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The impact of watershed management on coastal morphology: A case study using an integrated approach and numerical modeling

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ABSTRACT

Coastal morphology evolves as the combined result of both natural- and human- induced factors that cover a wide range of spatial and temporal scales of effect. Areas in the vicinity of natural stream mouths are of special interest, as the direct connection with the upstream watershed extends the search for drivers of morphological evolution from the coastal area to the inland as well. Although the impact of changes in watersheds on the coastal sediment budget is well established, references that study concurrently the two fields and the quantification of their connection are scarce. In the present work, the impact of land-use changes in a watershed on coastal erosion is studied for a selected site in North Greece. Applications are based on an integrated approach to quantify the impact of watershed management on coastal morphology through numerical modeling. The watershed model SWAT and a shoreline evolution model developed by the authors (PELNCON-M) are used, evaluating with the latter the performance of the three longshore sediment transport rate formulae included in the model formulation. Results document the impact of crop abandonment on coastal erosion (agricultural land decrease from 23.3% to 5.1% is accompanied by the retreat of ~35 m in the vicinity of the stream mouth) and show the effect of sediment transport formula selection on the evolution of coastal morphology. Analysis denotes the relative importance of the parameters involved in the dynamics of watershed–coast systems, and – through the detailed description of a case study – is deemed to provide useful insights for researchers and policy-makers involved in their study.

1. Introduction

Coastal areas are among the most dynamically-evolving types of natural environment. Located at the land–sea interface, they are subject to a series of natural- and human-induced pressures from both inland and coastal areas, that lead to a constant "battle" between different landforms and habitats. Regarding coastal morphology, the concept of the "coastal sediment budget" has for decades been a basic tool for identifying and quantifying changes at various scales of interest. In this context, the connection between watersheds and coasts has become more than evident, as rivers – and natural streams in general – constitute a major sediment source for the coastal environment.

According to Syvitski et al. (2003) about 90% of the sediment contributing to the coastal sediment budget originates from the upstream watersheds. The basis for similar studies had been set by researchers like Holeman (1968), Ahnert (1970) and Wilson (1973), in attempts to provide quantitative estimates of worldwide sediment delivery from the rivers to the sea. The studies that followed (i.e. Milliman, 1980; Milliman and Meade, 1983; Milliman and Syvitski, 1992; Milliman, 1995; Syvitski et al., 2003, 2005 among others) examined the effect of watershed- area, morphology, altitude and climate on the sediment yield, with one of the latest estimates by Syvitski et al. (2005) proposing a world sediment flux of about 12.6×10^9 t/year.

It is intuitively deduced that watershed management is of critical importance on coastal morphology. Every significant alteration (structure or management practice) within the watersheds will eventually affect the coastal sediment budget, resulting in morphological alterations at the coast as well. However, examples of the concurrent study and, most importantly, the quantitative correlation of the two fields are scarce in the literature (recent attempts in the framework of the CSDMS Project are an exception; see CSDMS, 2012 for details). In the terrestrial field, studies referring to the impact of watershed management are mainly focused on the changes in water/sediment discharge within the watersheds. Characteristic examples regarding the impact of dam construction and regulation works are Ibàñez and Prat (2003) and Rovira and Ibàñez (2007) for the River Ebro in Spain and Hu et al. (2009) and Xu and Milliman (2009) for the River Yangtze in China. As for the impact of management practices (mainly cultivation practices and land-use changes) on soil erosion and sediment discharge, one may refer to the papers of Erskine et al. (2002), Gao et al. (2002), Bracmort et al. (2006), Nobert and Shibayama (2007), Cebecauer and Hofierka (2008), Jiang et al. (2008), Moriasi et al. (2008), Munro et al. (2008), Abaci and Papanicolaou (2009) and Wei et al. (2010). Furthermore, in the coastal field, even when the impact of watershed

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management on erosive and accretive phenomena is studied, this is not done by analyzing the entire watershed–coast system. The focus is usually given to the qualitative correlation of the changes in both fields (e.g. Chen and Zong, 1998; Hsu et al., 2007), the identification and surveying of changes in estuarine morphology (e.g. Seker et al., 2003; Yang et al., 2003; Jaffe et al., 2007; Syvitski and Saito, 2007; Syvitski et al., 2009), or the direct use of acquired data (sediment discharges at the outlet of watersheds) without them being subject to evaluation or further examination (e.g. Fan et al., 2006; Bittencourt et al., 2007; Kökpinar et al., 2007; Samaras and Koutitas, 2008).

In the present paper a case study to investigate the impact of watershed management on coastal morphology is described and analyzed in detail. Applications are based on the integrated approach of Samaras and Koutitas (2012), which considers the watershed and coastal areas as an entity and proposes how to quantify the aforementioned correlation of phenomena through numerical modeling. The study area comprises a watershed in North Greece where extensive land-use changes took place since the mid-1990s (crop abandonment and transformation into grasslands), and the coast adjacent to the watershed main stream's mouth that faces severe erosion attributed to the alteration of the coastal sediment budget. The watershed model SWAT (Arnold et al., 1998; Srinivasan et al., 1998) and the shoreline evolution model PELNCON-M (Samaras, 2010) were applied to simulate the response of the watershed coast-system to land-use changes, following the methodology dictated by the approach of Samaras and Koutitas (2012) for the scenario of data availability only at the coast. Simulations were performed for the states before and after the land-use changes in the watershed (denoted by *ES0* and *CS1*, respectively), and for three different formulae used to calculate the longshore sediment transport rate (denoted by "LST") in PELNCON-M (USACE, 1984 denoted by "CERC"; Bayram et al., 2007 denoted by "BAY"; Kamphuis, 1991 denoted by "KAM"). The implementation of the specific approach is deemed to be successful, especially considering uncertainties introduced in the study of erosion and sediment transport at such large scales. Results and analysis provide a useful perspective on the assessment of the impact of watershed management on coastal morphology, and are deemed to be a useful tool for researchers and policy-makers involved in watershed and coastal zone management.

2. The integrated approach

As mentioned above, the present work is based on the integrated approach proposed by Samaras and Koutitas (2012) to study the impact of watershed management on coastal morphology through numerical modeling. Its essence refers to a coupled-calibration approach of the models in the watershed and the coast, which incorporates three scenarios of data availability regarding the parameters of interest in both areas (overland sediment transport and coastal sediment transport and morphology). The specific approach is divided in three discrete stages, namely: (a) the stage of preliminary operations, (b) the stage referring to the preparation for the applications of the numerical models and (c) the stage comprising the final applications of the numerical models.

The approach is presented in detail in Samaras and Koutitas (2012), from where the flowchart of Fig. 1 is adopted. As it was developed to not be model- or case- specific but rather of generic value/applicability, regarding Fig. 1 it should be noted that *MOD-W* and *MOD-C* denote the models selected as more suitable to describe the processes of interest in the watershed and the coastal field respectively. Likewise, *MEAS-W* and *MEAS-C* denote the available measurements in the watershed and the coastal field. Moreover, it is essential to underline the role of the sediment discharge at the outlet of the watershed (denoted by q_S) in the entire extent of the methodological approach, operating as the quantitative link between *MOD-W* and *MOD-C* during simulations (see Samaras and Koutitas, 2012 for further analysis).

For the scenario of data availability only at the coast (i.e. *MEAS-C*) that applies to the case study analyzed in the present work (coastal morphology available before and after the land-use changes in the upstream watershed), the approach of Samaras and Koutitas (2012) dictates the steps listed in the following. First, *MOD-C* should be

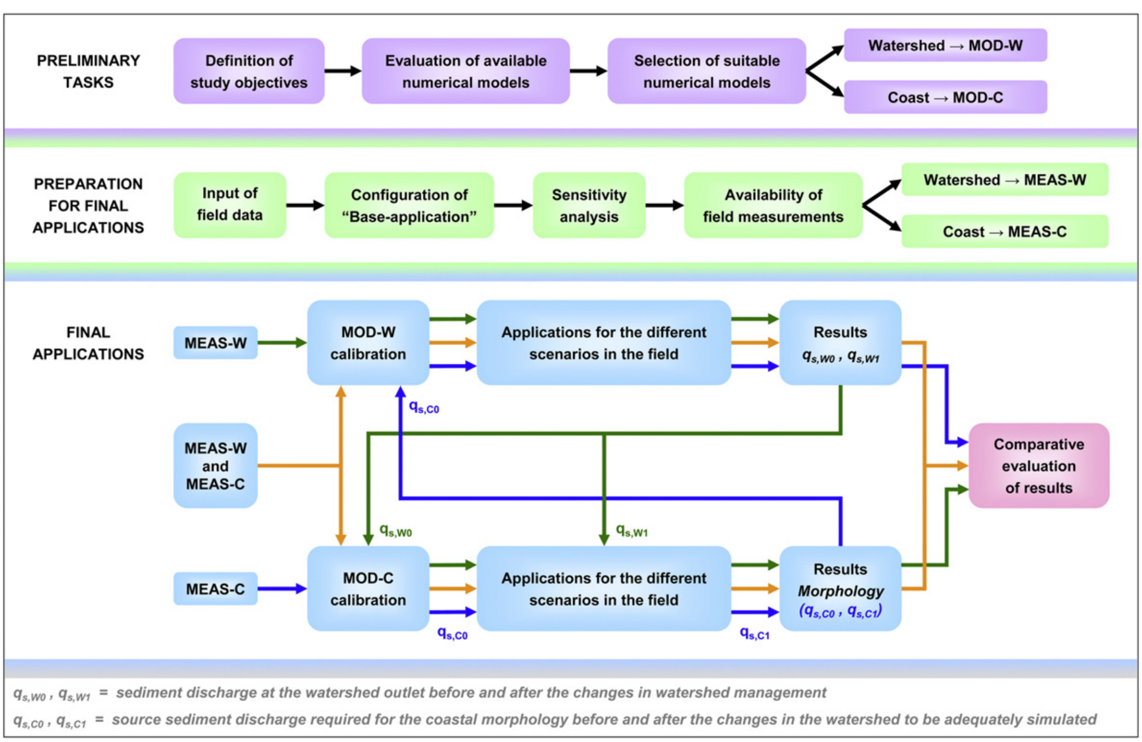

Fig. 1. Flow chart of the integrated approach to quantify the impact of watershed management on coastal morphology (adopted from Samaras and Koutitas, 2012). In the present work *MOD-W* is the watershed management model SWAT (Arnold et al., 1998; Srinivasan et al., 1998) and *MOD-C* the shoreline evolution model PELNCON-M (Samaras, 2010); the scenario that applies is that of data availability only at the coast (*MEAS-C*) and the respective path is followed (see also Section 2).