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Research article

# Platform of integrated tools to support environmental studies and management of dredging activities

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ABSTRACT

Dredging activities can cause environmental impacts due to, among other, the increase of the Suspended Solid Concentration (SSC) and their subsequent dispersion and deposition (DEP) far from the dredging point. The dynamics of the resulting dredging plume can strongly differ in spatial and temporal evolution. This evolution, for both conventional mechanical and hydraulic dredges, depends on the different mechanisms of sediment release in water column and the site-specific environmental conditions. Several numerical models are currently in use to simulate the dredging plume dynamics. Model results can be analysed to study dispersion and advection processes at different depths and distances from the dredging source. Usually, scenarios with frequent and extreme meteomarine conditions are chosen and extreme values of parameters (i.e. maximum intensity or total duration) are evaluated for environmental assessment. This paper presents a flexible, consistent and integrated methodological approach. Statistical parameters and indexes are derived from the analysis of SSC and DEP simulated time-series to numerically estimate their spatial (vertical and horizontal) and seasonal variability, thereby allowing a comparison of the effects of hydraulic and mechanical dredges. Events that exceed defined thresholds are described in term of magnitude, duration and frequency. A new integrated index combining these parameters, $SSC_{num}$, is proposed for environmental assessment. Maps representing the proposed parameters allow direct comparison of effects due to different (mechanical and hydraulic) dredges at progressive distances from the dredging zone. Results can contribute towards identification and assessment of the potential environmental effects of a proposed dredging project. A suitable evaluation of alternative technical choices, appropriate mitigation, management and monitoring measure is allowed in this framework. Environmental Risk Assessment and Decision Support Systems (DSS) may take advantage of the proposed tool. The approach is applied to a hypothetical dredging project in the Augusta Harbour (Eastern coast of Sicily Island–Italy).



## 1. Introduction

Dredging activities are commonly used in coastal areas to maintain or improve the designed depth of navigation channels or basins, for the creation or the improvement of facilities, and to carefully remove and relocate contaminated materials. These activities involve the processes of removing sediments from the bottom and subsequently relocating elsewhere. According to the working principles for these processes, dredges may be divided into two broad categories (EPA, 1993; OMOE, 1994; IADC, 1998; USACE, 2003; Anchor Environmental C.A. L.P., 2003; Eisma, 2006): mechanical (grab or clamshell and backhoe) and hydraulic (stationary and cutter suction) dredges.

The increase of the Suspended Solid Concentration (SSC) during dredging operations and the subsequent deposition of sediments (DEP), transported as a dredging plume, are considered a prominent environmental issue. In recent years, increasing attention has been paid to reduce any physical, chemical and biological changes related to the sediment resuspension and pollutants (if any) dispersion (Christensen et al., 2001; Wilber and Clark, 2001; HR

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Wallingford Ltd & Dredging Research Ltd, 2003). Tighter controls, in the form of strict regulations, and proper enforcement on monitoring and mitigating measures, help to prevent or minimize adverse impacts (Erftemeijer and Lewis, 2006). Specific operating precautions are now successfully used to minimize the sediment release due to "conventional" dredges, and a number of newer "environmental" dredges are specifically designed to carefully remove contaminated materials (Palermo and Averett, 2003).

Site and operational conditions affect the suspended rate (sediment loss rate) close to the dredging sources, and the resulting plumes are complex in terms of spatial distribution and temporal evolution (USACE, 2003; Hayes et al., 2000; Palermo and Averett, 2003; Bridges et al., 2008; Palermo et al., 2008; IADC, 1998; Hayes and Wu, 2001; Burt et al., 2000). For projects that involve the handling of sediments, a detailed Environmental Impact Assessment (EIA, Directive 2014/52/UE) should be carried out to determine the potential environmental impacts, to evaluate technical alternatives and design appropriate mitigation, management and monitoring measures. In the absence of local legislation and guidelines, well-established international guidelines, aimed to support environmental studies during these activities, are available. Most of these guidelines include the use of numerical modelling as a valuable tool (Jouon et al., 2006; Edwards et al., 2006; PIANC, 2010; EPA, 2011).

Models can help to support environmental studies before dredging programs begin, and interpretation of results can help to optimize environmental objectives while maintaining desired production rates (Savioli et al., 2013). Different models are currently used to forecast the planar and the vertical extension of the plume dynamics close (nearfield models) and far from to the suspension sources (far field models) (e.g. Shankar et al., 1997; Kim and Je, 2006; Bilgili et al., 2005; Bell and Reeve, 2010). Modelling results are usually presented for "extreme scenarios", mainly covering only one or few tidal cycles, high-energy or extreme events (e.g. storm or low-frequency flood event) and "seasonal scenarios" (Jiang and Fissel, 2011; Liu et al., 2002; IMDC, 2012). Under common guidelines (e.g. GBRMPA, 2012), results are rarely reported to cover a full year (Deltares, 2009), but are rather referred to much shorter periods. As stated by Johnson et al. (2000), to be truly effective as a dredging project management tool with respect to environmental protection, models should be capable of running multiple simulations in a relatively short time so that a number of alternative dredging scenarios can be evaluated to determine those with the least probabilities of detrimental impacts. A different approach, presented by SKM (2013), is focused on long-term migration of sediments and related effects on water quality and ecosystem condition, modelling the movement of dredged material both during dredging disposal operations and over 12 months.

Increases of SSC and DEP parameters at a distance from the dredging source are mainly used to evaluate the extension of the area interested by dispersion and deposition of suspended sediments. The SSC can be expressed as the depth-averaged value or as Total Suspended Solids Concentration (TSSC) (e.g. Bell and Reeve, 2010; Fitzpatrick et al., 2009; Jiang and Fissel, 2011; Je et al., 2007). Maximum excess of SSC is usually expressed in relation to certain thresholds (IMDC, 2012; Bell and Reeve, 2010; Deltares, 2009). GBRMPA (2012) recommends that model results should include, as minimum requirement, maps showing the predicted maximum and mean SSC at mid-depth and near the seafloor, and the predicted deposition rate ($g/m^2$) as well as time-series predictions of these three parameters at key sites over the duration of the project. Descriptive statistics of the SSC, such as the median, 95th percentile and the maximum (Hadfield, 2014) are sometimes reported. Total sedimentation and bottom thickness maps are usually presented for single time-step, at the end of the specified dredged material placement scenario, or at a certain time after placement (SKM, 2013).

The duration of environmental effects is usually reported in term of exceedance probability, which is calculated as the percentage of time during which an SSC threshold is exceeded throughout the dredging and dumping operation (IMDC, 2012; Savioli et al., 2013). The percentage of time that the SSC is above the "critical" threshold for more than 12 h within a 24 h period, is also reported (Fitzpatrick et al., 2009).

In few cases, magnitude is related to duration and frequency of resuspension (Schoellhamer, 2002). The CCME WQI is proposed by Canadian Council of Ministers of the Environment (CCME, 2001) as an index for simplifying the reporting of water quality data. The CCME WQI is based on three individual factors, relating the extent of water quality guideline non-compliance over the time period of interest (factor 1: scope), the percentage of individual tests ("failed tests") that do not meet objectives (factor 2: frequency), and the amount of failed test with values that do not meet objectives (factor 3: amplitude). This index gives a measure of water quality referred to the length of a vector calculated by combining the three factors and scaled to range between zero and 100.

The risk level and the severity of environmental impacts depend on the closeness of environmentally sensitive areas (i.e. Sites of Community Importance with specific habitats, etc.) to the dredging zone and local hydrodynamics. Thus, to address the severity of environmental effects related to dredging, it is appropriate to estimate the magnitude, duration and frequency of the exposure to SSC (or higher sedimentation; Clarke and Wilber, 2000). It also relates to pre-existing habitat stress, which may affect the tolerance of species to elevated turbidity and sedimentation. In particular, frequent short-term or chronic long-term exposure to high SSC or sedimentation events may result in mortality for some species, while moderate levels of increased SSC and sedimentation persisting for particularly long time may cause changes in diversity for more sensitive species that are then gradually replaced by more tolerant ones. Thus, the environmental management of the dredging works requires the quantification of these different aspects through the determination of temporal and spatial variability of SSC in the water column (PIANC, 2010; Clarke and Wilber, 2000).

At present, there is a lack of tools that synthesize results of validated numerical models and make them usable for decision support and environmental management (SKM, 2013). To address this need, this paper describes an integrated, flexible and replicable methodological approach for synthesizing parameters related to water quality variations that arise from dredging activities. This approach is designed for different dredging techniques in coastal areas, with a main focus on estuarine and semi-enclosed basin. The main objective of the approach is to capture the spatial (vertical and horizontal) and temporal variability of SSC and DEP levels using simple and intuitive parameters. The model considers a full year and multiple scenarios to account for seasonal variations. It results in a realistic understanding of outcomes related to the dredging plume development. Events of exceedance of SSC thresholds are spatially described in term of magnitude, duration and frequency, and through the definition of a new integrated index ($SSC_{num}$). The proposed approach is applied to Augusta Harbour (Eastern coast of Sicily—Italy) case study, for a hypothetical dredging project and for a SSC threshold arbitrarily defined.

## 2. Material and methods

### 2.1. Integrated methodological approach

The proposed methodological approach, Dr-EAM, has been developed to support environmental studies (Environmental