2009-6

Dredging and dredged material beneficial use in Ireland

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Recommended Citation

Sheehan, C., Harrington, J.R., Murphy, J.D., 'An overview of dredging and dredge material beneficial use in Ireland', Terra et Aqua, June Issue 2009, No. 115, pp. 3-14, The Hague, Netherlands.

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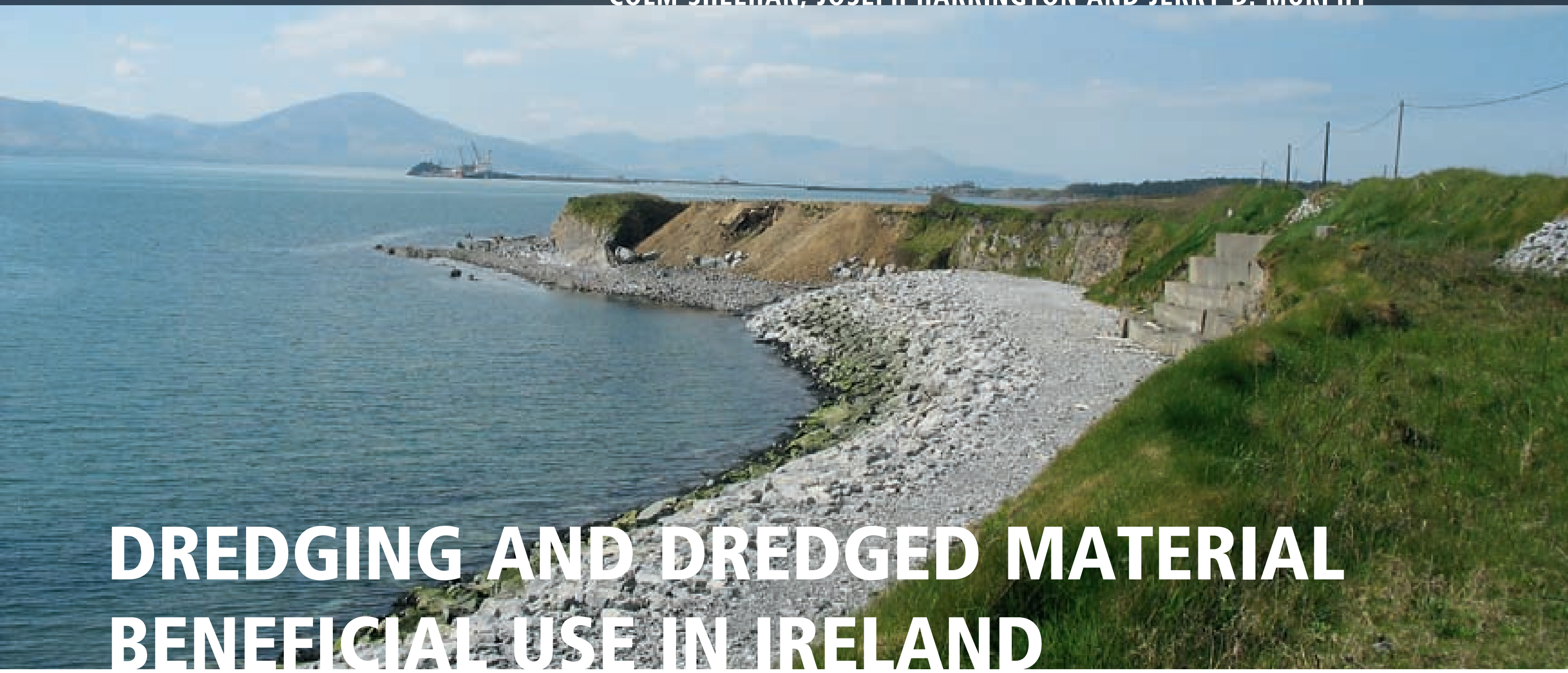

DREDGING AND DREDGED MATERIAL BENEFICIAL USE IN IRELAND

ABSTRACT

This article provides an overview of the dredging industry in Ireland which may be small by international standards but is of critical importance to the nation's Ports and Harbours. Open sea disposal of dredged material is most common, but a range of beneficial uses for the coarser fraction of dredged material has been practiced. Details on different aspects of dredging in Ireland are presented including a review of current beneficial uses. A specific site at Fenit Harbour in Tralee Bay is examined to assess the potential for a specific beneficial use of dredged material using geotubes in breakwater and revetment structures. By using the dredged material that is normally dredged and disposed at sea to fill the geotubes and construct a coastal structure a sustainable and feasible beneficial use of dredged material may be achievable. This case study may be applicable to other harbour sites in Ireland.

The authors wish to acknowledge the funding received from the Environmental Protection Agency under the Science, Technology, Research and Innovation for the Environment (STRIVE) Programme 2007-2013. They would like to thank Phil McGoldrick of GeoSolutions Ireland, Jonathon Wynn, Geosynthetics Consultant, Michael O' Carroll, Secretary & Harbour Master of Tralee & Fenit Harbour Commissioners and Ken Fitzgerald of Malachy Walsh & Partners Consulting Engineers. They also wish to gratefully acknowledge the input of personnel in the port and dredging industries, regulatory agencies and other organisations who have provided information for the project, as well as Dr. Tony Lewis and Dr. Jimmy Murphy, Hydraulics and Maritime Research Centre, University College Cork for their support.

INTRODUCTION

The Port and Harbour industry, and by extension the dredging industry, are vital to Ireland's economic performance. As an island nation located in the northwest of Europe, maritime transport accounts for 99% of Ireland's imports and exports by volume and 90% of Ireland's GDP representing a value in excess of € 120 billion. The shipping and maritime transport sector has grown rapidly over the past decade, in line with general economic growth (Shields *et al.*, 2005). However, owing to the current recession, the volume of ship traffic through Irish ports declined by approximately 20% in the second half of 2008 (Irish Maritime Development Office, 2009), with further reduction predicted as the global recession continues.

The twelve main commercial ports in the Republic of Ireland are primarily semi-state ports (two are privately owned) operating independently in a competitive environment. Fishery Harbours Centres, of which there are six in the Republic, are the primary fishing harbours in Ireland. A number of smaller commercial harbours operate under the auspices of local harbour commissioners or under the authority of local government. Some € 200 million was identified for investment under the National Development Plan 2007-2013 to provide for the future viability of the fishing industry (Burke, 2009) but as a result of the current recession this investment is no longer available and a national infrastructure bond is to be

Above: A site at Fenit Harbour in Tralee Bay was examined to assess the potential for the beneficial use of dredged material using geotubes in breakwater and revetment structures. Seen here, the R558 road to Fenit Harbour looking west with revetment structure on eroding shoreline in foreground and Fenit Harbour in background.

Table I. Legislative framework for dredging projects in Ireland (adapted from Harrington *et al.*, 2004).

Legislation	Responsible Agency	Comments
Fisheries Act 1959 to 2006	Regional Fisheries Board	Responsible for maintaining and improving environmental quality and the fishery resource.
Water Services Act 2007 (Water Framework Directive (2000/60/EC))	Local Authority (under the auspices of the Department of Environment, Heritage and Local Government)	Ensures water is maintained to a standard consistent with its various uses. This potentially can introduce additional controls on dredging and dredge disposal activities with potentially significant cost implications.
Dumping at Sea Act (1996 & 2004)	Department of Agriculture, Fisheries & Food	Application assessed by the Marine Licence Vetting Committee (MLVC) and may involve consultation with Local Authorities and Regional Fisheries Board. Typical permitting timeframe of 4 to 6 months.
Waste Management Act (1996 to 2005) - Licenses	Environmental Protection Agency (EPA)	Applied to any waste material segregated, stored or disposed onshore. Licenses are required from the EPA and take an average of 6 months to acquire. More complex cases can take up to 18 months. Applies to quantities greater than 100,000 tonnes.
Waste Management Act (1996 to 2005) - Permits	Local Authority	Applied to any waste material segregated, stored or disposed onshore. Permitting timeframe of 21 days. Applies to quantities less than 100,000 tonnes.
Waste Management Regulations 2007 – Shipments of Waste	Local Authority - Dublin City Council	Applies to the Transfrontier Shipment of Waste.
Planning and Development Regulations 2001 to 2002 (85/337/EEC, 97/11/EC)	Local Authority, Environmental Protection Agency, An Bord Pleanála (project dependent)	Commonly required for large scale dredging projects in the Republic of Ireland.
Foreshore Act (1933-1998)	Department of Agriculture, Fisheries & Food	Disposal between Mean High Water Mark and 12 nautical mile limit. Application assessed by the MLVC and may involve consultation with Local Authorities and Regional Fisheries Board. Typical permitting timeframe of 4 to 6 months.
Planning Permission (Planning & Development Act, 2000)	Local Authority	Generally required for all developments. Public Consultation process required. Typical 3 month permitting timeframe (in parallel with other required permits)
EC Quality of Shellfish Waters Regulations 2006	Department of Agriculture, Fisheries & Food	These prescribe shellfish water quality and designate the waters to which they apply. Designation of shellfish areas (as advised by the EU) may impact on dredging.
Conservation of Wild Birds Regulations 1985 to 2005 (79/409/EEC)	National Parks and Wildlife Service (DEHLG)	121 designated Special Protection Areas (SPA) in the Republic of Ireland for rare and vulnerable species with some impacting on dredging projects.
Natural Habitats Regulations, 1997 (92/43/EEC)	National Parks and Wildlife Service (DEHLG)	413 designated Special Areas of Conservation (SAC) with some impacting on dredging projects.
Wildlife Acts 1976-2000	National Parks and Wildlife Service (DEHLG)	This is an area considered important for the habitats present. Over 1100 proposed National Heritage Areas (NHA). Many overlap with SAC/SPA. Some may impact on dredging
National Monuments Act (1930 –2004)	National Monuments Service (DEHLG)	120,000 protected archaeological sites, some potentially impacting upon dredging.

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Table II. Dredging Questionnaire Details.

Type of Organisation	No. of Questionnaires distributed	No. of Responses
Ports	13	10 (77%)
Harbours	26	17 (65%)
Marinas	43	8 (19%)
Other *	16	5 (31%)
Total	**98**	**40 (41%)**

* includes Irish Naval Base, Shannon Ferry Group, Bord Gáis Éireann, Electricity Supply Board, Government Office of Public Works and Local Authorities

introduced by the Department of Finance to raise money for capital projects (Department of Finance, 2009). Figure 1 shows the investment in Ireland's Ports and Harbours from 2000 to 2007.

THE IRISH DREDGING INDUSTRY

The dredging industry in Ireland is small by international standards but is essential to the operation of Irish Ports and Harbours. The historic average annual maintenance dredge requirement for disposal at sea is approximately 1.2 million wet tonnes for the Republic of Ireland (OSPAR Commission, 1997-2006), accounting for approximately 73% of the total offshore disposal volume. Practically all maintenance dredged material is currently disposed off-shore with approximately 40% of capital dredge material (the coarser fraction) used in some form. An overview of the Irish Dredging Industry is presented in here based on an analysis of a dredging questionnaire survey supplemented by other available information.

The Legislative Framework

The legislative framework governing Ireland's dredging industry is rigorous and stringent. Depending on the type of project planned the various licenses and permits required can take between 3 months for a relatively simple project and over 18 months for a complex project. A summary of the current legislative framework is presented in Table I.

The Dredging Questionnaire Survey

A dredging questionnaire survey was sent to individual ports, harbours, marinas and other relevant regulatory agencies and organisations in Ireland in 2007. The aim was to gain a general understanding of the current status of the dredging industry and to update a previous national dredging survey undertaken in 2003 (Harrington *et al*., 2004). A postal survey was undertaken with a follow up by phone. This survey information was supplemented by information gathered from the Department of Agriculture, Fisheries and Food (formerly some of its responsibilities were under the Department of Communication, Marine and Natural Resources) website on recent dredging projects. The locations for which data is available are shown in Figure 2.

Questionnaires were sent to 98 groups/ organisations with an overall response rate of 41%. Details are presented in Table II. Additional information was gathered from regulatory agency data yielding information for a total of 47 locations. The data gathered included a wider range of dredging projects and locations then the previous 2003 survey (where 63 questionnaires were distributed with a 53% response rate).

The two-page questionnaire required information on the last major dredging project undertaken by the relevant organisation and specifically requested details on:

- Type of dredging project
- Volume dredged
- Equipment utilised
- Dredged volume used
- Type of beneficial use practiced

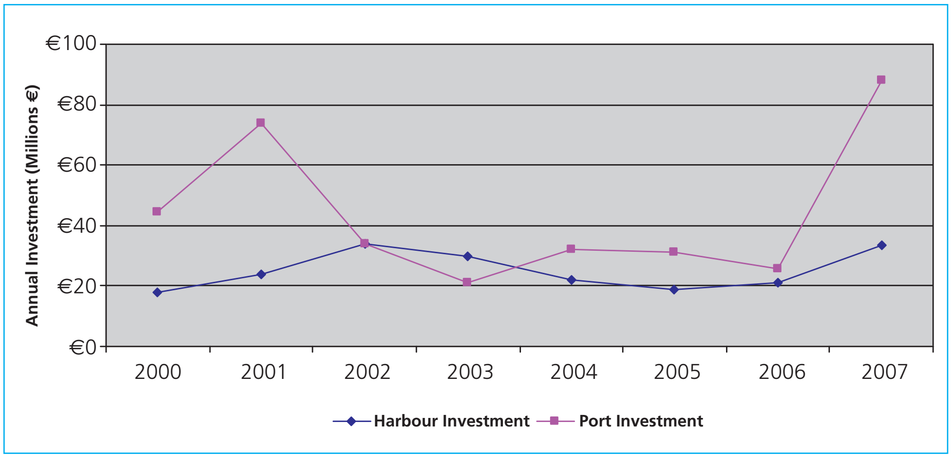

Figure 1. Investment in Irish Ports and Harbours from 2000 to 2007 (McNally, 2008; O'Brien, 2008).

The survey returned a significant amount of information that is stored in a database and has been analysed. This database is a *MySQL* database management system and will shortly be made available online to allow relevant organisations and regulatory authorities access to the data. The online system will allow additional information to be uploaded as necessary and will provide a key resource for the industry in Ireland.

Analysis of the survey data shows that 46% of the total dredged volume is from capital projects with the remainder from maintenance dredging projects. The dredged materials particle size distribution is 6% gravel, 38% sand and 55% silt and clay. Sediment contamination was found at a limited number of sites including the fishery harbours of Killybegs and Castletownbere (presence of TBT) where large scale dredging has been undertaken as part of pier developments. Approaches to dealing with the contamination varied – at Castletownbere the contaminated layer was dredged using an environmental grab dredger, brought ashore, stabilised with a cement product and then exported to Germany for treatment. However, at Killybegs the contaminated material was left undisturbed

The proportion of capital dredged material (46%) is significantly down from 71% in the previous survey of 2003, indicating that the amount or size of capital dredging projects around the country has decreased relative to the 2003 survey. This trend is likely to continue as funding for such developments is now more limited.

Recent capital dredging projects of note include

- Warrenpoint Harbour (25,000 m³) in Northern Ireland that deepened 300 m of quay from 5.4 m to 7.5 m and reinstated an old turning circle which had suffered extensive siltation.
- Rossaveel Harbour (66,100 m³), in County Galway, where dredging was required to create a new ferry basin, a small craft harbour basin and to widen existing berths.
- The Electricity Supply Board (ESB) upgraded one of their generating stations at Aghada in County Cork which involved the laying of a new pipeline 400 m from the shoreline. The total quantity dredged was 16,500 m³ of which 2,500 m³ of granular material was used as backfill.
- Dublin Port dredged 80,000 m³ to improve its bulk handling facilities.
- Castletownbere Harbour dredged 140,000 tonnes of mixed sediment and 29,000 tonnes of rock as part of a 120 metre pier development. A portion of the uncontaminated dredged material was used in land reclamation.

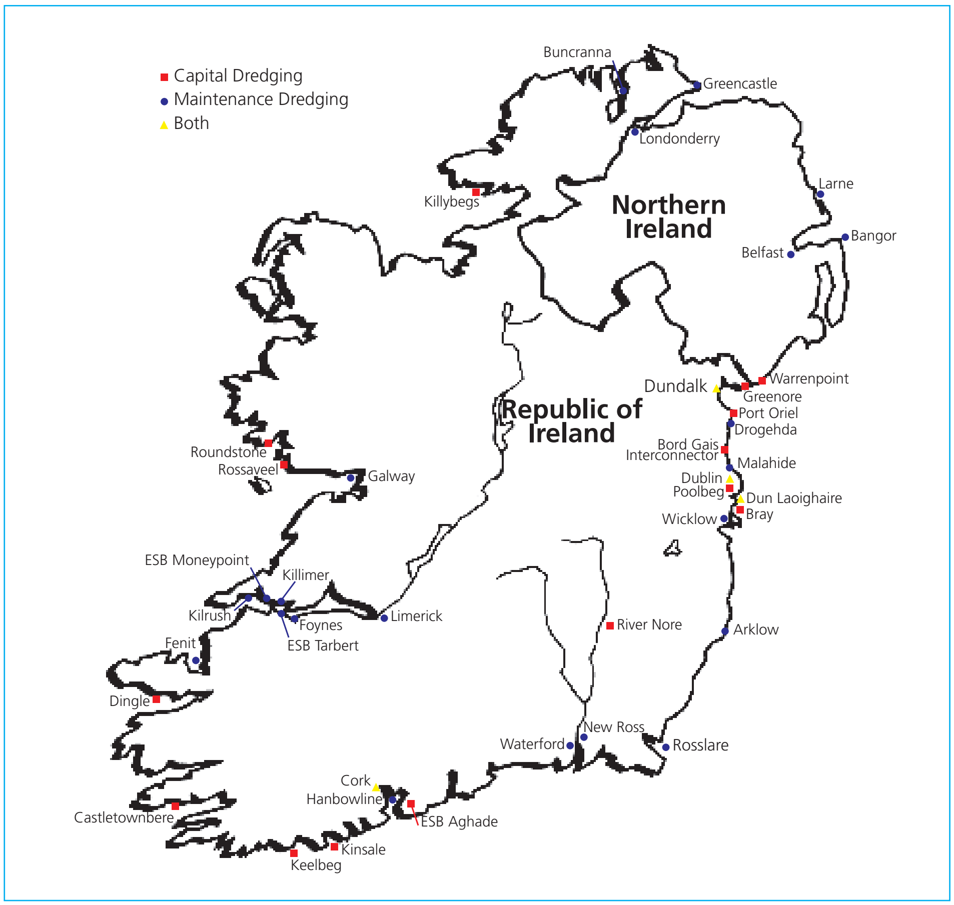

Figure 2. Locations of dredging projects with available data.

A number of dredging projects are currently underway or recently completed:

- The Limerick Tunnel is one of the largest dredging operations in Ireland in recent years with 900,000 m³ of material being dredged; it is currently under construction. 500,000 m³ of this dredged material is to be used in backfilling the tunnel.
- The dredging of approximately 18,000 m³ of material for a 2 km gas pipeline in County Mayo has just been completed.
- Caladh Mór in the Aran Islands in County Galway has recently completed dredging works of 35,000 m³, the majority of which is rock and has been used on site.
- The pier of Cill Ronain in the Aran Islands has also been dredged generating approximately 100,000 m³.
- A new € 300 million deepwater port for Bremore, County Louth is currently at design stage.
- A reclamation of 300,000 m² of land for a new port area for Waterford Port is planned.
- Other planned developments of note are the proposed Port of Cork relocation, development of Greystones Harbour, with Dublin Port and Belfast Harbour also planning reclamation works for expansion purposes.

The annual maintenance dredge requirement for the commercial ports is presented in Table III based on the survey analysis and other available information. The five ports with the largest dredge requirement contribute approximately 90% of the Republic of Ireland's total annual national maintenance dredge requirement. The larger ports currently operate under 5 year Dumping at Sea Licenses with a number of small harbours such as Bunbeg Harbour, Drogheda Harbour, Fenit Harbour, Portmore Harbour, Buncrana Harbour and Greencastle Harbour operating under or have applied for similar licensing arrangements.

The questionnaire survey indicates that 57% of the volume dredged is undertaken by the main commercial ports (see Figure 3). The harbours account for 21% of all dredged material generated with only 2% of the volume dredged attributed to marinas with the remaining 20% classified as 'Other' which consist of projects such as gas pipeline laying and tunnel construction. In capital dredging only 16% of material was generated by the commercial ports while harbours account for 35%, marinas 2% and other projects, as outlined above, account for 47%.

Table III. Annual Maintenance Dredge Requirement for the Main Ports.

Port	Average Annual Maintenance Dredge Requirements (Wet Tonnes)	Frequency of Dredging
Port of Waterford[1]	520,000	Annually
Dublin Port Company[2]	394,240	Annually
Drogheda Port Company[2]	317,120	Annually
Port of Cork[1]	176,400	Annually
Shannon Foynes Port Company[2]	126,000	Annually
Dundalk Port Company[3]	58,800	As Required
Rosslare Europort[1]	42,500	Approx. every 7 years
Port of New Ross[2]	27,276	Annually
Dun Laoghaire Harbour Company[1]	11,875	Approx. every 8 years
Galway Harbour Company[3]	9,000	Approx. every 10 years
Wicklow Port[1]	400	Approx. every 5 years
Port of Greenore[1]	None	Not Required

[1] Survey results, [2] Dumping at Sea Licence Applications & Permits Issued (Department of Agriculture, Fisheries and Food), [3] Harrington *et al*. (2004)

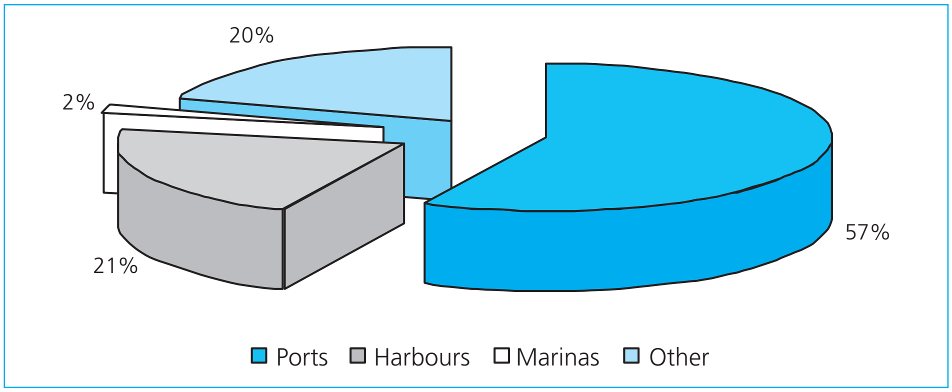

Figure 3. Proportion of dredging classified by type of organisation.

The method of dredging/type of dredging plant used was also investigated in the survey. The most popular type of plant for maintenance dredging was the trailing suction hopper dredger (TSHD) while for capital dredging the backhoe dredger was the most popular. In maintenance projects in recent times the TSHD and bed leveller have been used to achieve the optimum output for the dredging project. For the volume dredged the THSD is the most productive, dredging over 62% of the total; 88% of maintenance dredgings and 32% of capital dredgings.

External contractors are now used for all large-scale dredging works. These include, for example, Tideway, Royal Boskalis, UK Dredging, Dutch Dredging B.V., and Van Oord. There are a number of Irish ports and harbours who have purchased dredgers

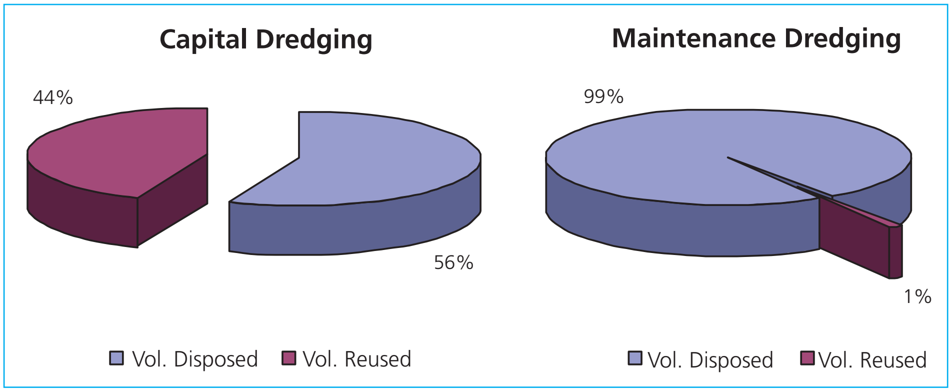

Figure 4. Volumes of dredged material disposed or used.

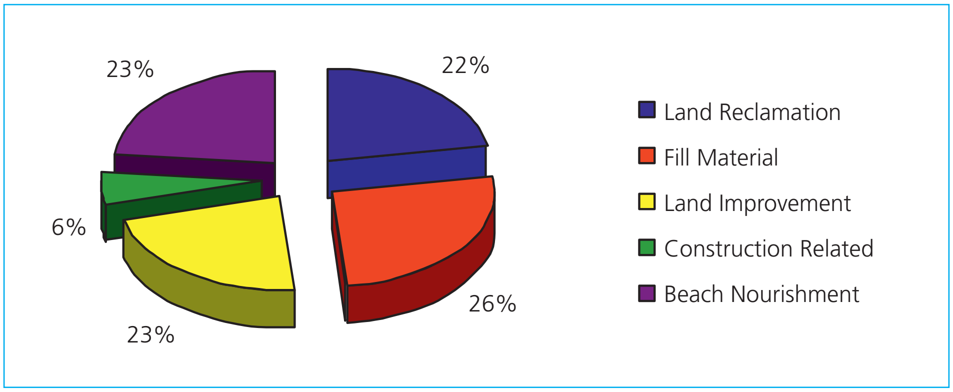

Figure 5. Beneficial uses of dredged material as a percentage of volume used.

in recent years. In some cases this has been a multi functional vessel that can be used for other activities on site. The most used is the grab hopper dredger (GHD), the *Hebble Sand*, which is based in Dundalk Harbour. The harbour purchased this dredger in 2004 as there was a gap in the market place for a dredger that would undertake dredging work in smaller harbours. This dredger has been used in various sites around Ireland, in conjunction with Dundalk's regular maintenance dredging. Shannon Foynes Port Company also has a GHD, the *M.V. Curraghgour II*, which is based in Limerick Harbour all year round. Recently in 2007, Shannon Foynes Port Company invested € 2.4 million in a new multi-purpose vessel, the *Shannon I*.

The boat is involved in dredging, bed levelling and the maintenance of jetties. The Port of Londonderry also purchased two dredgers in recent years. The Trailing Suction Hopper Dredger (TSHD), the *Lough Foyle*, was purchased for € 2.2 million to replace an older TSHD and to supplement the use of the Harbour's other dredger, the *Otterbank*, which is a plough dredger.

The *Otterbank* is leased out to several local sites annually. The Ports of Cork and Dublin recently purchased multi-purpose vessels. The *Rosbeg* and the *M.V. Denis Murphy* are used for buoy handling, plough dredging, towing and anchor handling.

BENEFICIAL USES: AN OVERVIEW

Based on analysis of the questionnaire survey approximately 20% of dredged material is being beneficially used with practically all coming from capital dredging projects. The use of maintenance dredged material is approximately 1% (see Figure 4), which may be unfavourably compared with some European countries. When questioned as to why beneficial uses were not practised, the main reasons given were the engineering aspects of the material, economic viability, transport logistics, environmental constraints and the length of time involved in instigating such a process owing to the licenses and permits required.

Figure 5 shows the beneficial uses practiced for the coarser grained fraction of dredged material. Some examples of use include, 16,000 m^3 in the Castletownbere Harbour Development, 238,000 m^3 in the Killybegs Harbour Development and 1000 m^3 in the Port of Larne for land improvements on site. Londonderry utilised its port owned dredger to bring ashore approximately 34,000 tonnes of sandy material annually for use by the general public. However, with the purchase of the new larger dredger, the *Lough Foyle*, this activity will no longer take place (McCann, 2008).

CURRENT ISSUES/TRENDS IN THE IRISH DREDGING MARKET

The larger ports (Cork, Dublin, Drogheda, Shannon Foynes and Waterford) now operate under 5 year Dumping at Sea Licenses. A number of smaller ports and harbours are currently investigating the possibility of acquiring a long term dredging contract or are operating under this licensing regime.

The Department of Agriculture, Fisheries and Food is encouraging the ports to apply for these licenses allowing timely and full consideration of alternatives to disposal at sea. These types of contracts benefit both parties as it ensures the dredging required is carried out for the port authorities while ensuring that the dredging contractor is guaranteed work over a longer time period.

Some ports and harbours have or are looking into the option of purchasing a small to medium sized dredger. This can provide additional income to the harbour through leasing if the market exists (O'Carroll, 2008). For example, The *Shannon 1* can be leased from its base in Limerick for a basic charge of € 2,750 per day (8 hours) including fuel and crew. It also provides the harbour authority with greater control and flexibility over its dredging operation.

Figure 6. Location and aerial photograph of Fenit Harbour in Tralee Bay.

The presence of contaminated sediments has to date been a localised problem in Irish ports and harbours but has involved export for treatment, at Castletownbere Harbour, for example. This will continue to be an issue and will need to be addressed, for example, in the proposed Bantry Bay Harbour Development.

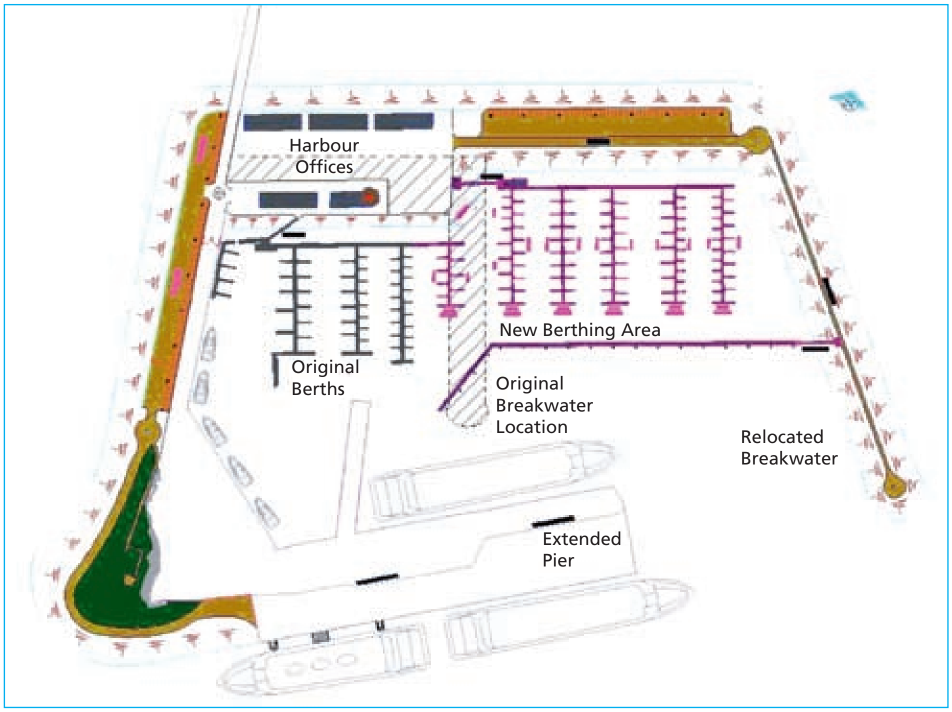

Figure 7. Layout of proposed Harbour Development (Malachy Walsh & Partners, 2008).

The beneficial use of the fine fraction of dredged material in Ireland is limited and long term planning is essential for the development of any such beneficial uses. It would be fair to state that in all but the larger capital dredging project that involve an Environmental Impact Statement (EIS) the potential for the use of the dredged material in the past may not have been fully explored.

The Department of Agriculture, Fisheries and Food has recognised this and now states on its Dumping at Sea License application form that *"The dumping of dredge spoil at sea is only acceptable when other means of disposal are ruled out for ecological or sound social or economic reasons. Even so, for ecological/ environmental/fisheries reasons the dumping of the waste may not be permissible in all cases"* (Department of Agriculture, Fisheries and Food, 2009).

This combined with the encouragement to operate under 5 year Dumping at Sea Licenses indicates the efforts being made to achieve a greater amount of sustainable use of dredged material.

One might also suggest that in the future changing the wording from "dredge spoil" to dredged material might encourage viewing dredged material as a useful product and not a waste.

SELECTION OF BENEFICIAL USE SITES

Harrington *et al*. (2004) identified the limited number of beneficial uses of dredged material practiced in Ireland. Cork Institute of Technology has since undertaken research in this area with some results having been presented in Murphy *et al*. (2008) and Sheehan *et al.*

Figure 8. Local Irish coastline suffering coastal erosion.

(2008). The current ongoing work has focused on analysis of proposed beneficial uses at specific dredging sites (where beneficial use of dredged material has not been practiced to date) to show the potential for such development at the site with possible application to other dredging sites. Analyses of beneficial uses for dredged material at the Port of Waterford and at Bantry Harbour, County Cork are near completion as part of this research effort. Another study is briefly presented below for Fenit Harbour in County Kerry.

FENIT HARBOUR

Fenit Harbour undertakes periodic maintenance dredging as required and is in the planning stages for a capital dredging project. The aim is to identify a potential beneficial use methods that can be utilised both for the proposed capital dredging project as well as subsequently for the irregular maintenance dredging on site. Fenit Harbour is typical of a number of small harbours around Ireland, allowing the research undertaken to be potentially applicable elsewhere and also to potentially influence more sustainable dredged material management.

Fenit Harbour is a small harbour in the south west of Ireland as shown in Figure 6. It is under the jurisdiction of Tralee and Fenit Harbour Commissioners. The harbour itself is on the north side of Tralee Bay and connected to the mainland by an 800 m causeway. The harbour includes a 130 berth marina which is full with a long waiting list (O'Carroll, 2008). The main deep-sea pier is 175 m long with extensive storage facilities available. Liebherr Cranes is the primary commercial user of the harbour.

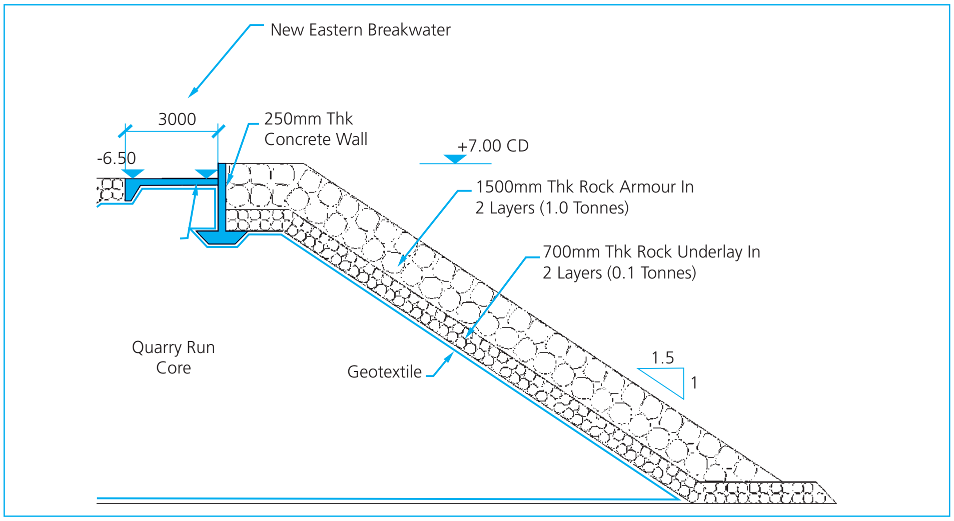

Figure 9. Cross-section of proposed traditional breakwater construction (Malachy Walsh & Partners, 2008).

The land surrounding Tralee Bay includes a number of protected areas. Fenit Island to the north of the harbour is a designated Special Protection Areas (SPA) for the protection of the local wildlife habitats. Most of Tralee Bay is a Special Area of Conservation (SAC).

Shoreline stretches along the bay suffer coastal erosion but available funding to address the problem is limited. Road collapses caused by the severe coastal erosion in the area have occurred; the most recent were in 2007 when two sections of road were damaged. The repair work for one section of road cost approximately € 4 million and Kerry County Council is still in debt as a result of that project, limiting the scope for further investment in coastal protection works. County Kerry, for example, has a coastline of 684 km and it is estimated that approximately 41 km of this coastline is considered to require protection at a cost of over € 30 million (O'Sullivan, 2006).

Current Proposal

The Harbour Commissioners currently envisage two proposed developments; one to extend the existing breakwater (Figure 7), the other to provide coastal protection for a stretch of road connecting Fenit Harbour to the nearby town of Tralee

(Figure 8). These schemes are outlined below and propose the use of traditional rubble round structures. An alternative approach is presented in here involving the use of geotubes with potential cost savings and use of dredged material. This illustrates the potential for such an approach at Fenit and also possibly elsewhere in Ireland.

The proposed harbour expansion involves an increase in the size of the marina and improvements to the commercial harbour facilities through extension and relocation of the breakwater.

Preliminary investigations and design have been undertaken by Malachy Walsh & Partners and have been funded by the sale of land owned by the Harbour Commissioners. Further funding is currently being sought, with initial estimates for the development of between € 10 million and € 15 million.

A schematic cross-section of the proposed rubble mound breakwater design is presented in Figure 9 consisting of a quarry run core, geotextile filter, a rock underlay and 1 tonne rock armour layer.
The original breakwater shown in Figure 6 was constructed of material from Ardfert Quarry (11 kms from Fenit), as well as from Killarney (45 kms from Fenit). For this analysis it is assumed that the Ardfert quarry will supply the project.

The second development involves the protection of a stretch of coastal road between Fenit Harbour and the town of Tralee, which is currently suffering severe coastal erosion, using a rubble mound revetment. The proposed construction is similar to a 200 m long local revetment project completed in 2005 as shown in Figure 10. This stretch of road has had coastal protection in place, however, this system is in disrepair and the remnants are visible in Figure 8. A survey of the road by Kerry County Council has been completed to identify the areas most at risk.

Alternative Proposed

This article proposes an alternative integrating the dredging activities into the construction of the breakwater and revetment using geotubes which have extensive applications in dewatering and marine structures. This would provide the benefits of reduced dredged material disposal at sea and an identifiable beneficial use. A further aim is to show that geotubes may be a practical, feasible and economic solution to local coastal erosion problems when combined with maintenance dredging, thus allowing future projects in the locality to consider this innovative solution, or alternatively at another similar location in Ireland.

The geotubes are designed to receive and retain pumped sediment while allowing the water to escape through the fine pores of the geotube. As the water drains from the geotubes, the contained slurry's density increases to the required density. The two proposed developments are close to the dredging project and, therefore, pumping distance is not an issue. Consultations with Geosolutions Ireland, Malachy Walsh & Partners, Kerry County Council, Ardfert quarry, the Department of Communication, Marine and Natural Resources and Tralee & Fenit Harbour Commissioners have been ongoing. Geosolutions Ireland have indicated that they would sponsor the cost of the geotubes for the revetment project should it be funded, however this is not taken into account for this analysis to reflect the normal costs involved for other potentially similar projects.

Geotube Design and Construction

The type of dredger is generally the most important aspect of such a project as to fill the geotubes requires pumping at as high a volume of solids as possible, preferably to at least 40% solids. A specialised dredger that can pump this high density slurry is required as most inland/port dredgers provide only a fraction of the density necessary to fill the geotubes. These pumps are submerged in the dredging area by hydraulic arms from onshore or from a pontoon allowing most dredging locations to be accessible. Also, smaller versions of cutter suction dredgers with 6-8" pipes can

Figure 10. Before (left) and after (right) revetment construction in 2005 (O'Murchu, 2008).

Table IV. Particle Size Distribution of sediment in Fenit Harbour (Aquatic Services Unit, 2005).

Sampling Location	**% Gravel** >2mm	**% Sand** 63μm-2mm	**% Silt/Clay** <63μm
Berths	0.0	45.6	54.4
Pier	0.0	40.7	59.3
Entrance to harbour	0.0	72.6	27.4

Table V. Amounts of quarry material required for the breakwaters.

Quarry Material	**Traditional Breakwater (tonnes)**	**Geotube and Riprap Breakwater (tonnes)**	**'Pseudo' Geotextile Breakwater (tonnes)**
Core	388,930	56,873	56,873
Filter	41,194	41,194	21,659
Armour	41,997	41,997	41,997
Total	472,121	140,065	120,529
Quarry Material Saving	0	332,056	351,592

Table VI. Amounts of quarry material required for the revetments.

Quarry Material	**Traditional Revetment (tonnes)**	**Geotube and Riprap Revetment (tonnes)**
Core	4,855	1,456
Filter	3,140	3,140
Armour	8,757	8,757
Total	16,752	13,353
Quarry Material Saving	0	3,399

Table VII. Cost of construction for the different coastal structures.

Type	**Cost per Metre (€)**	**Total Cost (€)**
Traditional Breakwater	€ 17,754	€ 7,921,000
Geotube and RipRap Breakwater	€ 11,545	€ 5,124,000
'Pseudo' Geotextile Breakwater	€ 10,669	€ 4,737,000
Traditional Revetment	€ 1,325	€ 265,000
Geotube and RipRap Revetment	€ 1,382	€ 276,500

be utilised. The filling of the geotubes from the dredger must be continuous until the geotube reaches its design height as interruptions allow consolidation of the material within the geotube, which may deform the final shape.

The material in Fenit Harbour has been tested for its suitability for filling geotubes. The sediment in the area was found to be more than 40% sand which is sufficient to allow the geotubes to be used as a structural core. The particle size distribution for three locations within the harbour are shown in Table IV. Chemical testing was also undertaken on the material and showed that the material complied with all relevant quality standards.

The designs of the geotube breakwater and geotube revetment are based on two different approaches. The first, a geotube and riprap structure, is similar to the traditional construction as only the quarry run core material is replaced by the filled geotubes. The geotubes are stacked into position to form the desired shape and covered with a geotextile, rock underlay and a 1 tonne rock armour layer (this rock armour size is also assumed for the revetment). Some quarry run core material may be required to shape the surface of the stacked geotubes. The only difference between this method and the traditional method is in the volume of quarry run core.

The second method, a 'Pseudo' Geotextile Breakwater, is different as it utilises generally only geotextile materials on the inner wave protected harbour side of the breakwater to replace the quarried material protecting the geotube. The exposed side of the breakwater remains as outlined in Figure 9 above with rock armour. A small amount of quarry run core material may still be required to develop the desired shape. This method utilises the geotubes but covers them on the sheltered side of the breakwater with a geotextile fabric such as NAG 550 (an erosion control blanket) or a Triton Mattress (plastic gabion mattress).

After consultation with Geosolutions Ireland and Jonathan Wynn (a geosynthetic consulting engineer), the design of the geotubes for the breakwater was 5 metres wide by 2 metres high. The revetment geotubes are slightly smaller at 3 metres wide by 0.75 metres high owing to the slope they are lying at and the size of the revetment required in comparison to the breakwater (for analysis purposes it is assumed to be similar in dimension to the revetment constructed in 2005 which included quarry run material under geotextile).

Utilising smaller tubes gives several benefits. With stacked tubes, as designed for the suggested breakwater, a better shape can be achieved. There is drainage between the geotubes and they can be tailored to the right size for slope and height purposes. Also, smaller tubes are less susceptible to breakage (Wynn, 2008). It should be noted during design that the final filled height will be 0.66 to 0.75 times the design diameter, as the geotube is elliptical in shape.

Table V shows the quantities required, based on the design of a 444 m breakwater length, for the three types of breakwater structures proposed and the amount of quarried material that can be replaced with used dredged material. This shows that significant savings can be made on the cost of quarried material while using local dredged material that would otherwise be disposed of at sea. Table VI shows the details for the revetment.

Economic Analysis

The costing of both the traditional method and the proposed alternative methods were developed after consultation with market sources. The quarried material was sourced and priced at the local quarry situated at Ardfert, approximately 11 km from the site. The geotextile material was priced from Geosolutions Ireland. Consultation with a Jonathan Wynn, geosynthetic engineer in the UK led to the design of the geotubes as well as the pricing and sourcing of the dredger required. Relevant costings and site drawings for the 2005 revetment were also acquired through the Department of Communication, Marine and Natural Resources. The volumes of quarried materials required were determined based on drawings acquired from Malachy Walsh & Partners.

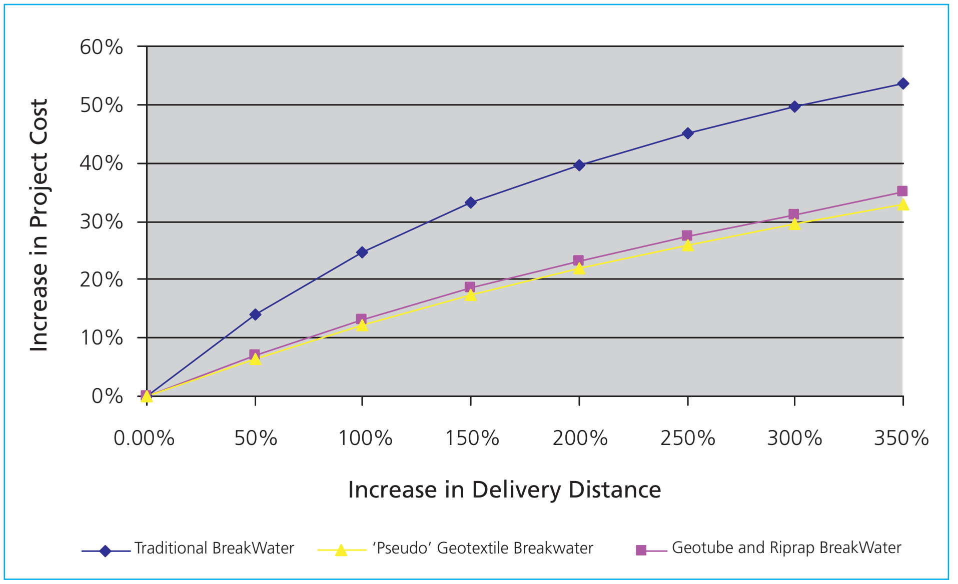

Figure 11. Influence of delivery distance on Overall Cost of Breakwater.

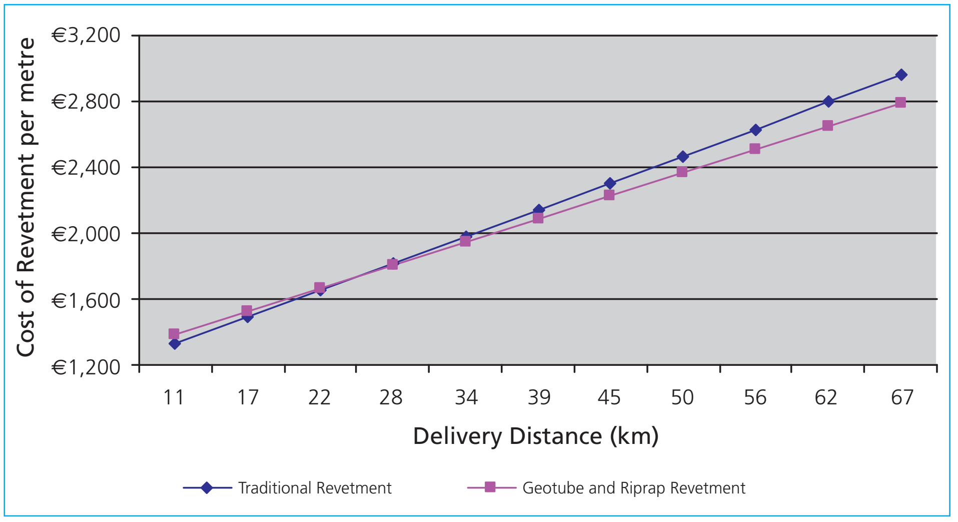

Figure 12. Cost comparison for revetments with increased delivery distance.

Table VII presents estimated current costings for the breakwater and revetment designs. The breakwater analysis shows that the traditional method is the most expensive with the geotube with riprap and the 'Pseudo' geotextile breakwater both being less expensive. The primary factor is the cost of transport from the local quarry.

For the traditional breakwater the transport costs account for approximately 33% of the overall cost of the project. The cost reduction in the two alternative geotube breakwaters results not only from the reduction in the volume of the quarried material required but also from costs in the delivery and placement of this material. From this it may be concluded that the delivery distance from the quarry is a key factor in the decision making process. This is highlighted in Figure 11 which shows the influence of an increase in the delivery distance.

The revetment is a smaller structure (at an assumed 200 m in length) with the estimated costs presented in Table VII. The geotube with riprap revetment is estimated to be more expensive for an 11 km quarry distance. The savings made in transporting and placing the reduced quarry material does not cover the capital costs of purchasing the geotubes and hiring the necessary dredging and pumping equipment for this transport distance. The impact of transport is outlined in Figure 12. For transport distances greater than approximately 25 km the geotube with riprap revetment is estimated to be more cost effective.

Integration into Dredging Programme
Fenit Harbour Commissioners plan a capital dredging programme for the proposed harbour re-development. In addition a regular maintenance dredging programme

is in operation with a current 5 year Dumping at Sea License in place allowing 44,800 tonnes of material to be dredged annually. There is potential for the proposed geotube coastal protection scheme to be constructed in tandem with the capital or maintenance projects.

However, good communication, co-operation and consistent objectives amongst all the relevant parties are essential for successful implementation.

The geotubes require a dredger that is not normally used in Ireland in standard dredging projects as it needs a higher density of slurry to sustain the required fill rate. Coordination would be needed amongst all parties including the Harbour Commissioners, the consulting engineers, the Local Authorities and the dredging contractor. This would allow one dredger to carry out the capital and/or maintenance dredging for the harbour but also produce a raw material for the geotubes.

The amount of dredged material that would be required for the proposed geotube breakwater is approximately 162,000 m³ and approximately 3,500 m³ per 200 m constructed of geotube revetment constructed. By using the dredged material that is normally dredged and disposed at sea to fill the geotubes and construct a coastal structure a sustainable and feasible beneficial use of dredged material may be achievable.

CONCLUSIONS

The analysis presented above suggests the cost savings associated with the use of geotubes for a breakwater development such as at Fenit Harbour and the potential for coastal revetment development. These economic benefits are also supported by the environmental benefits which would occur from a reduced volume of quarried material, with a consequent reduction in the transport demand and a reduced disposal at sea volume.

This research may be applicable to a variety of sites around Ireland once the coastal protection structure being considered is within pumping distance of a port or harbour with a dredging requirement. From a coastal protection point of view, for example, a report on Coastal Zone Management in Ireland identified 1500 km of coastline that is at risk from erosion, with some 490 km in immediate danger (Department of the Environment, Heritage and Local Government, 2001). Geotubes, with the use of dredged material, may provide a sustainable beneficial use for dredge material based on local site conditions.

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