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Prioritization of sediment management alternatives using stochastic multicriteria acceptability analysis

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ABSTRACT

Decision-making for sediment management is a complex task that requires the consideration of temporal and spatial impacts of several remedial alternatives as well as the associated economic, social and political impact. Multicriteria decision analysis (MCDA) is becoming increasingly recognized as an important environmental management tool that can be used to support the selection of suitable remediation alternatives and prioritization of management units in space and time. This paper proposes an MCDA framework for prioritizing sediment management alternatives. This framework involves identifying of a set of feasible options, as well as defining and evaluating criteria which integrate relevant technical, economic, social and environmental aspects of remedies. The methodology allows an explicit consideration of uncertainty in criteria scores and weights by assigning probability distributions and analyzing subsequent Monte-Carlo simulations. The consideration of different stakeholder simulated values is used to assess the robustness of alternative rankings and to guide the selection of remediation options. An application of this methodology to a case study in the Bay of Santander, Spain, is presented. An assessment is conducted for the case of unknown preferences as well as for hypothetical preferences profiles for four types of stakeholders: Idealist, Politician, Environmentalist and Balanced. The results are used to visualize stakeholder positions and potential disagreements, allowing for the identification of a group of least preferred alternatives for each stakeholder. Stakeholder involvement has the potential to ease the remedy selection process during all stages of the decision-making process and to eventually remedy implementation.

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1. Introduction

Selecting the best sediment management option is a complex and often controversial undertaking (Apitz et al., 2005; Gustavson et al., 2008). Resources should be allocated in the most cost effective way when developing remediation projects (Apitz and White, 2003). A wide variety of techniques and treatments are available for remediation of contaminated sediments (Alvarez-Guerra et al., 2008b) and many different and often conflicting criteria must be integrated and balanced against each other to make an informed decision (Linkov et al., 2006b).

Alvarez-Guerra et al. (2009) proposed a decision-making methodology for sediment management that incorporates the selection of areas for remediation and the assessment of options for any mitigation required. The methodology requires delimitation of management units within areas of study. MCDA methods are applied to rank these management units according to their need for remediation. This process considers not only scientific evidence on sediment quality, but also reviews other relevant aspects such as social and economic criteria associated with such decisions. In addition, Alvarez-Guerra et al. (2009) demonstrated that even though they show little risk, the integration of economic and social factors leads to areas that may require intervention due to stakeholder concerns. In such cases, action might be justified but includes other management options rather than active remediation. These might be focused on monitoring strategies, prevention of sediment degradation, and natural resource protection (Apitz and White, 2003). Taking into account the relative importance of stakeholder participation and input in such decision-making processes, there is a need for a more formalized framework for selecting management alternatives in such situations.

This paper builds on experiences of applying existing MCDA-based approaches in selecting the best management option to remediate contaminated sediments which were recently proposed (Hong et al., 2010; Kiker et al., 2007; Linkov et al., 2005, 2006a), applied in the USA (Kiker et al., 2008; Linkov et al., 2007a; Yatsalo et al., 2007), and South Korea (Kim et al., 2010). Even though uncertainty has been a crucial consideration in sediment management (US EPA, 2005; Wenning et al., 2006; Gustavson et al., 2008), the uncertainty analyses presented in these papers have been limited to assessing data uncertainty (e.g.,

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sediment quality triads). Other work has demonstrated that stakeholder preferences and associated uncertainties can have a significant impact on the decision-making process and may even drive management decisions (Linkov et al., 2006a).

To integrate explicit consideration of uncertainty and stakeholder preferences, stochastic multicriteria acceptability analysis (SMAA, Lahdelma et al., 1998) is used in this study. SMAA can be implemented with other MCDA methods to allow explicit uncertainty analyses in decision models. It uses Monte-Carlo simulations to explore all feasible values for weights and criteria measurements, and assesses the robustness of remedy selection for risk management purposes. SMAA has been applied to multiple environmental management problems, including land subsistence management (Merad et al., 2004), waste management (Lahdelma et al., 2002), selecting environmental dredging windows (Suedel et al., 2008), and oil spill response (Linkov et al., 2007b). SMAATRI, a version of SMAA applicable to sorting problems, has also been applied to nanomaterials management (Tervonen et al., 2009a,b).

The aim of this paper is therefore to propose a methodology based on the application of SMAA for prioritizing sediment management alternatives. This approach is developed to complete a multicriteria-based integrated methodology for decision-making in sediment management. This approach follows the first phase of a process that requires prioritizing the management units to determine where intervention is the most critical (Alvarez-Guerra et al., 2009).

2. Proposed methodology for prioritizing alternatives for sediment management

The proposed methodology follows the characteristic MCDA process of defining management alternatives, defining and evaluating criteria, eliciting criteria weights and scoring of management alternatives (Fig. 1).

2.1. Definition of management alternatives

The first step of the proposed methodology involves a selection of management options or alternatives applicable for a specific site. A wide variety of techniques and treatments can be applied to the remediation of contaminated sediments (Alvarez-Guerra et al., 2008b; Bortone et al., 2004; Detzner et al., 2007; Hakstege, 2007; Rulkens, 2005; US EPA, 2005). In summary, sediment management options can be divided broadly into monitored natural recovery (MNR), in-situ treatments and ex-situ approaches including the

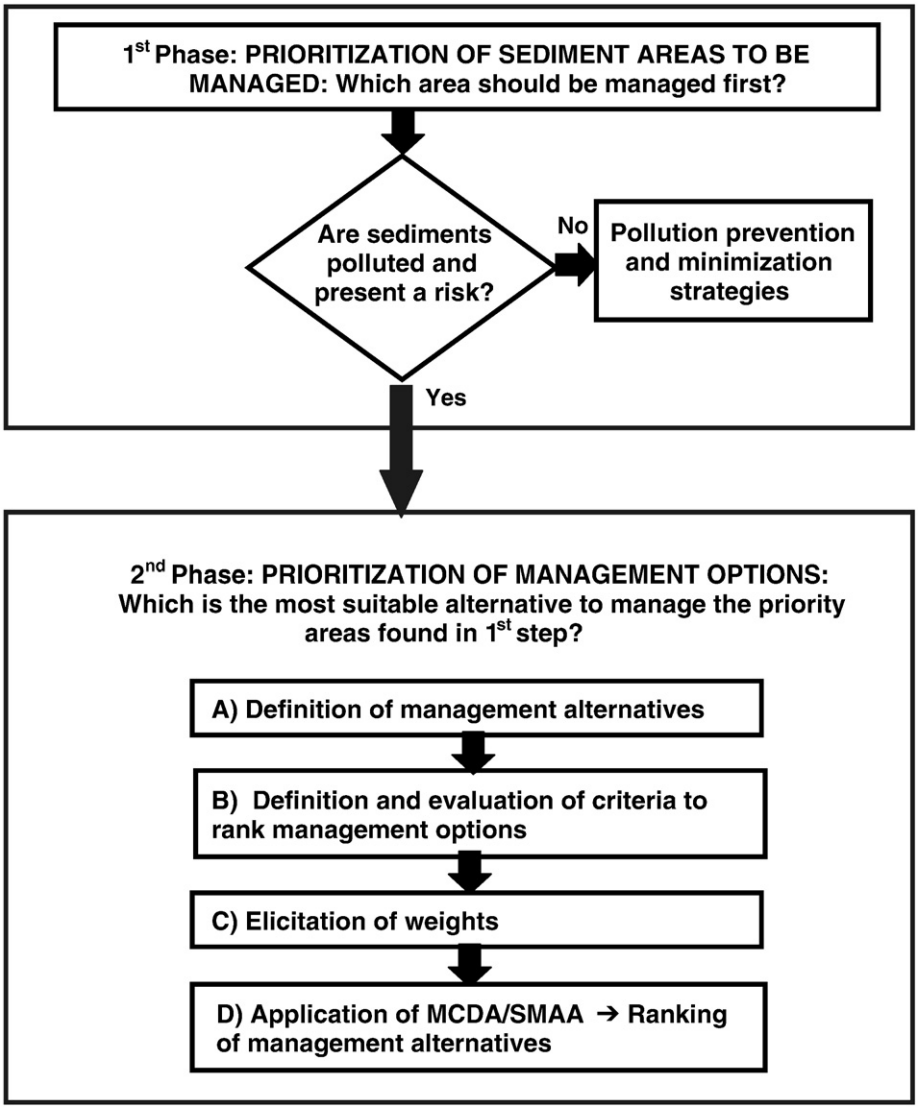

Fig. 1. Proposed methodology for decision-making in sediment management. The first part, concerning site prioritization, is the subject of a separate paper (Alvarez-Guerra et al., 2009).