Sediment Linkages Between the River Catchment and the Sea

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Introduction

Background and Summary of this Issue on Sediment Linkages

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1 Sediment Quantity and Quality Issues in the Catchment-Coast Continuum

Sediment, along with water, provides a link between the fluvial, estuarine and marine environments. Sediment eroded within the catchment is transported through the channel network into the sea. The present consensus is that the global flux of fine-grained sediment from the land to the global ocean is of the order of 15–20 x 10^9 t $year^{-1}$ (Syvitski et al. 2005, Dedkov and Gusarov 2006, Walling 2006), and this accounts for about 95% of the sediment entering the global ocean (Syvitski et al. 2003). In Europe, studies (Owens and Batalla 2003, Syvitski et al. 2005) estimate that the flux of fine sediment to the coastal zone is of the order of 0.7 x 10^9 t $year^{-1}$ (**Fig. 1**). Thus, sediment represents an important material which connects river catchments to the coastal zone, in what Salomons (2005) calls the 'catchment-coast continuum' (**Fig. 2**).

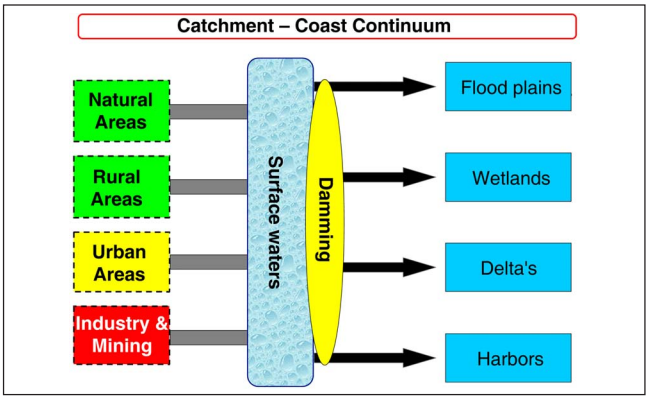

Fig. 2: The catchment-coast continuum, illustrating where changes in the quantity and quality of sediments can have an impact on system functioning (from Salomons 2005)

The quantity of sediment that moves between the river catchment and the coastal zone is important for many reasons, including aquatic ecology and habitats (e.g. saltmarshes and tidal mudflats). Furthermore, many settlements which lie on deltaic or other sedimentary deposits rely on the supply of sediment from the catchment and other local sources. If this supply is modified, by for example the construction of

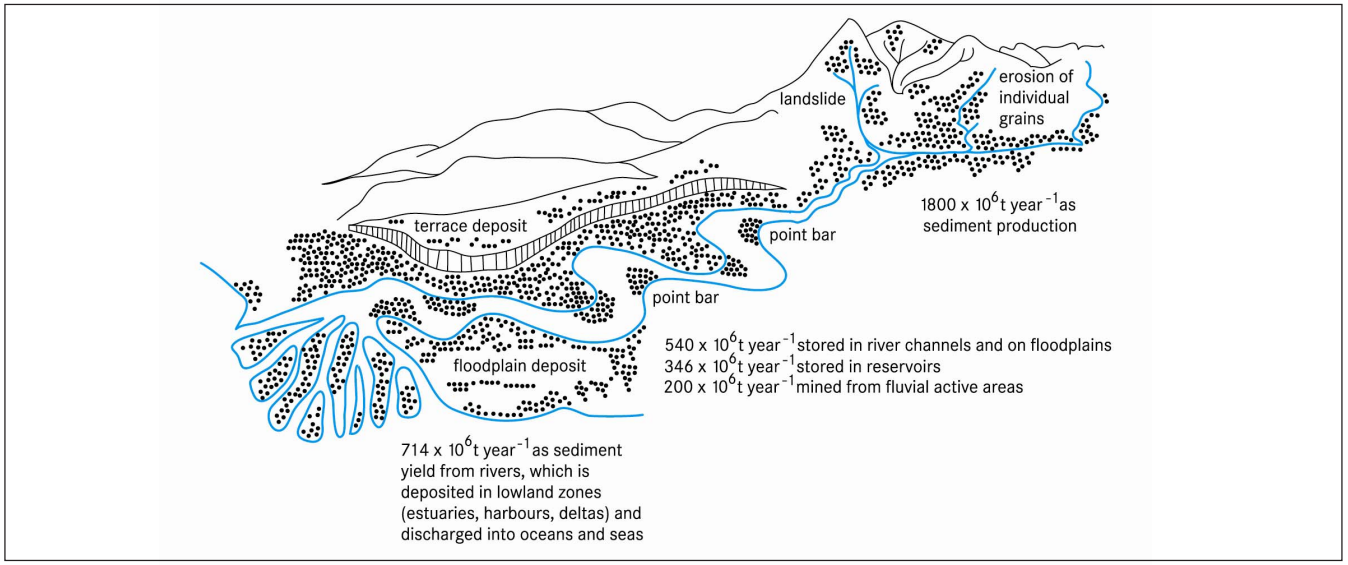

Fig. 1: Approximate delivery of sediment from the river catchment to the estuarine and coastal zones for the European continent (from Owens and Batalla 2003)

dams and impoundments in the catchment, then the future of these settlements is threatened. A good example of this is the Nile delta in Egypt, where 15–19% of the habitable land could disappear within the next 50 or so years due to a lack of sediment supply as a result of the Aswan Dam. This, in turn, could displace 15% of the population of Egypt (Leopold 1997). In Spain, the annual sediment flux to the coast from the Ebro River is presently only 3% of the sediment load that occurred at the start of the 20th century due to the construction of some 190 dams in the catchment over this period (Batalla 2003, Vericat and Batalla 2006). The recent problems of flooding in New Orleans in the USA were partly due to anthropogenic changes in the 'natural' flux of sediment, and in particular the loss of important sedimentary environments, in the catchment-coast continuum.

In addition to sediment 'quantity' (i.e. too little or too much sediment), sediment linkages between river catchment and the sea are also important from a 'quality' perspective (i.e. contaminated sediment). Indeed, the dual issues of quantity and quality, and the various space and time scales associated with these issues, are what make sediment management so difficult in many situations (Förstner and Owens 2007). The quality of the sediment that is delivered from the catchment to the coastal zone is important for several reasons because many nutrients and contaminants are associated with fine-grained sediment (Barceló and Petrovic 2007), i.e. that fraction of the sediment load that finds its way to estuaries and the coastal zone: most of the coarser fraction is deposited en route at intermediate storage sites (Owens 2005). There are many examples that illustrate the transfer of contaminated sediments to sites in downstream locations. Götz et al. (1998), for example, describe how typical patterns of dioxin congeners in sediments deposited in the Port of Hamburg, Germany, can be traced to the Bitterfeld area more than 300 km upstream on the River Elbe. The costs of dealing with contaminated sediments can be very high (Bortone and Palumbo 2007). Netzband et al. (2002) state that the Port of Hamburg spends of the order of 30 Million euros each year to dredge and treat between 2 and 5 x 10^6 m^3 of sediment, much of which is contaminated, thereby increasing costs. Sediment fluxes from upstream catchments are also important in delivering nutrients, such as C, N and P, to estuarine and coastal areas, and these are often the cause of problems such as eutrophication.

2 The 4th Annual SedNet Conference

To date, it can be argued that work on sediment dynamics and management in freshwater river catchments has tended to be isolated from work in estuarine and marine areas, except at where one provides input to the other, such as those studies described above which have estimated sediment fluxes. There are some notable exceptions to this and these include work as part of the UNESCO International Sediment Initiative (ISI) and the IGBP LOICZ programmes. Many of these programmes are concerned with global issues, although most have regional or continental subprogrammes. There have also been some important EU-funded research projects such as EUROCAT (Salomons 2004) which looked at the impacts of river catchments on European coastal systems, of which sediment dynamics was one part.

With the introduction of the European Union (EU) Water Framework Directive (WFD) and Marine Strategy (MS), and associated research and policy requirements for these, there is a need to assess the role of sediment at the catchment-sea interface within European water systems. In order to encourage this interaction, SedNet organized a one-day conference in Venice, Italy, in November 2006 entitled: Sediment key-issues between the river and the sea. This conference was itself part of the larger 4th annual SedNet conference, of which the other part was a round-table workshop on the theme *Sediment management – an essential element of River Basin Management Plans* (RBMPs). The driver for this workshop was the development of RBMPs as part of the WFD. The outcome of the workshop was published in the J Soils Sediments (SedNet 2007). This present article, which represents an introduction to this thematic issue of J Soils Sediments, focuses on the discussions and outcomes of the one-day conference.

The one-day conference was attended by about 100 delegates from 15 countries. There were 13 oral and 23 poster presentations grouped into three themes: (i) s*ediment contamination; (ii) sediment transport and dynamics;* and (iii) *sediment management*. There were also three invited keynote presentations. The first keynote presentation was by Patrick Meire (University of Antwerp, Belgium) on Estuaries: the transition zone between land and water. This presentation described the temporal and spatial dynamics associated with water, sediment and chemical fluxes and how estuarine environments are sensitive to hydrodynamic and geomorphological changes. Victor de Jonge's (Groningen University, The Netherlands) presentation on Functions of mud in estuarine and coastal ecosystems described the lessons that can be learnt from basic ecological theories for a wider understanding of sediment dynamics for improved sediment management in estuarine and coastal environments. Lindsay Murray (CEFAS, UK) talked on The benefits of the use of dredged material in the aquatic system using case study examples to illustrate how the physical management of sediment in estuarine and coastal areas can result in societal and ecological benefits.

3 This Thematic Issue of Journal of Soils and Sediments

This thematic issue of the J Soils Sediments is on the theme: *Sediment linkages between the river catchment and the sea*. It contains seven papers of which the first four were presented at the SedNet conference described above and the following three represent regular papers submitted to the journal that also fall within the theme of this issue. While seven papers are not able to cover all of the sediment-related linkages between the river catchment and the sea, they do provide excellent examples of issues at this key interface between land and sea. Furthermore, the four papers from the SedNet conference are drawn from the three sessions, and as such illustrate the range of presentations (in terms of topics and locations) given at the conference.

A useful opening paper is by Slob and Gerrits on the topic *The dynamics of sedimentary systems and the whimsicality of policy processes*. The paper uses three case studies to illustrate the inherent and induced complexity that is present in catchment-coast sedimentary systems. Inherent complexity arises from apparent non-linear and unpredictable events,

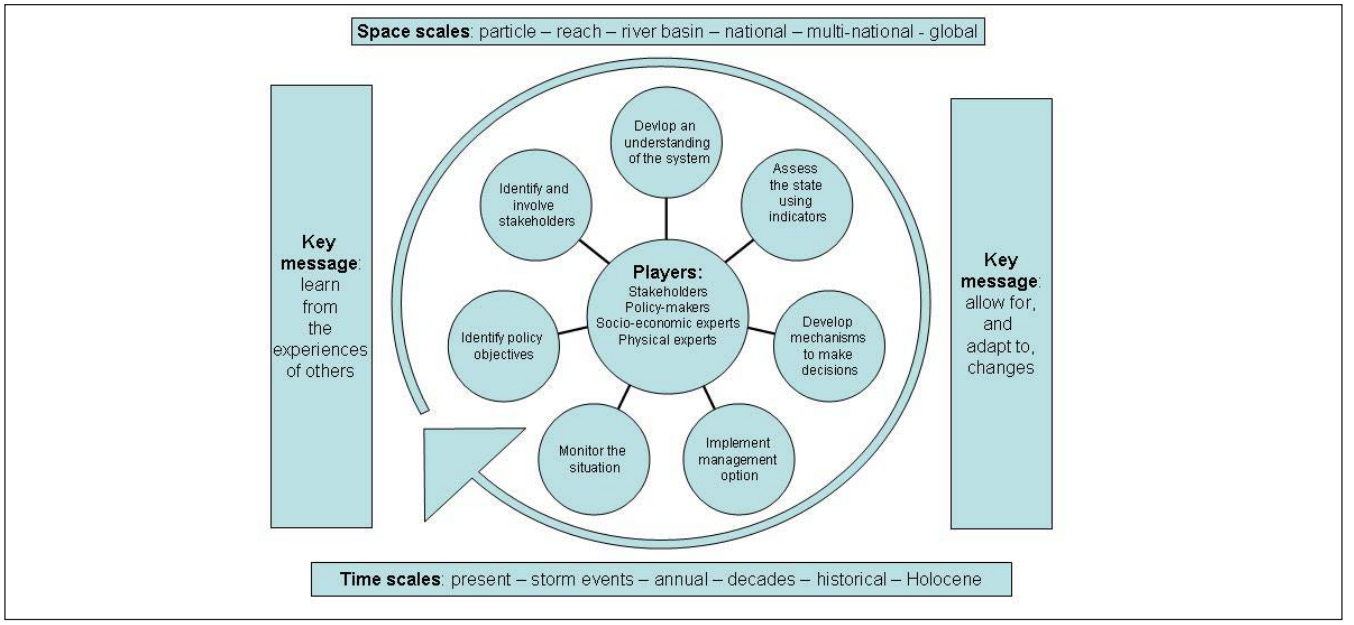

Fig. 3: Adaptive framework for sediment management at the river basin scale (from Owens et al. 2008)

such as extreme storm events or surges. Induced complexity is primarily a function of anthropogenic activities. The case study examples nicely illustrate that the development, implementation and success of sediment management plans at the catchment-coast interface is partly a function of how society interprets and responds to this complexity. The paper presents some important lessons which both physical and social scientists should consider for achieving successful and sustainable management plans, and advocates the development of adaptive management plans which incorporate some element of flexibility, similar to that shown in **Fig. 3**.

Rovira and Ibàñez, in their paper *Sediment management options for the lower Ebro River and its delta*, describe how the construction of dams in the Ebro River basin in Spain have influenced sediment transport and delivery to the coastal zone, which is likely to have profound effects on the emerged delta system. Their paper describes the development of a management plan – the Integrated Plan for the Protection of the Ebro Delta (PIPDE) – which aims to restore the sediment flux of the lower Ebro River by removing the sediment that is trapped behind dams and allowing the downstream transport of this sediment to the river mouth and delta plain. Importantly, this proposed PIPDR management plan aims to restore the links between the riverine and deltaic processes so as to achieve a more sustainable system. Although the management plan is primarily technical, it recognizes that economical and societal values, as well as ecological and morphological values, have to be considered in order to achieve a more sustainable and longer-lasting solution to sediment transport dynamics in the Ebro basin.

The theme of sediment supply from the catchment to the coast is continued in the paper by Freire et al. on *Sedimentary characterization of Tagus estuarine beaches (Portugal)*, which focuses specifically on the sources of the sediment. As with the paper by Rovira and Ibàñez, described above, the driver of this work is to understand better the sediment transport dynamics and sediment budgets of catchment-coastal systems so as to provide improved information for management. Results for the estuarine beaches of the Tagus show spatial variations in sediment type with contributions from both local and marine sources. Interestingly, while sediment input from local sources dominated until the last century, since this time sediment transfers have become dominated by anthropogenic-related activities, mainly connected with dredging activities and with the human occupation of estuarine margins.

The sources of the sediment in estuarine and coastal areas not only influences the physical nature and composition of the sediment deposited, it also influences the chemical composition of the sediment. This is demonstrated in the paper by Miko et al. entitled, *Influence of land use in small karst catchments on the chemical status of peloidic sediments on the eastern Adriatic Coast*. This study shows that land use activities in the contributing river catchments influence the supply of potentially toxic chemicals, such as Cu, Pb and Zn, to the coast. In this coastal environment, the supply of contaminated sediments from the catchment is particularly important because many of the sediment deposits are used as 'healing muds' or peloidic sediment. The determination of enrichment factors in the peloidic sediments of two coastal bays shows that high Pb values in one bay is due to road runoff, while high Cu concentrations in the sediments of another bay is due to extensive vineyard activity in the catchment. The authors argue that local authorities should use such information in planning which bays are suitable for therapeutic use. They also suggest that there is a need to determine probable effects levels of bioavailable metals.

The theme of the risk assessment of contaminated sediments in depositional environments at the land-sea or land-lake interface is continued in the three papers that were not presented at the conference (also see Heise 2007). In the paper *A geochemical analytical approach for the evaluation of heavy metal distribution in lagoon sediments*, Pacifico et al. use the Fusaro Lagoon in the south of Italy as a case study. They describe a sequential chemical analytical approach us-

ing the BCR-SEP method combined with information on the chemical and minerological properties of sediment. They found that the distribution of heavy metals among the sequentially extracted geochemical forms in the lagoon sediments is affected by sediment properties such as pH, clay content, organic matter content, and Fe easily reducible oxides, which are important in explaining the spatial distribution of the more contaminated sediment in the lagoon system (e.g. higher contaminant levels associated with finer grained sediment). Importantly, in the context of this thematic issue, although the lagoon sediments were classified as of middle-to-low contamination, the sources of the contamination were likely the contributing river catchment: agricultural practices (Cu); urban activity (Pb); and industrial discharges (Cd, Zn) – a finding echoed by other presentations in this thematic issue, and indeed the SedNet conference in general.

Apitz et al. present a thorough evaluation of the use of Sediment Quality Guidelines (SQGs) in their paper *The assessment of sediment screening risk in Venice Lagoon and other coastal areas using international sediment quality guidelines*. Similar to the paper by Pacifico et al., this paper also advocates the use of a more meaningful and robust procedure for assessing contaminated sediment. They provide a comprehensive discussion on the benefits and problems of SQGs for sediments in another lagoon in Italy, in this case the Venice Lagoon, based on different SQG criteria and approaches. Although there were differences depending upon which specific SQG was used, the Venice SQGs and other international SQGs provided the same general picture of screening risk, although there were spatial differences in results. While SQGs are clearly useful, under carefully controlled conditions, they should form part of a tiered assessment approach, itself part of a weight of evidence approach integrated within a comprehensive decision framework.

The theme of developing an improved approach for assessing contaminated sediments is continued in the paper by Stesevic et al. on *Application of a new sediment contact test with Myriophyllum aquaticum and of the aquatic Lemna test to assess the sediment quality of Lake Skadar*. While this paper does not strictly focus on the interface between the river catchment and the sea, it does deal with the interface between river catchments and a depositional environment, in this case a large lake on the border between Montenegro and Albania. As with the two lagoons in Italy, described above, Lake Skadar has also been exposed to decades of pollution from its contributing catchment. This paper also provides a nice extension to the previous papers by Specifico et al. and Apitz et al. which have focused on chemical assessment of contaminated sediments, in this case by considering bioassays. Again, the paper focuses on developing new tools for improved risk assessment, in this case plant assays for assessing eco-toxicological risk. Both plant assays were shown to be useful and the authors explain that they should become part of a standardized toolkit used for comprehensive sediment hazard assessment.

4 Conclusions and Perspectives

Given the limitations of space, it is not possible to cover all aspects of sediment linkages between the river catchment and the coast. However, the papers presented in this thematic issue, and indeed those others presented at the SedNet conference, provide an excellent illustration of the type of issues that scientists and managers are facing at this important interface between two different, but connected, environmental systems. The papers also demonstrate that further collaboration and exchange are needed if we are to develop sustainable water-sediment management plans.

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