Dredged Sediments, Web-GIS and Analysis Tools – The CEAMaS case study

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Abstract. Spatial analytical techniques are commonly used to inform critical aspects of dredging operations, providing powerful decision-making capacity when used with appropriate datasets. Geographical Information Systems (GIS) provide an operational framework within which a variety of dredging-relevant geospatial tools can be implemented. These may be generic or specific to particular dredging operations, in the latter case producing data for large numbers of relatively discrete dredging zones or operations. Pooling and cataloguing these individual operations can create a rich set of resources (data and tools) of value to decision makers, not only for use in managing dredging operations but also, to support the potential reuse of the material and the treatment needed for the use of the dredged material (DM). Web-based GIS are an ideal medium for displaying inputs required to complete spatial analyses, providing decision makers with an easy-access tool for use in combining information to optimise decisions. The early adoption of web-GIS technologies during the initial planning phase of a dredging process can lead to improved outcomes. Not only are end-users furnished with a more comprehensive view of the spatial aspects of a project but actual rates of sediment re-use may be increased through the provision of access to efficient tools with which to readily examine a selected set of high potential re-use options.

Keywords: GIS; Dredged Material; Decision Support System; Smart Atlas; Catalogue

I. INTRODUCTION

Dredging operations are frequently undertaken in order to adapt the physical geomorphology of the environment to meet specific sectorial requirements e.g. ports and shipping. In the context of coastal processes, the extraction of sediment as a means of adapting the marine environment for economic reasons can have far reaching consequences both offshore and onshore. ‘Dredging is essential to maintaining navigable access to Ireland’s main ports and harbours which account for 99% of Ireland’s imports and exports by volume and 95% by value’ [15].

Dredged material (DM) arising from such activities has commonly been considered as waste, however advances in technology and the increases in possible reuse options for marine sediments in a variety of civil engineering applications, frequently necessitate detailed case-by-case investigative studies to be carried out for operations where reuse of DM is intended.

The tools for analysing the specific of individual cases have also evolved with improvements in technology, and in some occasions, the adoption of tools from other fields of research to offer new perspectives to dredging studies; for instance, GIS tools and technologies. The geographical record of sediment relocation operations, dredging and reuse, is clearly better handled by a GIS. Whilst such spatial inventories are valuable and help to create a clear picture of the processes under investigation, the more advanced spatial analytical tools in a desktop GIS can be used to help identify where the reuse of sediments can match land use requirements.

The EU project CEAMaS (Civil Engineering Applications for Marine Sediments) provides a suitable work programme within which to test the potential of GIS tools for dredging and sediment recycling activities. The main aim of the project is to establish a uniform framework for the beneficial reuse of sediments at European-Level. The project is also reviewing the legal and policy frameworks from the different country members in order to encourage progress towards a more harmonized regulatory framework for the beneficial reuse of the sediments across all the member states. Several tools are under development through the project for enhancing decision making processes for dredging European dredging operations including: a bibliography, catalogue, uniform list of potential sediments for reuse and web-GIS tool.

The web-GIS tool created by the CEAMaS team (from now, the Web-GIS) provides an interactive graphical user interface which has been designed to facilitate decision support. The selection of layers displayed on the map is configured so as to facilitate decision making in specific contexts e.g. the identification of the areas where dredged may be required, the potential locations where sediments may be reused, and all the factors relevant to intermediate process steps such as transportation routes, civil engineering industries, dumping areas or sediments storage facilities. All the phases in the reuse of DM can be simulated, from the initial planning of the dredge campaign, until the final end-use of the DM.

Web-GIS tools are relatively intuitive in use with underlying modular designs providing the inherent functionality that can be rapidly adapted to suit specific requirements. The information displayed can be consulted, merged or printed, enabling the desired information to be compiled into maps or reports, which can be integrated in publications. The web-GIS maps also work as a catalogue database, allowing other services and users to import the information into their own environment through a WMS link.

II. STATE OF THE ART

Several GIS application tools are available on the web. The representation of any type of information in a geographical way, helps to contextualize the inputs available for any economical practice.

MapServer is an Open Source platform for publishing spatial data and interactive mapping applications to the web. Originally developed in the mid-1990’s at the University of Minnesota, MapServer is released under an MIT-style license, and runs on...
all major platforms (Windows, Linux, and Mac OS X). It is not a full-featured GIS system, nor does it aspire to be.

Smart Atlas is developed in-home by Beaufort UCC and is an “atlas in a box” that is easy to deploy and customise. It allows users to publish maps on the web in an easy way. Smart Atlas relies on UMN MapServer’s MapScript as a server side. It has a web graphical user interface developed using GeoExt and ExtJS. Many smart atlases were created using this technology: ie, the International Coastal Atlas Network (ICAN), Irish Coast Guard or ODINAFRICA.

The CEAMaS project has developed a Smart Atlas based on open source technology, which means that it can be adapted for the end users’ needs if necessary. The Smart Atlas is a web-enabled GIS map based catalogue and tool kit developed specifically for this project (see section III-C).

Additionally, the data represented in the survey needs to reflect the typology of the sediments from the different sampling sites. This approach will drive the characterization of the DM, identifying the physical properties materials present in the target areas, and secondly identifying their chemical properties, including the presence of contaminants. The treatment options for using the sediments for any specific operation will be strongly influenced by costs involved. Figure 1 gives an overview of the main factors to be considered in deliberations on the fate of DM.

As normalities, regulations, assessment criteria related to sediment management differ in each country, due to local regulations and standards, the project partners are making as one of the goals the identification, compilation and analysis information (technical, economical, regulatory, environmental and social), bibliographies, practices, options and solutions available in North-West European countries in order to better understand and evaluate the perspectives for the reuse of dredged marine sediments in civil engineering practices in Europe.

The geographical scope of the investigation and analyses will cover Ireland, UK, the Netherlands, Germany, France, and Belgium using the expertise available in University College Cork (IRE), Cork Institute of Technology (IRE), Delft University of Technology (NL), cd2e (FR) and Belgium Building Research Institute (BE).

Following the main lines of the project, CEAMaS will clarify and foster convergence between European and national legal frameworks for dredged sediment management and will bring perspectives for the reuse of marine sediments in civil engineering application in Europe.

As part of the initial CEAMaS output, some tools will be published by summer 2015:

- Online multi-criteria decision-making tool,
- Online training platform,
- Online Data Base,
- Online documents, studies & bibliography,
- Online (Web) GIS

The deliverables will be made available in an online format in order to improve availability of the tools and encourage their widespread adoption.

B. Spatial Analysis and GIS database

To strategically focus effort, CEAMaS will develop two detailed study cases for dredged material reuse: Cork Harbour (Ireland) and Nord Pas du Calais (France). The accessibility of information available to CEAMaS makes these two study cases ideal demonstrations for the Smart Atlas functionalities. Whilst localized, these examples demonstrate inherent capabilities which are expected to be broadly applicable across a diversity of dredging operations (Figure 2).

Coastal dynamics monitoring is a highly relevant activity for any port authority or related industry. By developing a working model of dynamics of the sedimentary processes that operate in the harbour itself and the coastal/estuarine/fluvial system where it is located, it may be possible to anticipate future problems that can negatively impact port operations. Compiling an accurate spatial database facilitates these types of analyses and supports more
informed decision making.

The toolset provided through a GIS, facilitates the processing of information, and the display of data spatially, both in 2D and 3D, highlighting relevant geospatial information through easily accessible data in the form of shapefiles. (Figure 3)

In order to undertake dredging activity responsibly, it is necessary to characterise the target sediments. Combining data from acoustic sources e.g sub-bottom profilers, multibeam echosounders, with results of physical site investigation techniques (coring, grab samples) etc., using spatial analytical and geostatistical techniques can produce an integrated volumetric map of the target area in which the variations in sediment properties are well delineated. (Figure 4)

GIS analyses for manipulating and integrating geophysical datasets have been commonly used by the industry for many years. The outputs collected from these types of analyses can be aggregated and stored in a catalogue to facilitate the compilation of further datasets to enable an interpretation of site dynamics of key benefit to end users.

One of the main goals proposed by CEAMaS is to feed the compilation of all the GIS products in an online catalogue directly to the European Resources Centre (ERC) (see below). This spatial catalogue should become a primary source of consultation for any decision maker, who will be able to appraise themselves of previous stages the dredging activity relevant to future planning. This data should be reinforced with proper metadata following ISO standards, with the process outlined in Figure 5 used to compile and create the datasets.

C. Web-GIS

Here, we define the Smart Atlas as: an online mapping application (web-GIS) that displays relevant information (mainly geo-data) about a specific topic, whilst offering users some of the standard toolsets and functionality provided by a desktop GIS, i.e. zoom, polygon drawing, pan, select, printing, etc., highlighted in the figure 6. The application enables online viewing of geo-data.

The CEAMaS geodataviewer has been implemented using open source software technology. The user interface is accessible from most web browsers. Online dynamic querying and visualization functions are driven by the MapServer web-based mapping system. Information pertaining to the layers displayed is also easily accessible.

For every dataset, a quality informative metadata is displayed compliant to ISO 19115 standard. Descriptive information on geo-spatial data including origin, quality, geographical extent, etc., pertains to individual features as well as hosting links to a range of additional non-spatial reference materials such as pdf files, graphics, or related reports. Data layers are organized and served over the internet using Mapserver (WMS standards compliant).

The figure 7 shows the architecture behind the information displayed in the web-GIS. All the functionalities are divided and processed through a central server, making of the main webpage a user friendly interface, accessible to all type of customers.
Content for the geospatial information layers (shapefiles) has been built from publicly available sources fused with newly acquired data in order to deliver information at different zoom levels (three tiers) from individual ports up to regional scale transport networks.

As outlined above, the web-GIS built with the smart atlas technology, is not a GIS substitute, so the datasets displayed have to be ‘pre-cooked’ with desktop software before being uploaded to the web through the server. A similar process is needed for non-spatial data which can be introduced to the server and then linked to the spatial data.

D. DM use – Decision Support System tool

‘DM can be considered as a valuable resource; a useful source of granulate material if properly handled and applied in a beneficial manner. Such beneficial use of DM, may significantly reduce the environmental impacts associated with the disposal of the DM and may reduce project costs with the potential added benefit of re-using a material which has traditionally in many cases been considered to be a waste material’ [8].

The data displayed on the web-GIS provides a local to regional context for the case studies. In combination, the data introduced and tools provided, enable end users to initiate an analytical procedure relevant to dredge planning in the area of interest. Once the dredging decision is taken, it is often necessary to consider the possibility of reusing the DM for an alternative purpose or find locations for storing it. Use of the web-GIS can facilitate this part of the overall dredge spoil management procedure.

The first step is the characterization of the potential DM. To enable this, sufficient sediment samples from the proposed dredge site must be collected, tested and analyzed. ‘DM properties are site specific hence the importance of developing independent surveying and sampling plans for a specific dredging project. These may vary according to the nature and perceived sensitivity of the environment, the volume and area to be dredged, and the need to address other activities nearby’ [1]. The sampling should also be representative of the size and depth of the area to be dredged.

Deciding the ultimate destination in terms of where the sediments maybe economically transported to, often represents a key issue in any decision process. Small increments in this variable can greatly increase project overall costs, with the potential to jeopardize overall economic feasibility. Promising locations can be identified using spatial multi-ring buffering techniques, around potential sediment discharge sites. This approach simplifies cost quantification DM transport, irrespective of whether material is destined for a treatment plant or storage location.

The Decision Support System (DSS) tool described in Mason, E. et al [16], enables the creation of an inclusion/exclusion buffer through calculating the Euclidean Distance from the dataset, which highlights the more suitable and unsuitable sites for the placement of any action as it could be a treatment plant. The creation of areas of influence or constraints, creates a positive or negative constraint, indicating the interest of the user in having the DM deployment site closer from any data point. (Figure 8).

To create a multi-criteria tool, it would be needed to cross all the constraints and made the calculations with a corrector multiplier for every single data, implying the interest of the user in every dataset. For that, all the information should be normalized using a distance factor:

\[ \text{RastDistNorm} = \frac{(\text{RastDist})}{\text{DistMax}} \]

\[ \text{InoRastDistNorm} = \frac{\text{DistMax} - \text{DistMax}}{\text{DistMax}} x - 1 \]

By excluding the spaces where sites cannot be build and, at the same moment, remarking the places where any action with the sediments are more likely to happen, the decision makers will have an extra-aid in the process, highlighting the availability of spaces in the region. The duality of the dataset as positive/negative constraint gives to the end users the flexibility to prioritize some locations above the others. These datasets from the DSS area are created with spatial analysis tools from a desktop GIS, and eventually can be exported to a web-GIS, making from the information available, a very accessible tool for any user.

Every case study requires a different approach due to the unique characteristics that every local region has, i.e. transport, natural protection, etc. As it is highlighted previously, in the CEAMaS project lifetime, only will be studied in detail the cases from Cork (plus the region of Munster) and Dunkerque (plus the region of Nord-Pas-de-Calais).

The import of the datasets created following the Spatial DSS into the web-GIS, would recreate different variables in the process, showing all the hypothetical solutions for the DM deployment and transportation.

The web-GIS could be a supporting tool at any stage, but also...
in later stages, as has been seen with the transport issue. The spatial analysis of coastal dynamics might indicate where the sediments are going to be needed in the future.

Having available DM suitability based on sediment characterisation (Figure 9) the approach shows which type of material is needed, highlighting on a map the treatment necessary to adapt the dredged material for the re-use.

The potentialities from the web-GIS Smart Atlas available through the CEAMaS platform are as large as we can imagine. The DM use study, from the very first idea of dredging until the moment of reused in a civil engineering application, can be monitored through the GIS software, both desktop and web.

The web-GIS was created by Beaufort (c/o Coastal and Marine Research Centre) on behalf of the project CEAMaS. The sampling approach and the analysis were developed in collaboration with the University College Cork (UCC), and specifically with the Professor Andy Wheeler, Head of Geology (School of Biological, Earth & Environmental Sciences – BEES, UCC).

Beyond the seismic data provided by the Geological Survey Ireland (GSI) and the Marine Institute (MI), the data used for every other analysis is freely downloadable from EUROSTAT webpage, believing in the good accuracy of it.

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