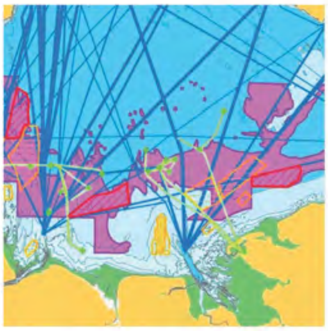
Internal White Paper

Using Dredge Sediment for Habitat Creation and Restoration: A Cost Benefit Review

A summary of the techniques, costs and benefits associated with using fine dredge sediment to 'recharge' intertidal habitat

September 2017

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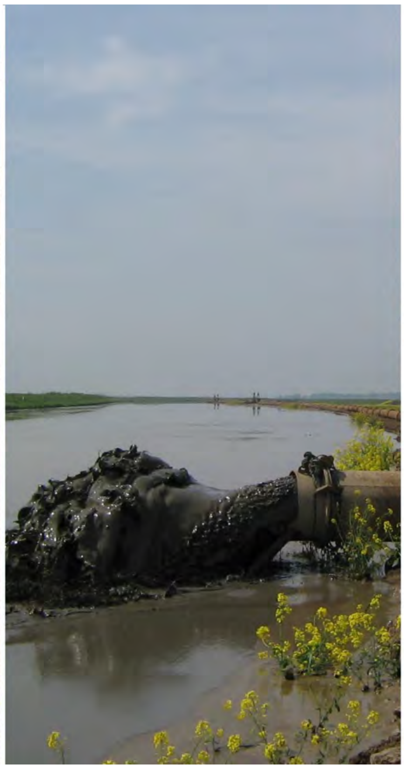


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Colin Scott	Susanne Armstrong	Stephen Hull

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Contributing Authors

Colin Scott, Dr Stephen Hull, Dr Susanne Armstrong,

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ABPmer
Quayside Suite, Medina Chambers, Town Quay, Southampton, Hampshire SO14 2AQ
T: +44 (0) 2380 711844 W: http://www.abpmer.co.uk/

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1 Introduction

1.1 Report background

This ABPmer white paper reviews the techniques, costs and benefits associated with using muddy dredged sediment to restore and create intertidal habitat. It has been prepared in recognition of the fact that one of the major barriers to implementing such 'recharge' schemes is that they often incur extra costs when compared with standard practices for dredge material disposal. These extra costs then present challenges with securing necessary funding and this limits the extent to which such projects can be implemented (PIANC 2009, ABPmer, 2014).

Beyond just thinking about the fees incurred though, there is also a need for a much better understanding about their benefits. This is because there is often a lack of agreement, and clarity, about the value to society of such work and this also makes it difficult to secure funding. There is also a situation where the costs and benefits fall on different actors. In particular, the costs for undertaking (and consenting) dredging and disposal activities often falls to dredging operators, marina owners and harbour authorities. However, these parties are often the least likely to benefit. This disparity between the 'winners' and 'losers' leaves a situation where there is no incentive for 'losers' to participate.

As a consequence of this funding limitation (alongside a number of other issues which are noted in Section 1.2.4), large volumes of dredged material are disposed of as 'waste' each year and very little of this sediment (generally a small fraction of 1%) is used to deliver any direct biodiversity gain. Also, those projects which are implemented, often very successfully, are typically only small in scale. To-date, no genuinely large-scale initiatives have been implemented in the UK coastal zone. As navigational approaches and harbours are generally dredged every year, there are therefore ongoing opportunities to deliver Ecosystem Services gains that continue to be missed. It is hoped that improving and updating our understanding about the costs and benefits of sediment recharge projects will help to inform and address this particular constraint to their implementation.

To throw some light on this subject, and promote further communication on it, this paper therefore reviews a selection of past and present projects that have employed a range of recharge techniques. It describes the lessons learned and what they tell us about how the opportunities for beneficial use of muddy dredged sediments can be realised. This paper then considers the costs and the benefits associated with these habitat restoration schemes based on: the fees they incur; the Ecosystem Services benefits they can deliver for society; and the findings from a hypothetical beneficial use test case.

> One of the major obstacles to using dredge sediment for habitat restoration is that extra costs may be incurred over standard disposal alternatives. This paper seeks to clarify the costs that can be incurred as well as the benefits that can accrue. This has been prepared to help inform future project implementations.

To place this review in context, this paper also summarises the existing policy situation and identifies some of the other beneficial use opportunities (in addition to habitat restoration) that are available. It is hoped that this review will inform and support the implementation of future projects, especially any that are planned at a large-scale to deliver substantial societal benefits.

1.2 Existing situation

1.2.1 Policy and guidance context

Every year around the UK, large volumes of sediment are dredged and disposed of at sea to maintain safe navigation and keep ports, harbours and marinas functioning. This is a vital socio-economic activity and one that is, necessarily, accompanied by a range of environmental, legal and policy considerations as well as consenting requirements. These requirements include those for Marine Licensing, Environmental Impact Assessment (EIA), Habitats Regulations Appraisal (HRA); and compliance testing under the Water and Waste Framework Directives.

These requirements are well understood by those involved in this sector because of the extensive history of navigation dredging as well as the sheer regularity with which such dredging needs to be undertaken (i.e. often annually and in perpetuity). That said, there is also an evolving consenting landscape which, over time, introduces new requirements, perspectives and evidence tests. These arise as new legislation is enforced, as new advice or guidance is provided and as new project and case-law lessons emerge.

While the legal and consenting landscape may shift, there has been a consistent, long-term 'desire' to see dredge arisings used beneficially for environmental and/or socio-economic activities. For example, the need to seek beneficial use opportunities was identified within the 1996 International Maritime Organisation (IMO) London Protocol and other dredge management reviews and guidance (OSPAR, 2014; HELCOM, 2015). It is also a requirement of marine licensing processes under the 2009 Marine and Coastal Access Act (as it was under the preceding FEPA/CPA[1] consenting arrangements).

In addition, the 2008 Waste Framework Directive specifies the need to adopt a hierarchy for which disposal at sea is a last resort. Under this approach, alternative/beneficial uses must be considered as the first step once the need for dredging is confirmed[2]. Identifying beneficial use opportunities is also set to become a policy under emerging Marine Planning Processes (MMO, 2016a) while the need to seek sustainable uses of dredged materials is also indicated in the National Planning Policy Framework (NPPF, 2012).

Motivated by this policy context, and the logic of the argument, many studies have been conducted over several years that have reviewed the value of dredge arisings and sought to illustrate that they are a valuable resource and not a problematic waste (CEDA 2010; IADC, 2009; PIANC 2009; Murray, 2008; Paipai 2003). These reviews often cite a contemporaneous and growing ground swell of support behind the idea of greater beneficial use, but they are also followed by only slight, if any, forward momentum in this field for various reasons.

This situation is, perhaps, even more true today. Certainly the 'ground swell' is still very evident and many parties have recently undertaken, or are currently engaged in, investigations into how sediments can be used more frequently for the combined purposes of coastal habitat restoration, flood protection and climate change adaptation. These include: the Marine Management Organisation (MMO, 2014 and 2016b), The Crown Estate, Royal Society for the Protection of Birds (RSPB) (in prep), The Central Dredging Association (CEDA) (in prep), Solent Forum (in prep) and the Thames Estuary Partnership. It may be that the combination of this impetus and the positive results from recent case examples (see Section 2) will lead to more momentum on this occasion.

1 FEPA -Food And Environmental Protection Act 1985; CPA - Coast Protection Act 1949.
2 MMO/UK GOV.: https://www.gov.uk/guidance/do-i-need-a-marine-licence

1.2.2 Types of beneficial use

Prior to considering how dredged sediments are used for intertidal restoration, it should be emphasised that a range of other beneficial use options exist. These can be divided into three category: engineering uses, environmental enhancements and agricultural/product uses (Harrington and Smith, 2013).

The environmental uses include, in particular, 'sustainable relocation' (HELCOM, 2015; CEDA, 2010, London Protocol, 1996). This is where arisings are placed within the same sediment cell that they were derived from (e.g. subtidally deposited within the source estuary). This helps to ensure that the sediment remains within the local system. A summary review by CEDA (2010) identified that 30% of dredged material is used in this way across the rivers, estuaries and inshore coastlines of Europe.

To identify the amount that is sustainably relocated in England and Wales, the Defra 'Disposal At Sea' (DAS) database for the period 1986 to 2012 was obtained and reviewed for this paper. This indicates that a total of around 727 million tonnes (or 27 million tonnes year^{-1}) of maintenance dredge sediment[3] was deposited at licenced disposal sites over this period. Over the last five years, from 2006 to 2012, the average volume of maintenance dredge excavations was 24 million tonnes year^{-1}. Of this annual average, around 9.4 million tonnes year^{-1} (40%) was sustainably deposited in estuaries (especially large systems such as the Humber, Wash and Severn) or in harbours such as Chichester and Poole. The great majority of this material has been used to maintain general sediment supply within estuaries and harbours rather than to create or restore intertidal habitat at a specific location.

There are also several other non-environmental beneficial use options that exist. These include applications within engineering projects, coastal defences, landclaim, beach recharges, agricultural enhancements, landfill capping/lining or in agriculture (London Protocol, 1996; Sheehan *et al.*, 2008; PIANC, 2009; Harrington and Smith, 2013; MMO, 2014; HELCOM 2015 Guidelines; CEDA in prep.). According to values quoted by Harrington and Smith (2013), between 20 to 30% of dredged material is used beneficially for all types of applications in Ireland, United States, and the Netherlands, whereas as much as 76% and 90% is used in Spain and Japan respectively.

In recent years there have been a number of other studies that have considered, or are now investigating, the multiple ways in which dredged sediments can be reused (including intertidal restoration), instead of dumping them at sea. Such recent initiatives include the CEAMaS project[4] which was completed in 2015 and the ongoing Interreg 2 seas USAR (using sediment as a resource) project[5] and the CEDA (in prep) beneficial use review. The USAR project, for example, is examining innovative approaches such as whether dredged material can be used to make compacted scour blocks as wave breaks.

1.2.3 Extent of beneficial use for intertidal restoration

While there is a clear recognition about the value of dredge material and a desire to see it used beneficially (as described above), there is an evident discontinuity between policy and practice because only a small proportion is actually used in this manner. Certainly very little is used for intertidal restoration. It is encouraging that around 30% of the annual dredge sediment resource is sustainably relocated and notable that a number of beach recharge projects have been carried out.

3 A further 134 million tonnes were deposited from capital dredge activities over this period.
4 www.ceamas.eu
5 www.wrt.org.uk/project/usar/

However, finer silt materials are only rarely used to directly protect coastal habitats and are instead disposed of at licenced deposit sites. Therefore, relatively few intertidal recharge projects have been implemented (as summarised in Section 2.1).

It can be difficult to obtain a clear up-to-date quantification of the amount sediment that is directly used for habitat restoration because there is no database which provides all the necessary information about dredge volumes, sediment types and locations. The marine licensing process does provide useful information and, more recently, valuable online mapping[6] of licenced dredging and disposal sites. However under these licensing processes[7] beneficial use projects are not consistently separated out from normal 'disposal to sea' operations, so it is difficult to identify discrete projects.

Based on past studies, however, and some extra analysis for this review, it appears that only a fraction of 1% of the available resource is used beneficially in this way. For example, Bolam and Whomersley (2005) (quoting Bolam *et al.*, 2003) estimated that around 40-50 million m^{-3} $year^{-1}$ of sediment was available and deposited at sea (at the time of that review), of which less than 1% was used for intertidal restoration nationally. Covering a similar period of time, Paipai (2003) provided a breakdown of the annual proportions and found that the annual tonnages of silt in England and Wales ranged from 29 to 57 million tonnes (approximately 22 to 44 million m^{-3} $year^{-1}$[8]) between 1992 to 2000. During the early years of that period, the proportion of available silt that was beneficially used was typically around 0.07% $year^{-1}$. However, this increased slightly over time with a peak value of 0.8% occurring in 1998 due, largely, to mitigation works carried out by Harwich Haven Authority.

A more recent investigation for the South marine plan area (MMO, 2014) indicated that 'a relatively modest' amount fine sediments (17,000 tonnes) had been reused in this region over a decade. This equates, very approximately, to 0.05% of the total available dredge resource on the basis that at least 30 million tonnes of material had been, or would be, dredged (mostly yielding silt during capital dredging campaigns, between 2011 and 2018). The value of 17,000 tonnes also equates to around 0.1% of the regularly available maintenance dredge resource. This is on the basis that licensed maintenance dredging campaigns in the South could cumulatively provide as much as 1.6 million tonnes $year^{-1}$ over the next few years (again this would be mainly silt).

> There are many ways in which dredge sediment can be beneficially used as well as a clear policy drive to see such projects implemented. However, the rate of project implementation for environmental measures remains limited. It is valuable that around 30 to 40% of the annual maintenance dredge resource is sustainably relocated (kept within the sediment system) but only a fraction of 1% is used directly for habitat restoration. This fraction can be particularly small in years when no notable projects are undertaken, or in areas away from Essex and Suffolk, where projects are most commonly undertaken.

To examine this issue further, it is possible to compare the disposal volumes in the Defra 'Disposal At Sea' (DAS) database against known projects. Over the decade from 2003 to 2012 the database shows

6 http://defra.maps.arcgis.com/apps/webappviewer/index.html?id=3dc94e81a22e41a6ace0bd327af4f346

7 Apparently it was easier to separate out in the past when there were two licence streams and when beneficial use projects were licensed as construction applications (Andrew Birchenough, Cefas, Pers. Comm. Nov 2016).

8 Using a 1.3 conversion factor for 'soft silt mud' HELCOM (2015)

that some 268 million tonnes (wet weight) were deposited offshore during this time (of which 250 million tonnes was from maintenance dredging and 18 million tonnes from capital dredging). This converts, very approximately[9], to 179 million m^3. Over this same period, in the region of 850,000 m^3 of silt was used beneficial for some form of intertidal habitat restoration nationally (see Section 2.1). This represents roughly 0.5% of the total available resource (although larger proportions, of sand particularly, will have been used beneficially in other ways).

The fact that this national percentage estimate is marginally higher than that quoted for the MMO South marine plan area will probably be because larger and more frequent projects have been carried out in Essex and Suffolk over this period. This includes the especially large Allfleet's marsh recharge initiative (550,000 m^3) which was undertaken on land prior to a managed realignment. To date however no particularly large-scale and sustained projects have been undertaken directly on intertidal habitats in the UK.

1.2.4 Barriers to intertidal beneficial use

There are many reasons why only a limited number of generally small-scale intertidal recharge projects have been carried out. These 'barriers to implementation' have been examined within many of the studies that have been cited above (CEDA 2010; IADC, 2009; PIANC 2009; Murray, 2008; Bray, 2008; Paipai 2003) as well as more recently by studies conducted by ABPmer (2014)[10] and the MMO (2014). A summary of these key reasons is presented in Table 1.

Among the central concerns though are that the use of finer (silt) sediment to protect and enhance the ecology of coastal marshes and mudflats is viewed as being difficult (and costly) and considered to pose greater environmental risks (with implications for damage to existing habitats/species or temporary water quality changes). The extra practical cost of beneficially using silts, and the additional fees incurred for obtaining consents, are therefore often seen as a showstopper to implementation. Crucially, also, there is no statutory leadership or sector-specific legislation on this subject that can be used to overcome these key hurdles.

In contrast to silt, larger volumes of sands and gravels are used for activities such as beach nourishment and flood protection and coastal infrastructure. In part, this reflects the fact that there is a clearer understanding, and consensus, about the economic motives for using such materials for such projects. Therefore, if more intertidal habitat restoration projects are to be realised using finer dredge arisings, an equivalent level of clarity and consensus is needed about the motives and costs for doing such work.

This lack of a full understanding about the costs and benefits of intertidal silt-recharge projects is, therefore, a key barrier to implementation and is considered to be a key information gap to be filled if future projects are to be undertaken, especially at a large scale (PIANC, 2009; ABPmer, 2014). Some of the key issues listed in Table 1 are also likely to be magnified for any attempts at large-scale intertidal beneficial use projects. In particular, larger-scale projects using silts will be accompanied by greater levels of uncertainty regarding: technical feasibility; the full range of costs and benefits; and environmental impacts (e.g. loss of or damage to existing habitats/species).

[9] Using a 1.5 conversion factor for mixed sediment created by averaging between the factors for various sediments including 'mud (containing organic matter)'; 'soft silt mud' and 'sand' as quoted within HELCOM (2015).

[10] This involved an ABPmer-hosted meeting in March 2014 which was attended by a range of interested stakeholders (The Crown Estate, Environment Agency, Natural England, Boskalis, ABP, Solent Protection Society) to clarify the barriers to beneficial use and the actions that could be undertaken to resolve them.

Table 1. Issues/barriers currently which constraining beneficial use of dredge sediment

Issues	Summary of the Barrier(s)
Leadership	There is an absence of statutory leadership and no Government department taking ownership of, or championing, this subject.
Legislation and Consenting	There is no centralised legislation pertaining to dredging. In large part because of this, and the multiple separate legal drivers, the consenting process is very complex and lengthy. This means that it is generally easier to get a disposal licence.
Economics: Cost	It is often cheaper to dispose of sediments subtidally and offshore than to use them beneficially for habitat restoration. This is because there are often extra technical challenges (and costs) for sediment handling, vessel change, installation of bunds etc.
Economics: Funding	Linked to the preceding point there is also a need for funding sources and to clarify who benefits - especially because the current situation is that the parties which could benefit are not necessarily the ones to incur the costs (i.e. the port/harbour operators). Also, funding for schemes under Flood and Coastal Risk Management (FCRM) process is not assured.
Market malfunction and poor co-ordination	There is an onus on the ports/harbours/marinas to re-use or recycle material but no corresponding requirement of coastal managers to find materials to recycle (i.e. there is supply without clear demand). Also, the available sediment may not match with FCRM scheme requirements and there are often issues of timing, with mismatches occurring between when sediment is available and when it is needed (or can be used/consented for use).
Sediment type and associated technical challenges	It is considered easiest to use coarser sand/gravel sediments rather than silt for mud and marsh recharge.
Uncertainty of impact	There are concerns over potential environmental impacts arising from habitat recharge works.

Source: Derived from ABPmer (2014)

The ABPmer (2014) review identified a range of possible actions to address these barriers of which clarifying the costs and benefits is one and is a motive for the production of this white paper. Another generic action highlighted by Murray (2008) is to maintain communication about projects with a view to gain trust between the public, regulators and other stakeholders. It is hoped that this white paper can also contribute to this required and ongoing process of communication.

1.3 Review methods

As described above, the costs and benefits of intertidal sediment recharge schemes are clearly subjects which warrant consideration to confirm whether such initiatives can be effectively implemented. This clarification is especially needed to understand whether large scale beneficial uses of muddy sediments can be undertaken in the UK for the first time. However, these are not issues that have been examined in much depth previously and in part this will be because there is no simple 'one size fits all' approach to beneficial use. Instead, there are multiple ways to carry out recharge work and multiple different levels of cost and degrees of benefit depending upon the particular site-specific conditions.

It is possible however to understand this subject through reference to different known strategies and case examples. To set a context for this review, therefore, Section 2 provides an initial overview of the four main technical approaches and the general status and costs of intertidal sediment recharge in the UK. Then Section 3 considers what is known about the benefits. Section 4 presents a cost benefit analysis framework and illustrates its application to a hypothetical intertidal sediment recharge. Section 5 presents conclusions and recommendations.

To inform this review of the practices and costs, information has been collated from a range of available published and unpublished documents as well as from a number of experts in the field. Indeed, because there is limited amount of written reporting on this subject, the main and most valuable information in this review comes direct from specialists as listed in the acknowledgments section at the start of this paper. To preserve the flow of text, each individual personal communication has not always been quoted here, but we would like to emphasise again that this study could not have been done without the support of these participants.

2 Intertidal Recharge Practical Review

2.1 Completed project and techniques

A summary of the main intertidal recharge projects that have been undertaken in the UK over the last 20 years or so is presented in Table 2. These are specifically projects that have used fine sediment placed directly onto intertidal marshes and mudflats.

Table 2. Intertidal or low shore recharge works over the last 20 years (1997-2017)

Operational Approach	Project	Year(s)	Volumes
Backhoe Extraction to Backhoe Placement (see Section 2.2)	Maldon (and Northey Island), Blackwater	2001 to present	Approx. 2,000 m^3 yr^{-1}
	Loder's Cut Island, Deben	2015	Approx. 800 m^3
Back-hoe Extraction to Pumped Placement (see Section 2.3)	Boiler Marsh, Lymington (Wightlink Project)	2012 and 2013	4,500 m^3 marsh recharge mitigation over two annual campaigns
Cutter Suction Extraction to Pumped Placement (see Section 2.4)	Lymington Intertidal Restoration (Lymington Harbour Commission Project)	2012 and 2013	3,125 m^3 marsh recharge mitigation over two annual campaigns
	Levington Marina, Orwell	Several years/ Annual	Approx. 10,000 m^3 yr^{-1}
	Blue Lagoon, Poole Harbour	Several years/ Annual	Very small scale regular work of around 600 m^3 yr^{-1}
Suction Extraction to Pumped/'Rainbowed' Placement (see Section 2.5)	Allfleet's Marsh, Wallasea, Crouch	2006	550,000 m^3 - one-off large scale placement on managed realignment before inundation
	Horsey Island, Hamford Water	1998 to 2006	After initial phases of shingle and silt import in early 1990s 107,750 m^3 used over four campaigns in two areas.
	Shotley (North), Orwell	1997	22,000 m^3 maintenance 'dredgings' pumped behind a 75,000 m^3 retaining gravel bund (fronting 2 km earth wall)
	Trimley, Orwell	2003	22,000 m^3 for gravel bund (1.4 km long 50-60 m in front of seawall) then backfilled with mud (volume of silt not known)
	Shotley (South), Orwell	2003	15,000 m^3 of dredged gravel and silt (retained using clay and gravel bund)

Source: www.omreg.net

In total there have been around 12 such projects over the last 20 years. Some of these have been one-off initiatives while others have been undertaken more regularly. There may be other projects that have been conducted that are not on this list and this may include other initiatives that have used a combination of silt and shingle recharge techniques. There will also be projects (such as recent initiatives at Lymington) which have involved placing material on the shallow subtidal areas which are not included here as they do not involve direct intertidal recharge. However, these nearshore 'subtidal placement' projects may well have indirect benefits for intertidal habitat.

For the intertidal recharge projects listed in Table 2, a range of different techniques were adopted for the dredging excavations and then for their subsequent placement. The most suitable approach at any given location will be dependent upon several factors including:

- The sediment type;
- The level of sediment contamination;
- The availability of appropriate equipment;
- The proximity of an appropriate receptor habitat; and
- The advice of regulators and stakeholders.

To recognise and describe this variability of approach, the projects in Table 2 are divided into the following four 'operational categories' based on the excavation and deposition approaches:

- Back-hoe Extraction translocated for Back-hoe Placement (Section 2.2);
- Back-hoe Extraction translocated for Pumped Placement (Section 2.3);
- Suction Dredge with direct Pumped Placement (Section 2.4); and
- Suction Dredge translocated for Pump/Rainbow Release (Section 2.5).

The following sections (Sections 2.2 to 2.5) review each of these categories of operation further and consider the outcomes and costs from selected project examples.

2.2 Back-hoe extraction and back-hoe placement

This is probably the simplest, and in many ways also the most effective, strategy for delivering dredged sediment to a receptor site especially at a small-scale. It involves excavating sediment with a back-hoe into a hopper, relocating to a receptor site and then depositing materials by a reversal of the same excavation/backhoe approach. This technique ensures that the sediment remains relatively well consolidated (with low water content) which maximises its stability at the deposit site.

This technique has been undertaken regularly at Maldon (Blackwater Estuary, Essex) for several years. Each year around 3,000 tonnes of channel maintenance (approximately 2,000 m^3) is taken from the upper Blackwater Estuary channel and harbours and then placed, mainly, on a saltmarsh spit on the north bank of the Chelmer River (immediately downstream of the Hythe Quay at Maldon). The material is dredged by an excavator mounted on a hopper barge itself and the barge then moves to the high water margins of the receptor marsh where the reverse operation takes place (see Image 1).

The approach has been used to nourish the Chelmer River saltmarsh spit (see Image 2) since 2001 and this nourishment followed on from an early marsh restoration initiative that was undertaken here in 1993. That original restoration and the ongoing recharge has repaired the marsh which was breaking up and causing erosion behind (Nottage and Robertson, 2005). The sediments deposited through this recharge approach are rapidly colonised by plant species and, consequently, the Chelmer Marsh has continued to grow and provide increased erosion protection over time. Therefore, while the sediment volumes are not large, this project has shown that repeated year-on-year small-scale applications of consolidated material deliver clear benefits.

Photos: ABPmer September, 2016

Image 1. Maldon saltings recharge showing barge-mounted excavator and recharge area

The costs for this work are likely to be in the region of £1,000 per barge load and each year around 25 barge loads are required for the Chelmer Marsh (with each barge carrying around 120 tonnes or around 80 m^3). Thus the annual cost is estimated to be around £25,000. In addition to this work, on an intermittent basis, material has historically been placed on the south bank of the river west of Northey Island. More recently this work has been carried out on Northey Island itself. At these sites, this work often takes place on the exposed drying intertidal (whether at the excavation and receptors sites).

An almost identical approach, incurring comparable fees, was adopted on Loder's Cut Island in the upper Deben Estuary in September 2015. This was as a one-off exercise that involved total of 16 barge loads being taken from Ferry Quay at Woodbridge and transported around 800 m to Loder's Cut Island. This 'Cut' is an adjacent and small navigation channel which was historically formed by manual (by-hand) excavation in this part of the estuary.

Photo: Jim Pullen UAV Surveys

Image 2. View of the recharged Chelmer River spit downstream of Maldon

For this work, a small 65 ft (20 m) barge was used that had an aft-mounted excavator and a carrying capacity of 75 tonnes (or around 50 m^3) each. This was suitable for use in the constrained and busy upper estuary. Like the work at Maldon, the material from each barge was back-hoed out on the top of the tide with the barge being floated in and out over one high water period.

A visit to the site a year later (see Image 3) indicated that the material had remained in place. It was still present as an elevated strip of around 0.1 ha in size (around just 15 m by 7 m) that had remained *in situ* with only some slumping on the channel or 'cut' side. Birds were observed roosting on the raised mound shortly after completion of the work. One year later the upper margins of this deposited strip had a thick cover of *Salicornia* spp. as well as occasional Sea Aster (6-7 plants) and one *Spartina* plant. There were also signs of invertebrate burrows and bird feeding on the unvegetated lower margins on the channel/cut side.

Photos: ABPmer September, 2016

Image 3. Loder's Cut Island recharge showing barge-mounted excavator and recharge area

This work cost in the region of £14,000 for the work itself plus a further £2,500[11] for the MMO licence. At this small-scale and at this location the main benefits are from: restoration of marsh habitat itself; provision of a potential bird roosting area and the fact that it will be helping to direct and maintain flows through a navigable 'cut'. The benefits also come from allowing the work to take place at all. This is because there are no real alternatives and taking materials offshore or into lower reaches of the Deben would have been more costly. Local subtidal relocation in the upper reaches would have adversely affected navigation in the constrained and silted upper reaches of the Deben Estuary.

2.3 Back-hoe extraction translocated for pumped placement

This technique typically involves a 'double-handling' approach in which dredge arisings are excavated using a back-hoe approach, but then transported in a hopper barge to a separate location where the sediment is then pumped to a receptor site. This double-handling approach is appropriate for projects where the receptor site is distant from the extraction location and especially where it is inaccessible to hopper barges. This technique has the advantage of allowing a high degree of targeted control over the location, rate, nature and extent of the sediment deposition to receptor sites that are otherwise difficult to access. It does, though, incur additional costs to cover the extra vessels, equipment and working time that are required.

It was necessary to use this strategy for the Wightlink Ltd. Boiler Marsh recharge project at Lymington. This project, which was carried out in 2012 and 2013, involved using sediments dredged from the Lymington marinas and navigable channel to recharge a discrete and deteriorating habitat at the heart of a large saltmarsh to the east of the harbour entrance. Back-hoed material was placed in a hopper barge which was then used to transfer the material along a tidally constrained creek. The

11 £700 being the actual fee under tiered Marine Management Organisation (MMO) licencing and the bulk of this fee being for sediment contaminant testing.

hopper barge was then moored alongside a spud platform and from there the sediment was pumped into marsh (see Image 4 to Image 7).

Photo: ABPmer March, 2013

Image 4. Wightlink recharge showing hoppers moored at spud barge and pumped deposit

The sediment was pumped from the barges at relatively high densities of up to 50% silt (ABPmer, 2013) and much of it settled quickly out of the water column and was retained within the deposit site and close to the site of the discharge. At the deposit site a series of 10 polder and hay bale fences had been placed for sediment retention. These fences were effective although a proportion of sediment left the area though the outer boundary. However, this exported material evidently settled close to the site and did not disperse widely (ABPmer, 2015) (see Image 5).

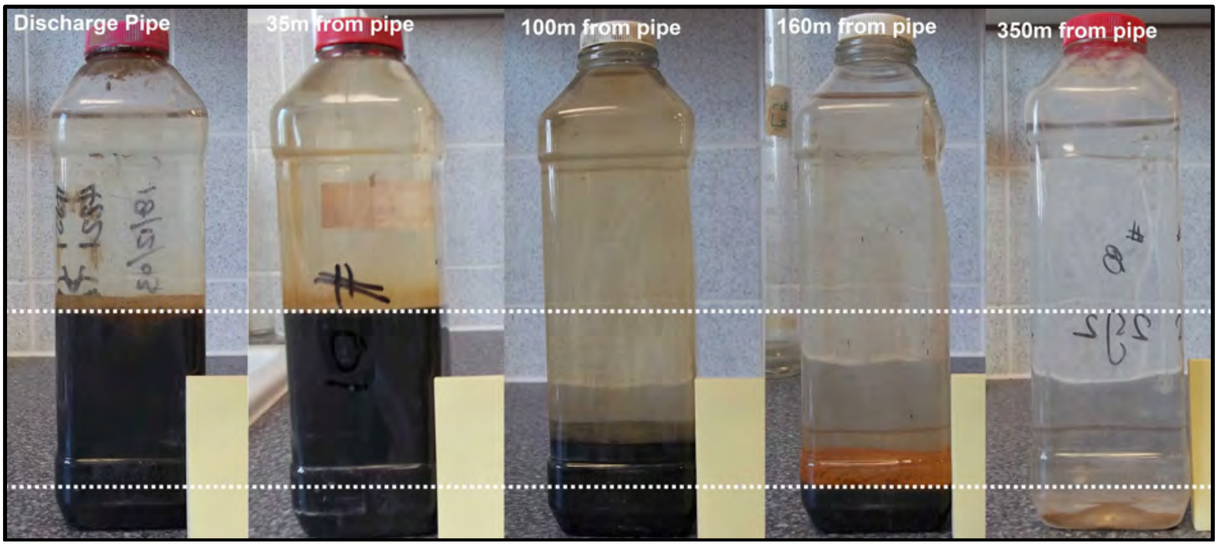


Image 5. Water samples in recharge area (3 on left) and outside (2 on right) in marsh creek

This recharge project was designed to offset potential effects on intertidal habitats arising from ferries operating between Lymington and Yarmouth. Crucially, this approach was designed to provide this mitigation in an adaptive manner so that, were impacts to be greater than anticipated, more restoration could be undertaken beyond the first two proposed campaigns. The approach proved to be successful over two campaigns (ABPmer, 2015), with the sediment still being retained at the deposit site after several years (long-term monitoring ongoing). The outcome has been an improvement to the quality of the habitat at the deposit site which changed from eroding clay mounds and anoxic channels to a mixture of mud, marsh and clay habitat (ABPmer, 2015).

This Wightlink Ltd project also reduced the rates at which the marsh surrounding the deposit site decays (a value calculated using a distinct 'hectare-year' metric that has been used on other Lymington projects). This was because the recharge was deliberately located at the end point of a large channel which was cutting through the marsh. Without intervention, the channel was going to soon fracture the marsh into two parts and then accelerate the rate at which the whole marsh eroded.

This delay to the loss of marsh also provides benefits from delaying the moment when the inner harbour and mooring areas of Lymington become exposed. It also, potentially, delays the moment at which the Lymington Harbour Commission (LHC) needs to extend construction of rock armoured harbour protection. This erosion of the Boiler Marsh has been taking place since at least the 1940s and the marsh habitat is expected to be lost entirely (assuming there is no intervention) by around 2040. It is inherently difficult though to quantify the benefits from delaying loss or delaying the costs incurred from the consequences of loss.

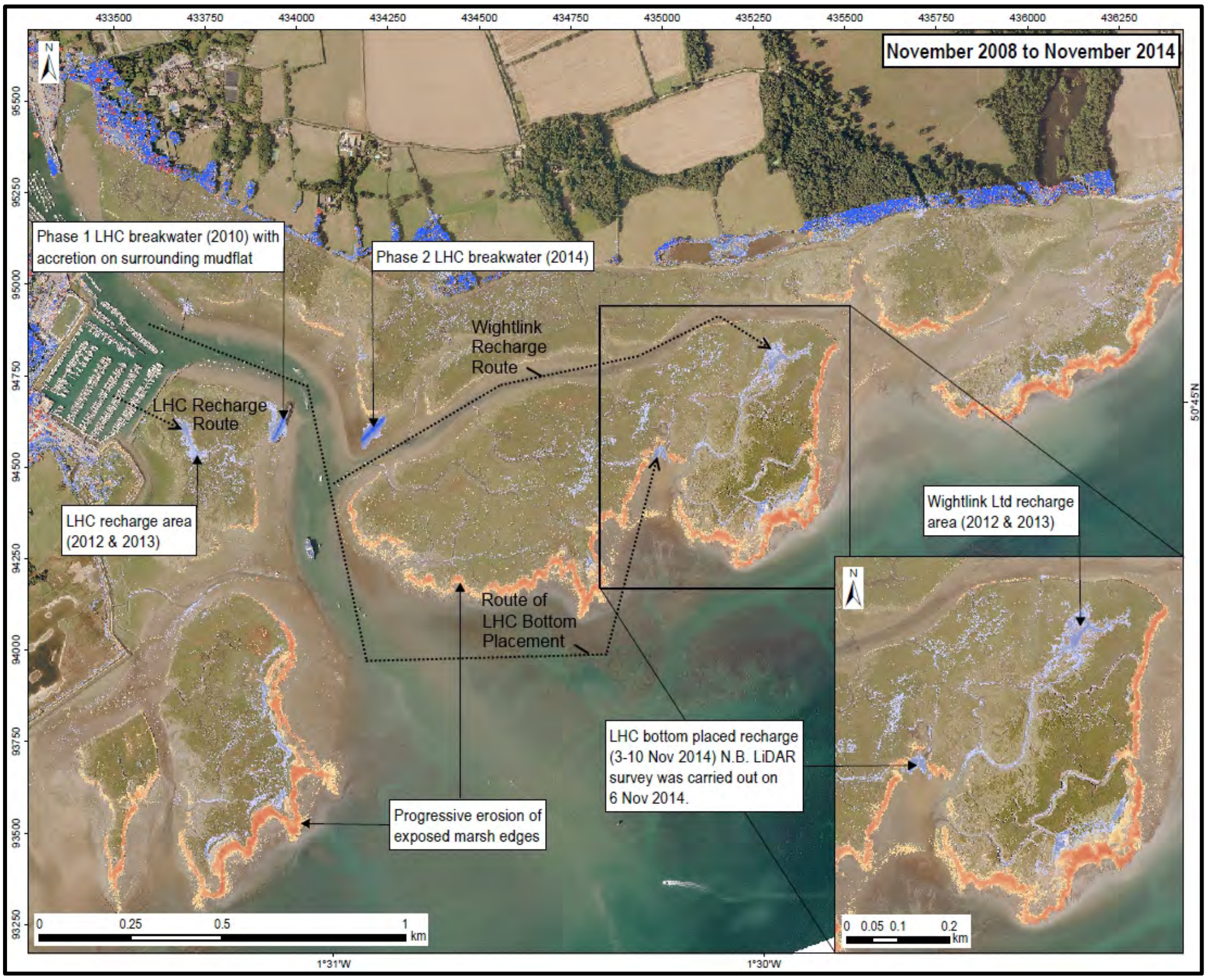
Photo: Land and Water Ltd, 2012

Image 6. Wightlink recharge work showing spud barge and discharge pipe to recharge area

This project was however atypically costly. The estimated total fee for this work was £500,000. This high fee was incurred for many reasons including the need to: accommodate a rapid turnaround following a public inquiry judgement; install fencing in difficult weather conditions at locations that were difficult to access; pay fees for leasing the compound site and for berthing/mooring; incur costs for the dredge material (with these fees equating to the extra costs incurred by the on-site contractor for operating under tidal constraints as compared against the fees incurred for offshore disposal without such constraints); as well as costs for a monitoring programme and hosting and overseeing a management panel and, where required, securing legal advice.

For the Wightlink project, several different pieces of equipment were needed to convert the back-hoe excavated material to a pumped discharge. However, it is also recognised that new equipment is now available that can undertake this whole process within the same craft and without the need to double handle. For example such an approach was used at Brightlingsea Marina where the hopper that receives the back-hoed materials has an integrated pressure jet that breaks the sediment up and integrated pump and pipe that allows for remote sediment dispersal into the adjacent tidal channel[12]. This is likely to be a cheaper approach than double handling. It was also helpful at Brightlingsea, where, although the project is relatively small scale, the working conditions are quite complex and the tidal working windows are relatively small.

12 https://www.youtube.com/watch?v=56lfRtfQ3dA



Environment Agency LiDAR Data

Image 7. Lymington Recharge activities against a 'LiDAR difference' backdrop[13]

2.4 Cutter suction dredger and direct pumped placement

This approach involves having a cutter-suction dredger working within a marina/harbour which then pumps sediment directly to a receptor site that is located nearby. There are a few examples of this approach and two particular examples are at Suffolk Yacht Haven (SYH) near Levington on the Orwell, Essex and further recharge project undertaken in 2012 and 2013 at Lymington by the Lymington Harbour Commission (LHC).

At Levington, recharge work has been undertaken using this approach since the late 1990s, with the first licence being issued in 1997/98. At this site, maintenance dredge arisings from the marina are pumped directly to adjacent foreshore areas (formerly the sediment had been pumped to land behind). In some areas sufficient material has remained to raise the tidal height of the foreshore to allow saltmarsh plants to colonise.

13 The difference plot illustrates the elevation changes between 2008 and 2014; marsh lowering/erosion areas are red, while marsh raising/recharges areas are blue.

Today, there are four intertidal locations surrounding the Suffolk Yacht Haven that are used for the placement of sediment from the marina. These receive around 10,000 m^3 of material excavated each year to maintain depths in the marina. Recently, in 2014/15, the material was pumped to a more distant but also more sheltered degraded marsh area ('North Marsh') which lies some 500-600 m away. At this site the soft fluid sediment was retained in the creek using a system of coir logs held in place by wooden posts (see Image 8).

Photo: ABPmer, February 2016

Image 8. North Marsh recharge site after receiving sediment from Suffolk Yacht Haven

As the material is pumped directly to site there is a low percentage of sediment in the water (perhaps 10%) as it is released to the discharge site. As it is very fluid there is inevitably a lot of dispersion of sediment into the wider environment. This dispersed material is understood to be retained locally within the estuary/creek system (which would match observations made at Lymington following the Wightlink work). During a site visit in February 2016 for instance it was clear that fluid mud was still being retained in the creeks behind the coir logs at the North Marsh site (see Image 8).

This is another example of a site where the beneficial approach is demonstrably the most cost-effective strategy. For this project, beneficially using maintenance dredge sediments on the adjacent marshes in this manner is cheaper than exporting the materials to a more distant location (even within the Orwell). The Suffolk Yacht Haven (SYH) owns the equipment and uses its own staff to carry out the work and therefore there are no sub-contractor costs, but all fees for the maintenance and implementation of the work fall to SYH. Very roughly, such costs are approximately £80-90,000 per year (for wages £40,000; insurance £5,000; fuel £15,000; maintenance £25,000). The process of repeat licencing was considered to be very low at around £2,000. On this simple basis, the annual beneficial deposit of 10,000 m^3 silt to the local intertidal areas incurs a fee of £8-9 m^{-3}.

At Lymington a similar technique was used by the LHC with a cutter suction dredger being employed to dredge the Yacht Haven Marina and then pump sediment direct to the adjacent marsh (see Image 7)[14]. This recharge work was undertaken as mitigation for losses of intertidal habitat caused by constructing a rock armour breakwater. As with the Wightlink Ltd recharge work at Lymington (see Section 2.3), the idea here was to achieve the mitigation by reversing a process of ongoing marsh decay which is occurring rapidly on the Lymington site. In this case both the recharge and the protection then afforded by the breakwater were designed to act in tandem to deliver a long term gain (Black and Veatch, 2012).

14 A similar but very small scale initiative is also carried out at Blue Lagoon Poole where sediment from an access channel is pumped to higher areas of the intertidal.

A 0.5 ha area of decaying marsh habitat was raised up using around 3,125 m^3 of sediment which was pumped directly from the nearby Lymington Yacht Haven over two campaigns (1,625 m^3 in 2012 and 1,500 m^3 in 2013). At the point of the discharge the sediment concentration in the water was 25% and the majority of the sediment (at least 80%) was estimated to have been retained within the defined recharge area (Lowe, 2012, and Black and Veatch, 2012). In contrast to the Levington example, the delivery of the retaining materials was quite complex because the marsh island was not easily accessible. This work cost a total of £100,100 (£61,500 in 2012 and £38,600 in 2013).

In more recent years, the LHC has also undertaken additional habitat replenishment work in which material is back-hoed into a hopper translocated to the lower marsh edge and 'bottom dumped into the shallow subtidal. This approach is similar to sustainable relocation in which sediment is excavated and then disposed of subtidally within the local sediment cell (see Section 1.2.2). However, the intention here is to get as close as possible to the marsh edge and create a sacrificial bund that reduces wave energy hitting the marsh behind.

To date, three LHC subtidal deposit campaigns have been undertaken (November 2014, January 2015 and January 2016) with volumes increasing on each occasion (2,000, 6,086 and 8,695 m^3 respectively). The effectiveness and benefits of this work are still being examined through monitoring but this approach is expected to be much better than taking the sediment out of the system to offshore deposit sites. The extra value for the purposes of this review is that three different recharge approaches have now been conducted at Lymington and this offers a very valuable opportunity to compare and contrast the costs and benefits of these different approaches with offshore disposal options.

2.5 Suction dredge translocated for pump/rainbow release

This method involves a cutter-suction dredger that carries out the sediment removal and placement. It is typically used for larger projects (e.g. for deepening harbour and port approach channels) and on projects where sediment needs to be translocated some distance from the dredging site. Due to the size (draft) of the dredger, it cannot then approach too close to the area that is being recharged and, therefore, the approach is to 'rainbow' the material in or to pump it in a more targeted fashion via a pipeline.

This approach has been used on a number of occasions as part of the beneficial use initiatives undertaken by the Harwich Haven Authority (and often in partnership with the Environment Agency and Defra) including at: Shotley foreshore (Orwell Estuary), Trimley foreshore (Orwell Estuary), Horsey Island (Hamford Water) and Allfleet's Marsh (Wallasea Island, Crouch Estuary) (Image 9 and Image 10). Many of these projects have been well monitored so that we have a good understanding about how they have functioned.

The Shotley and Trimley work involved the use of sediments from the Port of Felixstowe as mitigation measures. At Shotley (North), a trial recharge was carried out in 1997 involving the use of clay/shingle material to create a fronting bund, followed by silt and sandy gravel recharge behind. Six years later, in 2003, a similar approach was undertaken at Trimley. Before these initiatives, almost all the marsh in front of Shotley North had been lost while at the Trimley site, the foreshore had been eroded to clay. These recharges were carried out to raise intertidal elevations and therefore improve degraded foreshore areas, protect vulnerable sections of seawall and reduce flood risk to hinterland areas (including the Trimley Nature Reserve).

In 2003, further work was undertaken at Shotley (South) which included the creation of clay bunds around the Shotley Marina that were then infilled with silts. These measures were undertaken as mitigation for potential impacts arising from the Trinity III terminal development at Felixstowe (Royal HaskoningDHV, 2013).

Both gravel bunded sites (at Shotley (North) and Trimley) have functioned well and achieved a stable habitat configuration after a period of shingle roll back. A key distinction between them is their tidal elevation, with the habitat created behind the shingle bunds being different at the two locations. Shotley is 0.75 m higher than Trimley and, hence, the Shotley silt has been colonised by marsh plants, while the Trimley site has remained mainly as mudflat. In total, around 23 ha of intertidal habitat is believed to have been enhanced by this work (Royal HaskoningDHV, 2013).

Photo: Defra, May 2006

Image 9. Allfleet's Marsh recharge showing dredger and sediment entering retaining bund

As this approach requires much larger equipment it is inherently more expensive and the fees can be temporally very variable in response to shifts in the market. At Allfleet's Marsh the earthwork to build the new sea walls cost around £1.5 million while the recharge cost closer to £1 million[15]. This equates to the equivalent of just under £2 m^{-3} for the dredge sediment used and is based on the extra cost incurred to take the material to Wallasea rather than dispose of it at sea.

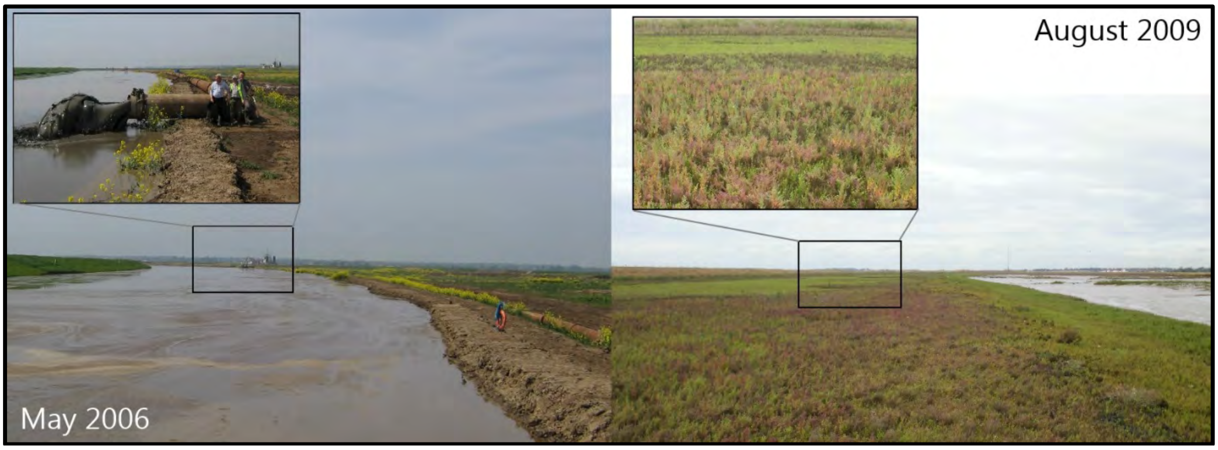


Photo : ABPmer 2006 and 2009

Image 10. Allfleet's Marsh during final recharge and then 3 years later with dense plant coverage

15 The realignment cost around £7.5 million.

This technique was also used on a number of occasions to protect the exposed north side of Horsey Island. Horsey Island lies at the centre of the Hamford Water coastal inlet (Essex) and, due to its location and size, the island plays an important role in providing wave protection for the wider 'Walton Backwaters' and the shoreline behind. The recharge work was carried out using shingle and silt to protect deteriorating coastal defences and eroding habitats. The sediments were derived from capital and maintenance dredging work at Harwich and Felixstowe and there were six phases of work over several years (ABPmer, 2016), as follows:

- **Phase 1 1988**: Installation of Thames Lighter Barges to act as wave energy breaks;
- **Phase 2 early 1990s:** Importation of shingle and sand (148,000 m^3) over several phases (starting with 18,000 m^3 in 1990) to create a new barrier along the alignment of the lighter barges;
- **Phase 3 1992:** Small-scale trial of silt recharge onto saltmarsh (<1,000 m^3) undertaken at the south-east corner of the island;
- **Phase 4 1998:** First major importation of silt (20,000 m^3) over 2.7 ha of mudflat behind the sand and shingle barrier to raise intertidal levels, stabilise the barrier and create marsh habitat;
- **Phase 5 2001 and 2003:** Second and third importation of silt in 2001 (15,750 m^3) and 2003 (25,000 m^3) to 'top up' intertidal area behind the sand and shingle barrier;
- **Phase 6 2005/06:** Importation of silt (47,000 m^3) over two phases in November 2005 (21,000 m^3) and January 2006 (26,000 m^3) on to a separate area of deteriorating saltmarsh to the west of the sand/shingle barrier to raise and restore this degraded habitat and protect the sea wall.

These phases of work have been successful because the mud and shingle have been relatively stable. The shingle barrier retreated shoreward after deposition but showed greater stability once the mud was placed behind it (ABPmer, 2016). A recent photograph of the site is shown in Image 11. Like the Trimley and Shotley (North) projects, this has demonstrated how both coarse and fine-grained dredged sediments can be used effectively to build up and restore intertidal habitats and enhance coastal protection. No details on the costs of this work are available but it has protected around 900 m of the shoreline as well as restoring around 15 ha of intertidal habitat (marsh, mud and shingle).

(Jim Pullen UAV Surveys April 2017)

Image 11. Horsey Island with recharged shingle barrier fronting recharged marsh and mudflat

In addition to this completed work, there is also a proposal to beneficially use 98,000 m^3 of material, again from the Harwich approaches, in front of selected sites near Mersea Island. The fee for the supply and delivery of this material has been quoted as £3/ m^3 (or £294,000) before consideration of the fees for the planning and marine licence submissions. As with the Allfleet's Marsh work, the costs here represent the addition fees incurred over and above those that would apply for standard at sea disposal. In this case the costs for these submissions have been around £80,000 but that fee did rely heavily on in-kind and voluntary work by local specialists and surveyors to the tune of an estimated further £70,000 (i.e. half as much again as the costs of the works).

2.6 Summary of costs for intertidal recharge projects

2.6.1 Indicative costs for dredging and disposal

Before considering the cost of the recharge work itself, it is recognised that standard fees are incurred for the dredging work against which the “differential costs” for alternatively beneficial using the sediment should be compared. This includes costs for buying, hiring, or maintaining equipment for a project as well as further costs for survey work and works licences.

Where the operator owns the equipment there will be annually-incurred fees for maintaining this which might be around £20,000-£40,000 although there can be additional fees for certain elements. There are also fees that need to be incurred for securing licences, consents and undertaking post consent monitoring. This can be a large part of the fees. The very small Loder’s Cut project for example had an estimated cost of £21 m^{-3}. Of this around 20% (£3 m^{-3}) was for the licencing (mainly sediment testing) while the remainder 80% (£17.5 m^{-3}) was for the practical work itself. For the slightly larger projects undertaken by the Lymington Harbour Commission (LHC), the fees for licensing and monitoring were typically around 10% of the overall costs.

In addition to these ongoing costs, there are then major fees for actually undertaking or sub-contracting dredging and disposal work itself. Here the cost will vary substantially depending upon whether it is local and small plant that is used or whether larger equipment needs to be subcontracted in. One key influencing variable is the distance between the dredging (excavation) site and disposal locations because this dictates the fuel costs and the rate at which each barge can be emptied and refilled. For example, using cost details provided by the LHC, the steaming distance from Lymington to the Hurst Fort disposal site is around 5 km (or approx. 3 nm) and has had a dredge/disposal cost of £8.70 m^{-3} on average over the last three winters. Similar values of around £9-10 m^{-3} apply in other UK locations where the deposit ground is relatively close. At greater distances the fees can be double these values (around £14- 18 m^{-3}) with even higher costs for complex dredging projects. For example, comparatively high costs are incurred by Solent marinas in the Hamble, Itchen and Chichester Harbour, where material needs to be taken some 25 to 45 km (or approx. 13-24 nm) to the Nab deposit ground. In such cases the steaming time can be up to 5.5-6 hours for each deposit and be very much dependent on the weather.

There can also be large temporal variability in the costs in response to the dredging market. This is especially the case where large plant are required (e.g. from projects such as Horsey Island or Allfleet’s Marsh) and where costs are influenced by plant availability and the degree to which such plant are diverted onto extant national and international projects.

2.6.2 Indicative costs for beneficial use

Set against the kind of fees described above, intertidal recharge does not always have to be more costly. It can be either cheaper, cost neutral or more expensive depending upon circumstances. However, the key cost is the operational work itself which is influenced by factors such as the volume of sediment, the time taken to empty and refill each barge, transport distance, the complexity of the initiative, the extent to which bespoke equipment needs to be brought in and the need for sediment retaining fences to be introduced. To demonstrate the variability of the costs incurred for beneficial use, the fees obtained from a selection of examples for this review are shown in Table 3. These show the general project expressed as costs m^{-3}[16].

One example of beneficial use being cheaper than an 'at sea disposal' alternative is at Levington. Here the equipment is owned and maintained by SYH as the marina operator and any alternative to pumping onto adjacent intertidal areas would incur additional fees to cover greater steaming distances, even if that was to a position locally within the Orwell Estuary. Using its in-house equipment in this way (see Section 2.4), SYH incur a cost of around £8-9 m^{-3}.

The projects at other Essex and Suffolk estuary sites (Maldon and Loder's Cut) will also be cheaper than the alternatives. This is because a higher cost would be incurred for the longer-distance transport (needed to dispose at sea) and also because these beneficial use projects use local plant and specialists so that they do not require any substantial changes to the equipment or mobilisation fees.

Another, very different, example of a cost beneficial project is from the Meyer shipyard on Ems Estuary (Germany) (Helmut Meyer, Federal Waterways and Shipping Agency Pers. Comm.). In 2015 the cost of dredging and then translocation over 60 km to a disposal area in the estuary was 14.5 € m^{-3} (based on dry weights). However, moving it 7 km to a nearby site for beneficial use (in this case to improve agricultural land) was less than half that (6.8 € m^{-3}). In addition to these transfer fees, it cost around 5.2 € m^{-3} for the extra work required for aspects such as: pipeline construction, pumping to the fields, building dams, dewatering, re-cultivation and natural compensation measures. Therefore the cost of beneficial use of the sediment was cheaper at 12 € m^{-3} than subtidal disposal. While this is not an intertidal recharge, the principles are the same and this shows the benefits of reducing the haulage distances and then what can be achieved with this cost saving.

Where projects are novel and require new equipment or preparatory work then the rates can be several '£10s' m^{-3}. This applies where recharge needs to be pumped in larger volumes directly onto higher intertidal elevations, because that requires extra costs for the construction of retaining fences and well as additional distinct equipment in certain cases. For the LHC at the Lymington Yacht Haven Marina in 2012 and 2013 (see Section 2.4) that used this approach, there was a total fee of £100,100 (£32 m^{-3}). Here, the main key cost elements were the fencing work in Year 1 (2012) and the subcontracting of larger plant in Year 2 (2013). However if the costs for fencing and sub-contracting are excluded then the fee was £10-11 m^{-3} (with monitoring) and closer to £5 m^{-3} (without monitoring). If such intertidal recharge work was carried out each and every year with regularity using local plant, then the costs for these big ticket items (fences and equipment) would proportionally reduce. Costs may reduce to a level where there is little difference from standard offshore disposal (or perhaps the fees would be lower).

For the slightly larger Wightlink projects on the other side of the Lymington Estuary that were carried out at the same time, and according to similar methods, but on a less accessible site, the overall costs were atypically large at £550,000 (or £122 m^{-3}). This was due to many factors listed in Section 2.3 including: the need for large plant to be mobilised, the distances covered, tidal constraints of operating plant, the need to double handle material and other fees.

In Table 3 cost details about the new shallow subtidal beneficial use at Lymington has also been included. This involves bottom dumping of sediment in the shallow subtidal area fronting the adjacent marshes. For this work the fees have been £10 m^{-3} on average over the last three winters. This is a 'slightly' greater fee than the rate for established offshore 'at sea' disposal which is £8.70 m^{-3} with the additional fees being due to extra licence, monitoring and reporting costs. If this project

16 These are not the "differential costs" between the available at sea disposals and beneficial use approach. If such difference costs were applied then the fees expressed would be much lower.

were allowed to continue then, over time, these extra fees are likely to reduce such that this could become the cheaper alternative to established disposal. It will be valuable to understand whether this happens and also the extent to which this project delivers benefit for the adjacent intertidal habitats over time.

Table 3. Indicative fees for selected recharge work (expressed as £m^{-3} of sediment moved)

Project	Sediment Composition and Retention	Distance	Estimated Cost £ m^{-3}
Direct intertidal recharge examples (see also Table 1)			
Maldon, Blackwater	Backhoed and 'dewatered' sediment; no fencing	1.5 to 2.5 km	£12.5 m^{-3}
Loder's Cut Island, Deben	Backhoed and 'dewatered' sediment; no fencing	800 m	£20.5 m^{-3}
Boiler Marsh Lymington (Wightlink Project)	50% sediment in pumped with water; 10 poldered fences with 3 m high stakes. Hay bales inlaid into fences and placed below them (to stop under cutting)	2 km	£122 m^{-3} as average over two years (2012 to 2013)
Lymington Intertidal Restoration (Lymington Harbour Commission Project)	25% sediment in pumped with water; polder fences/faggots, coir mats and a hay bale structure as well as corrugated plastic sheeting where needed	200 m	£32 m^{-3} as average over two years (2012 to 2013)
Suffolk Yacht Haven (SYH) Levington, Orwell	10% sediment in pumped with water; various techniques between locations includes: wattle hurdles, faggots (bundles of twigs) or coir logs	300-600 m	£8-9 m^{-3}
Other examples (not necessarily direct intertidal recharge)			
Lymington Intertidal Restoration (Lymington Harbour Commission Project)	Sediment bottom dumped in the shallow sublittoral fronting Boiler Marsh	1 to 2 km	£10.02 m^{-3} as average over three years (2014 to 2016)
Ems Estuary (Germany) Federal Waterways and Shipping Agency	Sediment pumped with water onto agricultural fields	7 km	6.8 € m^{-3} in 2015

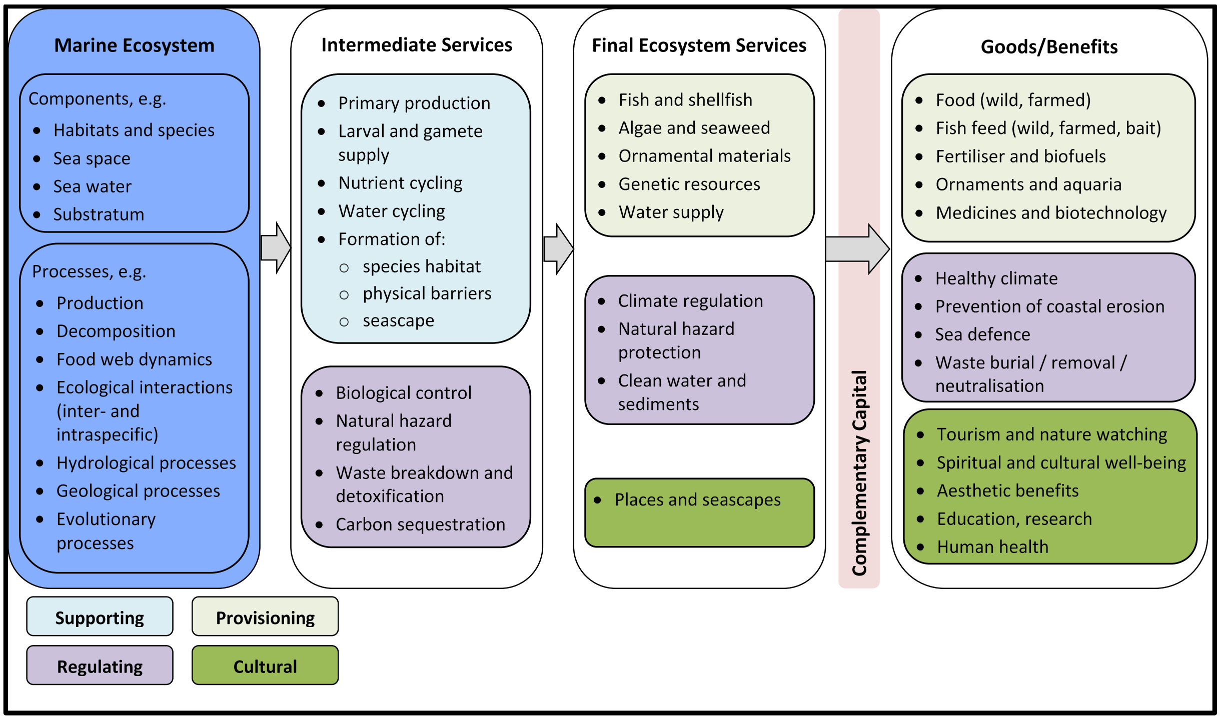
Overall therefore the costs are variable but it is the regularity and certainty of activity that is crucial to achieve cost effective interventions. It is also likely that projects involving larger volumes will bring economies of scale and reduced cost m^{-3}, although, to date, only relatively small scale low volume projects have been undertaken (typically between 1,500 m^{3} to 10,000 m^{3}).

3 Project Benefits

3.1 Understanding benefits

In order to fully understand the merits of intertidal sediment recharge projects, there is a need for clear information on project benefits. There is little project specific information on the quantified benefits of completed intertidal sediment recharge projects. This section therefore largely focuses on the generic benefits of saltmarsh and mudflat creation.

The National Ecosystem Assessment Follow-on project (NEAFO) developed a framework for describing marine ecosystem services (Turner *et al.,* 2014) (see Image 12) and the benefits that humans derive from them. This framework is useful in supporting valuation of environmental benefits as it focuses on the final ecosystem services benefits that humans derive from ecosystems and thus avoids the risk of double counting.



Source: Turner *et al.,* 2014

Image 12. Marine Ecosystem Services Framework showing key benefits to humans

Key benefits associated with the creation of marine habitats (principally mudflats and saltmarsh) through implementation of beneficial use projects include:

- **Food**: enhanced fish production (Colclough *et al.,* 2005; Brown *et al.,* 2007); shellfish and aquaculture.
- **Healthy climate**: carbon sequestration (Chmura *et al.,* 2003; IUCN, 2009).
- **Prevention of coastal erosion**: (Pennings and Bertness 2001; Aspden *et al.*, 2004).
- **Sea defence**: reduced costs of maintenance; delay/avoidance of requirement for new defences (Möller, 2006).
- **Waste burial/removal/neutralisation**: avoidance of impacts at disposal site (Kay *et al.*, 2005; Peterson *et al.*, 2008).

- **Tourism and nature watching**: increased opportunities for nature watching (Bakker *et al.*, 1997; Fletcher *et al.*, 2011).
- **Spiritual and cultural well-being**: increased recreational opportunities, non-use benefits (UK NEA, 2011).
- **Aesthetic benefits**: improved visual appearance (UK NEA, 2011).
- **Education/research**: opportunities to study restoration (UK NEA, 2011).
- **Human health**: the values for health and well-being (UK NEA, 2011).

Various estimates of the monetary value of marine ecosystem services and of the specific contributions from saltmarsh and mudflat habitats are available from The Economics of Ecosystems and Biodiversity (TEEB) database (Balmford *et al.,* 2008) and other online sources. However, care needs to be taken in seeking to transfer habitat values to other situations because the values often reflect bundles of marine Ecosystem Services relating to a specific location which may not be transferable to different situations (UNEP-WCMC, 2011).

Available data does, however, indicate that the Ecosystem Service values of intertidal habitats such as saltmarsh can be high. For example, a review of European wetland valuations by Brander *et al.* (2008) concluded that saltmarsh had a value of approximately £1,400 ha^{-1} yr^{-1} (across a range from £200-£4,500 ha^{-1} yr^{-1}), while intertidal mudflats were around £1,300 ha^{-1} yr^{-1} (ranging from £200-£4,300 ha^{-1} yr^{-1}). This was based on default 'indicative economic values' for habitats on the basis of providing the following 'bundled' ecosystem services of: water quality improvement, recreation, biodiversity and aesthetic amenity.

Importantly, these bundled values do not include benefits associated with carbon sequestration or flood protection. Both carbon sequestration and flood protection are potentially important additional ecosystem services benefits provided by saltmarsh compared to mudflat. In particular, healthy saltmarsh can sequester significant quantities of carbon (around 200 gC m^{-2} yr^{-1} (Chmura *et al.*, 2003)). Assuming a current non-traded price of carbon of £64 per tonne (2017 prices) (DBEIS, 2017) this equates to a value of around £469 ha^{-1} yr^{-1} in 2017. As non-traded carbon prices increase significantly over time, the economic value of carbon sequestration will also increase over time. For example the non-traded carbon price is estimated to reach £300 per tonne of CO_2 over the next 50 years.

Flood protection benefits associated with saltmarsh restoration can also be large. For example, Costanza *et al.* (2008) estimated that restored saltmarsh in the US provided an economic value of US$8,236 ha^{-1} yr^{-1} in reduced hurricane damages. However, such benefits are very site specific. For many UK saltmarshes, the main benefit may relate to reduced maintenance costs for landward flood defences. For example, Shepherd *et al.* (2007) estimated that fronting saltmarsh provided a net saving of £4,950 km yr^{-1} in flood defence expenditure on the Blackwater Estuary. The presence of healthy saltmarsh may also avoid the need for the construction of new flood defences. King and Lester (1995) indicated than an 80 m width of saltmarsh could avoid a construction cost of £4,800 m^{-1} of new sea defence. Hudson *et al.* (2015) indicate that the construction costs of impermeable revetments and seawalls can range between £700 – 5,400 m^{-1} (at 2007 prices)

There is limited information on wider non-use values associated with intertidal habitat restoration/ creation projects, but Willingness-to-Pay studies have indicated that non-use values can be significant. For example, Luisetti *et al.* (undated) estimated a non-use benefit of around £2,000 yr^{-1} for a hypothetical 81.6 ha managed realignment project on the Blackwater Estuary (around £25 ha^{-1} yr^{-1}). However, it is unclear whether the non-use value of saltmarsh might be different from mudflat and thus whether there is any additional non-use value associated with the creation of saltmarsh in place of mudflat.

From the above, it is clear that the creation of saltmarsh and mudflat habitats can generate significant benefits, but that the scale of the benefits can be quite site specific, particularly flood protection benefits. In addition, the scale of intervention can also affect the per-hectare benefits with a reduction in per-hectare benefits with increasing size of the intervention (Brander *et al.*, 2008 and Luisetti *et al.* (undated)).

4 Cost Benefit Analysis Framework

An initial cost benefit analysis (CBA) framework that can be used to support an analysis of the costs and benefits of intertidal sediment recharge projects is presented in Table 4.

It is noted that beneficial use schemes may result in both costs and benefits to individual services, often depending upon timescales. For example, the placement of dredged material at the beneficial use site may give rise to short-term impacts on ecological functions that support fish/shellfish production. However, the recharge work may then benefit these fish/shellfish functions and related ecosystem services in the longer term as the site then exhibits ecological recovery (e.g. by providing feeding and nursery grounds).

Table 4. Illustrative cost benefit framework for beneficial use projects

<table>
<tr><th>Potential Costs</th><th>Potential Benefits</th></tr>
<tr><td>Any additional cost of using dredged material beneficially compared to sea disposal option e.g.:
▪ Infrastructure at beneficial use site (mooring, pipelines, sediment retention structures);
▪ Additional costs of transporting/ discharging material at beneficial use site;
▪ Additional costs of alternative dredging methods.</td><td>Benefit associated with habitats created at the beneficial use site:
▪ Provisioning:
o Food through fish/shellfish habitat provision.
▪ Regulating:
o Healthy climate (carbon sequestration);
o Waste burial/removal/neutralisation;
o Prevention or slowing of coastal erosion;
o Improvements to the quality/longevity of sea defences.
▪ Cultural:
o Tourism and nature watching;
o Spiritual and cultural wellbeing;
o Aesthetic benefits.</td></tr>
<tr><td rowspan="2">Cost associated with damage to/loss of existing habitat within/outside of footprint of beneficial use project:
▪ Provisioning:
o Fish/shellfish – damage to existing habitats supporting fish/shellfish production.
▪ Regulating:
o Healthy climate – loss of carbon sequestration function.
▪ Cultural:
o Tourism and nature watching – loss of/damage to existing functions;
o Spiritual and cultural wellbeing – loss of/damage to existing functions;
o Aesthetic benefits.</td><td>Benefit associated with the reduction in environmental impacts at existing disposal site:
▪ Provisioning:
o Fish/shellfish.
▪ Regulating:
o Healthy climate.
▪ Cultural:
o Tourism and nature watching;
o Spiritual and cultural wellbeing.</td></tr>
<tr><td>Benefit to other users at disposal site
▪ There may be potential benefits to other users such as marine aggregates, for example, through reduced contamination of aggregate material</td></tr>
</table>

Project scale and location will also have major implications on costs as well as the scale and nature of the benefits and the duration of any temporary effects. Small projects generally accrue smaller gains that may be limited in duration (including for aspects such as water quality improvement, fish/shellfish habitat, biodiversity, coastal defence enhancement or cultural (existence) values). Larger projects, or smaller scheme regularly implemented, have the potential to have inherently larger, longer-term and more varied benefits, including wider cultural values (such as aesthetics and amenity).

There may also be a benefit to these functions and related Ecosystem Services at the former dredge disposal site as a result of a reduction in disposal volumes. The purpose of the CBA process is to identify all of the relevant costs and benefits and to seek to monetise them where data allow. Such information can be used to estimate costs and benefits over time and understand whether a project is likely to provide an overall benefit (i.e. have a benefit:cost ratio of >1).

4.1 Identifying the winners and losers

Identifying an overall benefit is helpful in making the case for carrying out more beneficial use projects. However, it is very important to understand who the potential 'winners' and 'losers' are as a result of a beneficial use/recharge project, particularly as 'losers' are unlikely to have much incentive to participate in such projects. Indeed this is a particular issue for beneficial use projects where the party providing the material may incur additional costs compared to an option of marine disposal. Table 5 identifies the potential winners and losers from intertidal recharge beneficial use projects. The range of stakeholders and the scale of costs/benefits they will experience will vary from project to project.

Table 5. Illustrative Winners and Losers from Beneficial Use Projects

Potential Winners	Potential Losers
▪ **Flood and coast protection authorities** (Environment Agency (EA), local authorities) – reduced maintenance costs for existing flood defences; delay/avoidance of requirement for new capital works; ▪ **Private landowners** – reduced maintenance costs for existing flood defences; delay/avoidance of requirement for new capital works; enhanced levels of protection of landside assets; ▪ **Foreshore/seabed owner** – increased revenues for additional use; ▪ **Conservation bodies, environmental NGOs** – achievement of conservation targets; ▪ **Commercial fisheries** – fish nursery function; ▪ **Aquaculture** – opportunities for shellfish production; ▪ **Recreational users** – gain of amenity at BU site and former dredge disposal site; and ▪ **Wider society** – healthy climate, non-use benefits.	▪ **Port and harbour authorities, third party dredging organisations such as marinas, private wharves and terminals** – additional costs for disposal of dredged material; ▪ **Conservation bodies, environmental NGOs** – damage to existing biodiversity; ▪ **Commercial fisheries** – damage to existing fish nursery function; ▪ **Aquaculture** – damage to existing shellfish production; and ▪ **Recreational users** – loss of amenity at beneficial use site.

Identifying the costs and benefits potentially experienced by different stakeholders helps to make explicit the potential trade-offs involved in a beneficial use project. This information can then be used to rebalance the costs and benefits, for example through Payment for Ecosystem Services. In case of beneficial use projects, significant transfers might include:

- Payments from flood protection authorities or private landowners to those incurring additional costs associated with the project (port authorities or private operators);
- Payments from SNCBs/environmental NGOs to those incurring additional costs associated with the project (port authorities or private operators);
- Accessing other sources of public funding (e.g. EU Interreg or LIFE funding[17]) in recognition of societal benefits of projects; and
- Granting those incurring additional costs from the project rights over habitat benefits which could be used to offset impacts from future development projects (habitat banking).

Lower levels of transfer might occur in relation to benefits realised by other marine users or foreshore/seabed owners. However, for these transfers to happen there needs to be sufficient certainty that benefits will accrue and on the scale of those benefits. It is recognised this is a challenge when working in dynamic marine environments.

4.2 Illustrative cost benefit analysis

To bring together the information presented in the preceding sections, this final section considerers the comparative monetary costs and benefits of a hypothetical beneficial use project (Box 1) involving the placement of muddy sediments derived from maintenance dredging of a navigation channel. In this example, the main benefits associated with the project are assumed to be:

- Additional benefits of saltmarsh compared to mudflat in relation to the following 'bundled' ecosystem services: water quality improvement, recreation, biodiversity and aesthetic amenity (after Brander *et al.*, 2008);
- Additional benefits of carbon sequestration within healthy saltmarsh compared to mudflat (after Chmura *et al.*, 2003); and
- Additional flood protection provided by healthy saltmarsh compared to mudflat.

Two different benefit scenarios have been considered in relation to flood protection. The first assumes that the creation of healthy saltmarsh reduces the costs of maintenance of the flood defences (based on Shepherd *et al.,* 2007). The second assumes that the creation of healthy saltmarsh avoids the need to construct a new flood defence in years 20 and 21 of the scenario (based on King and Lester, 1995), thus avoiding significant capital expenditure.

Estimation of the potential scale of benefits under these scenarios has been used to identify the level of additional cost associated with beneficial use that might be justified by these benefits. The additional costs have been assessed in relation to an average 'at sea' disposal cost of £10 m^{-3}.

Net Present Value (NPV) of benefits has been calculated over a period of 100 years using Treasury Green Book discount rates[18].

Based on the first scenario, the benefits are estimated to exceed costs up to a unit cost for intertidal sediment recharge of around £15 m^{-3} (£5 m^{-3} more expensive than standard sea disposal). Based on documented costs of intertidal sediment recharge projects (Table 3), this is towards the lower end of those costs. The main contribution to benefits derives from increased carbon sequestration (68% of total benefits value), with some contribution from flood protection benefits (28% of total benefits value).

17 The recent UK referendum decision to leave the EU may mean that the sources of available funding will change over time.

18 A discount rate of 3.5% has been used for years 1 to 30; 3% for years 31 to 75, and 2.5% for years 76 to 100.

Box 1. Hypothetical Beneficial Use Project:

It is assumed that a harbour authority has a requirement to dispose of 100, 000 m^3 muddy dredged sediment per annum to maintain navigable access to its quays. The material is currently dredged using a trailer suction hopper dredger and disposed to an offshore disposal site at a cost of £10 m^{-3}. It is proposed to beneficially use the material to support the re-establishment of saltmarsh along a 5 km length of coastline which is experiencing significant saltmarsh erosion. The recharge area comprises approximately 50 ha of mudflat habitat occupying a strip around 100 m wide along the 5 km length of the eroding marsh. It is proposed to deposit sediment to a depth of 1 m to raise the elevation of the mudflat to a level that is suitable for saltmarsh colonisation. The existing saltmarsh and mudflat are component habitats of a Special Protection Area, Special Area of Conservation, Ramsar Site and Site of Special Scientific Interest (SSSI).

The hinterland supports important infrastructure and residential areas and flood protection benefits would justify maintenance of flood protection. It is assumed that placement of material occurs over a five year period working sequentially along the coastline. Placement of the material is designed to convert existing mudflat habitat into saltmarsh with full saltmarsh function being achieved over a period of 5 years. For simplicity, it is assumed that there are no significant impacts outside of the footprint of the placement and thus no significant negative environmental effects associated with the placement. It is also assumed that there are no significant environmental benefits associated with cessation of disposal at the existing disposal site over this time period.

For the second scenario, the benefits are estimated to exceed costs up to a unit cost for intertidal sediment recharge of around £40 m^{-3} (£30 m^{-3} more expensive than standard sea disposal costs). This is at the upper end of costs identified in Table 3. The main contribution to benefits in this scenario derives from avoided flood protection costs (88% of total benefits value) with some contribution increased carbon sequestration (11% of total benefits value). Alternatively, if a lower capital cost for flood defences is used (construction cost of £1,000 m^{-1}), towards the lower end of values cited by Hudson *et al.* (2015), the benefits are estimated to exceed costs up to a unit cost for intertidal sediment recharge of around £20 m^{-3}. The analysis highlights the sensitivity of the benefits estimates to assumptions about flood protection benefits.

The scenarios demonstrate that there are potentially significant benefits associated with intertidal sediment recharge schemes. These benefits can help to justify beneficial use of dredged material in circumstances where the costs of beneficial use are greater than comparable costs for ‘at sea’ disposal.

Notwithstanding a potentially positive B:C ratio, intertidal sediment recharge projects may not progress because those paying the costs associated with such projects do not achieve any benefit. In the above scenario, the additional costs associated with intertidal sediment recharge would fall on the harbour authority, whereas the beneficiaries would primarily be the flood protection authority (and those benefitting from flood protection measures) together with the statutory nature conservation body (as a result of restoration of the damaged saltmarsh feature within the designated sites). Some level of funding towards the project from the flood protection authority and statutory nature conservation body is likely to be required to facilitate such a project.

5 Conclusions

This review has considered the lessons from past intertidal sediment recharge projects, including a number of relatively new initiatives undertaken in the last few years (most notably the three very different schemes undertaken at Lymington). This has included collation of detailed information on the costs of individual projects. Little, if any, information on the monetary benefits of such projects was identified by the review. A framework for comparing the costs and potential benefits of intertidal sediment recharge projects has been developed and applied. This framework incorporates impacts on ecosystem services and provides a consistent basis for evaluating projects. The main costs associated with intertidal sediment recharge are those associated with transport and placement of material but consenting and monitoring costs can also be significant. There may also be costs associated with the environmental impact of placement of the material on intertidal areas. Key benefits provided by intertidal sediment recharge projects are where the creation of saltmarsh on former mudflat or deteriorating marsh habitat provides additional carbon sequestration and flood protection.

The review indicates that both costs and benefits of intertidal sediment recharge projects are site specific. In some locations, the costs of intertidal sediment recharge projects are less than the alternative 'at sea' disposal option. In these instances, the benefits to society are effectively provided for free. In other situations, the costs of intertidal sediment recharge are more expensive than 'at sea' disposal. However, when taking account of the societal benefits of these projects, the overall benefits may exceed costs. In such circumstances, there is an overall benefit to society from such projects proceeding, but this may need to be facilitated by payments to those incurring costs (typically port and harbour authorities) by those deriving benefits (flood protection authorities and nature conservation bodies).

The costs of intertidal sediment recharge projects vary greatly on a site-by-site basis. This depends upon a range of factors such as the location, method and scale of the operation. In some instances it can be cheaper than standard 'at sea' disposal options. However, where that cost is higher, there is every indication that the 'cost differential' can be reduced over time by regularly undertaking the work. However, the up-front expenditure of such projects is often large and an obstacle to project implementations (especially at a large scale). This review highlights the benefits that can accrue, presents a cost benefit framework for these projects and highlights the key cost benefit considerations for future projects. It is hoped that this will help to inform future projects and their funding applications.

The review indicates that the costs of intertidal sediment recharge projects can be driven down over time, particularly for repeat operations. Often for new projects there is an upfront fee for securing infrastructure, installing fencing, securing consenting and carrying out monitoring, but thereafter costs can be reduced year on year. One key way to realise future projects is to identify 'long term' sites where the consenting requirements and infrastructure are all set up so that sediment can be placed regularly on an ongoing basis. These would, of course, need to be close enough to a reliable sediment source.

The case for intertidal sediment recharge is likely to be strongest where costs for 'at sea' disposal are high or where such projects create saltmarsh in front of important flood defences, delivering important carbon sequestration and flood protection benefits.

The following points summarise the key conclusions of this review:

- Costs of beneficial use of muddy dredge material for intertidal sediment recharge are site specific. They may be cheaper, the same, or more expensive compared to 'at sea' disposal;
- Benefits of beneficial use of muddy dredge material for intertidal sediment recharge are also site-specific. The main additional benefits relate to creation of saltmarsh habitat which (compared to mudflat) provides additional carbon sequestration benefits and can provide flood protection benefits. Based on available data, flood protection benefits are potentially the greatest benefit associated with beneficial use schemes, although carbon sequestration benefits are also substantial (particularly in the long-term);
- There is uncertainty concerning the scale of non-use benefits and whether there are additional non-use benefits associated with saltmarsh compared to mudflat;
- Where the costs of beneficial use of muddy sediments for intertidal sediment recharge are less than 'at sea' disposal there is a strong case for pursuing beneficial use to achieve societal benefits;
- Where the costs of 'at sea' disposal are less than beneficial use of muddy sediments for intertidal sediment recharge, there may be a case for pursuing beneficial use where this can deliver significant benefits. This may particularly be the case where beneficial use projects provide significant flood protection benefits;
- The long-term nature of potential benefits needs to be recognised and therefore that there is a long pay-back period for such investments. It is therefore important to take a long-term view when considering the merits of such projects;
- The distribution of costs and benefits may often require payment transfers from beneficiaries to those incurring costs in that schemes might progress. This might typically entail payments from flood protection authorities and nature conservation bodies to port authorities; and
- Based on the scenarios explored, larger (>100,000 m^3 yr^{-1}) beneficial use schemes might typically justify an increase in cost of 50% to 400% compared to 'at sea' disposal costs.

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7 Abbreviations/Acronyms

ABP	Associated British Ports
ABPmer	ABP Marine Environmental Research Ltd
BU	Beneficial Use
CBA	Cost Benefit Analysis
CEAMaS	Civil Engineering Applications for Marine Sediments
CEDA	Central Dredging Association
Cefas	Centre for Environment Fisheries and Aquaculture Science
CPA	Coast Protection Act
DAS	Disposal At Sea
DBEIS	Department for Business, Energy and Industrial Strategy
Defra	Department for Environment, Food and Rural Affairs
EA	Environment Agency
EIA	Environmental Impact Assessment
EU	European Union
FCRM	Flood and Coastal Risk Management
FEPA	Food and Environment Protection Act
HELCOM	Helsinki Commission - The Baltic Marine Environment Protection Commission
HR	HR Wallingford Ltd
HRA	Habitats Regulations Appraisal
IADC	International Association of Dredging Companies
IMO	International Maritime Organisation
Interreg	European Territorial Cooperation (ETC), [better known as Interreg]
IUCN	International Union for Conservation of Nature
LHC	Lymington Harbour Commission
LiDAR	Light Detection and Ranging
LIFE	EU's financial instrument supporting environmental, nature conservation and climate action projects throughout the EU
MMO	Marine Management Organisation
NEA	National Ecosystem Assessment
NEAFO	National Ecosystem Assessment Follow-on
NGO	Nongovernmental Organization
NPPF	National Planning Policy Framework
NPV	Net Present Value
OSPAR	Oslo/Paris convention (Protection of the Marine Environment of the NE Atlantic)
PIANC	Permanent International Association of Navigation Congresses
Ramsar	Wetlands of international importance, designated under The Convention on Wetlands (Ramsar, Iran, 1971)
RSPB	Royal Society for the Protection of Birds
SeaBUDS	Sea-change in the Beneficial Use of Dredgings (RSPB project)
SCOUP	Sediment Compatibility and Opportunistic Use Pilot
SNCB	Statutory Nature Conservation Body
SSSI	Site of Special Scientific Interest
SYH	Suffolk Yacht Harbour
TAMU	Texas A&M University
TEEB	The Economics of Ecosystems and Biodiversity
UAV	Unmanned Aerial Vehicle
UK	United Kingdom

UK NEA	UK National Ecosystem Assessment
UNEP-WCMC	United Nations Environment Programme's World Conservation Monitoring Centre
US	United States
USA	United States of America
USAR	Using Sediment as a Resource
WEDA	Western Dredging Association

Cardinal points/directions are used unless otherwise stated.

SI units are used unless otherwise stated.

Contact Us

ABPmer

Quayside Suite,
Medina Chambers
Town Quay, Southampton
SO14 2AQ

T +44 (0) 23 8071 1840
F +44 (0) 23 8071 1841
E enquiries@abpmer.co.uk

www.abpmer.co.uk