to make sure that no filling of real sinks had taken place in the course of the 'Fill Sinks' processing.

To delineate potential factors of influence for the establishment of root dams, a statistical analysis using cross tabulations and Fisher's exact test was performed to relate overland transport pathway segments exhibiting forest cover to the binary explanatory variables (see Table 2).

Results and discussion

Lateral sediment connectivity

Land use mapping – potential sediment source areas. The land use/vegetation cover of the total catchment is very heterogeneous, exhibiting the following land use classes: agricultural land (56%), forests and woodland (34%), grassland (7%) and built-up areas (3%) (see also Fig. 6). The valley floor located in the upper and middle reaches are dominated by agricultural areas (64%) (potential sediment source areas) and the following land use classes: forests and woodland (5%), grassland (27%) and built-up areas (4%). It is noted that 73% of these river reaches are lined bilaterally (93%) or unilaterally (7%) by forests and woodland, while 27% showed no forest and woodland cover. Riparian zones without forest and woodland cover are almost exclusively covered by grassland with only sporadic occurrence of agricultural or built-up areas directly adjacent to the river channel.

Overland flow pathway modelling – sediment transport. The overland flow pathway model identified 164 overland flow pathways that meet the needs of the following criteria: they originate in agricultural areas in the valley floor zone, cross the riparian zone, end in front of surface morphology breaklines and end at the border of the streambed zone. Fig. 6 shows a part of the model output and Table 3 shows a summary of all modelled overland flow pathways segments per land use and riparian vegetation cover within the valley floor zone. A total of 89 riparian segments exhibited grassland vegetation (mean segment length of 5.4 m), while 75 segments showed forest and woodland cover (mean segment length of 5.7 m).

Table 3. Summary of all modelled overland flow pathway segments per land use and riparian vegetation cover.

	Agricultural areas	Riparian forests and woodland	Riparian grassland
Mean segment length (m)	89.7	5.7	5.4
Min. segment length (m)	3.9	2.0	1.4
Max. segment length (m)	778.2	14.6	86.4
St. dev.: segment length (m)	113.7	2.7	10.4
Number of segments	164	75	89

Table 4. Summary of the geomorphic field survey results.

Parameter	No. of observations
Valley floor zone	
Overland flow pathway present	91
Overland flow pathway present, overland flow pathway modelled	54
Overland flow pathway present, no overland flow pathway modelled	37
Sediment connectivity between agricultural source area and river channel present	45
Farm track present	29
No farm track present	62
Plough direction: parallel	54
Plough direction: perpendicular	37
Riparian zone	
Agricultural land only	3
Forests and woodland (incl. shrubland) only	8
Grassland only	62
Mixture: forests and woodland (incl. shrubland), grassland	18
Root dams present	16
No root dams present	11

Geomorphic field surveys – sediment transport. A total of 91 overland flow pathways were surveyed in the field. These meet the following criteria: continuous rills (vegetated or non-vegetated), continuous indications of overland flow processes (sheet flow or concentrated flow). At 45 locations sediment connectivity between the agricultural areas and the river channel was found. A total of 54 out of 164 modelled overland flow pathways could be verified in the field, while in 37 locations, overland flow pathways were detected where no flow pathways had been modelled. In Table 4 the results of the geomorphic field surveys are presented, while Table 5 shows a summary of all observed overland flow pathway segments per vegetation cover within the riparian zone. A total of 80 riparian segments exhibited grassland vegetation (mean segment length of 3.7 m), while 26 segments showed forest and woodland cover (mean segment length of 2.4 m).

Table 5. Summary of observed overland flow pathway segments per riparian vegetation cover type.

	Riparian forests and woodland	Riparian grassland
Mean segment length (m)	2.4	3.7
Min. segment length (m)	1	1
Max. segment length (m)	6	32
St. dev.: segment length (m)	1.6	4.3
Number of segments	26	80

Validation of overland flow pathway modelling. A total of 54 out of 164 modelled overland flow pathways could be verified in the field, which indicates a model overestimation of 303.7%. A total of 59.3% of all overland flow pathways detected in the field were assigned correctly by the model. At 37 locations overland flow pathways were detected where no flow pathways had been modelled, which leads to a model underestimation of 41.7% (see also Table 4). To gain information for potential improvement of the model performance, causes of model over- and underestimations are discussed in the following sections.

The applied overland flow pathway modelling approach provides information on potential pathways of overland flow. However, the occurrence and site at which overland flow takes place in reality further depends on factors that have not been considered in this study which may lead to model over- or underestimations. These factors include rainfall intensity, rainfall distribution patterns, differences in soil infiltration capacity, micro-relief and subsurface drainage. Although the applied approach takes into account the amount of water from upland/hillslope zones that potentially reaches the valley floor zone (flow accumulation), other factors governing flow generation and overland flow processes in the upland/hillslope zones are not considered. For a comprehensive lateral sediment connectivity assessment it might thus be of added value to extend the present approach to the hillslope/upland area zones as well as to include the explanatory factors mentioned above.

To estimate factors relevant to the overland flow pathway modelling that are potentially influencing model overestimation, a statistical analysis was performed. For segments with agricultural land use

Table 6. Results of the statistical analysis showing the ratios between the mean values of explanatory variables ('Len_AL', 'Flo_AL', 'Slo_AL', 'Cur_AL') of verified modelled overland flow pathways ('field_yes') and the modelled overland flow pathways where no related features were observed in the field ('field_no').

	field_yes : field_no
Len_AL	1.05
Flo_AL	1.87
Slo_AL	1.59
Cur_AL	2.03

'AL', the ratios of mean values 'Len', 'Flo', 'Slo' and 'Cur' were calculated for field-verified observations ('field_yes'). These were divided by mean values where no flow pathways could be verified in the field ('field_no') (see Table 6).

The ratios presented in Table 6 indicate that the mean values of the explanatory variables 'Flo_AL', 'Slo_AL' and 'Cur_AL' are significantly higher in field-verified modelled overland flow pathways ('field_yes') than in modelled overland flow pathways where no related features had been observed in the field ('field_no'). On the one hand, these results suggest that these factors are influencing lateral sediment connectivity. On the other hand, they imply that a possible reason for model overestimation is the use of too high threshold values for the explanatory variables. To estimate possible threshold values for the present data (threshold analysis), the lowest values of explanatory variables for 'field_yes' have been evaluated. An explanation of these variables is given below:

- 'Flo_AL': 'Flo_AL' is the only factor, where a threshold value was principally assumed, because only modelled Flow Accumulation values above the mean (>586) have been considered in the modelling procedure. The lowest value of 'Flo_AL' for 'field_yes' was 779, while the average value of 'field_yes' was 36 820. Hence, only a small difference between the lowest value of 'Flo' for 'field_yes' and the threshold of Flow Accumulation values above the mean suggest that factors other than 'Flo_AL' are preferably governing the model overestimation.
- 'Slo_AL': the lowest value of 'Slo_AL' for 'field_yes' was 0.31°, which suggests a lower mean slope angle threshold of roughly 0.3° within the study area.
- 'Cur_AL': no 'field_yes' observation showed 'Cur_AL' values below –0.57, indicating a lower mean profile curvature threshold of about –0.6.

Another reason for model overestimation involves the use of the DTM 'Fill Sinks' tool. If real depressions are filled, the flow routing might not stop in existing sink areas, but can be modelled further downslope until potentially reaching the streambed zone. This may occur in transition areas between the valley floor zone and forested riparian zone areas where the presence of small-scale real sinks due to the establishment of root dams and filling of real sinks is highly probable. The same effects are expected to occur at the boundaries of agricultural source areas and farm tracks, where a filling of small-scale real sinks may also take place.

Model underestimations can generally occur at locations where the flow along the overland flow pathways is sufficient to overcome the surface morphology breaklines. This may also depend on conditions in the upland/hillslope zones that are enhancing flow generation and overland flow processes and determines the amount of water reaching the valley floor zone which is then available for sediment transport (e.g. high local rainfall intensity, low soil infiltration capacity and subsurface drainage). Furthermore, model underestimation can be caused by errors in the DTM which potentially lead to flow misroutings. Another reason for model underestimation could be related to the choice of flow direction algorithm. Flow direction algorithms generally have been categorized into two types: single direction and multiple direction. A single-direction algorithm transfers the flow from the centre cell to one downslope neighbour, while multiple-direction algorithms are able to partition flow to multiple downslope neighbours (Erskine *et al.* 2006). The Flow Direction tool in ArcGIS 9.3 uses a single-direction algorithm based on the D8 (eight flow directions) method that assigns flow from each pixel to one of its eight neighbours in the direction with steepest downward slope (Jenson and Domingue 1988). Great relative differences between single- and multiple-direction algorithms have been observed by Erskine *et al.* (2006) especially in divergent areas such as ridges and side slopes using high-resolution DEMs. Moreover, model underestimation could be due to a non-consideration of factors influencing the potential for soil loss, such as the soil erodibility factor, which has not been integrated in the present study due to a lack of data.

Table 7. Factor loadings of the five PCA factors. Bold numbers indicate the strongest correlations between PC scores and variable values; values were $\log_2$ transformed All factors were used as explanatory variables in the logistic regression model.

Variables	Dif_Slo_GL	Flo_AL	Cur	CumLen	Dif_Flo
Per_FL	**–0.759**	–0.042	0.094	0.498	0.063
Per_GL	**0.878**	0.026	–0.047	–0.002	0.067
CumLen	–0.085	–0.044	–0.001	**0.964**	0.016
Flo_AL	0.439	**0.650**	0.005	0.000	0.314
Slo_ AL	0.096	**–0.769**	–0.337	–0.162	0.246
Cur _AL	0.039	0.126	**0.819**	–0.115	0.254
Dif_Cur_AL	0.017	–0.061	**0.833**	0.122	–0.172
Dif_Slo_AL	**0.687**	–0.058	0.197	0.021	–0.276
Dif_Flo_AL	–0.131	–0.119	0.044	0.034	**0.910**
Len_AL	–0.074	**0.819**	–0.145	–0.185	–0.094

Statistical analyses. In the course of the PCA, five factors were extracted, explaining 77.7% of the variability in the data. The factors are in order of decreasing importance: 'Dif_Slo_GL' (principal component (PC) 1, influenced mainly by the percentage contribution of grassland and the difference in slope between agricultural land and buffer zone), 'Flo_AL' (PC2, influenced by characteristics of the agricultural land, e.g. its width, its flow accumulation and its slope (negatively)) , 'Cur' (PC3, mainly affected by the curvature of the arable land and the difference in curvature between arable land and buffer zone), 'CumLen' (PC4, affected by the total width of the buffer zone) and 'Dif_Flo' (PC5, affected by the difference in flow accumulation between arable land and buffer zone) (see Table 7). All five PCs were used as explanatory variables in the logistic modelling procedure.

In *logistic regression modelling: scenario 1*, the five axes from the PCA and the three binary variables – plough direction, farm tracks and root dams – were used as explanatory variables. The general model performance resulted in a Nagelkerke R^2 of 0.417 (Nagelkerke 1991) and an Omnibus test significance of $p < 0.05$. It was observed that 75.9% of the observations were assigned correctly. The following explanatory variables remained after backward elimination: 'Dif_Slo_GL', 'Fat', 'Rod' (see Table 8).

In *logistic regression modelling: scenario 2*, all observations with explanatory variables, which had been examined in the field, were integrated into the logistic regression model (i.e. 'Per', 'CumLen', 'Rod', 'Plo' and 'Fat'). Within this scenario, 83.3% of the observations were assigned correctly, showing a Nagelkerke R^2 of 0.523 (Nagelkerke 1991), and an Omnibus test significance of $p < 0.05$. The following explanatory variables remained after backward elimination: 'Fat', 'Rod' and 'Per_GL' (see Table 9).

Table 8. Results of the logistic regression scenario 1 (backward elimination method).

Explanatory variables	Regression coefficient B1	Standard error	Wald	df	Sig.	Exp(B)
Dif_Slo_GL	0.671	0.497	1.826	1	0.177	1.957
Fat	–1.199	0.551	4.734	1	0.030	0.302
Rod	–20.821	13 243.806	0.000	1	0.999	0.000

Table 9. Results of the backward elimination for logistic regression scenario 2.

Explanatory variables	Regression coefficient B2	Standard error	Wald	df	Sig.	Exp(B)
Fat	–2.683	0.592	20.564	1	0.000	0.068
Rod	–3.921	1.090	12.939	1	0.000	0.020
Per_GL	0.330	0.085	14.910	1	0.000	1.390

Scenarios 1 and 2 produced very similar results. The results of both model scenarios suggest that the occurrence of root dams ('Rod') has strong disconnecting effects on lateral sediment connectivity (B1 (scenario 1) = –20.821, B2 (scenario 2) = –3.921). In the first scenario the covariate 'Rod' is not significant due to a very large standard error of the regression coefficient, which is probably a combined effect of a smaller number of observations and 'Rod' being a binary variable. However, the fact that it is retained in the final regression solution shows its strong effect in scenario 1 (together with the large absolute values of the regression coefficient B1). Hence, the presence of root dams is interpreted as having a high potential to dam sediments which are delivered from adjacent agricultural areas and thus preventing them from entering the stream. In both scenarios the presence of farm tracks within the valley floor zone ('Fat') leads to a disconnection between the valley floor zone and the riparian zone (B1 = –1.199, B2 = –2.683). Damming processes are expected to be related to the presence of farm tracks running parallel to the river channel since elevation differences and real sinks occur between the farm tracks and adjacent agricultural source areas. As the farm tracks within the valley floors of the study area are very flat features, deposition preferably takes place there.

However, given enough transport capacity these features might further act as conduits for sediment transport redirecting water and sediment towards locations where material potentially enters the channel network. It should be further mentioned that only farm tracks were considered in the course of overland flow pathway modelling where a slope angle threshold of 2° had been reached. Nevertheless, a significant decrease of slope angle and hence transport capacity also occurs below a slope angle of 2°. Thus, including a lower slope angle threshold to improve the validity of the overland flow pathway model is necessary.

The results of scenario 1 indicate that high differences in slope angle between the valley floor zone and the percentage of riparian zone covered by grassland ('Dif_Slo_GL') lead to an increase in sediment connectivity (B1 = 0.671). In the study area, grassland segments within the riparian zones exhibit much higher mean slope angle values (10°) than agricultural segments (0.9°). This strong increase in slope angle is related to an abrupt increase in sediment transport capacity and hence sediment connectivity. The results of the PCA (see Table 4) suggest that the explanatory variable 'Dif_Slo_GL' is positively correlated with the variable 'Per_GL'. An increase in sediment connectivity with increasing proportions of grassland within the riparian zones can therefore be derived. This relationship is also reflected by the results of scenario 2, revealing that sediment connectivity generally increases with increasing proportions of grassland in riparian zones 'Per_GL' (B2 = 0.330). Since high proportions of 'Per_GL' are always related to low proportions of 'Per_FL', it can be stated that sediment connectivity decreases with 'Per_FL'. Furthermore, proportions of forested areas within riparian zones ('Per_FL') are shown to be negatively correlated with 'Dif_Slo_GL' (see Table 4). This again implies a decrease in sediment connectivity with increasing proportions of riparian forest vegetation.

Biogeomorphic processes

Biogeomorphic field surveys. Overall, 27 riparian forest segments were examined in the course of the geomorphic field surveys. In 16 forest segments (= 59.3%) root dams were present. The field surveys further revealed that root dams occur discontinuously along the river banks, both bilaterally and unilaterally, which is visualized in Fig. 7:

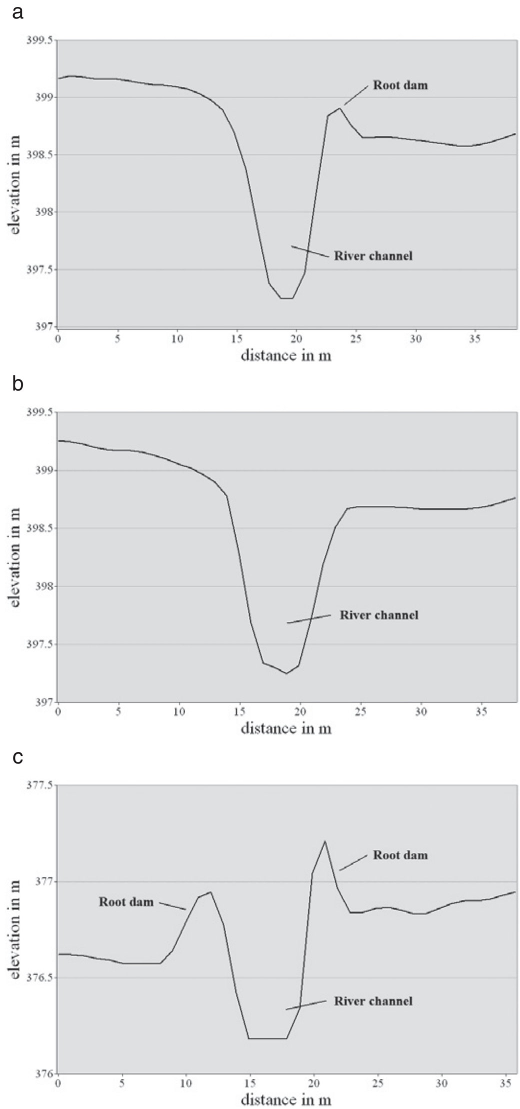

Fig. 7. Valley floor cross sections: (a) unilateral root dam occurrence along the right river bank; (b) no root dam present (location next to cross section a); (c) bilateral root dam occurrence.

Statistical analyses. Statistical analysis using cross tabulations and Fisher's exact test resulted in the delineation of 'Fat' (Farm Tracks) being the only significant factor ($p < 0.05$) potentially influencing the establishment of root dams (see Table 10).

The results presented in Table 6 suggest that the presence of 'Fat' reduces the development of root dams. This is most likely related to the disconnecting effects of farm tracks that prevent sediment of

Table 10. Cross-tabulations for presence/absence of root dams and farm tracks.

Factors		Rod		Total
		Absent	Present	
Fat	Absent	6	16	22
	Present	5	0	5
Total		11	16	27

agricultural source areas from reaching the riparian zones (see also Tables 8 and 9). However, neither the methodology nor the low number of observations (27) is sufficient to derive general statements. Further research is required to unravel the influence of biogeomorphic processes on the establishment of root dams. A more detailed assessment considering factors such as species-specific root morphology, historical land use, tree age and density, frequency of floods, and human disturbance is necessary.

Summary of results

The use of an overland flow pathway model and threshold analysis produced results showing that the lateral sediment connectivity is strongly influenced by flow accumulation, slope angle and profile curvature. In addition, the assessment of biogeomorphic processes in forested riparian zones indicated that the presence of farm tracks adjacent to the riparian zones reduces the development of root dams. These results support the hypothesis that root dam establishment is driven by sediment supply from agricultural land, as farm tracks seem to re-direct sediment flow away from the river.

The effects of riparian vegetation on diffuse lateral sediment connectivity assessed using PCA and a logistic regression model produced three significant findings.

- Lateral sediment connectivity decreases with an increasing proportion of forest vegetation in the riparian zone and the occurrence of root dams.
- High slope angles in riparian grassland areas compared with those in adjacent agricultural areas increase the lateral sediment connectivity due to an abrupt increase in sediment transport capacity.
- Farm tracks located in the valley floor zone contribute to a disconnection between the valley floor zone and riparian zone.

Conclusions

With respect to the two objectives of this study, that is, (i) to assess the influence of riparian vegetation cover type on diffuse lateral sediment connectivity on valley floors, and (ii) to investigate biogeomorphic processes acting in forested riparian zones of a medium-sized agricultural catchment, the following conclusions are drawn.

Forested riparian zones significantly reduce sediment inputs and act as strong disconnectors between the agricultural source areas and the river channel. Root dams are topographical features which are acting as buffers that limit the sediment connectivity as they hinder the sediment transport between the catchment areas and the river channel. In addition, root dams emerge from biogeomorphic processes which are driven by factors including the sediment supply from agricultural land.

It is important to note that vegetation plays an important role in governing lateral sediment connectivity due to its local capacity to store sediments. Furthermore, topographical features emerging from biogeomorphic processes act as stores and sinks which limit the lateral connectivity as they hamper the sediment transport between landscape compartments. Riparian zones therefore require specific attention with regards to connectivity research, connectivity assessment and river management. Since knowledge about the role of riparian vegetation is rare and presents an important gap in connectivity research, this contribution is a step forward to grasp the effects of riparian vegetation on lateral sediment connectivity as well as to understand the processes and factors that govern them.

Acknowledgements

The authors are grateful to the administration staff of the Thayatal National Park, Reinhard Roetzel (member of the GBA), Peter Strauss (head of the IKT), Matthias Waldstein and the provincial government of Lower Austria for data provision and support. We would further like to thank Astrid Poeppl, Kerry Bobbins and Melanie Kappes for proofreading as well as Robert Bertsch for his assistance during fieldwork. The authors appreciate the comments and support from the reviewers and the editors.

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Manuscript received 23 Feb., 2011, revised and accepted 15 Jun., 2012