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SEDIMENT CHALLENGES AND OPPORTUNITIES

A downscaled economic model validated and applied to sediment management projects in Ireland and Scotland

J. Harrington[1] · R. O.' Sullivan[1] · A. Hamilton[2] · R. Lord[3] · K. Torrance[3] · A. Wijdeveld[4] · T. Debuigne[5] · E. Masson[6] · B. Batel[1]

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Abstract

Purpose This paper presents a regionally downscaled economic model developed to assess the impacts of the management of dredged sediments on Gross Domestic Product (GDP) and jobs created; the model is validated and applied using real project data from sediment management projects in Ireland and Scotland. The model provides significant insight into and allows impact analysis for the economic aspect of sediment management projects with the potential to facilitate and inform stakeholders across the sediment management sector.

Methods The economic model facilitates regional analysis of the impacts of sediment management projects on GDP and job creation for direct, indirect and induced effects. Methods for estimating the economic induced impacts are based on industry-specific type I and type II economic multipliers and coefficients, derived for the EU Interreg SURICATES partner countries (Ireland, Scotland, France and the Netherlands) using symmetric input–output tables and application of the open Leontief model and based on available economic data for the identified countries.

The model is applied to sediment management projects in Ireland (a harbour development project at Castletownbere) and in Scotland (a bioremediation project at Falkirk). Model results are compared to project data for direct contribution to GDP and direct jobs created, and the model also estimates the indirect and induced economic project impacts. The model has been applied to undertake sensitivity analyses and compare different sediment management options.

Results Model results provide a satisfactory comparison to real project data for direct cost and jobs created. Indirect economic benefits for GDP and employment created were estimated from 47 to 53% of direct impacts**.** The model has been applied to undertake sensitivity analyses and assess a range of different site-specific sediment management options with indirect economic impacts ranging from 42 to 53% of direct impacts.

Conclusions The economic model results are compared to real project economic data, the validation exercise providing satisfactory with promising results. Sensitivity analyses and site-specific sediment management options have been assessed. The positive economic impacts of the Castletownbere Harbour project in particular are evident. These results highlight the potentially different economic impacts of the implementation of different sediment management options and in different regions and countries.

The model allows the quantification of the economic benefits of sediment management projects. The model provides significant insight into and allows impact analysis for the economic aspect of sediment management projects and has the potential to facilitate and inform stakeholders and decision-makers across the sector.

Keywords Dredging · Sediment management · Economic · Model · GDP · Jobs created · Falkirk · Castletownbere · Sensitivity analyses · Option analyses · SURICATES

1 Introduction

This paper presents a regionally downscaled economic model developed to assess the impacts of the management of dredged sediments. The model can support the sustainable use and management of dredged sediments, a major

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✉ J. Harrington
joe.harrington@mtu.ie

Extended author information available on the last page of the article

challenge for many ports, harbours and river authorities worldwide. This paper contributes to enhancing the knowledge base of dredged sediment management in an economic context.

Dredging involves the removal of sediments from the aquatic environment, including port and harbours, an essential activity in providing navigable access to international port and waterway infrastructure. The primary sediment management approaches generally involve disposal or beneficial use (with or without treatment). Disposal practice may involve disposal at sea or on land. Beneficial use with an identified positive end-use for dredged sediment is preferred, if feasible, and many different forms of beneficial use are practised and are often presented as engineering uses, environmental enhancement and agricultural and product uses. Dredged sediment management issues and practice have been presented for Ireland by Harrington et al. (2004), Riordan et al. (2008), Sheehan et al. (2008), Sheehan et al. (2009), Sheehan and Harrington (2012) and Harrington and Smith (2013) and in an international context, for example, by Bortone and Palumbo (2007), Laboyrie et al. (2018) and United States Army Corps of Engineers (2013).

Different factors influence the most appropriate sediment management technique(s) required including the sediment characteristics, whether it is contaminated or not, dredge volumes involved, local site conditions and current local, national and international practices. These feasibility issues generally depend on a range of often inter-related technical, direct cost, environmental, legislative and societal factors.

Traditional sediment management feasibility assessment and practice have been typically undertaken in the context of the 'linear' economy. The transition in the European Union from linear to circular economy principles (European Commission 2020) in conjunction with the requirement to seek to increase the reuse of sediment has highlighted the need to more broadly assess sediment management projects (in addition to the more traditional approaches to assessment). This paper focuses on one such assessment tool involving economic modelling to quantify the economic benefits potentially accruing from the beneficial use of sediment. Such an assessment tool has not been applied to date to dredged sediment management assessment and practice and fills an identified knowledge and assessment gap in current practice. It is recognised that this new economic modelling work is one assessment tool; a range of other assessment approaches may also be applied, both traditional for example, technical and direct cost approaches, and recent ecosystem services (Boerema et al. 2016) and quantitative environmental assessment (Lord and Torrance 2022) approaches.

The downscaled economic model presented facilitates the regional analysis of the effect of a dredged sediment project on Gross Domestic Product (GDP) and job creation. The economic model analyses the direct, indirect and induced effect on GDP along with the direct, indirect and induced jobs created. The economic effects were downscaled to a regional EU NUTS3 (EU Nomenclature of Territorial Units for Statistics—NUTS) level using Simple Location Quotients (SLQs) for a number of countries in North West Europe (the partner countries in the EU Interreg NWE SURICATES Project (2022)). The model assesses the potential economic impact, accounting for costs and benefits in a temporal context within the time period of the project and in a spatial context within the downscaled EU NUTS3 region. Longer-term economic benefits which may be derived from beneficial use projects such as land reclamation, for example, are not included in the analysis as such an analysis would require significant assumptions to be made on, for example, the use to which the reclaimed land is put and the rate at which future income would be discounted to present value. This analysis would be sensitive to the assumptions made and may not be sufficiently reliable or robust. However, it is reasonable to assume that the model will underestimate the full longer-term economic benefits of dredge sediment management projects assessed.

The model allows stakeholders including port and sediment asset managers, local and government authorities and engineering consultants to gain key insights into the economic benefits of different sediment management approaches. The model allows the quantification and comparison of the direct, indirect and induced benefits of a range of sediment management projects yielding key information for project planning and decision-making purposes. The model user can economically assess and compare various potential sediment management options. For example, in an Irish context, the model can be applied as part of the mandatory sediment management option assessment as an alternative to the widely practiced disposal at sea approach, as part of the permitting process (Irish Environmental Protection Agency (2009)).

The economic model developed will be made available at the completion of the EU Interreg NWE SURICATES Project (2022) as a user-friendly and accessible MS Excel application.

2 Methods

2.1 Economic modelling approach

The methods for predicting wider economic impacts of dredging are based on the use of multipliers derived from symmetric input–output tables (SIOT), where the outputs of one industry sector correspond to the input of another industry (Leontief 1951) allowing identification of the impact of activities within a sector across a regional or national economy. These input–output models generate a multiplier index measuring the total effect of an increase in investment on employment or income. There are three types of multiplier effect; direct, indirect and induced. Direct effects refer to the impact on the economic activity of the industry/development. Indirect effects refer to the impact arising from upstream or inter-sectoral linkages, such as the income or jobs accruing to suppliers. Induced effects are impacts arising from general household spending of those directly and indirectly employed by the industry/development. This approach is well established to model the economic impacts of developments, for example by Hawdon and Pearson (1995) and Ivanova and Rolfe (2011).

Figure 1 presents the overall modelling approach applied including the primary model inputs (including the Economic Impact Area, the project site, sediment characteristics and unit costs from an extensive unit cost database), the available sediment management options (the full logistical chain of project activity from dredge sediment generation through to ultimate placement or disposal) and the model outputs (direct, indirect and induced contributions to GDP and employment).

2.2 Economic model — direct costs

The direct costs are the actual costs associated with the project and are the sum of all the individual costs (the product of the process quantity by the unit cost) of the processes involved. The essential processes in a sediment management project include design, environmental assessment, monitoring, dredging, dewatering, treatment, transport, placement and any other relevant process.

3 Economic model — direct, indirect and induced impacts

The direct, indirect and induced impacts are presented as two specific outputs: contribution to GDP and the resulting impact on jobs. The number of jobs created in a particular industry can be estimated based on the total output from that industry.

3.1 Direct contribution

GDP activity measures the total monetary value of all goods and services produced within a country's borders and is the most common indicator of financial activity (Leontief 1951). The expenditure approach estimates the direct impact on GDP by how much money is invested in a specific project. The direct jobs created include those directly associated with the project and any additional jobs created. The number of full-time equivalent (FTE) direct jobs created is estimated based on Eq. (1) (Cassar 2015).

$$E_c = FEJ(i)/TO(i) \quad (1)$$

where

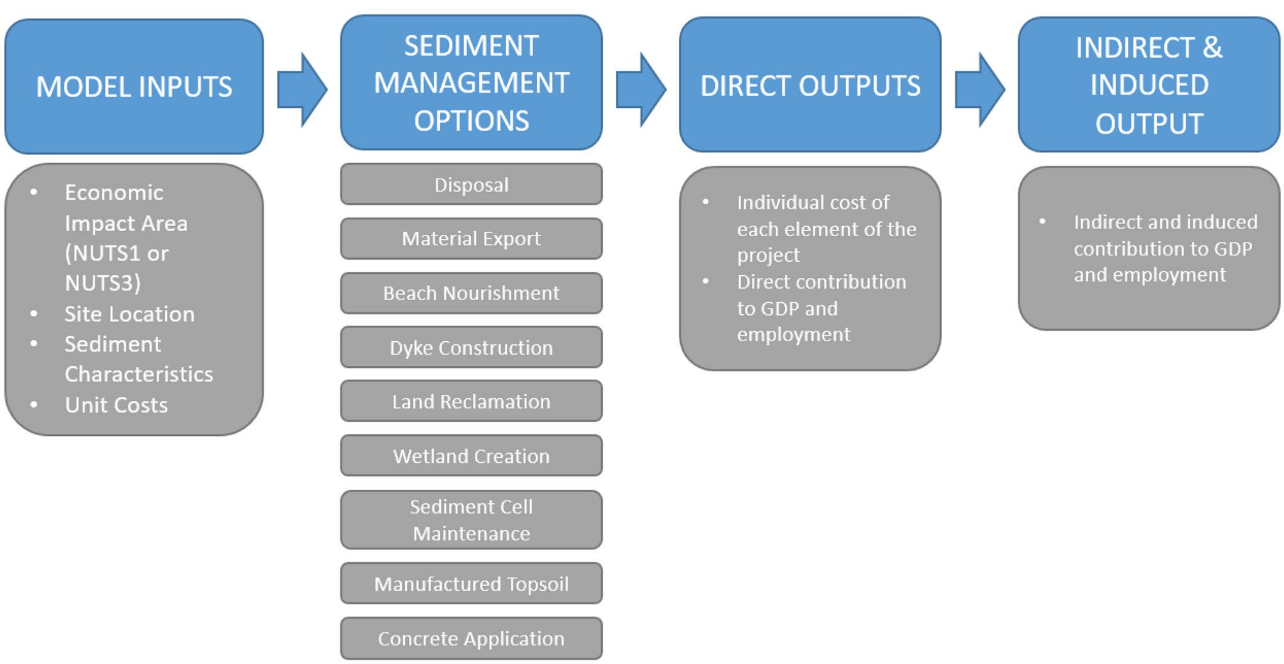

Fig. 1 Overall economic model structure — inputs and outputs

E_c = employment coefficient [FTE jobs per million € invested]

$FEJ(i)$ = full-time equivalent jobs in specific industry

$TO(i)$ = total output in the specific industry [millions of €]

The number of direct jobs created per million of Euro (€) invested is the sum of the individual sectoral direct employment as presented in Eq. (2).

$$DE = \sum DC(i) * E_c(i) \quad (2)$$

where

DE = direct jobs created [FTE jobs]

DC = industry-specific direct cost [€]

$E_c(i)$ = industry-specific employment coefficient

3.2 Indirect contribution

An increase in the final demand from a particular industry results in an increase in demand for other linked industries further down the supply chain. This is called the indirect contribution to GDP and is estimated by applying sector-specific Leontief type I multipliers to the corresponding sectoral GDP. The direct cost of the individual elements is then deduced from this value as presented in Eq. (3) (Central Statistics Office Ireland 2013).

$$IC = (DC * MI) - DC \quad (3)$$

where

IC = indirect contribution to GDP [€]

DC = direct contribution to GDP [€]

$M1$ = Leontief type I output multiplier

Leontief type I multipliers are derived from the domestic symmetric input–output tables (SIOT) using Eq. (4) (Cassar 2015).

$$L = (I - A)^{-1} \quad (4)$$

where

L = Leontief inverse matrix

I = identity matrix

A = direct requirement matrix

The indirect employment represents the number of full-time equivalent jobs that are created as a result of the economic activity generated by the project. The indirect employment is estimated by Eq. (5) (Cassar 2015).

$$IE(i) = IC(i) * E_c(i) \quad (5)$$

where

IE = industry-specific indirect jobs created [FTE jobs per million € invested]

IC = industry-specific indirect contribution to GDP [€]

E_c = industry-specific employment coefficient [FTE jobs per million € invested]

The total number of indirect jobs created is the sum of these individual industry-specific indirect jobs.

3.3 Induced contribution

The induced contribution to GDP is the result of increased personal income caused by the direct and indirect effect on GDP, or in other words, the spending of employees. A proportion of this increased income will be re-spent and returned to the economy. The induced effect is estimated using the Leontief type II output multipliers. Similar to type I output multipliers, the type II output multipliers are also derived from SIOT tables using matrix analyses containing information on the consumer's behaviour. The indirect contribution to GDP is estimated using Eq. 6 (Central Statistics Office Ireland 2013).

$$InC = (IC * M2) - IC \quad (6)$$

where

InC = induced contribution to GDP [€]

IC = indirect contribution to GDP [€]

$M2$ = Leontief type II output multiplier

The induced employment represents the number of FTE jobs created by household spending as a result of the economic activity generated by the project. The induced employment is estimated by Eq. (7) (Cassar 2015).

$$InE(i) = InC(i) * E_c(i) \quad (7)$$

where

InE = industry-specific induced jobs created [FTE jobs per million € invested]

InC = industry-specific induced contribution to GDP [€]

E_c = industry-specific employment coefficient [FTE jobs per million € invested]

The total number of induced jobs created is the sum of these individual industry-specific indirect jobs.

4 Downscaled economic model

4.1 Economic impact areas — national and regional

The economic model has been developed for Ireland, France, the Netherlands, Scotland and the UK (excluding Scotland), in the context of the EU Interreg NWE SURICATES Project (2022). The output multipliers and employment coefficients embedded in the model were derived for each country individually based on available data from national statistics offices, the OECD and Eurostat. These multipliers and employment coefficients are used in the first instance to estimate the economic impacts of dredging projects at a NUTS1 level.

However, there are often considerable regional differences in terms of economic performance and these can be reflected through a downscaling approach to a regional NUTS3 level (Fig. 2). The SLQ method (Eq. 8) is a common estimation procedure quantifying how concentrated a particular industry is on a regional NUTS3 level relative to the reference NUTS1 level (Carey and Johnson 2014). Eurostat provides employment data for eleven NACE (a statistical classification of economic activities in the EU) categories to a NUTS3 level. The NUTS3 employment data form an 'asset' to generate the SLQ ratios which are applied to the national level multiplier and employment coefficients. In the case where a region is over-represented as a proportion of employment in a particular sector, the national multiplier and employment coefficients were used for that region and where a region is under-represented the national multiplier was downscaled to reflect the degree of under-representation.

$$SLQ = (X/Y)/\left(X^{'}/Y^{'}\right) \quad (8)$$

where

SLQ – simple location quotient

X – amount of asset in a region (sectoral employment)

Y – total amount of comparable asset in a region (total employment)

X′ – amount of asset in a larger reference region (sectoral employment)

Y′ – total amount of comparable asset in a larger reference region (total employment)

5 Model application

5.1 Background

The model has been applied to two dredging projects, Falkirk, Scotland, and Castletownbere, Ireland, allowing comparison of model outputs to actual project data for GDP and jobs created. Scottish Canals provided all necessary information for the Falkirk Project. L&M Keating Ltd., the dredging contractor for Castletownbere Harbour Development, provided relevant project information.

Project information gathered included sediment volumes, sediment contamination levels, particle size, dredging methods, treatment, beneficial use practice, disposal and volumes of imported and exported material. Information was also gathered on the cost of the dredging project and the number of jobs created. Direct cost data was collected for the individual activities/processes including staff time, excavated sediment, transportation, treatment, placement and disposal. The total direct cost of the project was estimated as the sum of staff time and the cost of the dredging operation. The jobs created from the project were calculated based on the data gathered on the total number of staff involved including full time, part time, sub-contracted and also those hired by sub-contractors.

5.2 Description of projects

5.2.1 Falkirk Bioremediation Project, Scotland

Scottish Canals as the client were responsible for this project (a Pilot Project forming part of the EU NWE Interreg SURICATES Project (2022) which involved mechanically dredging approximately 533 m^3 of uncontaminated sediment from a canal near Falkirk, Scotland, in July 2019 (Fig. 3). The material 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 material into a haulage contractor's tipper lorries, which transported the material to the placement site a trucking distance of approximately 38 km. The material was applied to a bio-engineering pilot scheme (Fig. 4). The dredge sediment was dewatered naturally via a water drain into the ground and overflow into a nearby rubble drain. The sediment deposition site was then treated by planting with reed canary grass, a phytoconditioning process.

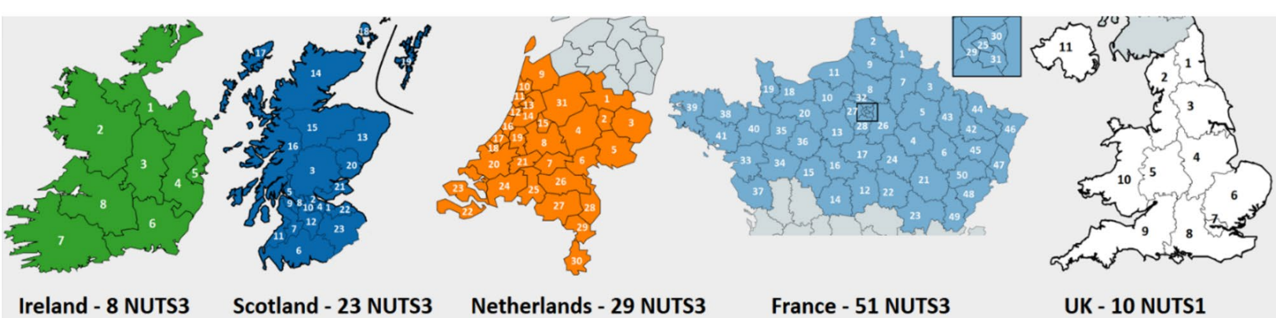

Fig. 2 NUTS3 (& NUTS1) NWE country regions in the economic model

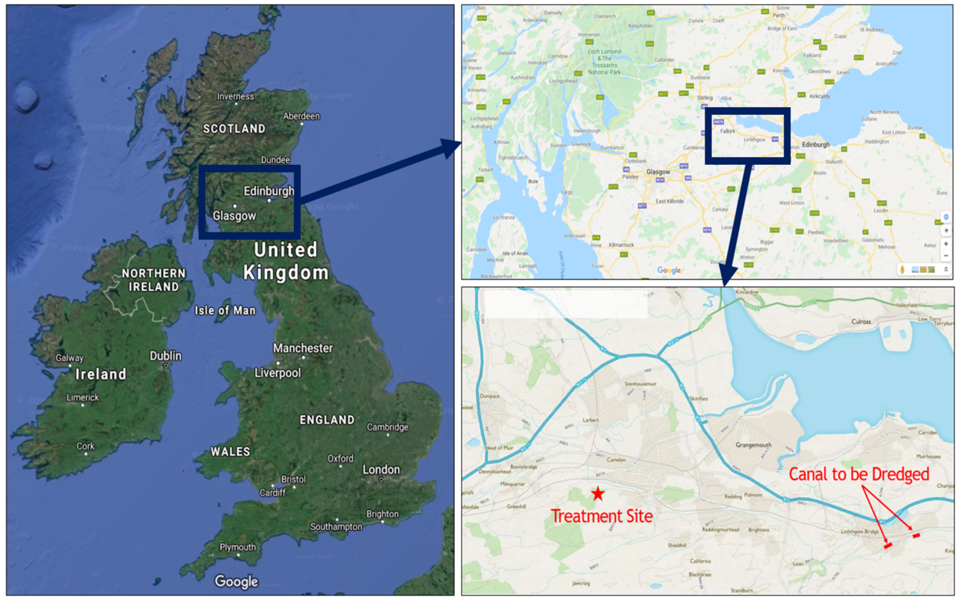

Fig. 3 Falkirk site location

5.2.2 Castletownbere Harbour Development, Ireland

L&M Keating Ltd., an Irish dredging contracting company, completed the dredging aspect of the Castletownbere Harbour Development project which is located in County Cork on the southwest coast of Ireland (Figs. 5 and 6). The dredging works took place primarily over an approximately 3-month project timeframe.

The scope of the project comprised an extension to an existing reinforced concrete wharf, dredging of a berthing pocket, construction of two breakwater structures and land reclamation as a quay extension, all works undertaken on the Irish Government-owned Dinish Island in Castletownbere Harbour. The total quantity of dredged material was 66,000 m^3. Soft material was excavated with a long reach excavator, and hard material was broken by a rock ripper and then excavated with a long reach excavator. The dredged sediment was deemed uncontaminated for beneficial use and did not require treatment. Dredged material was dewatered naturally on-site. All rock and fine dredged material was beneficially reused for land reclamation, as a breakwater material and as a quay wall structural fill. The project required an additional 28,000 m^3 of rock to be imported from three nearby quarries, located distances of 10 to 120 km from the site. The overall project cost is estimated at €20 million and is now at the completion stage after significant project time delays.

Fig. 4 Falkirk sediment deposition bioremediation site

5.3 Model application to projects

5.3.1 Falkirk Bioremediation Project, Scotland

The economic model was applied to the sediment management project with the results presented in Table 1. The actual cost of the sediment management project was €57,100 (£48,000) with the equivalent of 0.67 full-time equivalent (FTE) jobs created. The economic model estimated a direct cost of €61,630. The economic model estimated that the dredging project would create 0.43 FTE direct jobs. Indirect and induced contributions to GDP and employment created are also presented from the model; the indirect contribution to GDP is approximately 47% of the direct contribution (and 44% for jobs created, albeit for a very limited level of employment) and is of benefit to the region while the induced contribution is approximately 4.5% of the direct contribution. The indirect and induced numbers of jobs created yield similar values as a proportion of the direct contribution but are not significant due to the small project size. In this case, the model has been applied to a small project; the preliminary results indicate that the direct cost comparison is satisfactory (as there will be some differences between actual direct cost and the estimated direct costs from the

Fig. 5 Castletownbere Harbour location

model). The direct jobs created comparison is limited by the size of the project and the very small level of employment created.

The model has been applied to undertake a sensitivity analysis where the sediment volume has been varied to assess the potential impacts with all other project parameters remaining constant. Figure 7 presents the direct, indirect and induced impacts on GDP and jobs created for increased dredged sediment volumes of 1000 m^3, 1500 m^3 and 2000 m^3; these results show increased contribution to GDP and jobs created as the sediment volume increases (albeit for the small dredge volumes involved).

The model has been further applied to assess the economic impact of undertaking other potential sediment management options for the project dredge volume of 533 m^3. The sediment management options assessed are (1) disposal to the nearest Marine Scotland Licensed Offshore Disposal Site in the Firth of Forth involving a trucking distance of 8.5 km and a sail distance of 1.3 km and (2) land disposal to the nearest Scottish Environmental Protection Agency (SEPA) licensed land disposal facility, a trucking distance of 38 km from the dredging site. Figure 8 presents the predicted economic impacts for GDP contribution and jobs created for the completed phyto-conditioning project and the two identified disposal options. These results show (assuming the full feasibility of offshore and onshore disposal) that the direct cost of the bioremediation project would exceed either of the selected disposal options and providing a larger economic impact, the offshore disposal option provides the lowest direct cost option.

The bioremediation project's indirect contribution to GDP was approximately 47% of the direct contribution, and different values were found for offshore disposal (52%) and onshore disposal (49%). The induced effects for the identified sediment management options remained relatively small at approximately 5%. The overall impact of the project on employment is not significant. These results for the direct and indirect economic analyses highlight the potentially different economic impacts of the implementation of different sediment management options.

Fig. 6 Visualisation of completed Castletownbere Harbour Development

Table 1 Economic model output vs. actual figures — Falkirk Bioremediation Project

	Economic model estimates	Actual project data
Direct contribution to GDP/cost [€]	61,630	57,100
Indirect contribution to GDP [€]	28,899	
Induced contribution to GDP [€]	2750	
Number of direct jobs created [FTE]	0.43	0.67
Number of indirect jobs created [FTE]	0.19	
Number of induced jobs created [FTE]	0.02	

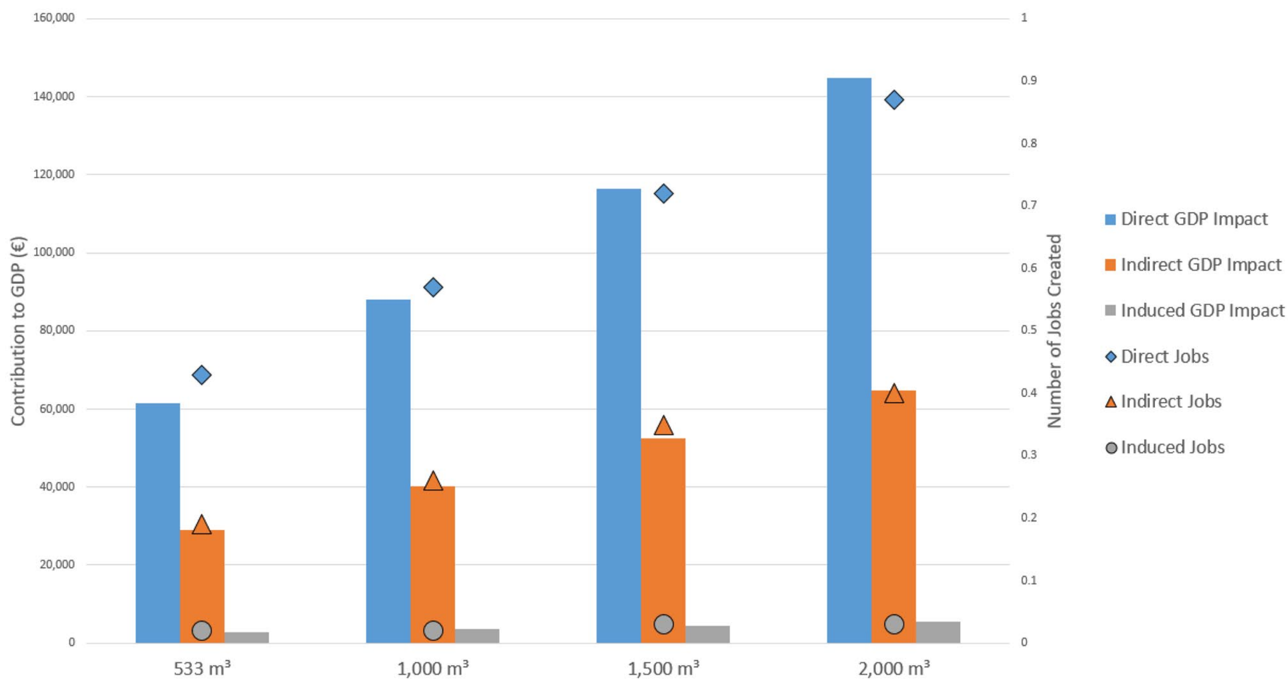

Fig. 7 Sensitivity analysis — Falkirk Bioremediation Project

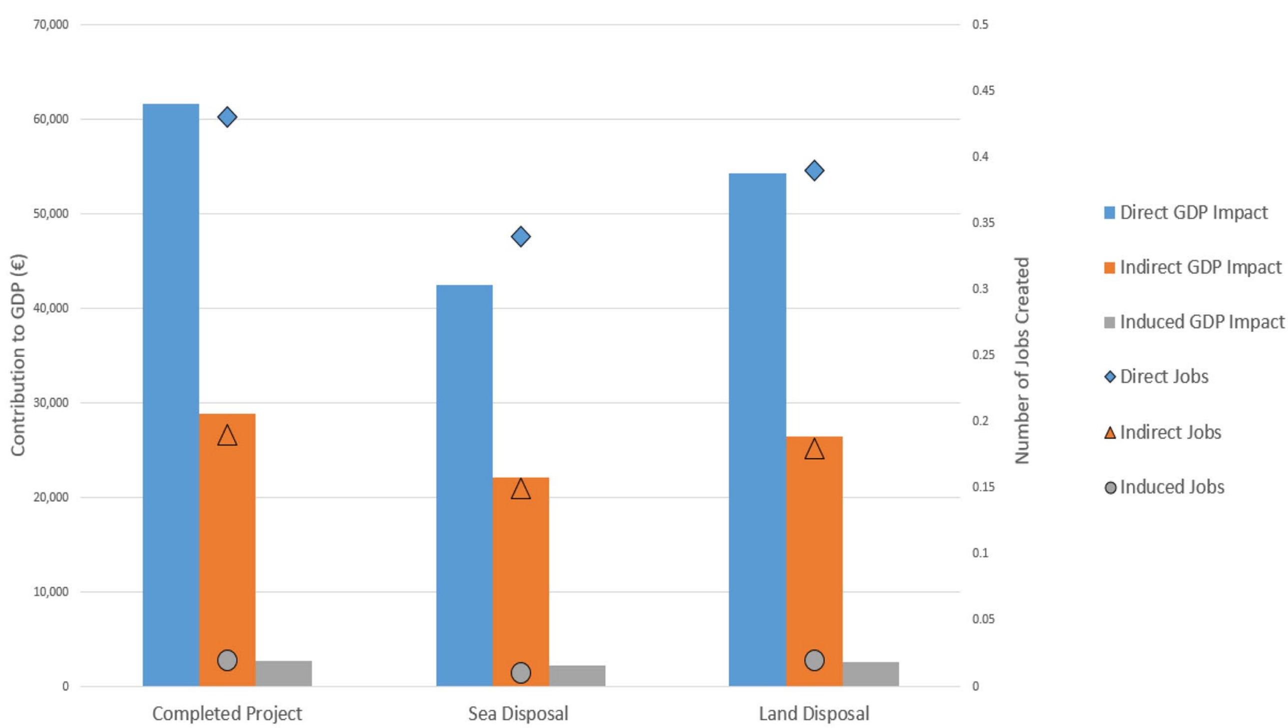

Fig. 8 Sediment management option analysis — Falkirk Bioremediation Project

Table 2 Economic model output vs. actual figures — Castletownbere Harbour Development

	Economic model estimates	Actual project data
Direct contribution to GDP/cost [€]	6.495 million	7 to 8 million
Indirect contribution to GDP [€]	3.805 million	
Induced contribution to GDP [€]	0.367 million	
Number of direct jobs created [FTE]	40	35 to 40
Number of indirect jobs created [FTE]	21.2	
Number of induced jobs created [FTE]	2.3	

5.3.2 Castletownbere Harbour Development, Ireland

The economic model was applied to the Castletownbere Harbour Development project, see Table 2. The model estimated the direct cost of the dredging and quay extension and breakwaters (all the sediment management-related aspects of the project) at €6.49 million. The actual cost of these elements of the project was in the range from €7 to €8 million. The actual project created 35 to 40 FTE jobs with a satisfactory model prediction of 40 FTE jobs. These directly created project jobs include site personnel such as engineers and technical staff, plant and machines operators and subcontractors' staff. Indirect and induced contributions to GDP and employment created estimated from the model are presented indicating the substantial benefits accruing to the region from the project, such valuable information is not generally available for these projects. The indirect jobs created include, for example, quarry employment to supply rock for the breakwater construction and the induced jobs include the increased employment in the local service industry (shops and restaurants, for example) due to household spending as a result of the project economic activity generated. The indirect contribution to GDP and to jobs created is estimated at 52% and 53% respectively of the direct contribution confirming the significant benefit to the local region. The induced effects (approximately 5% of the direct benefits) are relatively small by comparison. For the Castletownbere Harbour Development project, the model has been applied to a sediment management project of small to medium size in an Irish context with satisfactory direct cost and employment-created comparisons.

The results of the model application for this dredging project are satisfactory, given the complexity of the project which included, in addition to dredging, the construction of breakwaters and quay walls, land reclamation and several material imports from off-site. The lower end of the actual project cost was approximately 7.2% higher than the simulated cost with the model predicting the direct employment created of 40 FTE jobs which is the same as the upper estimate of the number of direct jobs created.

The model has been applied to undertake a sensitivity analysis to assess the economic impact of varying the

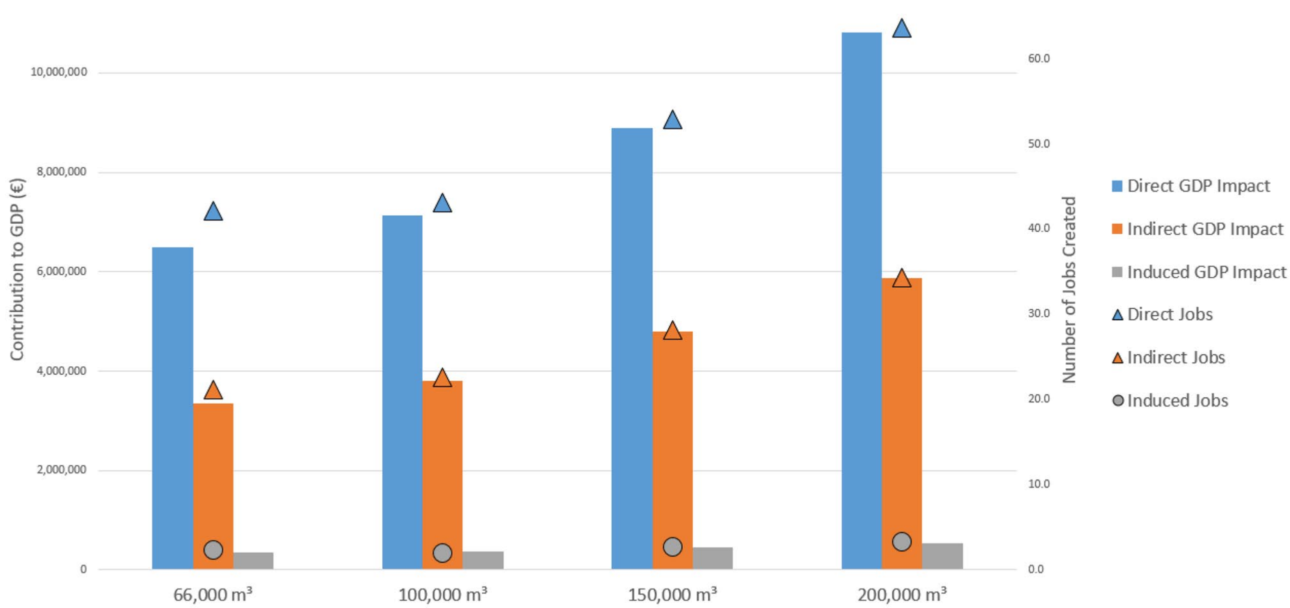

Fig. 9 Sensitivity analysis — Castletownbere Harbour Project

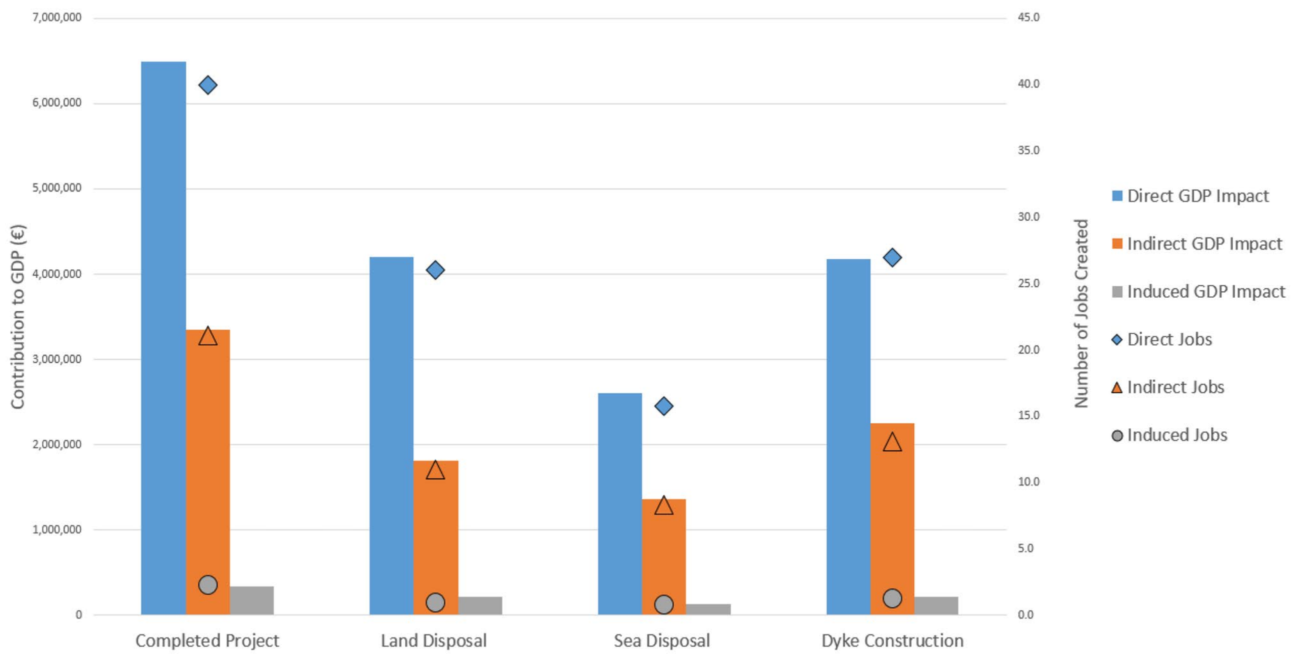

Fig. 10 Sediment management option analysis — Castletownbere Harbour Project

potential dredge volume in the project with all other project parameters remaining constant. Figure 9 presents the direct, indirect and induced impacts on GDP and employment created for increased dredged sediment volumes of 100,000 m^3, 150,000 m^3 and 200,000 m^3 (with the assumption that all sediment can be reused on site). The results in Fig. 9 generally show the increased economic benefits of a larger sediment management project.

The model has been further applied to assess the economic impact of undertaking other potential sediment management options for the project dredge volume of 66,000 m^3. The sediment management options that are assessed for this paper and with assumed potential feasibility for the Castletownbere Harbour site are (1) the beneficial use of sediment as the primary construction material for a flood protection dyke on Dinish Island, (2) the option of offshore disposal to the closest Irish Environmental Protection Agency licensed disposal site (a sail distances of 6.3 km from the project site on the open coast external to Castletownbere Harbour) and (3) the option of land disposal to the nearest Irish Environmental Protection Agency licensed land disposal facility at Derryconnell, County Cork, which is located a trucking distance of 70 km from the project site. Figure 10 presents the economic impacts predicted by the model for GDP contribution and jobs created for the completed project and the three additional sediment management options. These results show that the direct cost of the completed project would exceed the direct cost of the other options and would provide a more positive economic impact than the other options, including the beneficial use option of dyke construction. The offshore disposal option provides a lower direct cost option than onshore disposal, based on the locations of the available licensed disposal facilities; this is consistent with Irish practice where offshore disposal typically yields the lowest direct project cost.

The completed project's indirect contribution to GDP and to jobs created was approximately 52% and 53% respectively of the direct contribution; different values were found for dyke construction (54% and 48% respectively), offshore disposal (52% for both) and onshore disposal (43% and 42% respectively). The variation in these values reflects the different processes involved in the different sediment management options and the varying inputs from the different industry sectors to complete these projects. The induced effects for the identified sediment management options remained relatively small at approximately 5%. The results, particularly for the direct and indirect economic analyses, highlight the potentially different economic impacts of the implementation of different sediment management options.

6 Conclusions

This paper presents a new and downscaled regional economic model to analyse the economic impacts (GDP and jobs created) of sediment management projects. Type I and type II output multipliers and employment coefficients were derived for a range of countries in North West Europe by applying an open Leontief model to standardised symmetrical input–output tables. The model estimates the direct, indirect and induced effects of GDP and jobs created for sediment management projects. The model has been downscaled to a NUTS3 level using the SLQ method to reflect economic differences on a regional level.

An economic analysis was undertaken for sediment management projects in Falkirk, Scotland, and Castletownbere, Ireland, to provide model validation and application. Model results were compared to these real project economic data with the validation exercise providing satisfactory and promising results. The indirect economic benefits for GDP and employment created were estimated to be 47% and 44% respectively for the Falkirk project and 52% and 53% respectively for the Castletownbere project. The induced benefits were approximately 5% for both projects. Model applications were presented for sensitivity analyses at both sites by varying the dredge sediment volumes. A number of site-specific options for sediment management at both project sites were also modelled. For the Falkirk project, the options included disposal to nearby licensed onshore and offshore disposal sites, and for the Castletownbere project, nearby licensed disposal site options were also assessed and in addition to beneficial sediment use for dyke construction. For both projects, the actual project completed provided greater economic benefits to the region that the other sediment management options assessed. The indirect economic impacts (as a proportion of the direct impacts) ranged from 43 to 52% for GDP and from 42 to 53% for jobs created. The induced economic impacts were relatively low at approximately 5% of the direct impacts. These results highlight the potentially different economic impacts of the implementation of different sediment management options and in different regions and countries.

This modelling work is currently being extended to include application to a number of larger sediment management projects across North West Europe in France and the Netherlands and also to analyse broader sediment management project impacts in a regional context.

The model allows the quantification and comparison of the direct, indirect and induced benefits of a range of sediment management options and projects yielding key information for project planning and decision-making purposes. The model user can economically assess and compare various potential sediment management options. The model thus provides significant insight into and allows impact analysis for the economic aspect of sediment management projects and has the potential to facilitate and inform stakeholders across the sediment management sector. It should be recognised however that such modelling and analysis work forms one aspect of a broader consideration required including technical, environmental, ecosystem service and societal analyses and impacts.

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Declarations

Competing Interest The authors declare no competing interests.

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Authors and Affiliations

J. Harrington[1] · R. O.' Sullivan[1] · A. Hamilton[2] · R. Lord[3] · K. Torrance[3] · A. Wijdeveld[4] · T. Debuigne[5] · E. Masson[6] · B. Batel[1]

[1] Sustainable Infrastructure Research & Innovation Group, Munster Technological University, Cork, Ireland

[2] Scottish Canals, Canal House, Applecross St, Glasgow G4 9SP, UK

[3] Department of Civil & Environmental Engineering, University of Strathclyde, 75 Montrose Street, Glasgow G1 1XJ, UK

[4] DELTARES, P.O. Box 177, 2600 MH Delft, Netherlands

[5] Ixsane, 23 Av. de la Créativité, 59650 Villeneuve-d'Ascq, Lille, France

[6] University of Lille, 42 Rue Paul Duez, 59000 Lille, France