Deliverable 2.3 Implementation of Economic & Environmental Impacts and Benefits Tools to Partner Ports

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WPT1 partners with coordination by Dr. Joe Harrington and Branislav Batel (Munster Technological University)

IMT Lille Douai for Armines, Ixsane, University of Strathclyde, University of Lille, University College Cork

Lead Partner: Munster Technological University

SUMMARY

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LIST OF ABBREVIATIONS

BAU – Business as Usual

BRO – Beneficial Reuse Option

CD – Chart Datum

EIA – Environmental Impact Assessment

EPA – Environmental Protection Agency (Ireland)

FTE – Full Time Equivalent

GDP – Gross Domestic Product

IMT - Institut Mines-Télécom

MTU – Munster Technological University

NWE – North-Western Europe

mg/kg – milligrams per kilogrammes

OPW – Office of Public Works (Ireland)

QGIS - Quantum Geographic Information System

SedEcon – Sediment Economic Model

UCC – University College Cork

UoL - University of Lille

UoS – University of Strathclyde

WP – Work Package

1 Introduction

This document provides Deliverable 2.3 for Activity 2 of the SURICATES T1 Work Package. Activity 2 involves implementation of global cost and benefits methods to increase the use of fine sediment in river and coastal engineering with an emphasis on flooding and erosion protection markets.

Deliverable 2.3 - *Implementation of economic & environmental impacts and benefits tools to partner ports. Implementation of the methods to the Ports of Dunkerque and Cork/Waterford as pilot sites with local data. Replication tests with Rotterdam Port and Bowling demonstration site* [1].

Four tools (GIS, Direct Cost, Economic and Environmental) have been developed as a part of Work Package T1 (WP T1) to support the dredge sediment management decision process.

These four tools have been applied to dredge sediment management projects in the SURICATES Project partner countries of Ireland, Scotland, France and the Netherlands. The sediment management projects chosen represent a range of different applications of the reuse of dredged sediment.

The RAIES (Repulsion - Attraction - Included -Excluded - Sanctuarised) GIS tool developed by the University of Lille, France provides stakeholders with a GIS solution to support selection of the best location(s) for sediment reuse. The tool uses a spatial decision support system, which determines the best location available based on inputs from a range of different stakeholders.

The USAR Direct Cost Model developed by IMT Douai, France allows selection of the most suitable sediment management option based on criteria including sediment granulometry and chemical characteristics, project costs, environmental criteria, site location(s) and local and national regulations.

The SedEcon (Economic) model developed by Munster Technological University, Ireland estimates the direct, indirect and induced impacts of a sediment management project in terms of Gross Domestic Product (GDP) and jobs created and based on industry specific economic multipliers and coefficients, derived for each of SURICATES partner countries. The economic and employment contributions were downscaled to a regional EU NUTS3 level.

The BROADSEAT (Beneficial Reuse Of Any Dredged Sediment Environmental Assessment Tool) Environmental Model developed by the University of Strathclyde, Scotland is designed to analyse the environmental merits of a beneficial use dredging project. It compares a real or hypothetical Beneficial Reuse Option (BRO) to the Business as Usual (BAU) Case. It provides a qualitative assessment on a relative scale. i.e., ‘the better’/’the same’/’worse’.

The four tools have been applied to analyse the impacts of four different sediment management projects at sites across the project partner countries of Ireland, Scotland, France and the Netherlands (Table 1-1). The sediment management projects were chosen where sufficient site information and data was available for sediment management projects for application of all four tools; these sites were thus not necessarily the same in each partner country as per the original project proposal.

This work package report presents detailed analyses of a number of sediment management options across the different projects including wetland nourishment, dyke construction, land reclamation, bioremediation, breakwater construction, sediment cell maintenance and sea disposal.

The integrated tools have been applied to the individual sites and this work involved substantial transnational collaboration between the various project partners.

Site	Application	BAU/BRO
Port of Fenit, Ireland	Sea Disposal	BAU
	Wetland Nourishment	BRO
	Dyke Construction	BRO
Port of Calais, France	Breakwater Construction	BRO
	Land reclamation	BRO
Port of Rotterdam, The Netherlands	Sediment Cell Maintenance	BRO
Falkirk, Scotland	Phytoconditioning	BRO

Table 1-1: List of Sites where the Integrated Tools were applied.

2 PORT OF FENIT, IRELAND

2.1 INTRODUCTION

The Port of Fenit is a mixed function Irish seaport under the auspices of Kerry County Council, a Local Authority. It is the most westerly commercial port in Ireland and is located on the northern side of Tralee Bay (Figure 2-1). Maintenance dredging is an ongoing requirement to provide safe navigable access and berthage for commercial shipping and recreational craft, the current sea disposal location is shown in Figure 2-1. Current harbour planning envisages dredging of approximately 1m tonnes of dredged sediment over the coming 8-year period from 2023 to 2031 [2].

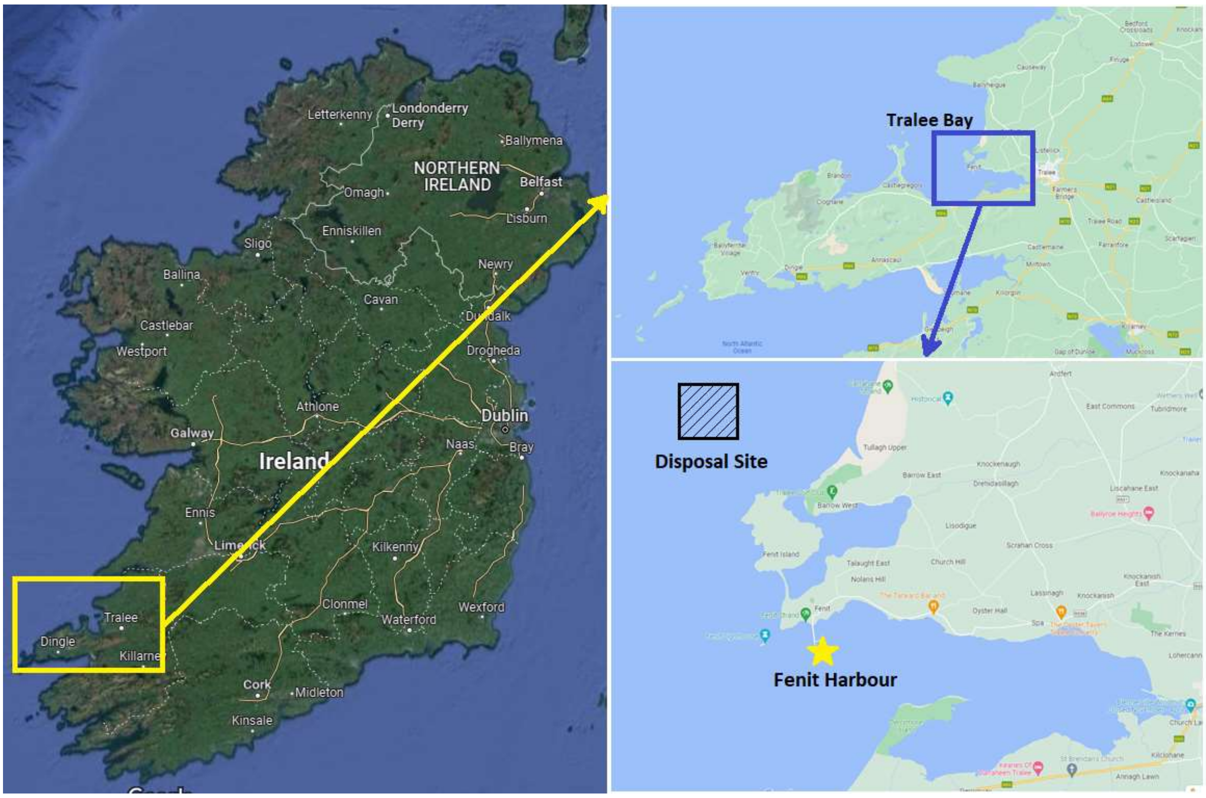


Figure 2-1: Location of the Port of Fenit and Sea Disposal Site

Recent dredging work was undertaken by an external dredging contractor, Dutch Dredging, in May 2021 as a combination of primarily suction hopper dredging with some plough dredger activity (Figure 2-2). In this first phase, 57,770 m^3 of sediment was dredged and disposed at sea.

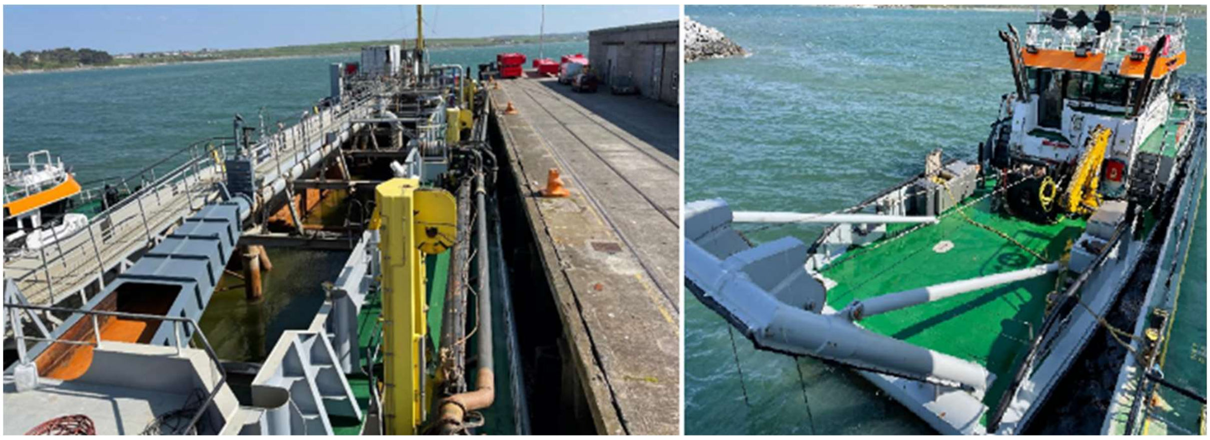


Figure 2-2: Hydraulic Dredger Marbury (left) and Plough Dredger (right) used at the Port of Fenit

Kerry County Council contracted Aquafact International Service Ltd. to carry out a pre-dredge sampling campaign and analysis of sediment samples in the Port of Fenit, the survey was undertaken on the 23rd November 2017. Dredge samples were obtained from Dutch Dredging on behalf of MTU on the 6th May 2021 and analysed at BRGM's laboratory (Project Partner) in France. The post-dredge samples were collected by Hydrographic Surveys Ltd. on the 24th September 2021 under contract to MTU and analysed in the accredited Socotec Laboratories in the United Kingdom. The dredge and post-dredge sampling and subsequent analyses undertaken formed part of the SURICATES Project.

The average particle size distribution of the analysed pre-dredge, dredge and post-dredge samples is summarised in Table 2-1. The analyses show that the sediment samples were predominantly sand or silt with a negligible gravel fraction. A visual inspection of the samples showed that all samples were similar in composition with a light brown surface and an anoxic black mud/medium sand below.

Fraction	Size	% of Total
Gravel	> 2mm	0.56
Sand	63 – 2000 µm	44.52
Silt	< 63 µm	54.92

Table 2-1: Average particle size distribution for Port of Fenit sediment samples

Heavy metals concentrations in pre-dredge samples from 12 locations (Figure 2-3) in the Port of Fenit, for example, are presented in Table 2-3 [2]. Nickel and arsenic concentrations were slightly above the Lower Action Limits for sea disposal for Ireland (Table 2-2). The dredged sediment is hence classified as Class 2 sediment where contaminant concentrations are between the lower and upper levels. Further sampling and analysis is necessary to determine suitability for sea disposal [3].

Chemical Compound	Units (dry weight)	Lower Level	Upper Level
Heavy Metals			
Arsenic (As)	mg/kg	9	70
Cadmuim (Cd)	mg/kg	0.7	4.2
Chromium (Cr)	mg/kg	120	370
Copper (Cu)	mg/kg	40	110
Lead (Pb)	mg/kg	60	218
Mercury (Hg)	mg/kg	0.2	0.7
Nickel (Ni)	mg/kg	21	60
Zinc (Zn)	mg/kg	160	410
Organic Contaminants			
PCB 28	µg/kg	1	180
PCB 52	µg/kg	1	180
PCB 101	µg/kg	1	180
PCB 118	µg/kg	1	180
PCB 138	µg/kg	1	180
PCB 153	µg/kg	1	180
PCB 180	µg/kg	1	180
Sum PCB7	µg/kg	7	1260
y -Hexachlorcyclohexane	µg/kg	0.3	1
Hexachlorbenzene	µg/kg	0.3	1
TBT + DBT	mg/kg	0.1	0.5
Total Extractable Hydrocarbon	µg/kg	1000	-
PAH16	µg/kg	4000	-

Table 2-2: Dumping at sea action levels for Ireland [3]

All other parameters were below the Lower Irish Action Limit within the proposed dredge area. Further assessment deemed the sediment suitable for sea disposal [4].

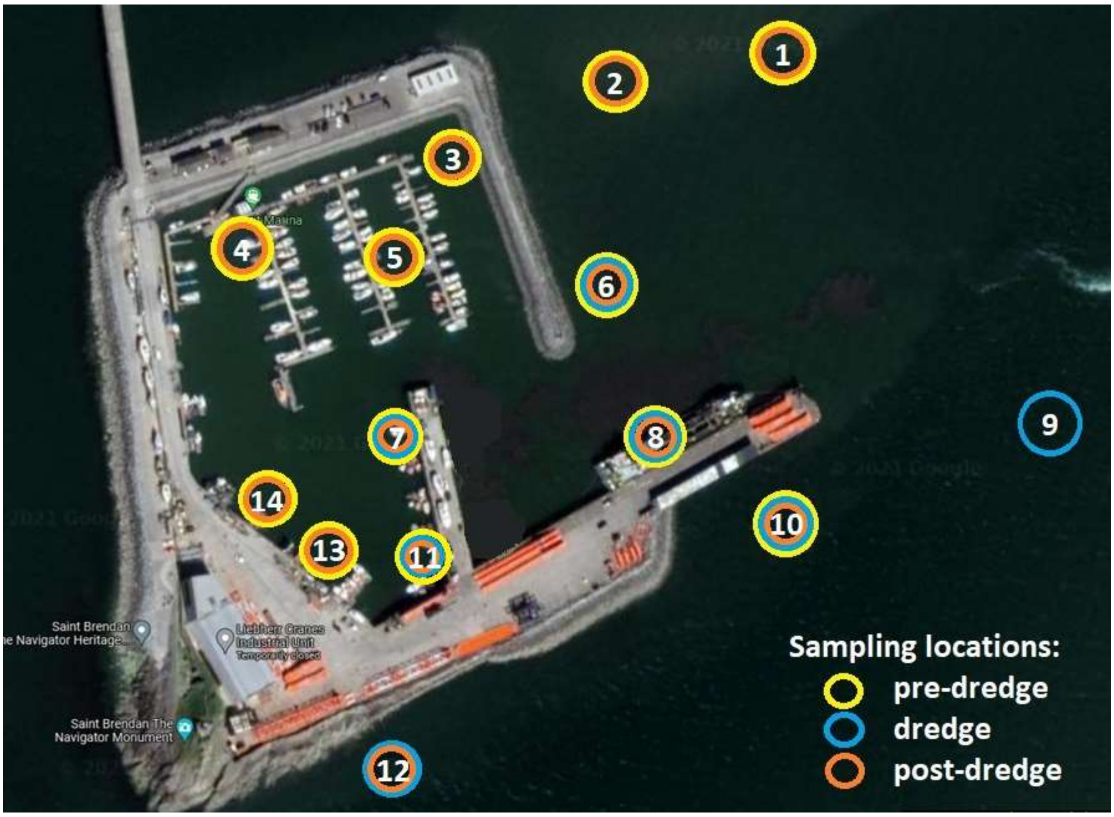


Figure 2-3: Sediment sampling locations in the Port of Fenit

Sampling Location	As	Cd	Cr	Cu	Pb	Ni	Zn	Hg	Al	Li
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
1	7.9	0.3	29.4	13	9	14.3	47.5	0.02	17900	12.7
2	7.9	0.4	32.7	11.8	11.5	16.1	52.5	0.02	20100	14.3
3	15.6	0.6	54.9	18.8	21.9	28.7	89	0.05	33700	22.4
4	18.6	0.4	54.9	31.4	22.9	26.5	118	0.05	33800	22.2
5	16.5	0.5	52.1	19.3	21.8	26.6	82.6	0.05	34600	23
6	9.8	0.4	40.7	14.1	15.4	20.2	61.6	0.03	25100	17.2
7	18.4	0.4	54.7	20.5	22.9	27.5	87.9	0.05	35400	23.4
8	13.9	0.5	51.1	36.9	27	23.7	149	0.05	28400	19.4
9	10.8	0.4	40.1	18	15.9	20.4	68.7	0.04	27500	18.3
10	16.7	0.5	53.8	30.3	26.1	27	106	0.05	33500	22.5
11	18	0.4	53.6	18.2	21.6	27.3	146	0.05	34200	22.5
12	18.6	0.3	62.6	263	49.8	28.2	205	0.05	34800	22.8

Table 2-3: Pre-dredge heavy metal concentrations at 12 locations in the Port of Fenit

2.2 Sediment Management Applications Analysed

The SURICATES tools were applied to assess a number of potential sediment management applications/scenarios based on an assumed project involving a dredging volume of 200,000 m^3. This volume is likely to be similar to the volume to be dredged in the next phase of the ongoing dredging campaign.

The three different scenarios analysed are a mixture of the Business as Usual (BAU) case and Beneficial Reuse Option (BRO):

1. Sea disposal (BAU)
2. Wetland nourishment/restoration using dredged sediment (BRO)
3. Dyke construction (Flood Protection) using dredged sediments (BRO)

2.2.1 Sea Disposal

The disposal at sea sediment management option (BAU) has been used by the Port of Fenit in its previous dredging campaigns as the most viable sediment management option. The tools application presented in this report is based on 200,000 m^3 of dredged sediment transported by sea and disposed at the Irish Environmental Protection Agency (EPA) licenced offshore site which is located approximately 7 km sail distance north of the Port of Fenit (Figure 2-4).

Figure 2-4: Sea disposal site for Port of Fenit dredge sediments

Table 2-4 presents a summary of the key model inputs for sea disposal at the identified Port of Fenit site.

Item	Description
Dredging site coordinates	52.2706301°, -9.862063°
Disposal at sea site coordinates	52.321442°, -9.900344°
Dredger used	Hydraulic Dredger
Volume of dredged sediment	200,000 m^3
Transport	Water Transport (7 km)

Table 2-4: Key characteristics for the Port of Fenit Site - sea disposal - model inputs

2.2.2 Wetland Nourishment

The finer dredged sediment from the Port of Fenit is potentially suitable for nourishing and enhancing the existing and valuable Tralee Bay wetlands which are located approximately 2.5km sail distance from the Port of Fenit. It is a large wetland area covering 314 hectares and contains estuarine silts and clays (Figure 2-5). This is a potential Beneficial Use Option (BRO).

Figure 2-5: Identified wetland areas in Tralee Bay

The wetland restoration scenario involves 200,000 m^3 of dredged sediment transported via trailer suction dredger approximately 2.5 km sail distance and placed into a designated wetland area via high-pressure discharge. The thickness of the applied sediment layer is generally lower in the vegetated areas and higher in the open water areas. No berm or weir box installation is required. It is assumed for modelling purposes that the dredged sediment is appropriate for such use and the thickness of the applied sediment is 0.3 m. In reality this sediment application would require extensive site investigation, sampling and environmental assessment prior to such works. Table 2-5 provides a summary of key model inputs for the wetland nourishment scenario.

Item	Description
Dredging site coordinates	52.2706301°, -9.862063°
Wetland site coordinates	52.251689, -9.829255
Dredger used	Hydraulic Dredger
Volume of dredged sediment	200,000 m^3
Transport	Water Transport (2.5 km)

Table 2-5: Key characteristics of the Port of Fenit – wetland nourishment – model inputs

2.2.3 Dyke Construction

A flood protection dyke is proposed to be located on a coastal stretch approximately 7.6 km from the Port of Fenit dredging site where there is a high probability of flooding (Figure 2-6) based on predictions by the Irish Office of Public Works [5]; this is a Beneficial Reuse Option (BRO). It is assumed that all 200,000 m^3 of fine dredged sediment would be reused for the construction of the 3.7 km long engineered dyke structure with a dyke height of 6.5 m and crest width of 2.5m, a geotextile filter layer and a rock armour outer layer requiring 12,500 m^3 of rock material supplied by the nearby Ardfert Quarry (52.33634982940954, -9.754277615342676), a trucking distance of approximately 11km from the dyke construction site. It is assumed for purposes of this modelling work that the dredged sediment is suitable for such an application [6].

Figure 2-6: Proposed dyke location and areas of high flood risk in Tralee Bay

Table 2-5 shows the summary of key model inputs for the flood dyke construction scenario.

Item	Description
Dredging site coordinates	52.2706301°, -9.862063°
Dyke site coordinates	52.260798°, -9.744737 °
Dredger used	Hydraulic Dredger
Volume of dredged material	200,000 m^3
Volume of Imported Rock	24,400 m3
Dewatering Method	Natural 8€/m3 =5€/T
Transport	Water Transport (dredged sediment - 7km) + Road Transport (rock import – 11km)

Figure 2-7: Key characteristics of the Port of Fenit – dyke construction – model inputs

2.3 Model 1 Application – RAIES

The RAIES model was applied to the Port of Fenit site and Figure 2-8 presents the result generated by the model based on a stakeholder interview with the Port of Fenit harbour master.

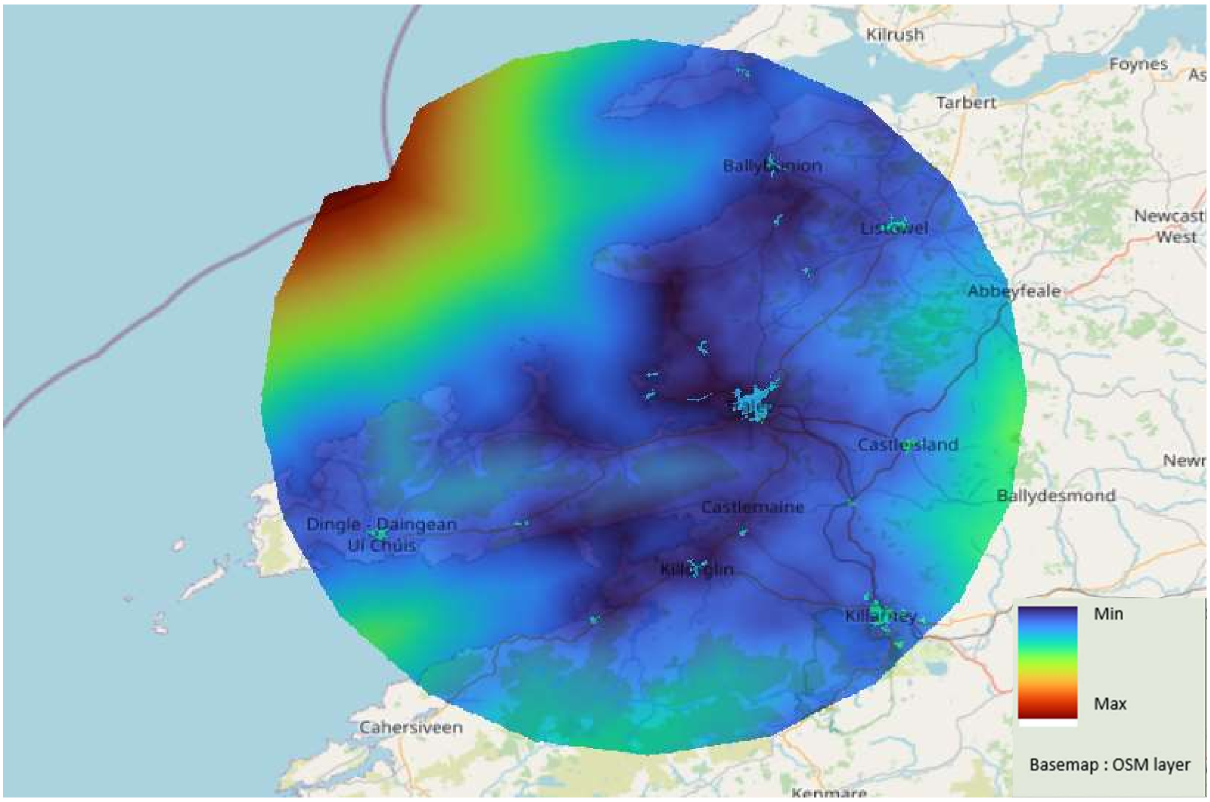


Figure 2-8: RAIES Model Output – Port of Fenit – Restraint Levels

Figure 2-8 graphically indicates the level of restraint for dredge sediment applications on a colour spectrum from dark blue (minimum restraint) to dark red (maximum restraint) within a radius of 40km from the dredging site location. The cartographic result of the RAIES model, parameterised by a decision maker, represents a gradient of spatial constraint values from low (0 - minimal) to high (1 - maximal), i.e. the blue areas are more suitable for the sediment application than the red areas. The details of the RAIES tool inputs/outputs are presented in Deliverable WPT1 D2.2 [7].

2.4 Model 2 Application – Direct Cost Optimisation Tool (USAR)

Figure 2-9 presents the USAR software application for the port of Fenit.

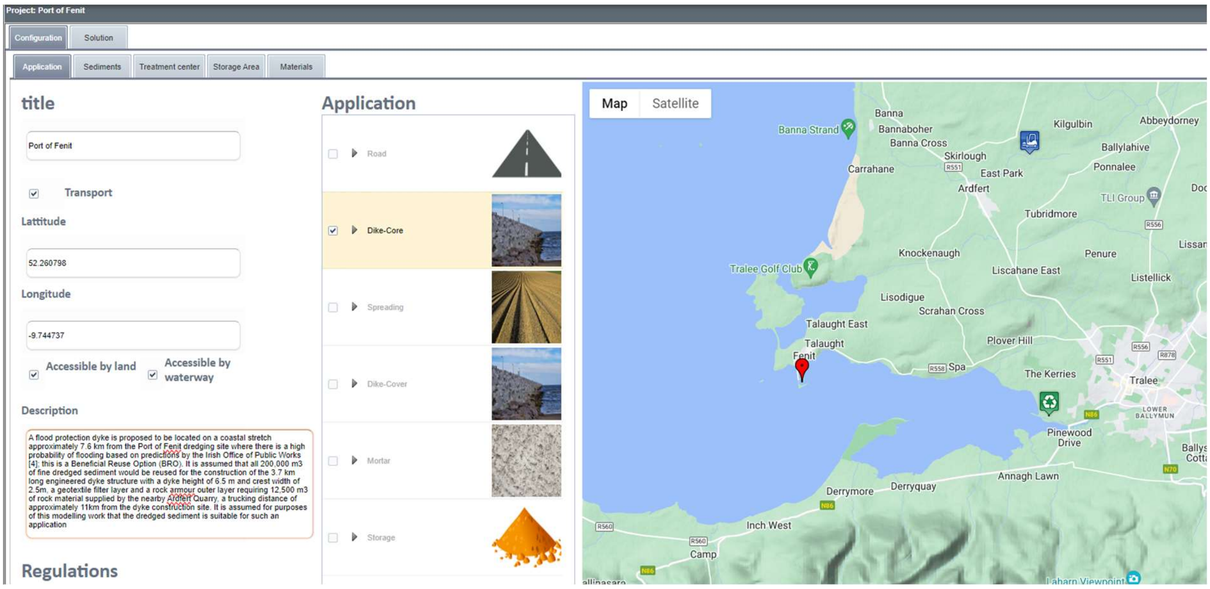


Figure 2-9: USAR software application to the dyke construction application in the Port of Fenit.

The sediment applications and the results are summarised in Table 2-6 for the three sediment management options. The USAR model does not contain a wetland creation/nourishment management option; therefore, it was replaced by an agricultural application which is deemed sufficiently similar for analysis purposes. For the dyke construction (BRO) management option the ‘dyke core’ option was selected as it includes the core material optimisation and the proposed dyke has a rock armour outer layer.

ITEM	BAU Sea Disposal	BRO Wetland	BRO Dyke
Overall cost per tonne of new material (including transport)	€ 2.5	€ 2.2	€ 7.05
Sediment chemical properties suitability for chosen application	Meets the Irish regulation for sea disposal	Dyke cover Arsenic/Chrome/Nickel/ Zinc need additional assessment	Dyke core Arsenic/chrome/Nickel/ Zinc need additional assessment
Sediment physical properties suitability for chosen application	Meets the Irish regulation for sea disposal	Available characteristics suitable for agricultural application (substitute for wetland nourishment)	Available characteristics suitable for dyke core application

Table 2-6: USAR Model output table – Port of Fenit

The USAR tool estimated the cost of the disposal at sea management option to be €2.5 per tonne; the dyke construction management option cost was estimated at €7.05 per tonne. The estimated direct cost for the agricultural application (as a substitute for the wetland) is €2.2 per tonne.

The physical characteristics of the dredge sediment are suitable for sea disposal and for both beneficial reuse options. The chemical characteristics show that the average levels of heavy metals (Arsenic and Nickel) are above the Lower Action level for Ireland but were deemed suitable for disposal at sea. The presence of heavy metals could pose an environmental risk for both beneficial reuse options. A substantial physical, chemical and biological testing regime would be required to determine suitability for wetland nourishment. The dredge sediment might require some form of additional treatment prior to use as fill for dyke construction.

2.5 Model 3 Application – SedEcon

SedEcon was applied to the Port of Fenit site (Figure 2-10) and the results are summarised in Table 2-7.

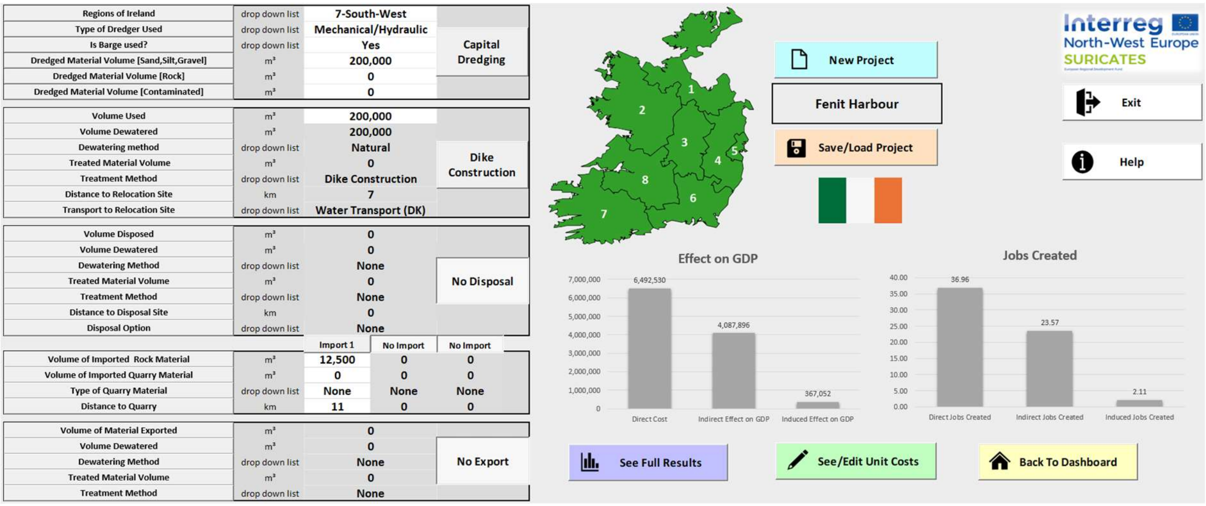


Figure 2-10: Economic model results for the dyke construction sediment management option – graphical display

ITEM	BAU Sea Disposal	BRO Wetland	BRO Dyke
Direct contribution to GDP	€ 1,708,000	€ 2,217,000	€ 6,492,000
Indirect contribution to GDP	€ 1,002,000	€ 1,251,000	€ 3,722,000
Induced contribution to GDP	€ 82,100	€ 108,860	€ 327,800
Direct jobs created	12.19 FTE	13.45 FTE	36.96 FTE
Indirect jobs created	7.59 FTE	7.79 FTE	21.34 FTE
Induced jobs created	0.60 FTE	0.67 FTE	1.88 FTE
Total cost per m^3	€ 8.54	€ 11.09	€ 32.46
Total cost per tonne	€ 5.34	€ 6.93	€ 20.29

Table 2-7: SedEcon output table – Port of Fenit

The estimated direct cost (or contribution to GDP) per tonne from SedEcon applied to the BAU sea disposal scenario was €5.34 (the direct unit cost for the reduced volume actual recent dredging project at the site was €8.11/tonne; clearly some economies of scale are involved). The direct contribution to GDP of the wetland creation management option was estimated to be €6.93 per tonne and the dyke construction management option direct contribution to GDP was estimated to be €20.29 per tonne. The sea disposal scenario estimate for the indirect and induced contributions to GDP were €1,002,000 and €82,100 respectively and was estimated to create 12.19 direct, 7.59 indirect and 0.6 full time equivalent jobs.

The wetland nourishment option is estimated to contribute €2,217,000 directly to GDP, indirectly with €1,251,000 and with the induced GDP contribution of €108,860. This option is estimated to create 13.45 direct, 7.79 indirect and 0.67 full time equivalent jobs.

The dyke construction direct, indirect and induced contributions to GDP are estimated at €6,492,000, €3,722,000 and €327,800 respectively. This scenario is estimated to create 36.96 direct, 21.34 indirect and 1.88 induced full time equivalent jobs.

Over the different sediment management scenarios the indirect economic impacts as a proportion of the direct impacts ranged from 56 to 59% for GDP and from 58 to 62% for jobs created. The induced economic impacts as a proportion of the direct impacts are approximately 9% for GDP and 5% for jobs created.

2.6 Model 4 Application – Environmental Model (BROADSEAT)

The BROADSEAT model was applied to the Port of Fenit sediment management options. BROADSEAT contains 48 questions across four categories; Energy, Waste, Environment and Societal [8]. Thirty-eight questions were applicable to the project, ten questions were deemed not to be relevant. The baseline for assessment is the BAU application (sea disposal).

The BROADSEAT assessment results for the wetland nourishment management option are summarised in Figure 2-11 and Table 2-8. The wetland nourishment scenario assessment yields all four category ratings as positive.

The results for the dyke construction management option are summarised in Figure 2-12 and Table 2-8 (and which provides a summary output for all three scenarios assessed). The dyke construction scenario assessment yields positive waste, environment and societal rating and the energy rating is negative.

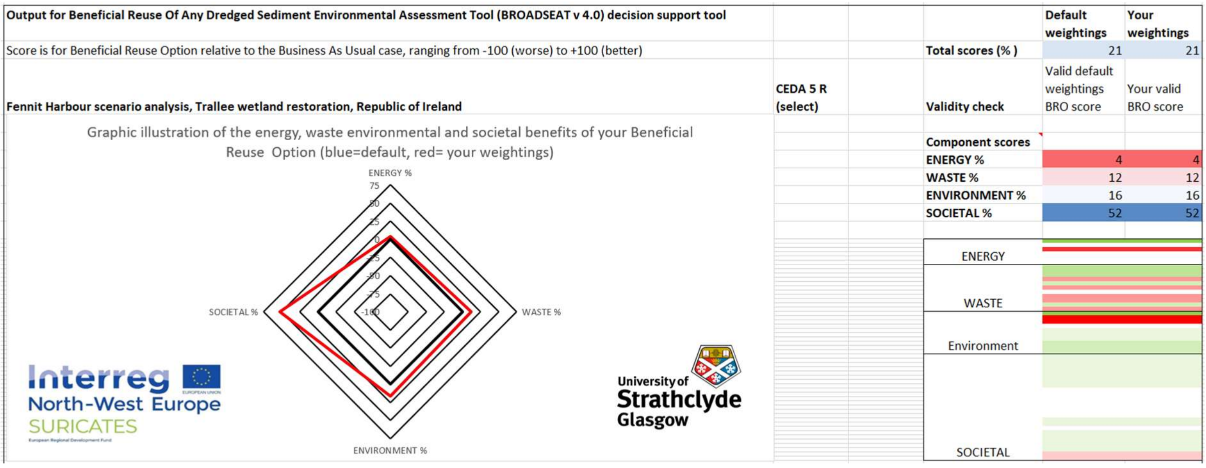


Figure 2-11: BROADSEAT Model output radar plot – Port of Fenit - Wetland Nourishment

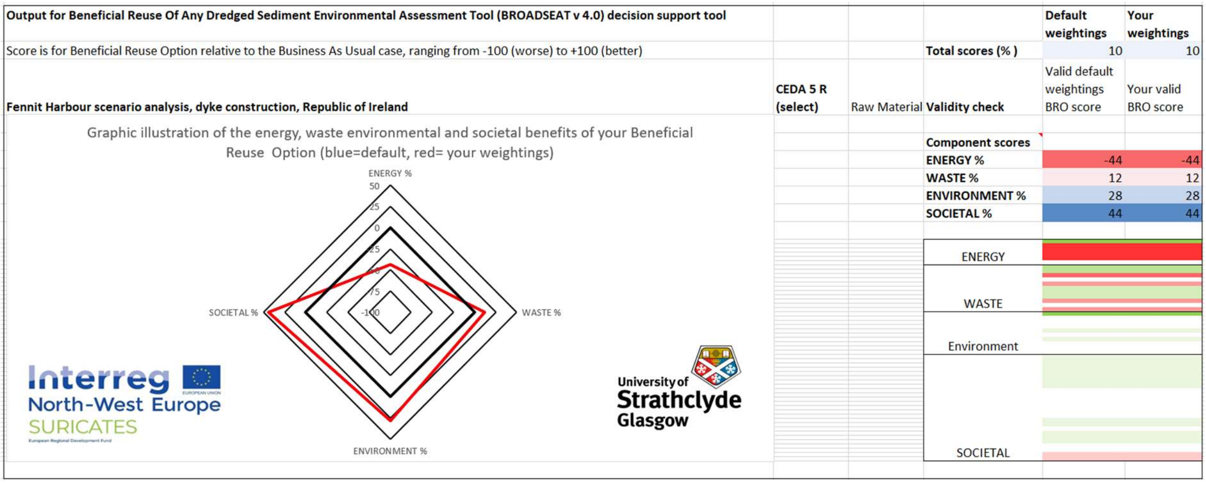


Figure 2-12: BROADSEAT output – Port of Fenit – Dyke Construction

ITEM	BAU Rating [-100:100] Sea Disposal	BRO Rating [-100:100] Wetland Nourishment	BRO Rating [-100:100] Dyke Construction
Energy	0	4	-44
Waste	0	12	12
Environment	0	16	28
Societal	0	52	44

Table 2-8: BROADSEAT output summary table – Port of Fenit

2.7 Analyses of Model Results

A summary of the results from all four models/tools applied to the Port of Fenit scenarios is presented in Table 2-9.

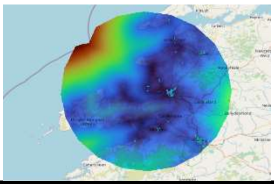
MODEL	ITEM	BAU Sea Disposal	BRO Wetland Nourishment	BRO Dyke Construction
RAIES	Suitability/Acceptability score		See Figure 2-8	
USAR	Sediment chemical properties suitability for chosen application	Elevated levels of heavy metal might require additional assessment	Elevated levels of heavy metal – additional assessment required	Elevated levels of heavy metals – treatment might be required
	Sediment physical properties suitability for chosen application	✓	✓	✓
	Overall cost per tonne of new material	€ 2.5	€ 2.2	€ 7.05
	Overall project cost	€ 800,000	€ 704,000	€ 2,254,800
SedEcon	Direct contribution to GDP	€ 1,708,000	€ 2,217,000	€ 6,492,000
	Indirect contribution to GDP	€ 1,002,000	€ 1,251,000	€ 3,722,000
	Induced contribution to GDP	€ 82,100	€ 108,860	€ 327,800
	Direct jobs created	12.19 FTE	13.45 FTE	36.96 FTE
	Indirect jobs created	7.59 FTE	7.79 FTE	21.34 FTE
	Induced jobs created	0.60 FTE	0.67 FTE	1.88 FTE
	Total cost per m^3	€ 8.54	€ 11.09	€ 32.46
	Total cost per tonne	€ 5.34	€ 6.93	€ 20.29
BROADSEAT	Energy rating [-100:100]	0	4	-44
	Waste rating [-100:100]	0	12	12
	Environment rating [-100:100]	0	16	28
	Societal rating [-100:100]	0	52	44

Table 2-9: Summary table of Model Outputs for the Port of Fenit site

The RAIES spatial decision support tool results show a gradient of spatial constraint within a radius of 40 kilometres around the dredging site at the Port of Fenit. There are substantial areas identified with highest acceptability for sediment reuse; the areas with the highest restraint values are primarily approximately offshore. This is based on a single stakeholder interview.

The USAR model estimated the wetland nourishment scenario as the most viable direct costs option with a direct cost of € 704,000 (€2.2 per tonne) followed by the business as usual sea disposal scenario at € 800,000 (€2.5 per tonne). The dyke construction scenario yielded the highest overall cost of €2,254,800 (€7.05 per tonne).

SedEcon estimated the direct contribution to GDP of sea disposal to be €1,708,000 or €5.34 per tonne. Wetland nourishment yielded a direct contribution to GDP of €2,217,000 (€6.93 per tonne) with the dyke construction direct contribution estimated at € 6,492,000 (€20.29).

The differences in cost estimates between USAR and SedEcon are as a result of the different approaches of the two models. The direct cost approach applied in SedEcon sums up each element of the selected management option, e.g. filter layer, revetment, compaction etc. for dyke construction to yield a total direct cost. USAR is specialised to estimate the cost of a new material mix as opposed to the overall cost of the project (and thus may not necessarily reflect full project cost).

The USAR model assessed the physical properties of the dredge sediment as suitable for all three scenarios. The chemical characteristics of the sediment indicate some elevated levels of heavy metals. The sea disposal Lower Action Levels for Ireland were exceeded in two instances (Arsenic and Nickel), but this did not impact on the allowed sea disposal option. The presence of heavy metals might limit the use of the dredge sediment as wetland nourishment and a substantial physical, chemical and biological testing programme would require to determine feasibility. The dyke construction scenario is likely to accept use of marginally contaminated sediment as a fill material, however, some treatment might be necessary.

The BROADSEAT tool yielded positive impacts for dyke construction in the Waste, Environmental and Societal categories with negative impact in the Energy category. The wetland nourishment scenario yielded positive impacts in all four categories. The wetland nourishment scenario has the highest positive societal rating, while the dyke scenario has the highest positive impact in the environmental category. The dyke scenario has the lower energy category rating. The waste rating is slightly positive for both the wetland nourishment and dyke construction scenarios.

2.8 Conclusions and Recommendations

The tools/models were applied to a sediment management project and options at the Port of Fenit, Ireland. Three different scenarios were assessed; the nonbeneficial business as usual sea disposal of dredged sediment, dredged sediment beneficially used for wetland nourishment at a nearby site in Tralee Bay and dredged sediment beneficially used to construct a 3.7 km long flood protection dyke. The sediment chemical characteristics are compliant with the Irish Dumping at Sea limits [3]. However, the suitability of the dredged sediment for wetland nourishment might require further assessment due to the slightly elevated levels of heavy metals in the sediment samples tested. The dredged sediment might also require some form of treatment and/or use of binders to 'lock' the contaminants when used as a dyke construction material.

SedEcon estimated the direct contribution to GDP of the sea disposal management option at €5.34 per m^3 (which from a direct cost point of view is most viable), while the USAR model assessed the wetland nourishment as the most viable direct cost option with the cost of €2.2 per tonne. Both SedEcon and the USAR model estimated the dyke construction as having the highest direct cost and thus with the largest contribution to GDP and jobs created.

The BROADSEAT model assessed both beneficial use scenarios as having positive impact in the Waste, Environmental and Societal categories when compared to the business as usual scenario. The dyke construction scenario was assessed as having a negative impact in the Energy category, relative to the disposal at sea scenario.

The four integrated tools were applied to the Port of Fenit site and sediment management scenarios and this modelling approach allowed assessment of a range of sediment management options and their associated social, economic and environmental aspects. The detailed analyses undertaken allow comparison between the different potential contributions and impacts of the selected sediment management approaches. This modelling approach has the potential to inform upcoming dredging campaigns at the Port of Fenit.

More generally this is the first application of this integrated tools assessment approach for Ireland and it has significant potential to inform stakeholders and add value to sediment management project assessment for Ireland.

3 PORT OF CALAIS

3.1 INTRODUCTION

The Port of Calais is located in northern France and is the largest port for passenger traffic in France and the fourth largest national port (Figure 3-1). The infrastructure of the port was previously deemed insufficient with the volume of cross-channel freight tripling over the last 20 years. The Port of Calais has undertaken a major extension in what is considered the largest recent European port infrastructure project. The project was completed in 2021 and included generation of 4 million m^3 of dredged sediment, construction of a seawall more than 3 kms long (Figure 3-2), development of a 170-hectare basin, 65 hectares of new land and including 45 hectares reclaimed from the sea and three deep-water quays [9] [10].

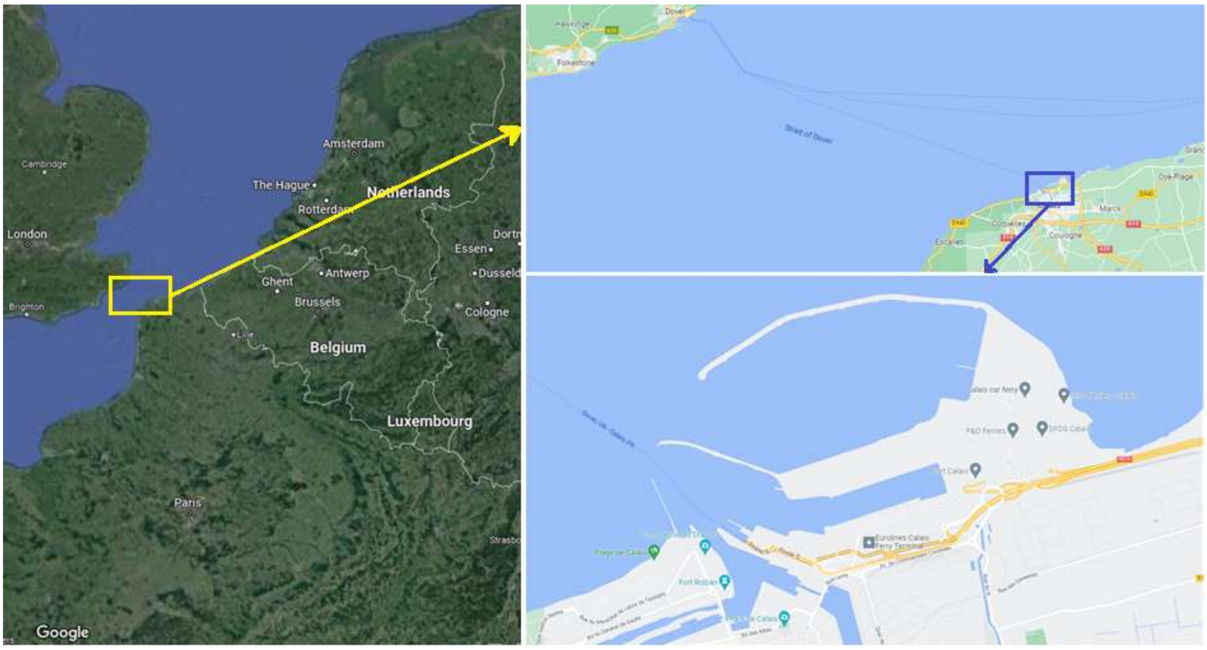


Figure 3-1: Location of the Port of Calais and Port Development Site

Figure 3-2: Breakwater construction at the Port of Calais

This large-scale project took six years to complete (2015 – 2021). Figure 3-3 presents satellite images of before and during the project work.

Figure 3-3: Port of Calais development status in 2015 and 2020

3.2 Sediment Management Applications Analysed

The SURICATES integrated tools have been applied to assess this overall project at the Port of Calais. This involves the construction of a breakwater and also land reclamation; both are beneficial reuse options (BRO). A number of assumptions for key parameters have been made to allow for tools application including the following:

- All dredged sediment (4 mil m^3) is reused
- The dredged sediment is sand/silt
- Breakwater structure parameters:
    - 3.2 km long
    - average height is 15m
    - crest width is 10 metres
    - rock armour thickness 1.5m
- Land reclamation of 45 ha (breakwaters included)
- Dredged sediment reused: 60% for land reclamation and 40% for breakwaters
- Rock import from Carrieres de Bouloinnais quarry 30 km away: volume of 170,000 m^3
- Dredging site coordinates: 50.964830 N, 1.849743 E
- Reuse site coordinates: 50.982216 N, 1.871756 E
- Dewatering method: natural
- Dredge sediment transport to the dewatering basin via pipeline: average distance 2.5 km
- Dredge sediment transport to the reuse site via road transport: average distance 2 km

3.3 Model 1 Application – RAIES

Interviews conducted with the Port of Calais stakeholders were used to generate QGIS map of minimal and maximal restraint for dredge sediment application (Figure 3-4). The interviewed stakeholders included Port of Calais managers and Haut de France Infrastructure manager.

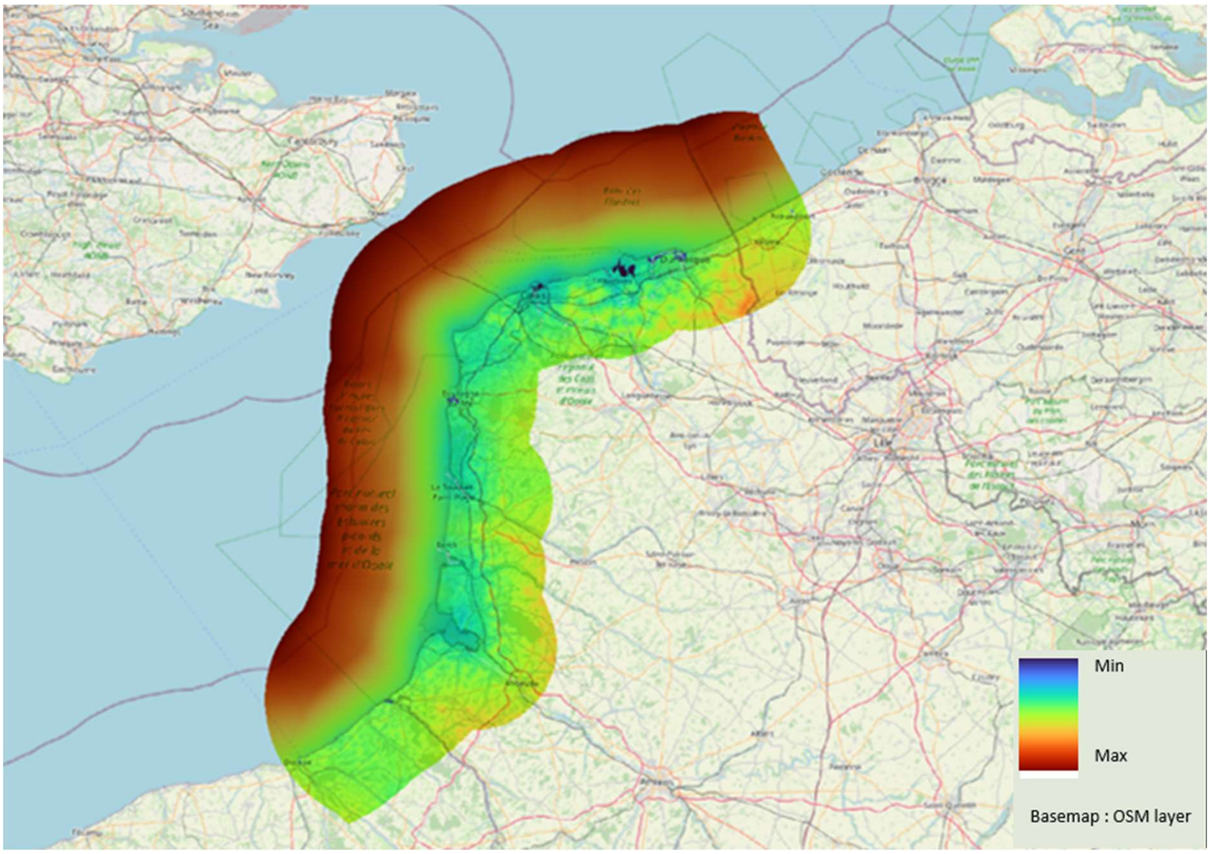


Figure 3-4: RAIES Model output – Port of Calais

Figure 3-4 graphically indicates the level of restraint for dredge sediment applications on a colour spectrum from dark blue (minimal restraint) to dark red (maximal restraint) for a coastal area of approximately 200 km long and 50km wide.

3.4 Model 2 Application – Direct Cost Optimisation Tool (USAR)

The USAR software was applied to the dyke construction and land reclamation project in the Port of Calais (Figure 3-5).

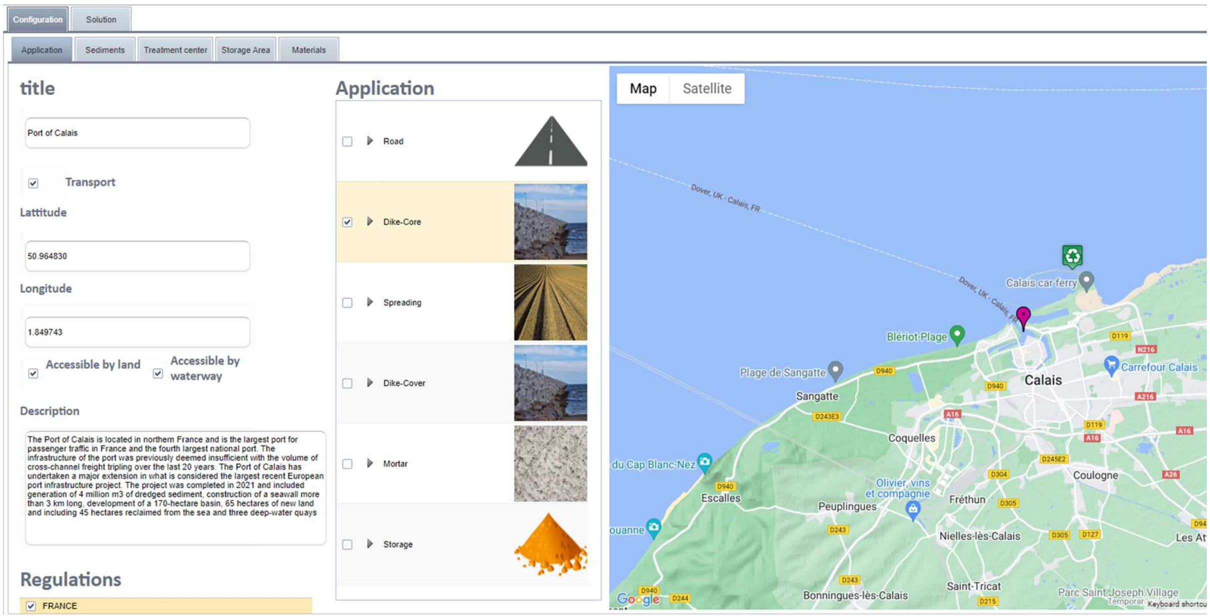


Figure 3-5: The USAR software application to the Port of Calais

The results from the USAR model are summarised in Table 3-1.

ITEM	BRO Land Reclamation	BRO Breakwaters Construction
Overall cost per tonne of new sediment (including transport)	€ 5.24	€ 9.2
Sediment chemical properties suitability for chosen application	Available chemical properties are suitable for land reclamation application	Available chemical properties are suitable for breakwaters construction application
Sediment physical properties suitability for chosen application	Available physical properties are suitable for land reclamation application	Available physical properties are suitable for breakwaters construction application

Table 3-1: USAR Model output table – Port of Calais

The USAR tool does not explicitly contain land reclamation and breakwaters applications, therefore similar applications in USAR were selected as a substitute. The land reclamation application was replaced by the dyke construction (core) application in USAR as dyke core material has similar physical and chemical requirements to land reclamation material. The breakwater application was replaced by dyke cover application as it can take into account of rock armour that is included in the design. These are approximations to the proposed sediment management scenarios but are similar.

The USAR tool estimated the direct cost of the land reclamation sediment management option to be €5.24 per tonne (€8.38/m^3) of the new material (dredged sediment which may/may not require mixing), including transport. Approximately 60% of the dredged sediment from the Port of Calais was reused in the land reclamation, amounting to a direct cost of € 20,121,600. The USAR tool assessed all the dredged sediment as suitable for the land reclamation application, based on its known physical and chemical properties.

The USAR tool estimated the cost of the breakwater sediment management option to be €9.2 per tonne (€14.72/m^3) of the new material/dredged sediment. This direct cost included for imported rock and its transport, and the transport of the used sediment. Approximately 60% of the dredged sediment from the Port of Calais was reused in the breakwaters construction at the cost of €23,552,000. The USAR tool recommended the breakwaters to be composed of 74% sediment and 26% rock for rock imported from Carrieres de Boulonnais based on the sediment physical characteristics (and which is similar to the actual construction). The chemical characteristics of the dredged sediment were assessed by USAR as suitable for breakwater application.

3.5 Model 3 Application – SedEcon

SedEcon was applied to the combined breakwater and land reclamation sediment management project (Figure 3-6). The results are summarised in Table 3-2.

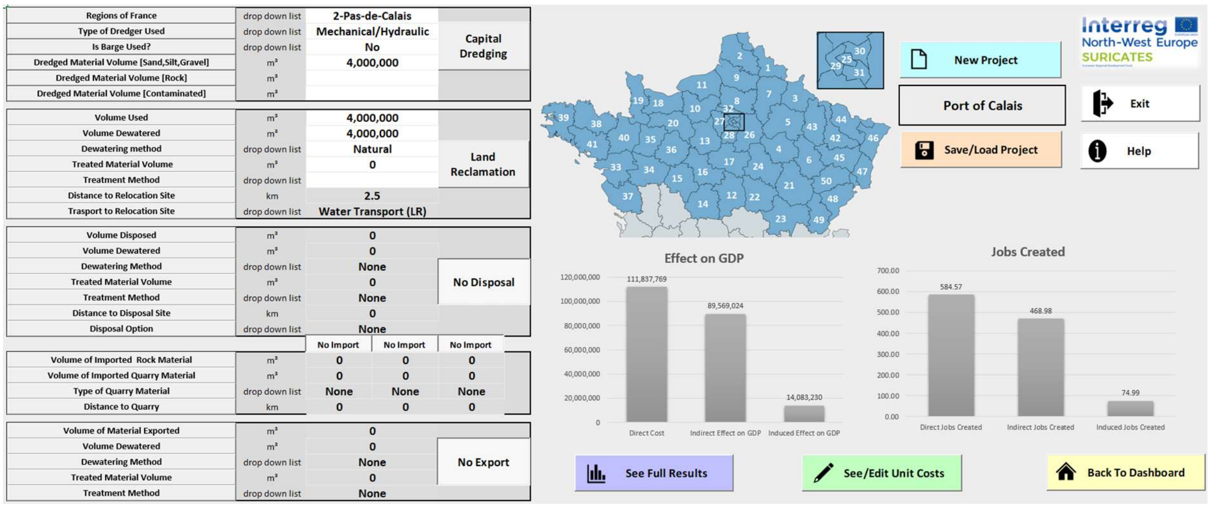


Figure 3-6: SedEcon results for the Port of Calais

ITEM	BRO – Land Reclamation & Breakwater Construction
Direct contribution to GDP	€ 111,800,000
Indirect contribution to GDP	€ 89,600,000
Induced contribution to GDP	€ 14,100,000
Direct jobs created	585 FTE
Indirect jobs created	469 FTE
Induced jobs created	75 FTE
Total cost per m^3	€ 27.95
Total cost per tonne	€ 17.2

Table 3-2: SedEcon output table -the Port of Calais

SedEcon estimated the direct contribution of the project to GDP to be €111,800,000 and the direct jobs created by the project at 585 full time equivalent jobs. The indirect and induced contributions to GDP were estimated to be €89,600,000 and €14,100,000 respectively. The project is estimated to create 469 fulltime equivalent indirect jobs and 75 fulltime equivalent induced jobs.

The indirect economic impact as a proportion of the direct economic impact is estimated to be approximately 80% for both GDP and jobs created. The induced economic impacts as a proportion of the direct impacts is estimated at approximately 16% for GDP and 13% for jobs created.

3.6 Model 4 Application – Environmental Model (BROADSEAT)

The BROADSEAT model [8] was applied with the results summarised in Table 3-3 and Figure 3-7. The reference case is assumed to be sea disposal.

ITEM	BRO - Land Reclamation & Breakwater Construction
Energy rating [-100:100]	20
Waste rating [-100:100]	32
Environment rating [-100:100]	64
Societal rating [-100:100]	68

Table 3-3: BROADSEAT output table – the Port of Calais

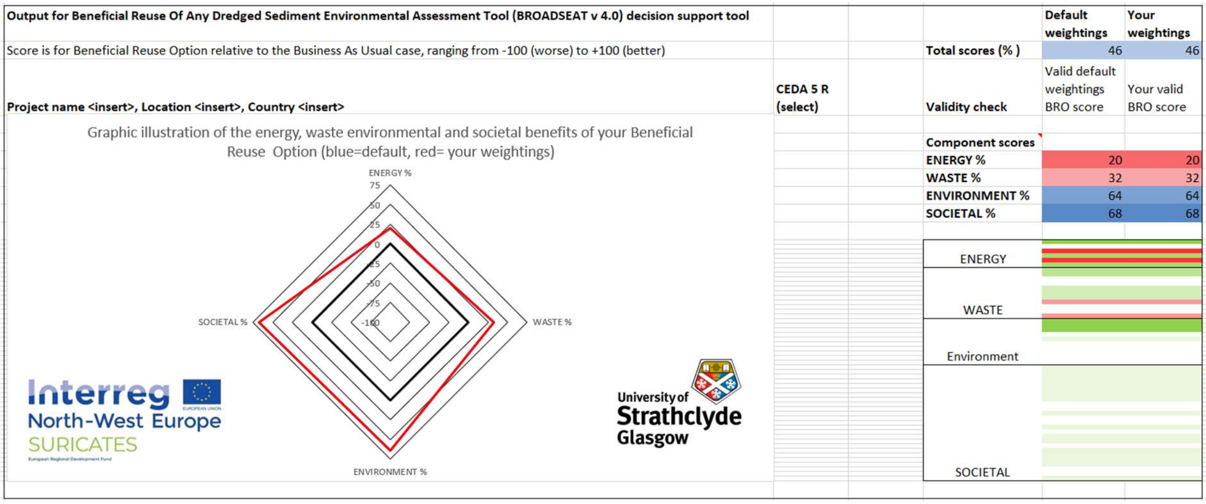


Figure 3-7: BROADSEAT output for the Port of Calais land reclamation & breakwater construction analysis

The BROADSEAT model assessed the land reclamation & breakwater construction scenario as positively contributing to all four categories with the highest ranking for the Societal category, followed by Environmental, Waste and Energy categories.

3.7 Analyses of Model Results

A summary of the results from all four models is presented in Table 3-4.

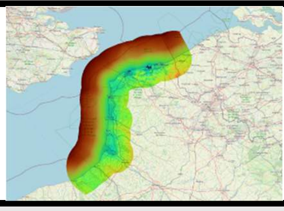
MODEL	ITEM	BRO Land Reclamation & Breakwater Construction	
RAIES	Suitability/Acceptability score		See Figure 3-4
USAR	Sediment chemical properties suitability for chosen application	✓	
	Sediment physical properties suitability for chosen application	✓	
	Overall cost per tonne of new material	€ 6.82	
	Overall cost	€ 43,673,600	
SedEcon	Direct contribution to GDP	€ 111,800,000	
	Indirect contribution to GDP	€ 89,600,000	
	Induced contribution to GDP	€ 14,100,000	
	Direct jobs created	585 FTE	
	Indirect jobs created	469 FTE	
	Induced jobs created	75 FTE	
	Total cost per m^3	€ 27.95	
	Total cost per tonne	€ 17.2	
BROADSEAT	Energy rating [-100:100]	20	
	Waste rating [-100:100]	32	
	Environment rating [-100:100]	64	
	Societal rating [-100:100]	68	

Table 3-4: Output summary table for the Port of Calais

The RAIES spatial decision support tool results show spatial constraints along and within a certain distance of the coastal area northeast and southwest of Calais. The areas of highest acceptability (minimum restraint) for sediment reuse applications are located within the large ports of Calais, Dunkirk and Boulogne-sur-Mer. Restraint for sediment applications has a correlation with the distance seaward from the coast with the highest restraint values occurring further away from the shoreline, at the boundary of the area of interest. Correlation of sediment applications restraints occurred also with the distance landwards with the lower restraint areas being near the inland boundary. This is based on the stakeholder interviews undertaken.

The USAR tool estimated the direct cost of the breakwater construction at €9.2 per tonne (€14.72 per m^3) and the direct cost of the land reclamation at €5.24 per tonne (€8.38 m^3). The overall direct cost of the sediment reuse application was estimated to be €43,673,600 or €6.82 per tonne. All the dredged sediment was deemed suitable for the application in terms of its physical and chemical properties. USAR recommended that the breakwaters be composed of 74% of sediment and 26% of rock imported from Carrieres de Boulonnais, based on the sediment physical characteristics.

SedEcon estimated of the direct contribution to GDP at €111,800,000 or €17.47 per tonne (€ 27.95/m^3) and estimated the creation of 585 full time equivalent jobs. The indirect economic impacts as a proportion of the direct impacts are approximately 80% for both GDP and jobs created. The induced economic impacts as a proportion of the direct impacts are approximately 16% for GDP and 13% for jobs created.

The BROADSEAT tool indicates that, for the Port of Calais project, positive results for all categories (with sea disposal as the reference scenario). The societal and environmental categories were rated most highly at 68 and 64 respectively. The waste and energy ratings were also positive but with lower values of 32 and 20 respectively.

3.8 Conclusions and Recommendations

The integrated tools were applied to a large scale project at the Port of Calais, France. The extension project for the Port of Calais included a breakwater more than 3 kms long, a 170-hectare basin, 65 hectares of platforms and roads, three new ferry berths, over 50 new buildings, roads, parking facilities and rail-road-sea infrastructure. The extension and modernisation of the Port of Calais involved a total direct cost of €863 million and created from 1,000 to over 2,000 jobs during its construction [10]. The cost of the dredging operation itself, the construction of the breakwater and the land reclamation costs are not known exactly.

The actual large-scale project undertaken at the Port of Calais was simplified significantly, for tools application purposes, to a beneficial use of sediment scenario consisting of land reclamation and breakwater construction. The volume of the dredged and reused sediment (4 mil. m^3), as well the dimensions of the breakwater and the reclaimed land area were all assumed.

The physical and chemical characteristics of the dredged sediment were assessed by the USAR tool as being suitable for the selected sediment management options. The cost of the new material for the breakwater construction and land reclamation was estimated to be €14.72 per m^3 and €8.38 m^3 respectively. The overall cost of the new material produced including dredging and transport was estimated by USAR at €43,673,600 or €6.82 per tonne (€10.91/m^3).

SedEcon estimated the direct contribution to GDP at €111,800,000, 13% of the actual overall cost of the project. However, this contribution only includes for the sediment management asepexts including dredging, breakwater construction and land reclamation; it does not take into account the construction of other port infrastructure and its modernisation. The indirect and induced contribution to GDP was estimated at €89,600,000 and €14,100,000 respectively. SedEcon estimated that the selected sediment management option generated 585 full time equivalent jobs, 469 indirect jobs and 75 induced full time equivalent jobs. The estimate of the actual number of jobs created by the entire project varies from 1,000 to over 2,000 [10] [9].

The BROADSEAT tool ranked the Port of Calais project positively with the highest score in environmental and societal rating, followed by waste and energy rating (all relative to a reference scenario of sea disposal.

The integrated tools have been applied to a large-scale development project at the Port of Calais; a very large scale project in an international context. The sediment management scenario analysed is based on the actual port development project. The detailed analyses undertaken allows assessment of the social, economic and environmental impacts of a large scale sediment management project. The integrated tools assessment presented here illustrates the potential applicability of such a suite of tools to large scale projects and its potential value to the relevant stakeholder community, in a French, North West Europe and broader geographic context.

4 PORT OF ROTTERDAM

4.1 INTRODUCTION

The Port of Rotterdam in the Netherlands (Figure 4-1) is the largest seaport in Europe and a key asset in the international maritime supply chain. The Port has a large annual dredging requirement to maintain navigable access and it invests heavily in sediment management. As part of the EU NWE SURICATES Project the Port led a large-scale pilot project involving the dredging and reallocation of approximately 500,000 m^3 of sediment (locations shown in Figure 4-1). The overall aim of this pilot study was to assess the efficacy of sediment reallocation to support formation of wetland areas to provide erosion protection of channel banks and to determine if such an approach could reduce the dredger sailing distance, thereby saving on CO_2 emissions.

Figure 4-1: Port of Rotterdam dredging & relocation locations

The sediment reallocation is considered as Beneficial Reuse Option (BRO). The Business as Usual (BAU) in the Port of Rotterdam context is sea disposal of the sediment in designated areas north-west of the Port of Rotterdam in the coastal channel (Figure 4-2). This option is also considered to be beneficial use of dredged sediment as the disposal locations are located in the areas that tidally supplies the coastal areas with sediment [11].

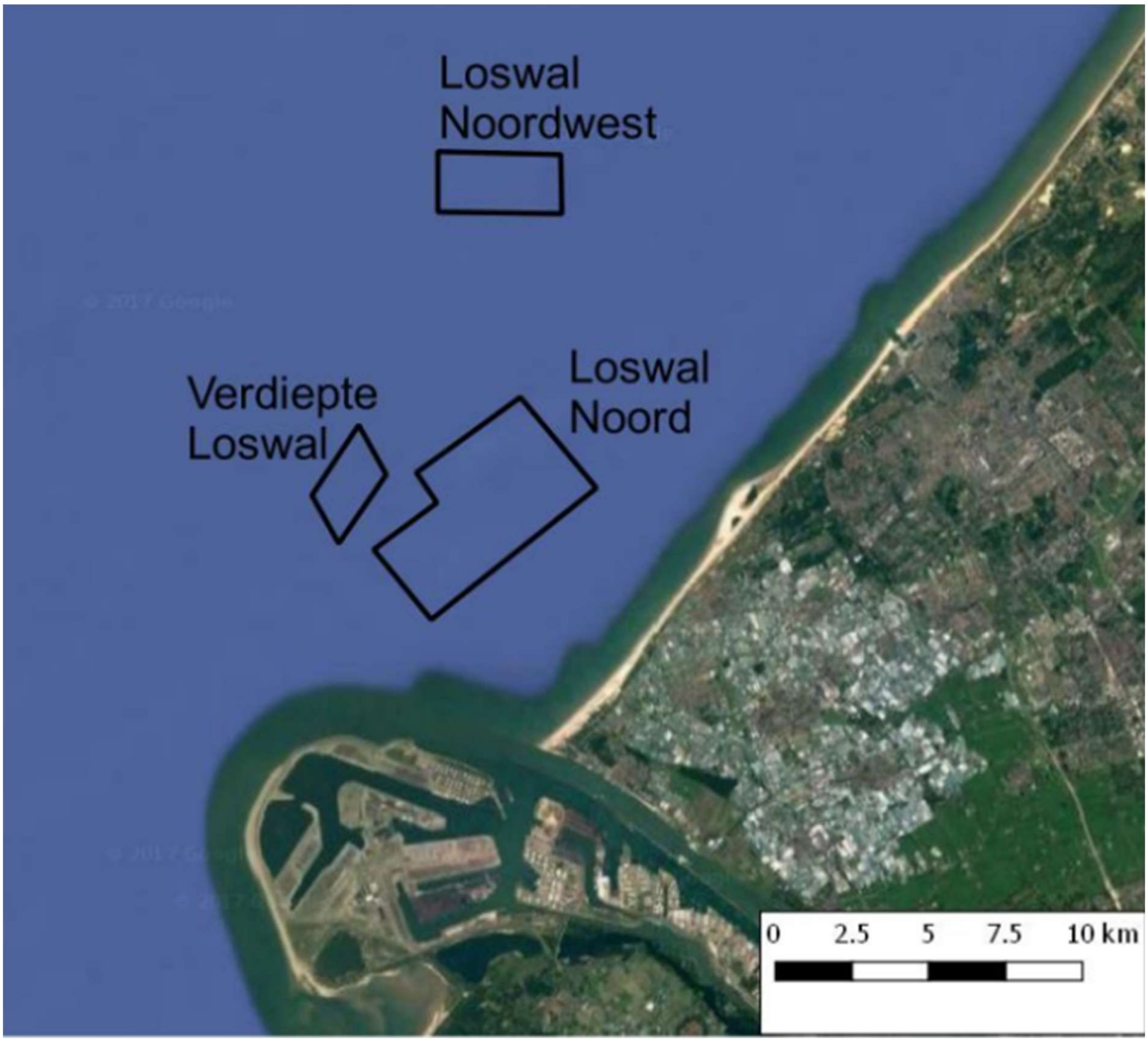


Figure 4-2: Three designated sea disposal areas for Port of Rotterdam dredged sediments

4.2 Sediment Management Applications Analysed

The integrated tools have been applied to the sediment reallocation (sediment cell maintenance) management option. The sediment was dredged by a hydraulic dredger *Ecodelta* with an in-built hopper from the inner berthing areas of the Port (freshwater) and then reallocated approximately 10km downstream within a tidally controlled Port waterway area via hopper through clam shell doors opening on the hull; Figure 4-1 shows the dredged and sediment reallocation areas. The reallocation site (Figure 4-3) was selected based on numerical modelling work undertaken to mimic the behaviour and transport of the dredged sediments; this modelling work indicated this location as a potential zone of sediment deposition.

Figure 4-3: Hydraulic dredger Ecodelta at the reallocation site

The cumulative particle size distribution curves for each sample location in the port (Figure 4-4) are presented in Figure 4-5. The sediment samples varied, two samples were composed of mostly sand (2 – 64 µm) followed by silt (> 64 µm) and a small clay (<2 µm) fraction. One sample was mostly silt followed by sand and clay.

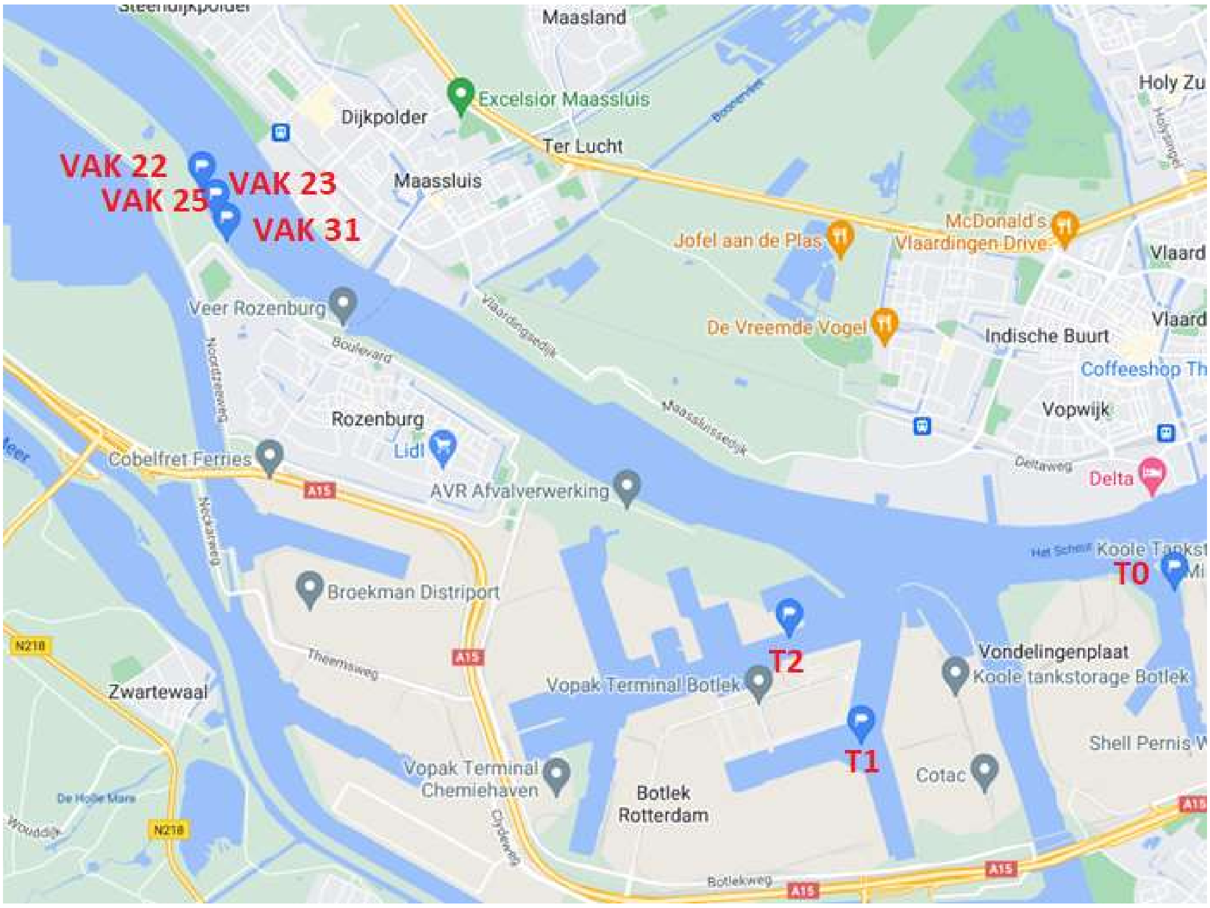


Figure 4-4: Sampling Locations Port of Rotterdam - dredging site & reallocation site

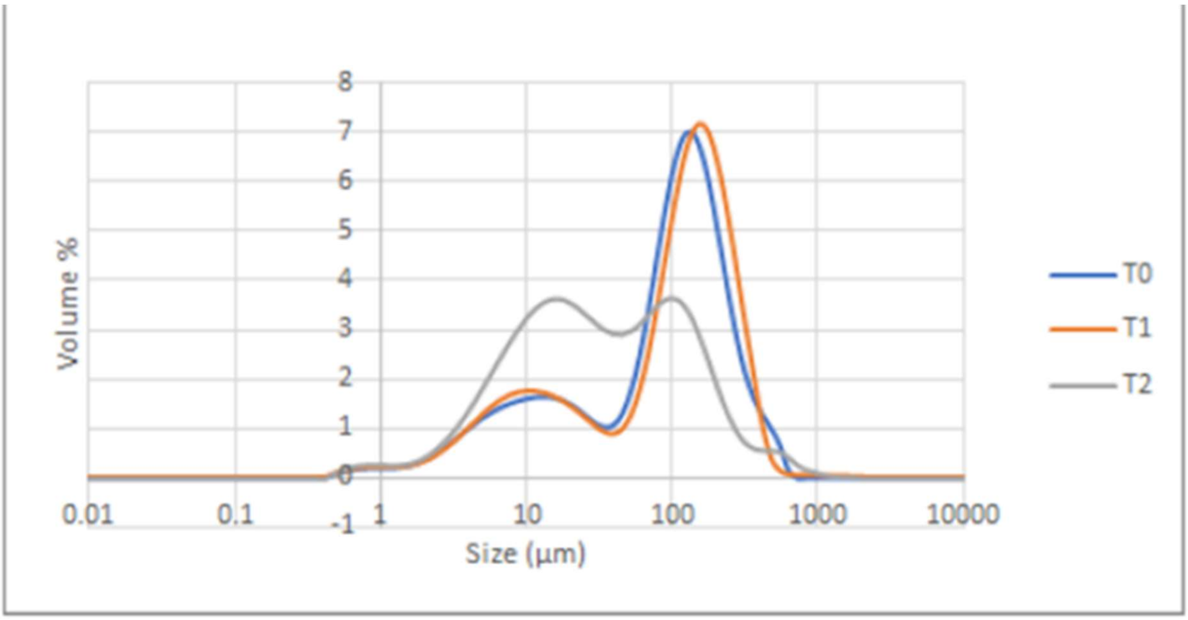


Figure 4-5: Continuous particle size distribution for the Port of Rotterdam samples – Inner Harbour

The cumulative particle size distribution curves for each sample location at the reallocation site are presented in Figure 4-6. The sediment samples were composed of mostly silt (2 – 64 µm) with some sand (> 64 µm) and a small clay (<2 µm) fraction.

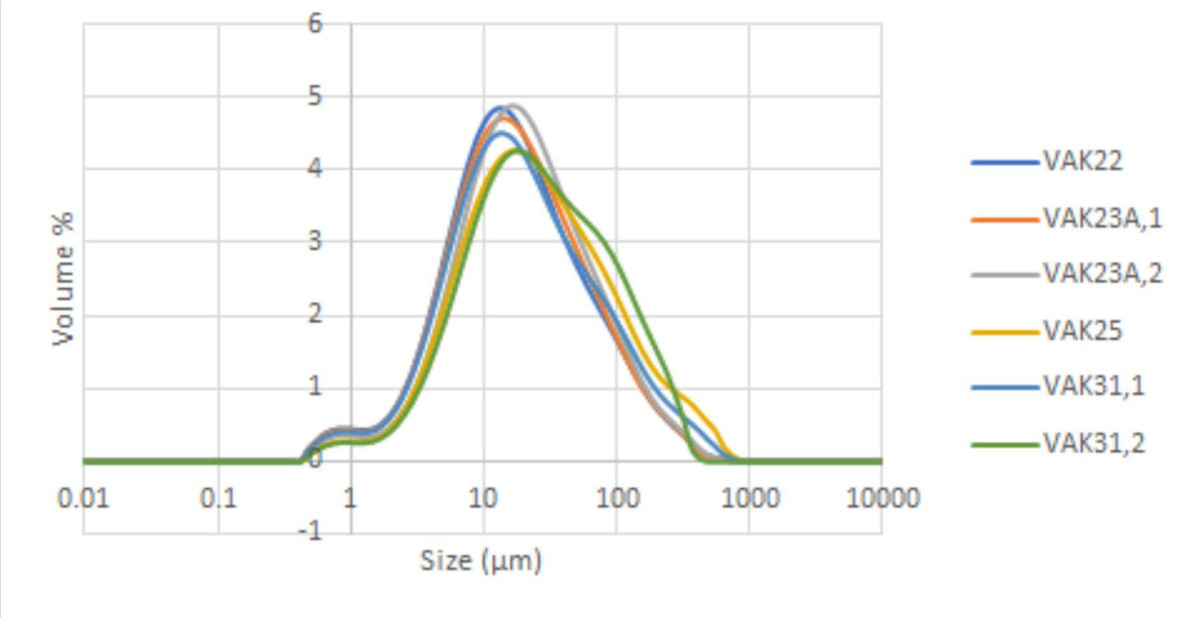


Figure 4-6: Continuous particle size distribution for the Port of Rotterdam samples – Reallocation Site

All dredged sediment is uncontaminated and meets the Dutch criteria for sea disposal [3].

Table 4-1 presents a summary of the model inputs for the sediment reallocation project for the Port of Rotterdam.

Item	Description
Dredging site coordinates	51.893403°, 4.415365°
Rellalocation site coordinates	51.923986°, 4.227223°
Dredger used	Hydraulic Dredger
Volume of dredged material	500,000 m^3
Transport	Water Transport (10 km)

Table 4-1: Basic characteristics of the Port of Rotterdam - model inputs

4.3 Model 1 Application – RAIES

An interview conducted with a Port of Rotterdam manager were used to generate a QGIS map of minimum and maximum restraint levels for dredge sediment applications (Figure 4-7).

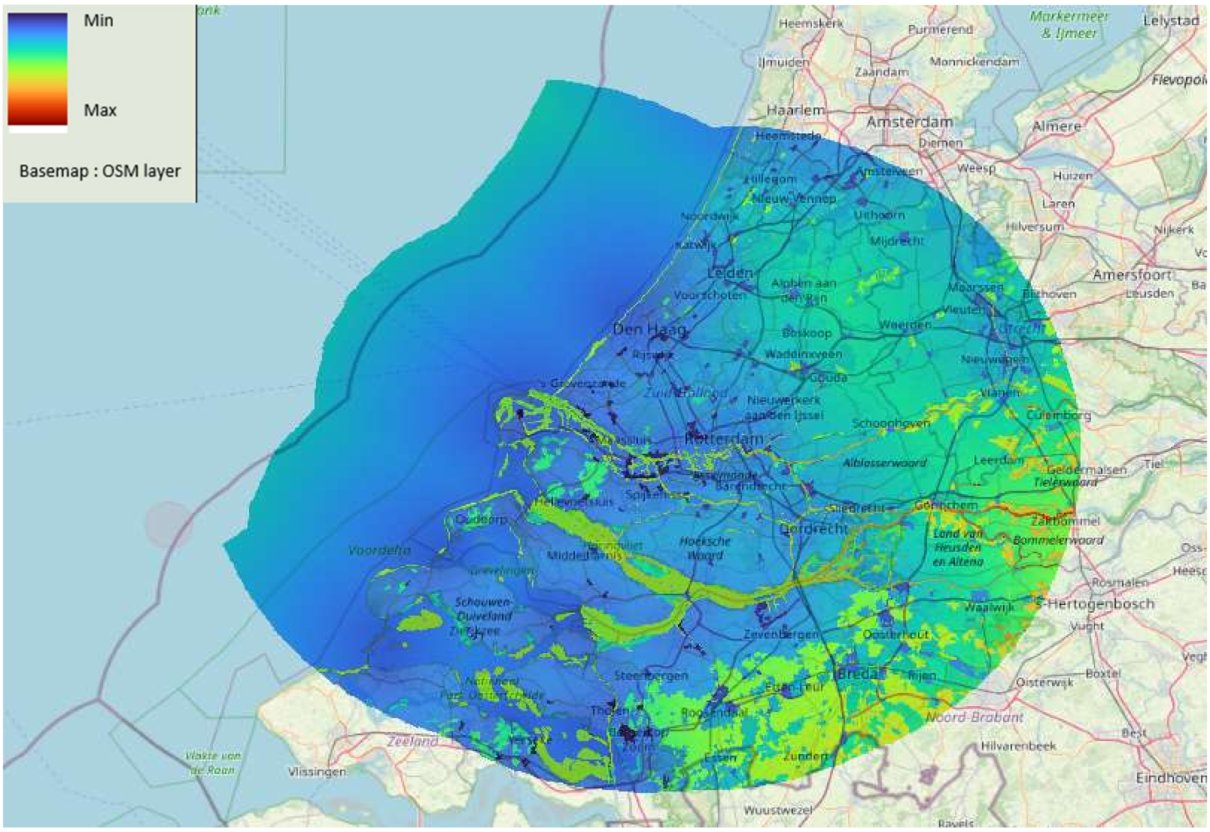


Figure 4-7: RAIES Model output – Port of Rotterdam

4.4 Model 2 Application – Direct Cost Optimisation Tool (USAR)

The USAR software was applied to the Port of Rotterdam reallocation sediment management option (Figure 4-8).

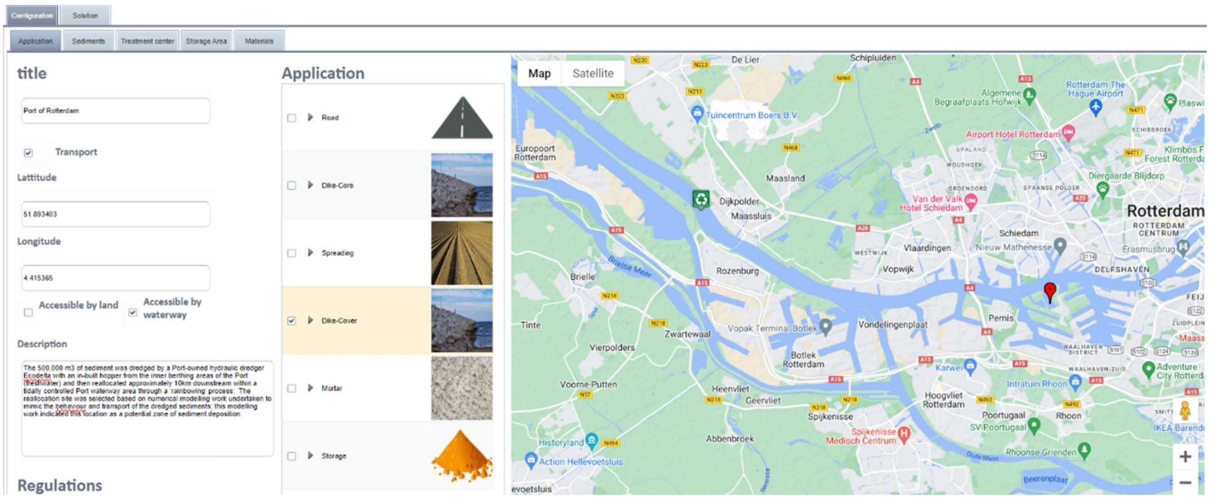


Figure 4-8:The USAR software application to the Port of Rotterdam

The results from the application of the USAR model are summarised in Table 4-2. The USAR model does not contain the option of applying the channel maintenance scenario; therefore, the physical and chemical properties of the dredged sediment were assessed for the dyke construction management option within USAR; this was found to be suitable for this particular application.

ITEM	BRO – Sediment Reallocation (Sediment Cell Maintenance)
Overall cost per tonne of new material (including transport)	Cost dredging + transport € 6.33
Sediment chemical properties suitability for chosen application	Dike cover application No formulation with other materials
Sediment physical properties suitability for chosen application	Dike construction cover application No formulation with other materials Inner harbour location T2 more suitable because of a higher silt content

Table 4-2: USAR Model output table – Port of Rotterdam

The USAR model estimated the direct cost of the channel maintenance scenario to be €6.33 per tonne (€10.13 per m^3) and that the sediment chemical and physical properties were suitable.

4.5 Model 3 Application – SedEcon

SedEcon was applied to the sediment management scenario (Figure 4-9) and the results are summarised in Table 4-3.

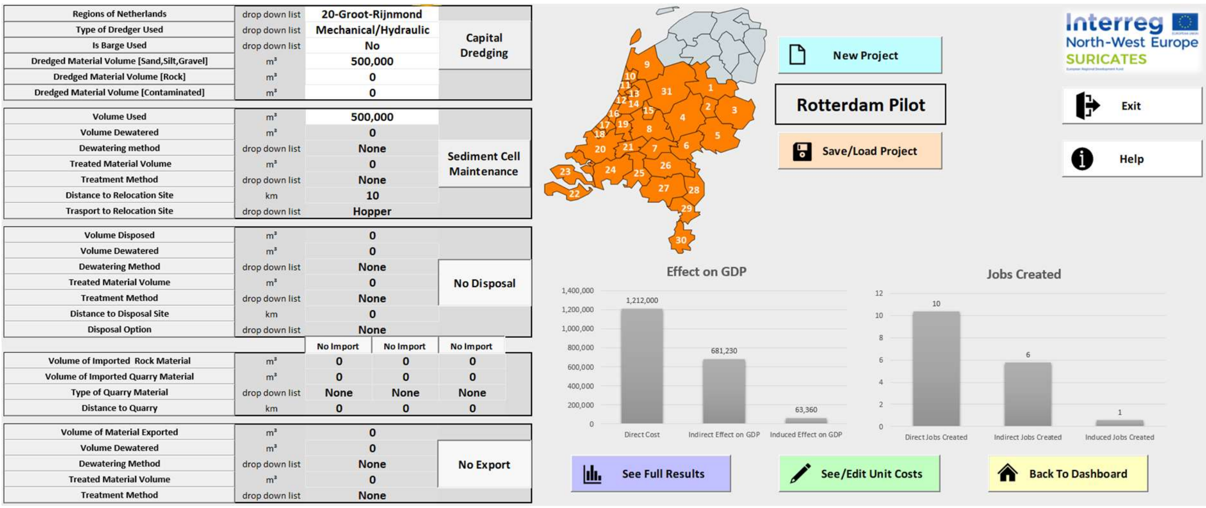


Figure 4-9: SedEcon results for the Port of Rotterdam Reallocation Project.

ITEM	BRO – Sediment Reallocation (Sediment Cell Maintenance)
Direct contribution to GDP	€ 1,212,000
Indirect contribution to GDP	€ 675,300
Induced contribution to GDP	€ 61,700
Direct jobs created	10.22 FTE
Indirect jobs created	6.41 FTE
Induced jobs created	1.44 FTE
Total cost per m^3	€ 2.42
Total cost per tonne	€ 1.51

Table 4-3: SedEcon output summary table – Port of Rotterdam

SedEcon estimated the direct contribution to GDP to be approximately €1,212,000 which is approximately 21% greater than the actual direct project cost expenditure for the Port. SedEcon estimated that 10.22 full time equivalent direct jobs would be created which is approximately 14% greater than the actual direct jobs created by the project. The indirect and induced contribution to GDP were estimated by SedEcon to be €675,300 and €61,700 respectively. SedEcon estimated that 6.41 fulltime equivalent indirect jobs and 1.44 fulltime equivalent induced jobs would be created.

SedEcon indicates that the indirect economic impact as a proportion of the direct impacts is 57% for GDP and 63% for jobs created with the induced economic impact estimated to be approximately 9% for GDP and 14% for jobs created (relative to the direct impacts).

4.6 Model 4 Application – Environmental Model (BROADSEAT)

The BROADSEAT model [8] was applied to the project with the results summarised in Table 4-4 and Figure 4-7.

ITEM	BRO – Sediment Reallocation (Sediment Cell Maintenance)
Energy rating [-100:100]	86
Waste rating [-100:100]	24
Environment rating [-100:100]	75
Societal rating [-100:100]	44

Table 4-4: BORADSEAT output summary table – Port of Rotterdam Reallocation Project

The BROADSEAT model assessed the sediment cell maintenance scenario as positively contributing to all four categories with the highest ranking for the Energy category, followed by Environmental, Societal and Waste categories (relative to the disposal at sea reference case).

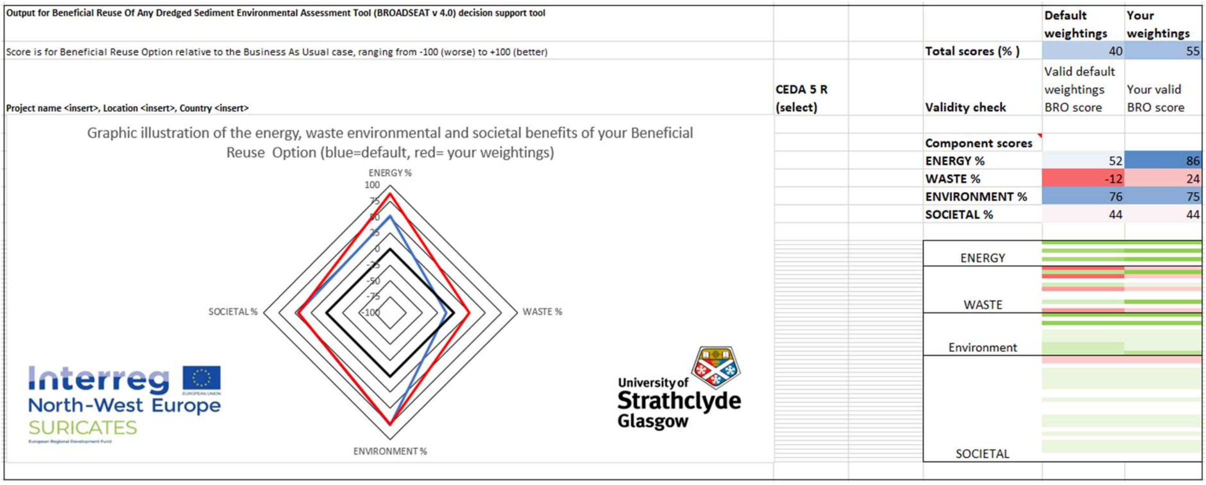


Figure 4-10: BROADSEAT output for sediment cell maintenance – Port of Rotterdam

4.7 Analyses of Model Results

A summary of the results from all four models/tools is presented in Table 4-5.

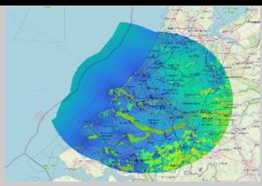
MODEL	ITEM	BRO – Sediment Reallocation (Sediment Cell Maintenance)
RAIES	Suitability/Acceptability score	 See Figure 4-7
SedEcon	Direct contribution to GDP	€ 1,212,000
	Indirect contribution to GDP	€ 675,300
	Induced contribution to GDP	€ 61,700
	Direct jobs created	10.22 FTE
	Indirect jobs created	6.41 FTE
	Induced jobs created	1.44 FTE
	Total cost per m^3	€ 2.42
	Total cost per tonne	€ 1.51
USAR	Sediment chemical properties suitability for chosen application (Dyke construction)	Suitable
	Sediment physical properties suitability for chosen application (Dyke construction)	Suitable
	Overall cost per tonne of new material	€6.33
	Transport cost per tonne of new material	€1.33
BROADSEAT	Energy rating [-100:100]	86
	Waste rating [-100:100]	24
	Environment rating [-100:100]	75
	Societal rating [-100:100]	44

Table 4-5: Output summary table - the Port of Rotterdam

The models were applied to this large scale pilot project in the Port of Rotterdam. The project involved reallocating 500,000 m^3 of dredged sediment, a process known as sediment cell maintenance.

The RAIES model shows a relatively high acceptance level of the sediment applications across the area with a 50 km diameter around the dredging location. Model output shows increased restraint towards inland areas and higher restraint within water bodies. This is based on the specific stakeholder interview undertaken.

The USAR model estimated the direct cost of the project to be €6.3 per tonne (€10.13 per m^3) divided into €5 per tonne of dredged material and €1.33 per tonne of material transported. Both the physical and chemical properties of the sediment are deemed suitable for dyke construction (which is the substitute application in the USAR tool for sediment cell maintenance).

SedEcon estimated the direct contribution to GDP at €1,212,000 or €2.42 per m^3 while estimating the creation of 10.22 full time equivalent jobs; these estimates are higher than the actual project cost and jobs created values. It is likely that the use of the Port's own dredger and staff influences the lower cost and jobs created relative to the estimates from SedEcon. SedEcon indicates that the indirect economic impact as a proportion of the direct impacts is 57% for GDP and 63% for jobs created with the induced economic impact estimated to be approximately 9% for GDP and 14% for jobs created (relative to the direct impacts). Again the real values may be lower based on the direct contribution values found from the actual project data.

As previously noted the difference in estimates using SedEcon and the USAR model may be explained by the different approach taken. The USAR model generated costs including the cost of dredging, transport and the new material mix. The new material is the sediment based material mixed with an additional material if required optimised for use in the selected application. SedEcon includes dredging and transport and other elements of the selected management option such as modelling and the placement by 'rainbowing'.

The BROADSEAT model indicates that the selected sediment management option provides strongly positive results for the Energy and Environment categories and also positively for the Waste and Societal categories (relative to the reference disposal at sea scenario).

4.8 Conclusions and Recommendations

The models were applied to a large scale sediment cell maintenance project in the Port of Rotterdam where 500,000 m^3 sediment was reallocated to support formation of wetland areas potentially providing erosion protection for channel banks.

The dredge sediment's physical and chemical characteristics were assessed by the USAR tool as suitable for the selected sediment management option. The USAR model estimated the direct cost of the sediment reallocation project in the Port of Rotterdam at €6.33 per tonne.

SedEcon estimated the direct contribution to GDP at €1,212,000, which is 21% higher than the actual cost of the project. The direct jobs created by the project were estimated by SedEcon to be 10.22 full time equivalent jobs.

The BROADSEAT model ranked the sediment reallocation project positively in all four categories with the highest ranking for the Energy category, followed by the Environmental, Societal and Waste categories.

The integrated tools were applied to this large scale sediment reallocation (sediment cell maintenance) project at the Port of Rotterdam, The Netherlands. The integrated tools application to a real SURICATES pilot project in the Netherlands highlights its positive economic, social and environmental impacts. The tools have the potential to facilitate and inform stakeholders across the sector and can be applied to ports and sites that are practicing sediment reallocation approach. The integrated tools may also be applied at a regional level across the Netherlands to support the sediment management decision making process.

5. Falkirk Site

5.1 Introduction

The SURICATES pilot project involved mechanically dredging approximately 533m^3 of uncontaminated sediment from a canal at Falkirk, Scotland, in July 2019. Sediment was dredged using a floating excavator and loaded onto barges and transported to an offloading point approximately 1.8 km distance where a long reach excavator transferred the sediment into a haulage contractor's tipper lorries which was then transported to the placement site approximately 38 km distant (Figure 5-1).

Figure 5-1: Dredging and placement location

5.2 Sediment Management Application Analysed

The dredged sediment was applied to a bio-engineering pilot scheme. The dredge sediment was dewatered naturally via a water drain into the ground with overflow into a nearby rubble drain. The deposition site was then treated by planting with reed canary grass, commonly named phytoconditioning (Figure 5-2).

Figure 5-2: Falkirk site - dredged sediment placement

The basic characteristics of the project that will form the input parameters for the models are presented in Table 5-1.

Item	Description
Dredging site coordinates	55.970176°, -3.611357°
Placement site coordinates	55.995434°, -3.839049°
Dredger used	Mechanical
Volume of dredged material	533 m^3
Dewatering method	Natural
Treatment method	Phytoconditioning
Transport	Water transport (1.8 km) + Road transport (38km)
Direct cost	€ 56,000
Jobs created	0.67 FTE

Table 5-1: Basic characteristics of the Falkirk dredging project – model inputs

5.3 Model 1 Application – RAIES

Interviews conducted with the Scottish Canals stakeholders were used to generate QGIS map of minimal and maximal restraint for dredge sediment applications (Figure 5-3). The stakeholder interviewed was Paul Berry, Scottish Canals manager.

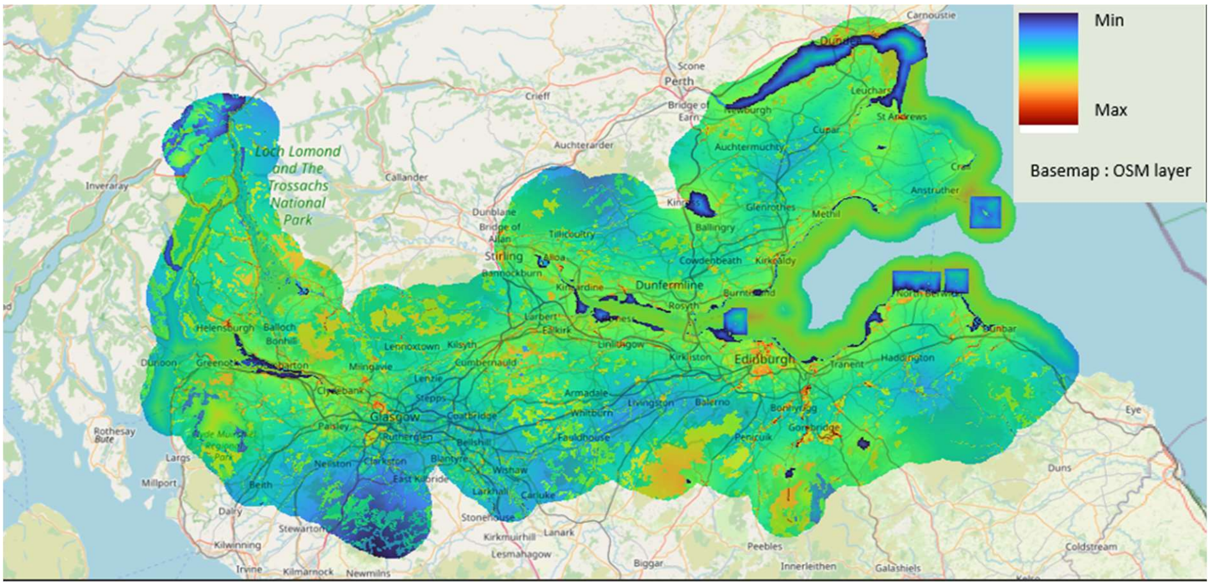


Figure 5-3: RAIES model output – Falkirk site

5.4 Model 2 Application – Direct Cost Optimisation Tool (USAR)

The input data for USAR included the average particle size distribution of the dredged material (Figure 5-4), the chemical characteristics (Table 5-2), transport cost per tonne per kilometre and the cost per tonne of dredged seidment. The cost per tonne of dredged material needs to be estimated based on the average cost of dredging, dewatering, dredger mobilisation etc. The cost was estimated to be €50 per tonne with refinement undertaken by SedEconling work presented in the next section.

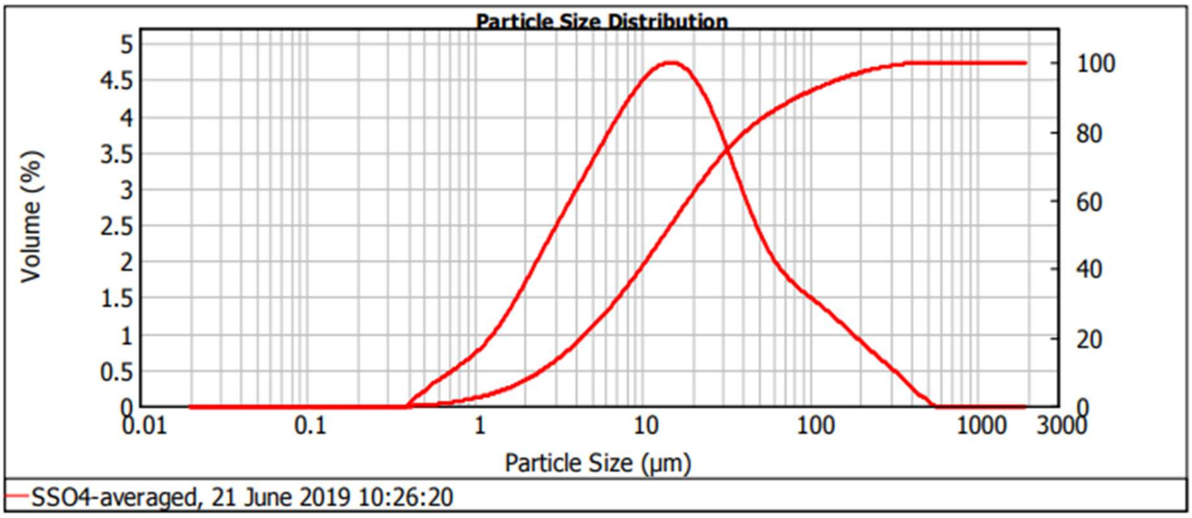


Figure 5-4: Average particle size distribution in 5 Falkirk site samples

Contaminant						Average	Unit
Arsenic	12	6	11	<1	6	8.75	mg/kg
Barium	165	175	181	82	123	145.2	mg/kg
Boron	3.7	3.6	2.4	<1.0	1.6	2.825	mg/kg
Cadmium	1.1	1.1	1	0.6	0.7	0.9	mg/kg
Copper	71	52	80	19	37	51.8	mg/kg
Chromium	50	47	48	30	35	42	mg/kg
Chromium	<1	<1	<1	<1	<1	<1	mg/kg
Chromium	50	47	48	30	35	42	mg/kg
Lead	136	97	94	20	50	79.4	mg/kg
Mercury	1.69	1.03	1	<0.17	0.58	1.075	mg/kg
Nickel	89	76	81	37	55	67.6	mg/kg
Zinc	308	249	237	71	151	203.2	mg/kg
Total PAH-16	5.54	2.89	1.85	0.25	1.71	2.448	mg/kg

Table 5-2: Heavy metals and PAH contaminants in 5 Falkirk site samples

Figure 5-5 presents the USAR software application for the Falkirk site.

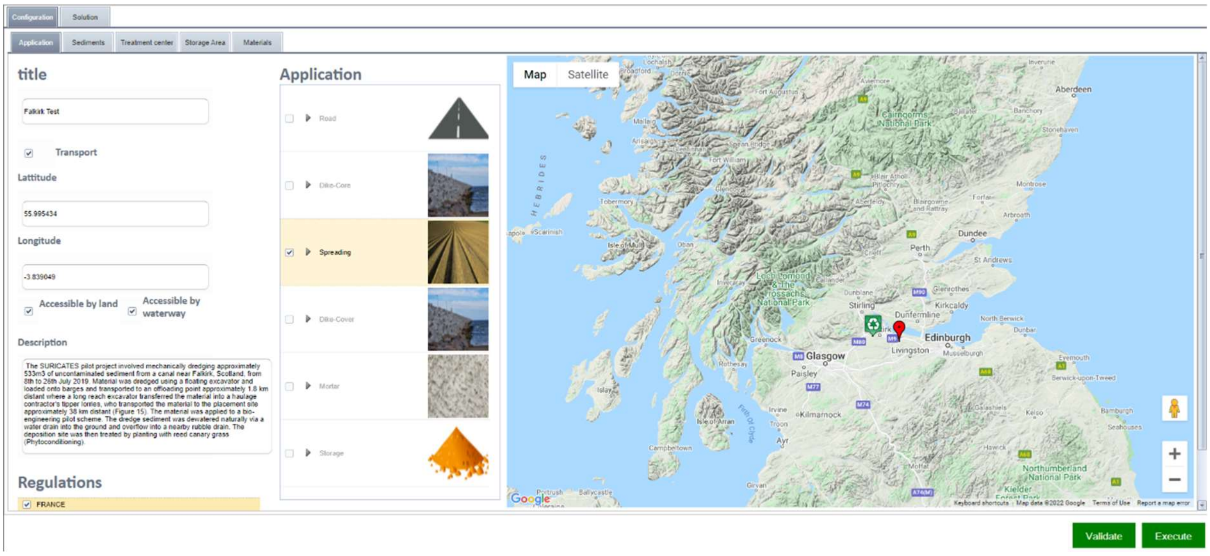


Figure 5-5: USAR application to Falkirk

Figure 5-6 present the USAR results showing the cost per tonne of new material. All observed contaminants were below the threshold limits for the agricultural application. The USAR model confirmed that the material dredged from the canal near Falkirk is suitable for this particular application. The overall cost per tonne of dredged sediment was estimated to be €59.24., divided into an estimated €50 per tonne of sediment plus €9.24 per tonne of sediment transported.

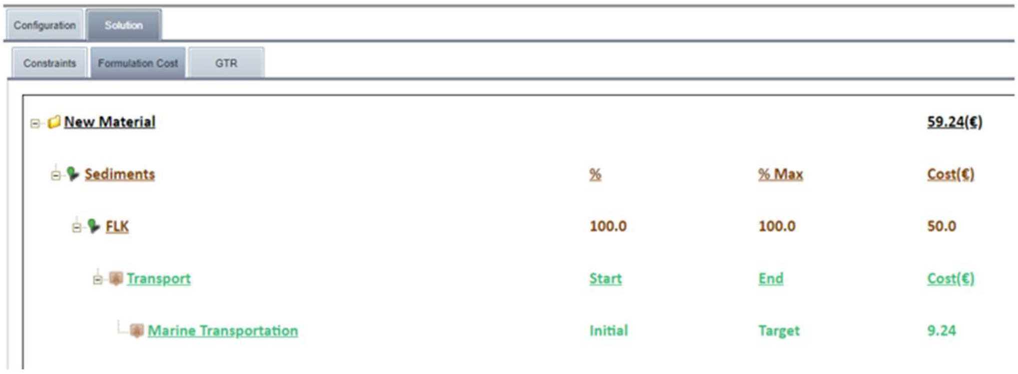


Figure 5-6: USAR application to Falkirk – economic results

ITEM	Value
Overall cost per tonne of new material (including transport)	€ 59.24
Cost of transport per tonne	€ 9.24
Overall cost per tonne of new material (excluding transport)	€ 56
Sediment chemical properties suitability for chosen application	✓
Sediment physical properties suitability for chosen application	✓

Table 5-3: USAR results summary table

5.5 Model 3 Application – SedEcon

SedEcon was applied to the project (Table 5-1) (Figure 5-7) with model outputs presented in Table 5-4.

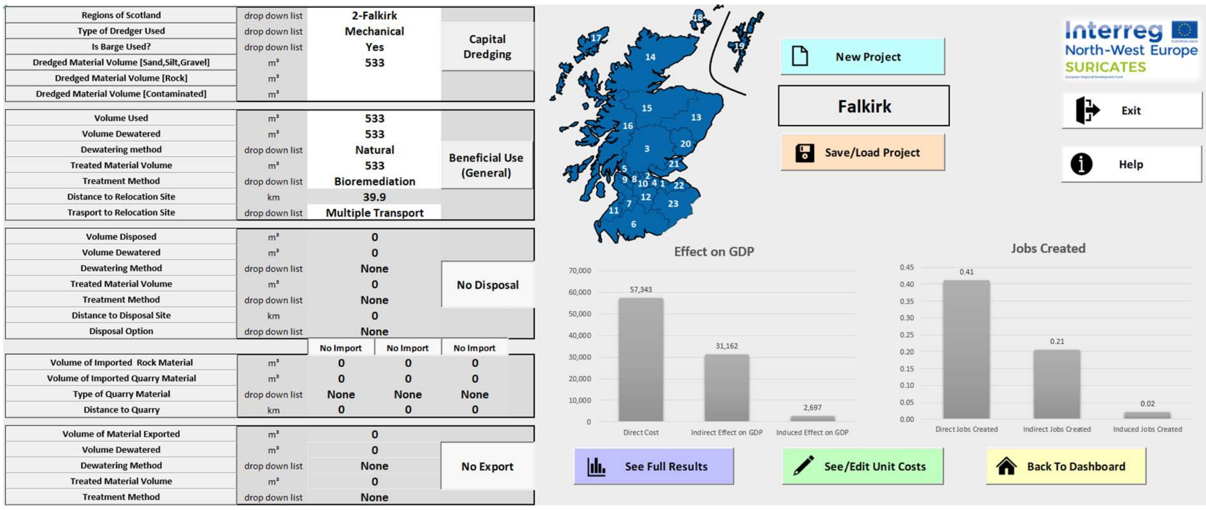


Figure 5-7: SedEcon output

ITEM	Value
Direct cost	€ 57,343
Indirect cost	€ 31,162
Induced cost	€ 2,697
Direct jobs created	0.41 FTE
Indirect jobs created	0.21 FTE
Induced jobs created	0.02 FTE
Cost per m^3 (excluding transport)	€ 89
Total cost per m^3	€ 107
Cost per tonne (excluding transport)	€ 56
Total cost per tonne	€ 67

Table 5-4: SedEcon output summary table

The results from SedEcon were satisfactory; the estimated direct contribution to GDP of €57,343 is within 3% of the actual cost of the project, however the number of direct jobs created was underestimated by approximately 38% but this is in the context of a small scale project.

The project indirect contribution to GDP was estimated at 54% of the direct contribution and the induced effect on GDP was estimated to be 4.7% of the direct contribution. The overall cost per tonne of dredged material was estimated to be €107 (€89 excluding transport). The project's direct effect on employment is estimated to be 0.41 full time equivalent jobs with the indirect and induced jobs to be at approximately 51% and 4.8% of the direct jobs respectively.

5.6 Model 4 Application – Environmental Model (BROADSEAT)

The BROADSEAT mode was applied and the various parameters and characteristics of the Falkirk project were assessed. BROADSEAT contains 48 questions in four categories; Energy, Waste, Environment and Societal. Thirty-eight questions were applicable to the project with ten questions deemed as not relevant [8].

The results of the model application are summarised in Figure 5-8 and Table 5-5. The Falkirk project has positive energy and waste ratings, with slightly negative values in the environment and societal ratings. The application of BROADSEAT to the Falkirk site was undertaken by the University of Strathclyde. The phytoconditioning BRO option was compared to the BAU scenario, which in this case was landfill disposal.

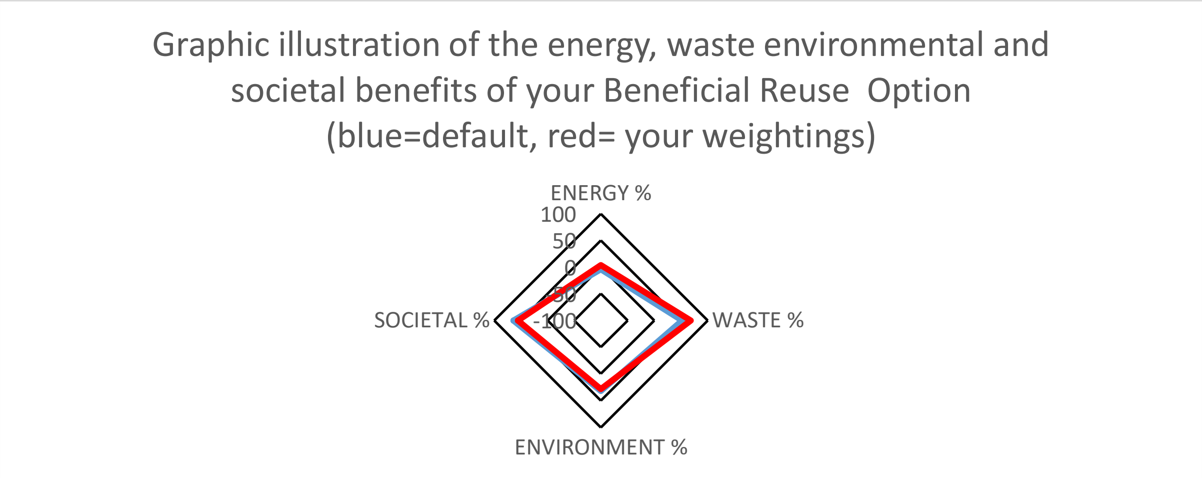


Figure 5-8: BROADSEAT output – Falkirk site

ITEM	BRO Rating [-100:100] Phytoconditioning
Energy	+4
Waste	+68
Environment	+28
Societal	+56

Table 5-5: BROADSEAT output summary – Falkirk site (BAU – business as usual, BRO – beneficial reuse option)

5.7 Analyses of Model Results

A summary of the results from all four models for application to the Falkirk site is presented in Table 5-6.

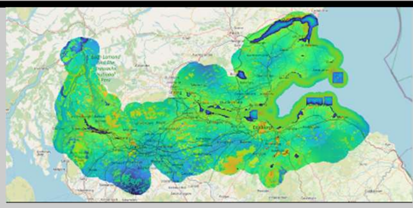
MODEL	ITEM	VALUE
GIS	Suitability/Acceptability score	 See Figure 5-3
SedEcon	Direct cost	€ 57,343
	Indirect cost	€ 31, 162
	Induced cost	€ 2,697
	Direct jobs created	0.41 FTE
	Indirect jobs created	0.21 FTE
	Induced jobs created	0.02 FTE
	Overall cost per tonne of new material (including transport)	€ 67
	Transport cost per tonne of new material	€ 11
USAR	Sediment chemical properties suitability for chosen application	✓
	Sediment physical properties suitability for chosen application	✓
	Overall cost per tonne of new material	€ 59.24
	Transport cost per tonne of new material	€ 9.24
BROADSEAT	Energy rating [-100:100]	+4
	Waste rating [-100:100]	+68
	Environment rating [-100:100]	+28
	Societal rating [-100:100]	+56

Table 5-6: Output summary table - Falkirk site

The RAIES model results show a wide range of levels of restraint spanning from the east coast to the west coast of Scotland. Generally, higher restraint levels for sediment applications are found offshore and in the inland areas of water bodies and forests. This is based on one stakeholder interview.

The USAR model estimated the overall cost of the material used to €59.24 per tonne. This cost can be divided into €50 per tonne of dredged sediment plus €9.24 per tonne of sediment transported.

SedEcon refined the overall cost per tonne to €67, divided into €56 per tonne of dredged sediment and €11 per tonne of sediment transported.

The differences between SedEcon and USAR transport unit cost estimates is partly linked to the approach to the transport distance. USAR's algorithms generate the distance between the dredging site and the reuse site automatically, based on the shortest possible land and/or water distance.

SedEcon estimated the direct contribution to GDP at €57,300, similar to the actual direct cost of €56,000. The estimated jobs created was lower than the actual 0.67 FTE jobs created by Falkirk project, likely due to the very small scale of the project.

The BROADSEAT results show positive impacts of the Falkirk project when compared to the business as usual scenario in the Energy and Waste categories with slightly negative impacts in the Environment and Societal categories.

5.8 Conclusions and Recommendations

An initial application of the tools/models to the Falkirk site shows that the Tools Application concept is achievable. The sequence in which the models are applied appears to be appropriate. A necessity of estimating the overall cost of dredging at the beginning of the Model 2 (USAR) application might appear inconvenient; however, the primary objective of USAR is suitability assessment of the physical and chemical properties of sediment. This overall cost is then re-calculated by SedEcon.

A larger scale project is needed to assess more complex scenarios that would include, for example, sediment treatment.

The application of the models to a small-scale project in Falkirk confirmed that the selected phytoconditioning application is suitable for the sediment dredged from the canal near Falkirk. The estimated overall cost/direct contribution to GDP from SedEcon is in agreement with the actual cost of the project. The BROADSEAT model indicates that the Falkirk project has positive energy and waste ratings, with slightly negative environment and societal ratings relative to the land disposal BAU option.

An economic comparison of beneficial (re)use scenario (BRO) and business as usual (BAU) scenarios was not undertaken in this case.

6 Conclusions and Recommendations

Four integrated tools (RAIES, USAR, SedEcon and BROADSEAT) have been developed to support the decision-making process. The tools have been applied to analyse the impacts of a range of different sediment management projects and techniques at a number of SURICATES pilot sites and ports. The results of the detailed analyses presented in this report are based on the following sediment management projects and techniques applied across the SURICATES Partner Countries: wetland nourishment, dyke construction, land reclamation, bioremediation, breakwater construction, sediment cell maintenance and sea disposal. The projects analysed ranged from small scale (500 m^3) to large scale (4 mil. m^3) and included pilot sites in Falkirk, Scotland and Port of Rotterdam, the Netherlands, an ongoing dredging campaign in the Port of Fenit, Ireland and the Port of Calais expansion project in France [12]. A summary table for the tools application to pilot sites and ports is presented in Table A 1 of Appendix.

The RAIES GIS tool identified the best locations available for sediment reuse applications across the partner countries based on inputs from a range of different stakeholders. The stakeholders' inputs were in the form of interviews that were undertaken in each country. The interviews were designed in a way that allows to adjust the length of the interviews by focusing on the most relevant parameters. The RAIES tool generated the cartographic results parametrised by the stakeholders for each of the selected project sites. The results are in a form of comprehensive maps showing a colour gradient of spatial constraint values.

The USAR optimisation tool was successfully applied to all selected sediment management options. The USAR's optimisation tool, based on user's inputs, performed satisfactorily. The type of inputs used for each of the applications varied slightly for each of the applications and ranged from basic sediment parameters to a complex sediment characteristics including detailed chemical and physical analysis. The USAR tool outputs, depending on inputs, included the formulations of the new material, its cost, transport cost and environmental constrains. The USAR tool had the ability to substitute the sediment management options that are not included in USAR with the alternative solutions.

An economic analysis was undertaken for sediment management projects using the SedEcon model. A new approach included downscaled regional economic model to analyse the wider economic impacts in terms of direct, indirect and induced contribution to GDP and jobs created. The scenarios included in the model were applicable to the selected management options and adequately covered complex aspects involved in them. The results were satisfactorily compared to the actual costs and jobs created where applicable.

The environmental merits of the four dredging project were successfully analysed using the BROADSEAT Model. A qualitative assessment of whether the selected management options are better/the same/worse than business as usual scenario included answering project related questions divided over 10 categories, arranged into four main groups; energy, waste, societal and environmental. The results are scores in each of the category for all sediment management options assessed.

The detailed analyses undertaken allow an overview of the different potential impacts of specific sediment management approaches in a site-specific context and allows, as appropriate, comparison of the 'Business as Usual' with one or more beneficial use options. It also shows that for different projects and beneficial use the techniques that the impacts can vary across social, economic and environmental criteria emphasising the complexity of the analyses undertaken and ultimately the challenges faced by stakeholder in managing dredge sediments in the context of the Circular Economy.

The four models can be used as an analytical decision making tool for a wide range of sediment reuse applications, either as integrated tools or individually as a standalone models in NWE NUTS 3 regions across all partner countries.

7 REFERENCES

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APPENDIX

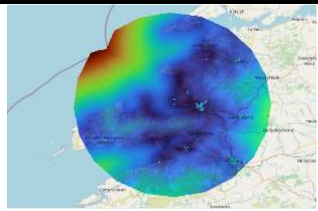
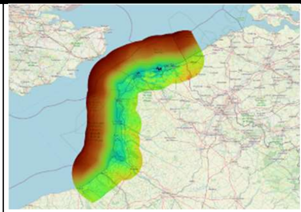
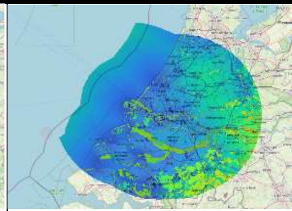
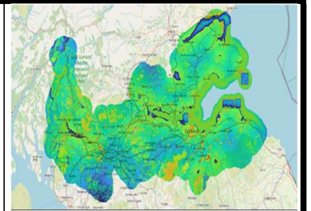
MODEL	ITEM	Port of Fenit BAU Sea Disposal	Port of Fenit BRO Wetland Nourishment	Port of Fenit BRO Dyke Construction	Port of Calais BRO Land Reclamation & Breakwater Construction	Port of Rotterdam BRO Sediment Reallocation	Falkirk Site BRO Bioremediation (Phytoconditioning)
RAIES	Suitability/Acceptability score						
USAR	Sediment chemical properties suitability for chosen application	Elevated levels of heavy metal – additional assessment might be required	Elevated levels of heavy metal – EIA required	Elevated levels of heavy metals – treatment might be required	✓	✓	✓
	Sediment physical properties suitability for chosen application	✓	✓	✓	✓	✓	✓
	Overall cost per tonne of new material	€ 2.5	€ 2.2	€ 7.05	€ 6.82	€ 6.33	€ 59.24
	Overall cost	€ 800,000	€ 704,000	€ 2,254,800	€ 43,673,600	€ 5,064,000	€ 47,392
Economic Model	Direct contribution to GDP	€ 1,708,000	€ 2,217,000	€ 6,492,000	€ 111,800,000	€ 1,212,000	€ 57,343
	Indirect contribution to GDP	€ 1,002,000	€ 1,251,000	€ 3,722,000	€ 89,600,000	€ 675,300	€ 31,162
	Induced contribution to GDP	€ 82,100	€ 108,860	€ 237,800	€ 14,100,000	€ 61,700	€ 2,697
	Direct jobs created	12.19 FTE	13.45 FTE	36.96 FTE	585 FTE	10.22 FTE	0.41 FTE
	Indirect jobs created	7.59 FTE	7.79 FTE	21.34 FTE	469 FTE	6.41 FTE	0.21 FTE
	Induced jobs created	7.59 FTE	0.67 FTE	1.88 FTE	75 FTE	1.44 FTE	0.02 FTE
	Total cost per m^3	€ 8.54	€ 11.09	€ 32.46	€ 27.95	€ 2.42	€ 67
	Total cost per tonne	€ 5.34	€ 6.93	€ 20.29	€ 17.2	€ 1.51	€ 11
BROADSEAT	Energy rating [-100:100]	-	4	-44	20	86	8
	Waste rating [-100:100]	-	12	12	32	24	16
	Environment rating [-100:100]	-	16	28	64	75	-4
	Societal rating [-100:100]	-	52	44	68	44	-8

Table A 1: Integrated Tools application summary table