

1 **TRANSFER OF SEDIMENTS AND CONTAMINANTS IN CATCHMENTS AND**  
2 **RIVERS**

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4 José A. López-Tarazón<sup>1,2,3,4</sup>, Patrick Byrne<sup>4</sup>, Marcel van der Perk<sup>5</sup>

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6 <sup>1</sup>Mediterranean Ecogeomorphological and Hydrological Connectivity Research Team,  
7 Department of Geography, University of the Balearic Islands, Palma, Spain

8 <sup>2</sup>Institute of Earth and Environmental Science, University of Potsdam, Germany

9 <sup>3</sup>Fluvial Dynamics Research Group, Department of Environment and Soil Sciences, University  
10 of Lleida, Lleida, Spain

11 <sup>4</sup>School of Natural Sciences and Psychology, Liverpool John Moores University, Liverpool, UK

12 <sup>5</sup>Department of Physical Geography, Utrecht University, Utrecht, Netherlands

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32 \*Corresponding author. E-mail: [ja.lopez@uib.cat](mailto:ja.lopez@uib.cat)

## 1 **1. Background**

2 The transfer of sediments in catchments controls the morphodynamic development of  
3 hillslopes, river channels, and floodplains. The transfer of fine sediments in particular  
4 also plays a crucial role in catchment ecosystems as it affects water quality and  
5 biogeochemical cycles by supplying or removing nutrients and contaminants, providing  
6 substrate for organisms, and directly influencing light climate in surface waters. The  
7 extent to which sediments affect catchment ecosystems is largely determined by the rate  
8 at which sediments are delivered to surface water bodies, the residence time of  
9 sediments in catchments, as well as biogeochemical transformation processes. Human  
10 activities have altered the quantity and quality of fine sediment in rivers (Owens et al.  
11 2005). In general, these activities have increased the delivery of fine sediments to rivers  
12 through accelerated soil erosion, but reduced the global sediment flux to the coastal  
13 ocean through retention in reservoirs (Owens 2005; Syvitski 2005).

14

15 Understanding the nature and rates of the processes controlling sediment and associated  
16 contaminant transfer in catchments and river basins is essential to make informed  
17 decisions on the management of rivers in general and the prevention or mitigation of  
18 hazards related to soil erosion, water quality, or flooding in particular. However, the  
19 dynamics of sediment and contaminant transfer are highly variable in space and time  
20 due to the complex and often non-linear processes involved. The responses of sediment  
21 and contaminant transport to environmental change or disturbance are therefore not  
22 straightforward (Owens et al. 2010), which hampers an adequate evaluation and  
23 prediction of such responses.

24

25 Research in the field of sediment and contaminant transfer in catchments finds its origin  
26 in studies of sediment transport and budgets in the 1960s and 1970s (e.g. Guy 1964;  
27 Holeman 1968; Dietrich and Dunne 1978; Bogen 1980). In the same time period, other  
28 studies demonstrated the usefulness of tracers, first radionuclides (Perkins et al. 1966;  
29 Ritchie and McHenry 1975) and later heavy metals (Wolfenden and Lewin 1978;  
30 Nriagu et al. 1979), for identifying the sources of sediment and for tracking sediment  
31 through river systems. In the 1970s, concerns about deteriorating water quality extended  
32 the research interest to sediment transport in catchments, as sediment was considered  
33 itself as a contaminant and its role as a carrier for other contaminants, such as metals  
34 and nutrients, was increasingly acknowledged (Stall 1972; Williams 1975; Karr and

1 Schlosser 1978). The increased knowledge of processes involved in the catchment-scale  
2 transfers of sediments and associated contaminants led to the development of a range of  
3 conceptual and physically based models of sediment and contaminant transport (e.g.  
4 Young et al. 1989; Malmon et al. 2003; Owens 2005; Davison et al. 2008; Armour et al.  
5 2009; Neitsch et al. 2011). Yet, despite the ongoing stream of publications in the field  
6 of sediment and contaminant transport, the lack of sufficient field data and adequate  
7 descriptions of governing processes persist to be the major limitations to applying these  
8 models. Therefore, the quest for empirical data to gain an understanding of these  
9 processes and to improve the models remains topical.

10  
11 This special issue contains a selection of papers that were presented at the  
12 HS9.3/SSS2.32 session on ‘Transfer of sediments and contaminants in catchments and  
13 rivers’ at the General Assembly of the European Geosciences Union (EGU GA) in  
14 Vienna in 2016, which was organised by the authors. This session was one of a series of  
15 sessions organised at the EGU GA since 2011 bringing together scientists from many  
16 subdisciplines of Earth science, including hydrology, soil science, geomorphology, and  
17 geochemistry. The majority of the contributions to these session focused on the sources  
18 and fate of sediments and contaminants, the remobilisation of legacy contaminants in  
19 river systems, and the response of sediment and contaminant dynamics to changing  
20 boundary conditions. These topics reflect the recent trends and advances in this  
21 interdisciplinary field of research. Here, we provide a brief synthesis of the papers in  
22 this special issue in the context of these recent advances.

## 23 24 **2. Sources and fate of sediments and contaminants**

25 Four papers of the present special issue are related with sources and fate of sediments  
26 and contaminants, from sediment sources identification, e.g. via fingerprinting  
27 techniques, to quantification of sediment and contaminants retention and trapping in  
28 different compartments of the fluvial system. García-Comendador et al. (2017) applied  
29 radionuclide tracers (i.e.  $^{137}\text{Cs}$  and  $^{210}\text{Pb}_{\text{ex}}$ ) to recognize the first post-fire flush effect on  
30 the source ascription of bed sediments temporarily stored in a Mediterranean stream  
31 severely affected by a wildfire. It is well known that first flushes can be crucial to  
32 sediment transport in dryland Mediterranean fluvial systems, especially after  
33 catastrophic disturbances (e.g. wildfires) when storm flows may enhance runoff delivery  
34 to channels, hence increasing such first-flush effects. The authors found that bed

1 sediments were mostly generated (67%) on burned hillslopes because of the fire's effect  
2 on soil and sediment availability, the high-intensity rainfall and the limited contribution  
3 of channel banks as these are fixed by dry-stone walls. Such a hydro-sedimentary  
4 response indicates a clear association between the factors which drive the erosion and  
5 the sediment delivery thus generating a totally effective slope-to-channel sediment  
6 connectivity. It must be highlighted that the study is independent of the long-term  
7 monitoring that the research team is carrying out in the catchment; however, the  
8 integration of the short-response with the medium and long term analysis will allow for  
9 the analysis of the evolution of catchment sediment sources in future studies,  
10 determining if fire modifies the catchment sensitivity to that specific disturbance.

11

12 The next two papers carry out a thorough analysis of the historical contaminants  
13 deposited in different river systems of East Europe, an area dramatically affected  
14 historically by different anthropogenic impacts. Grygar et al. (2017) described the  
15 historical deposition of contaminants from metal mining and metallurgy (mainly Cu, Pb,  
16 Sn, U, Zn) in the Ohře River (Czech Republic). Contamination has entered the river  
17 system, during the previous five centuries, through its middle reach, where the channel  
18 is incised and bedrock-confined, hence impeding overbank deposition. Three former  
19 channel bars that have coalesced with the riverbank were examined, revealing that they  
20 have trapped sufficient sediment to produce a record that correlates with the history of  
21 contamination in the drainage basin. The amount of contamination (i.e. Cu, Pb, Sn)  
22 passing through the river channel associated with the pollution climax of the 16<sup>th</sup> and  
23 17<sup>th</sup> centuries is remarkable, while modern contamination (i.e. Hg, U) deposited in the  
24 19<sup>th</sup> and 20<sup>th</sup> centuries was entrapped with a much lower efficiency. Therefore, the  
25 approach used in the study, which has allowed the bar deposits to be correlated with the  
26 local mining and pollution history, may be applicable to other montane rivers with  
27 historic ore mining and processing in their basins. Grba et al. (2017) provide a complete  
28 picture of the geochemical character of the sediments deposited in the eastern Posavina  
29 region (Serbia). Results show that all the analysed sediments contained higher heavy  
30 metals concentrations than the upper continental crust, suggesting dynamic natural and  
31 anthropogenic processes. From the different indexes which were calculated to classify  
32 the substances it can be highlighted that the geo accumulation index ( $I_{geo}$ ) classified the  
33 pollution risk due to Cr as strong, Cd, Zn, and Hg as moderate to strong, and Ni as  
34 moderate, while a principal component analysis (PCA/FA) grouped the substances

1 differently, with anthropogenic activity found to be responsible for much of the Hg, Cd,  
2 and Cr pollution present in the sediments. Consequently, several different substances  
3 have been found to be of great interest for the Posavina region; therefore, these  
4 parameters must be the focus of future monitoring programs, in support of appropriate  
5 remediation techniques and/or dredging activities. These are required in order to comply  
6 with the new Serbian regulations and the relevant EU recommendations.

7  
8 The remaining paper of this section deals with the different mechanisms controlling the  
9 erosion and sedimentation processes in a freshwater tidal wetland, knowledge that is  
10 vital for the proper assessment of the effectiveness of delta restoration techniques.  
11 Accordingly, Van der Deijl et al. (2017) identified the factors controlling the sediment  
12 trapping of two newly created freshwater tidal wetlands under varying conditions of  
13 river discharge, tide, and wind in the Netherlands. A positive sediment budget and  
14 trapping efficiency was found where there was a continuous supply of river water and  
15 sediment, while sediment was lost where the wetland lies further from the river and had  
16 a lower sediment supply. The daily sediment budget was positively related to upstream  
17 river discharge, with export taking place during ebb and import during flood periods.  
18 However, strong wind events overrule this pattern. Therefore, for an effective delta  
19 restoration process, managers need to enhance the trapping efficiency of the incoming  
20 sediment by directing sufficient river flow into the wetland, ensuring the supply of  
21 water and sediment within the system during a tidal cycle. In this way, a sufficiently  
22 large residence time of water within the polder areas for sediment settling will be  
23 created, hence decreasing wave shear stress by the establishment of vegetation or  
24 topographic irregularities.

### 25 26 **3. Remobilisation of legacy contaminants**

27 Three of the papers focus on the remobilisation of legacy contaminants (trace metals) by  
28 physical and biogeochemical processes. These three papers can be broadly categorised  
29 as addressing contamination issues in headwater and urban catchments. Shuttleworth et  
30 al. (2017) studied Pb storage in degraded peatlands in the Peak District National Park,  
31 UK, and the mechanisms controlling sediment and Pb transport. Lead contamination of  
32 the peatlands is the result of anthropogenic pollution during the Industrial Revolution  
33 which has been exacerbated by land use and climate change pressures. The authors  
34 found erosion of interfluvial areas is exposing high concentrations of Pb (up to 1660 µg

1 g<sup>-1</sup>) and a variety of physical factors, including vegetation, wind action, aspect, and  
2 gully depth, are apparently controlling Pb storage and release. Crucially, vegetation  
3 appears to play an important role in retaining Pb-contaminated sediment while wind  
4 action has been identified as a new potential vector for metal transport in peatland  
5 environments.

6  
7 The two remaining papers in this theme address the issue of trace metal contamination  
8 in the predominantly urban catchment of the River Mersey, UK. The River Mersey  
9 drains the historical industrial cities of Liverpool and Manchester, as well as numerous  
10 other smaller towns and cities, and papers in this special issue highlight the persistent  
11 nature of trace metals in this region. Hurley et al. (2017) investigated sediment quality  
12 across the Upper Mersey and Irwell catchments. Despite recent improvements in water  
13 quality, there remains widespread contamination of river sediment with trace metals and  
14 metalloids (e.g., As, Cr, Cu, Pb, Zn) across northwest England. Source apportionment  
15 through multi-variate analyses points to a complex network of point sources across the  
16 catchment and in particular highlights the role of the textile industry on Cu  
17 concentrations. Chemical mobility of metals in the sediments is considered low which  
18 may explain the improvements in water quality. Nevertheless, the polluted sediments  
19 remain an environmental risk and a barrier to healthy ecological communities.

20  
21 Byrne et al. (2017) focussed on the environmental mobility and long-term fate of Cr in  
22 sediments from an urban water body in Manchester, UK. The Salford Quays and the  
23 Manchester Ship Canal were constructed in 1894 to provide access for ocean-going  
24 ships to the heart of Manchester. It is part of the River Mersey catchment through its  
25 connection to the River Irwell. Despite recent improvements in water quality of the  
26 Manchester Ship Canal, there remains a significant legacy of metal contamination in the  
27 canal sediments. Specifically, the authors considered the biogeochemical cycling of Cr  
28 in the Salford Quays sediment. A combination of geochemical and mineralogical  
29 analyses revealed high concentrations of Cr in the sediments (133,400 µg g<sup>-1</sup>). However,  
30 the dominant Cr species was found to be Cr(III), a relatively inert form, suggesting  
31 limited bioavailability or toxicity. The environmental conditions in the sediment  
32 (anoxic, neutral pH) favour the existence of Cr(III). However, future re-working of the  
33 sediment could re-mobilise Cr as the carcinogenic form, Cr(VI).

#### 1 **4. Response of sediment and contaminant dynamics to changing boundary** 2 **conditions**

3 Finally, the last section includes two papers addressing how changing the boundary  
4 conditions (i.e. global change understood as the combination of climate change and land  
5 use changes, either from a natural or an anthropogenic origin) of river catchments can  
6 alter the sediment and associated contaminants transport processes and spatiotemporal  
7 dynamics. The first paper by Herrero et al. (2017) applied the hydro-sedimentological  
8 TETIS model to evaluate the effects of global change on the water and sediment yield in  
9 a large mountain catchment of Spain. Quantification of water and sediment yield in  
10 river catchments is very complex due to the different physical processes involved,  
11 especially in the light of current global change, but results vital for all the environmental  
12 problems which can be related with, as well as for water storage and hydropower  
13 infrastructures. Climate scenarios show a general decrease in average annual  
14 precipitation and an increase in temperature and extreme rainfall events; these in  
15 conjunction with the global change scenarios lead to a counteracting effect between the  
16 increase in sediment transport during extreme events and the decrease in sediment  
17 erosion associated with afforestation following the abandonment of agricultural land.  
18 Such modelling exercises, besides emphasizing the potential of the models as a tool for  
19 evaluating water and sediment yield for large catchments, provide crucial data for water  
20 and sediment management in light of future climate and land use change scenarios.

21  
22 The last paper, by Lynch et al. (2017), studied the potential for remobilisation of trace  
23 metals in floodplain soils in a mining-impacted headwater catchment in central Wales,  
24 UK, as a consequence of climate change. The UK has a substantial metal mining legacy  
25 that has resulted in widespread contamination of river catchment soils and sediments  
26 with trace metals such as Zn and Pb. Specifically, the authors investigated the potential  
27 role of climate change by studying the effects of predicted hydro-meteorological  
28 extremes (floods and droughts) on the biogeochemical cycling of Zn between riverbank  
29 sediments and stream water. Through a series of controlled laboratory column  
30 experiments, the authors found accumulation of soluble Zn sulphate minerals during  
31 simulated droughts was followed by the release of high concentrations of dissolved Zn  
32 during first flood wetting. For prolonged flood periods, reductive dissolution of Mn  
33 (hydr)oxides released partitioned Zn to dissolved phases in pore waters. Subsequent  
34 drying of the sediment caused oxidation and precipitation of Mn (hydr)oxides and

1 sorption of Zn. Diffusion of mobilised Zn from riverbank pore waters was calculated to  
2 have a significant effect on stream water quality. This research highlights the transient  
3 nature of Zn contamination in mining-impacted catchments and the environmental risk  
4 posed by the predicted effects of climate change.

## 5 6 **5. Summary**

7 This volume presents innovative methods and case studies to analyse, quantify, and  
8 model the transfer, deposition, and remobilisation of sediments and contaminants in  
9 river catchment transfer processes from the micro to the macro scale, from  
10 Mediterranean drylands to temperate regions, and from pristine-mountainous to urban  
11 areas. Transport processes between the main landscape components, i.e. hillslopes, river  
12 system, reservoirs, and wetlands/deltas, as well as the different remobilisation  
13 mechanisms by physical and biogeochemical processes are addressed. The research  
14 results enhance our process knowledge, methods of data analysis, and modelling  
15 capability of sediment and contaminants fluxes in the fluvial environment. Results  
16 partly address the spatial scales relevant for water and land management, therefore also  
17 informing the sustainable use and management of water, sediment, and soil resources.

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