Using Sediment as a Resource

Sediment Recycling Strategy

Interreg
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2 Seas Mers Zeeën
USAR
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Hoogheemraadschap van Schieland en de Krimpenerwaard

De Vlaamse Waterweg nv

Westcountry Rivers Trust

Brightlingsea Harbour Commissioners

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This document has been brought together by the partners working on the Using Sediment as a Resource project. USAR is an Interreg 2 Seas project, part-funded by the European Regional Development Fund, running from 2016 to 2020.

Dredging taking place on the Dutch Polders (copyright @ Vincent Blom)

Introduction

Using Sediment As a Resource (USAR) is a project running from 2016 to 2020 and funded by the European Union's Interreg 2 Seas Programme. Partners from the Netherlands, Belgium, France and the United Kingdom are working together to promote a resource-efficient approach based on the potential for the beneficial use of dredged sediments.

Water management authorities are responsible for keeping waterways in the Interreg 2 Seas region free from accumulating sediments. The key aim of this management is to reduce the risk of flooding and to keep waterways open for navigation. Excess sediment in rivers and estuaries - often resulting from inappropriate land management - is also damaging for wildlife as it can clog spawning gravels, an important habitat type for fish, and carries pollutants in the form of heavy metals, chemical and nutrients.

Currently, most dredged sediment is transported and dumped as waste, a very costly and wasteful operation.

A key aim of USAR is to develop ways of recycling this sediment and using it in innovative ways. Three of the USAR partners - Flemish Waterways (FW) in Belgium, the Schieland and Krimpenerwaard Regional Water Authority (HHSK) in the Netherlands and Brightlingsea Harbour Commissioners (BHC) in the UK – will be undertaking pilot projects in a number of novel applications. USAR will identify, demonstrate and test new methods and develop the business models and tools that water managers need to apply this circular approach in practice.

Pilot 1 **HHSK – blending organic sediments with green and agricultural waste for soil elevation and improvement**

Pilot 2 **FW – geotechnical treatment of polluted sandy sediment to provide material for waterway embankments**

Pilot 3 **BHC – use of marine dredged sediment in coastal saltmarshes as coastal defence**

The Institute of Mines and Telecommunications (IMT), Lille Douai is the French partner in the USAR project, and is developing key information tools to help sediment managers.

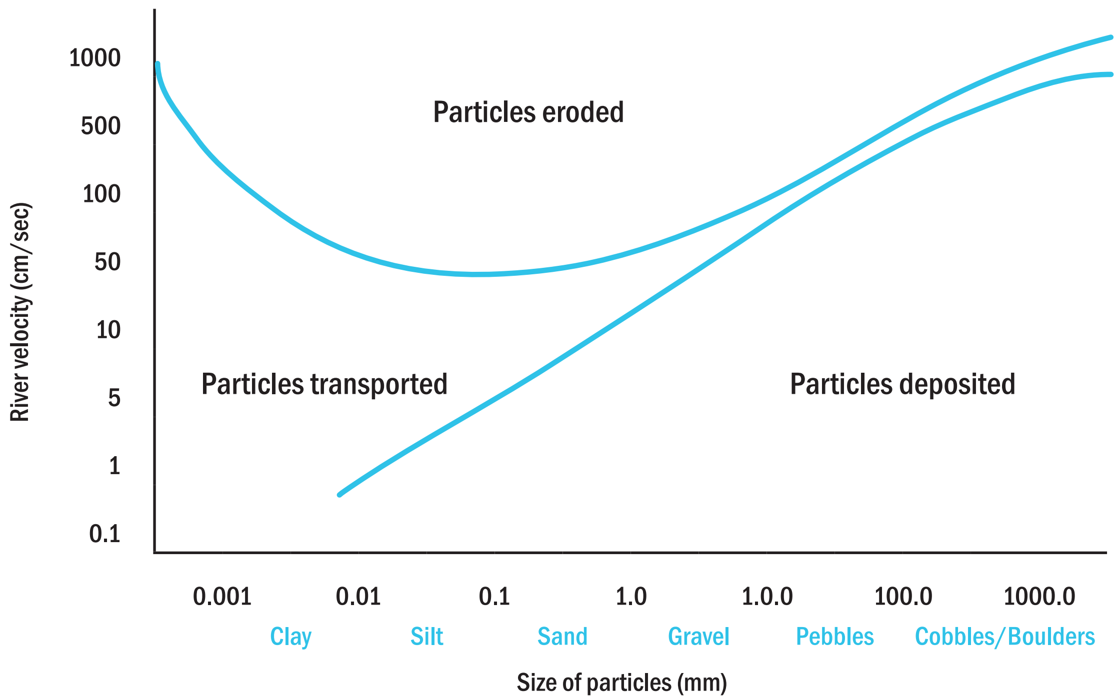
- Inventory catalogue of uses of sediment as a resource and limitations for use;
- Operational Sediment Management System: ICT (Information and Communications Technology) tool for water managers to make business cases and management decisions for recycling of sediment.

Westcountry Rivers Trust (WRT), the second partner from the UK, is an environmental charity working to restore and protect the water environment in the Westcountry for the benefit of people, wildlife and the local economy. WRT is focussed on reducing sediment input at source through targeted land management advice and local interventions. The aim is to trap sediment before it reaches rivers, therefore allowing local beneficial use. WRT will also work with local ports and harbours to share information from the pilot projects and introduce the Sediment Inventory Catalogue and the Operational Sediment Management System.

This Regional Sediment Recycling Strategy builds on the work of all the USAR partners, and aims to provide a strategic guide to sediment managers across the Interreg 2 Seas region to help them consider options for more sustainable management of dredged material.

What is sediment?

In the strictest definition, sediment is the mineral material that travels down streams and rivers, transported by flowing water, ranging from boulders and large rocks to finer sand, silt and clay. However, often, and in this document, the term sediment is used to cover all the particles which move down the river, including organic and inorganic matter. Larger sediment material needs high flow speeds to move it – so tends to move only relatively short distances in each storm event. Smaller particles are held in suspension in much slower flowing water so tend to move much further, eventually settling out when flow velocities drop. This can be seen in the Hjulstrom Curve below.



Sediment transport is a natural and vital function of rivers systems and has played a fundamental role in shaping our landscapes for millions of years. However, recent changes to the way land is used (such as intensive modern farming, mining, forestry and urbanisation) have led to far greater amounts of finer material being eroded and washed into streams and rivers. Changing climate is also leading to more intense rainfall events - which in turn increase erosion and sediment transport.

Why is it a problem?

Where rivers widen to meet the sea at estuaries or lakes, or flow into artificial reservoirs, deposition of this fine sediment happens on a large scale. Estuaries are where most major ports and harbours are situated so this sediment deposition leads to a constant battle by harbour authorities to keep channels and berths free for navigation and for efficient port operations.

Any contamination - from industrial processes, mining or road runoff - will also accumulate in the sediment and can stay there for centuries if left undisturbed. This means that the dredged sediment recovered from ports and harbours can often contain harmful levels of toxic contaminants and needs to be treated with care.

How will USAR help?

This Regional Sediment Recycling Strategy is designed to help water and land managers to prevent the movement of sediment into waterways in the first place, to use sediment which needs to be removed from watercourses locally and efficiently, and to provide inspiring case studies on successful projects.

The aim of this document is to build on the growing recognition that sediment need not be viewed as waste, but can be a valuable product with a wide range of potential uses, forming part of a more efficient circular economy.

Policy

The use of sediment as a resource is inspired by the concept of a ‘circular economy’. A circular economy looks beyond the current linear system of ‘take, make, dispose’ to a system which is restorative and regenerative by design. Resources are kept in the system for as long as possible, reducing waste, minimising negative impacts, and building economic, social and natural capital[1].

Though there is positive ambition to move towards a more circular economy, currently, legislation and regulations are predominately based on the existing linear economy model. In terms of sediment, therefore, current legislation tends to categorise it as waste.

In the EU, waste is legislated for through the Waste Framework Directive (WaFD)[2]. This framework sets the basic concepts and definitions related to waste management, such as definitions of waste, recycling and recovery, and dictates that EU Member States must adopt the Waste Hierarchy in their waste prevention and management plans.

The Waste Hierarchy

Prevent
If you can’t prevent, then...

Prepare for reuse
If you can’t prepare for reuse, then...

Recycle
If you can’t recycle, then...

Recover other value
If you can’t recover other value, then...

Dispose
If no other alternative is available.

In addition, the WaFD requires waste be managed without endangering human health and harming the environment. It also explains when a product is no longer waste, but instead becomes a secondary raw material. This is when it has been recovered or recycled, and complies with specific criteria, which usually include:

- The substance or object is commonly used for specific purposes;
- There is an existing market or demand for the substance or object;
- The use is lawful (meets the existing legislation);
- The use will not lead to overall adverse environmental or human health impacts.

Therefore, the EU WaFD provides the basis for a more circular economic model where materials are recovered and reused.

Sediment & the Circular Economy

For the circular economy model to be applied to dredged sediment, there are several key considerations:

The movement of sediment must be prevented as far as possible - resulting in it not becoming waste in the first place

The use of the sediment must be lawful and must not lead to adverse effects on the environment or on human health

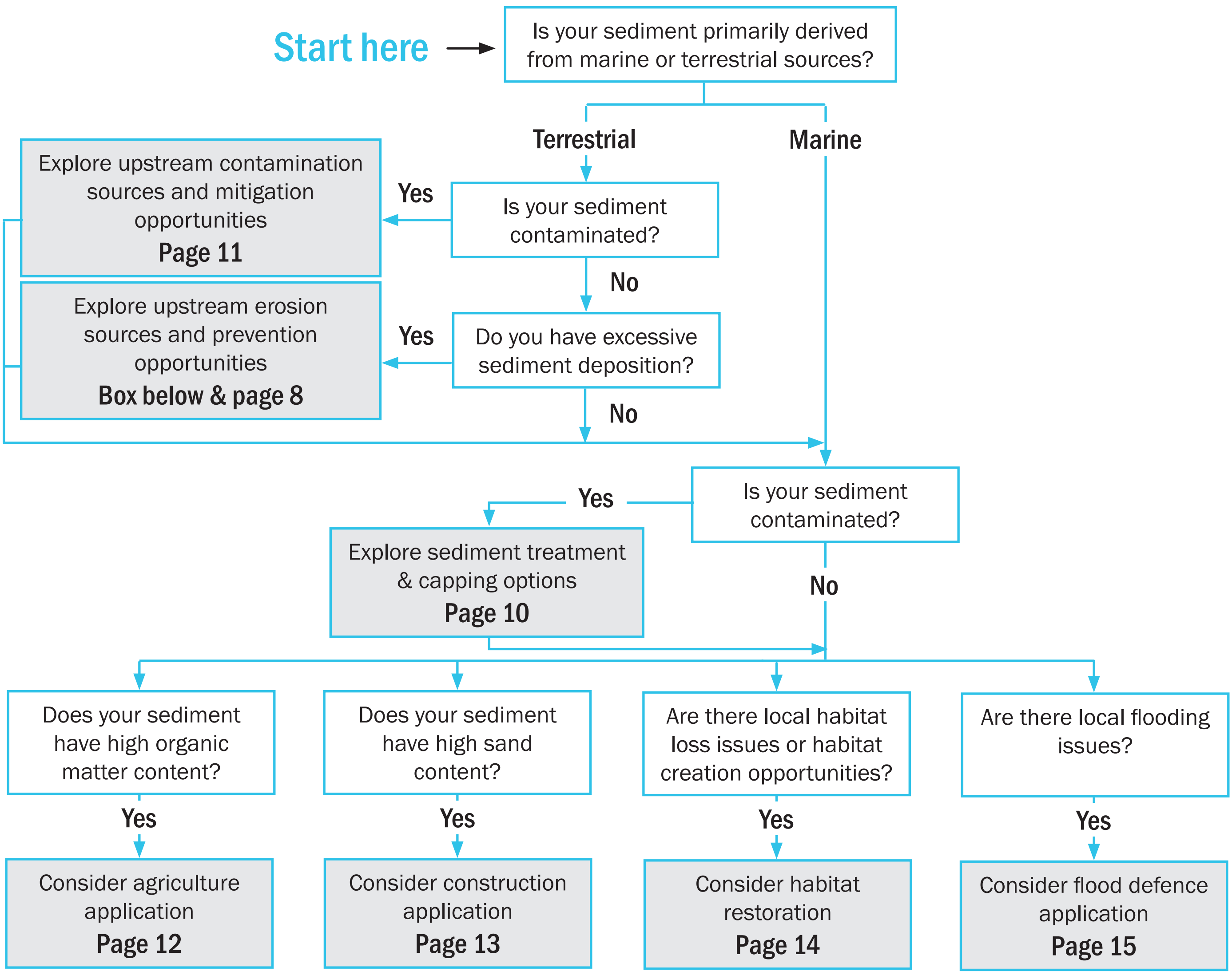
The use of the sediment must be of a high quality and contribute to the efficient use of natural resources

There must be certainty around the intended use of the sediment, allowing the sediment to be viewed by all organisations involved as a resource and not as waste, and therefore for a market to develop for dredged sediment

By addressing these criteria, it will be possible for non-hazardous sediment to no longer be viewed as waste, but instead be used for high-quality and legitimate applications.

Sediment Decision Tree

The diagram below is a tool to explore the potential for management, treatment and beneficial use of sediment. By keeping in mind the sediment available, the questions allow an exploration of the possible options.



Using data & evidence to target catchment interventions

Using good data and evidence is key to understanding causes of erosion. These causes may include land use or management, sources of sediment, such as soil types and condition, and the paths water takes to waterbodies when it rains. With this information it is possible to effectively target land management advice and practical interventions to prevent sediment problems in rivers and estuaries.

A wide range of datasets are available for use to assess the risk of sediment erosion and contamination at a river catchment scale. Sentinel satellite data can be used to determine land cover and Lidar imagery can be used to examine land topography and associated flow pathways of water across the land. Models such as SCIMAP can also be used to explore how connected a piece of land is with the nearest waterbody and in-channel erosion risk. Water quality monitoring tools, such as spot testing, passive sampling devices, and laboratory analysis can be used alongside mapping and modelling to ground-truth the model outputs.

Prevention

The first stage of the waste hierarchy is to prevent the waste. In the case of sediment, this means keeping the material on the land, through catchment management and good soil husbandry.

Small particles of sediment, like sand, silt and clay, tend to be the most problematic for managers of ports and estuaries, as it is at this point when the water travels slowly enough for this sediment to settle out of the water. As it has travelled in suspension, the sediment may have been generated a long way from where it becomes a problem. In some cases across Europe, sediment may have originated in neighbouring countries or even further afield.

Therefore, organisations responsible for keeping ports and estuaries clear of sediment should consider where it has originated from, as there may be opportunities to work with stakeholders across the catchment to reduce sediment inputs. This could reduce the level of management required at the estuary.

There are also many additional benefits of preventing sediment from being eroded off the land and into waterbodies. Human activities and land use has increased soil erosion, meaning a valuable resource is being lost from the land. In addition, excessive amounts of small particles like silt and clay settle into, and clog up, gravels and cobbles, degrading these valuable habitats for invertebrates and for spawning fish.

Below are some of the methods which can be used to prevent sediment movement into watercourses during agricultural, highways and forestry land management.

Prevention: Agriculture

Preventing Soil Compaction

Use of heavy farm machinery, especially when the soil is wet, will lead to soil becoming compacted. This creates dense impermeable soil that easily becomes waterlogged and is therefore prone to erosion during rainfall. Prevention of soil compaction requires good soil management, including ensuring adequate organic matter is incorporated in the soil and that the use of heavy plant is limited. It can still take many years to reverse badly compacted soils.

Selecting Appropriate Crop Types

Cultivation of any kind can lead to increased soil erosion, especially where land is steep or where there is high connectivity between a field and watercourse. Maize is a particular and growing problem in the UK. It is harvested in the Autumn, leaving the soil surface unprotected during the wettest winter months, and involves a large volume of tractor movements, which accelerates soil compaction. The impact of cultivation is gaining recognition at government level and there is now advice available to farmers about how to minimise soil erosion and the importance of maintaining soils in healthy condition.

Preventing Stock Access to Rivers

Livestock access to rivers and streams for drinking causes damage to the river bank, degrades bankside vegetation, leaving bare soil, and disturbs the surface of the soil, all of which increases soil erosion. This can be prevented by fencing watercourses to restrict or prevent access.

Prevention: Highways

Soils and sediments can be eroded from road verges, at field entrances, and from the disturbance of country tracks. In addition, runoff from roads can be contaminated with chemicals from vehicles.

Intercepting Road Runoff

Sediment traps, constructed wetlands and sustainable drainage systems can allow time for contaminants to break down and can intercept sediment to prevent it leaving the field boundaries. This can allow local reuse, before the sediment becomes a waste product.

Field Entrances

Around the gates to fields is an area where there can be a high intensity of vehicle movement which can disturb soils, which may then be washed into the road during wet weather. The solid surface of the road means that the sediment can move a long distance, and may reach the rivers at bridges. Using gravel or paving to strengthen field entrances can reduce soil disturbance and movement.

Prevention: Forestry

Woodland and forested areas are generally beneficial for protecting soil and preventing erosion. However, commercial forestry operations often use heavy plant, particularly during felling. Operations on steeply sloping land can therefore increase soil erosion. During wet weather, heavy machinery moving over newly exposed soil can turn the surface to mud, which is easily transported by further rainfall. Felling operations near to streams can be particularly damaging.

Whilst it may not be possible to avoid the use of heavy machinery in commercial forestry there are techniques that can be applied, through the preparation of an integrated site plan, to ensure that soil erosion is minimised.

Buffer Strips

Coniferous forests typically have little vegetation on the forest floor so streams running through these areas often have bare banks. Leaving an appropriate buffer strip either side of a watercourse, where native, broadleaved species or undergrowth can grow, provides protection from erosion of the river bank.

Forest Stream Crossings

Where forest tracks cross small streams, forest machinery repeatedly passes through the streams, which can result in significant movement of mud and sediment directly into connected waterbodies. Culverts with resilient track surface over the top, or temporary ‘log bridges’, can be constructed and then removed on completion of the works.

Felling operations

The impact of felling operations (harvesting and extraction) can be minimised by felling away from streams and removing brash (smaller branch fragments) from the stream buffer area. Work should be planned with consideration of the weather so that sensitive areas can be worked in drier conditions.

High use areas

Areas subject to a high intensity of movements of heavy plant, such as forest tracks and loading areas, can become badly disturbed and vulnerable to sediment erosion. A layer of aggregate can be used to form a robust, drained hard standing for timber loading bays and tracks. A layer of brash laid on top of the aggregate can be used as a “disposable mud mat” for forwarders and timber transporters to work on.

Silt Traps / Sumps

Silt traps and sumps can be used to intercept dirty water and direct it onto well-vegetated, flatter areas. A well-designed silt trap will capture most of the larger particles, with finer material filtered out by directing the outlet onto an appropriate area. Silt traps are quick and easy to install before works begin and can be added to or altered as dictated by local conditions.

Monitoring

Water quality in silt traps, drains and streams can be easily checked, and ongoing monitoring will help ensure that traps are maintained appropriately and that sources of sediment pollution are quickly identified. Turbidity – or the ‘cloudiness’ of water is a good indicator of the sediment content. This can be measured using anything from sophisticated turbidity sensors with real-time alarms to a very simple visual assessment comparing a water sample against a colour chart.

Treatment

When sediment is dredged from a waterway, it is rarely in a suitable state to be reused in one of the applications described in the following pages. There may be issues in its physical composition or with chemical contamination, which mean it needs treatment to allow its beneficial reuse. Often, these treatment processes account for large proportion of the cost of a project making beneficial use of dredged sediment [3].There are two key groups of treatment; treating the physical properties of the sediment and treating the chemical properties:

Physical treatment

Treatment of the physical properties of the sediment are needed to separate different elements of the initial dredged sediment, to aid the beneficial use of some or all of these elements.

One of the most common treatment processes to address the physical properties of the sediment is de-watering, whereby either natural settlement processes or filter presses are used to separate water from the solid fraction. As described below, this can also aid the removal of chemical contaminants, and is often used as a pre-treatment, followed by further treatment.

A further physical treatment is the separation of different particle sizes, to enable the use of one or more of the fractions for specific purposes. An example of this is shown in the Storage section of this report (page 17), where sediment is sprayed into a storage facility in a way that allows larger sediment to be deposited first, followed by smaller particles.

Chemical treatment

Sediment may need treatment to remove organic or metallic contaminants which would otherwise render the chemical properties of sediment undesirable for beneficial use.

Chemical contamination typically means that use of the sediment could pose a risk to the environment or human health. Treatments for contaminated sediment aim to reduce, remove or immobilise the contaminants and therefore render the dredged material less hazardous.

The following are examples of treatment techniques[3]:

- Mechanical - *Mechanical De-watering* involves using filter presses to reduce the water content of dredged material by up to 80%, which therefore also removes suspended or soluble contaminants. Alternatively a *Geotextile Tube* can be used to 'sieve' the material and reduce contaminant concentrations. *Soil Washing* involves separating contaminated sediment from the reusable fraction. In both these processes a filter-cake is produced which is stabilised for further treatment or disposal. Contaminated water is usually also a by-product which requires treatment before release into the environment.
- Biological - *Landfarming* or *Ripening* is a technique whereby dredged sediment is spread over land and undergoes natural aerobic degradation to remove organic contaminants. *Bio-reactors* are vessels of varying sizes which are used to contain the sediment while it undergoes various microbiological processes to degrade organic contaminants.
- Chemical - *Stabilisation* involves adding chemical compounds to the contaminated dredged sediment, which stabilises the material for reuse or reduces the bioavailability of contaminants. This method may require pre-treatment by de-watering.
- Thermal - in *Thermal Desorption,* hazardous organic compounds, and some volatile metals, are heated and converted into gases/liquids which are collected for safe disposal. *Thermal Immobilisation* is a method whereby the dewatered dredged material is melted and crystallised. Organic contaminants are destroyed in the process whilst inorganics are accumulated for safe disposal or treatment. *Thermal-chemical Immobilisation using a Cement Kiln* is where dredged material is mixed with fuel, air, and modifiers in a cement kiln. Organic contaminants are destroyed and heavy metals are immobilized in the cement matrix.

An issue regarding any treatment process is that any one method may be only eliminate or reduce a particular type of contaminant. Therefore if the sediment contains more than one contaminant the costs incurred can be considerable. For more details on the types of sediment each method is suitable for use on and the types of contaminants the method can tackle, see the Cork Institute of Technology Guidance for Beneficial Reuse of Dredge Material in Ireland [3].

Sediment and metal contamination from historic mining sites

The long history of metal mining in England and Wales has polluted sediments in rivers, estuaries and floodplain soils. Early mining methods were primitive, with tailings and other mining effluent often disposed of directly into rivers.

Sediment is the main way metals are stored and transported in the river systems, with floodplains, wetlands, lakes and particularly estuaries[4] acting as long-term sinks for metals in river basins in England & Wales. In short systems with limited floodplains, such as in South West England, much of the mine waste has been deposited in estuaries[5].

These sediments are likely to be causing ongoing ecological damage. For example, contaminants may be re-suspended during floods, damaging the invertebrates and fish in the water, and contaminating floodplain soils used for agriculture. As floods increase in frequency and strength, a greater level of contamination may be an unexpected side effect of climate change[6]. Controlling sediment-associated sources of contamination is therefore important in managing affected river systems to achieve good ecological status[7].

Management, mitigation and remediation

The EU Mining Waste Directive[8] recognises the central importance of the Water Framework Directive (WFD) to the remediation of mining-contaminated river systems by referring to the WFD's catchment-based approach to water management. The MWD is also key to tackling the issue of contamination of river systems as it requires the drawing up of an inventory of closed waste facilities.

Although mitigation of contamination across entire catchments is unlikely to be appropriate, it may be necessary to control active, or potentially active, point sources of metals, such as former mine sites, to reduce the potential for erosion, dispersal and deposition of contaminated sediment. Remediation of mine sites usually focuses on two areas of concern – contamination from exposed spoil heaps and remediation of contaminated minewater discharges.

Mining spoil heaps contain high levels of contamination and, as they weather, they can leach harmful materials into the surrounding landscape and watercourses. To reduce the environmental impact it is necessary to introduce a barrier slows the weathering process. An artificial impermeable membrane layer can be used to ensure hydrological isolation of spoil material – but in most cases this would be expensive and impractical. The most sustainable way of doing this is to encourage natural revegetation. However, this can also be problematic for a number of reasons:

- Spoil heaps can be toxic and lacking the organic matter necessary for natural revegetation. They can be dressed with an introduced substrate, however this can involve the transportation of large amounts of material to potentially remote and inaccessible locations. It does, however, provide a potential use for dredged sediment. Under the USAR project, WRT have been investigating the performance of different waste materials, including sediment recovered during drinking water treatment, as an introduced growing medium.
- In some areas, mining spoil heaps are designated as heritage assets due to their visual impact in historic industrial landscapes. In these areas, full vegetation of the spoil heaps would not be aesthetically acceptable. With the University of Plymouth, WRT are investigating ways of stabilising loose spoil heaps using biopolymers.

Water discharging from abandoned mine sites is typically very acidic (low pH) and contaminated with dissolved metals. The main method of treatment involves raising the pH so that the metals precipitate out of solution. They can then be separated from the water using a combination of aeration, settlement ponds and reed beds.

Passive treatment systems move contaminated water under gravity. Alkalinity can be raised by diverting the contaminated minewater across a bed of limestone before discharging through a wetland. Wetlands trap precipitates and encourage microbial activity which accelerates the precipitation process. Reed beds also provide valuable habitat for birds. The area of land needed to treat contaminated water via a wetland system can sometimes be prohibitive. Active treatment systems generally work on the same principle but usually involve pumping contaminated water into tanks where pH is raised by addition of chemicals (highly alkaline substances and flocculants). They may also include active aeration. The aim is to achieve the same effect but in a smaller space than a passive system.

An alternative approach to managing the risks from mining-related contamination is catchment-scale mapping. This approach allows the identification of hotspots that should not be used for crop production or animal grazing, and the targeting of erosion control management to prevent bank erosion from remobilising highly contaminated soils.

In addition, sediment and its chemical composition are currently rarely analysed by existing environmental monitoring networks. Metallic elements tend to have a long residence times in the fluvial environment, and sediment-associated metals are dispersed, sequestered and remobilised in river systems in complex ways. Therefore, to understand this issue there needs to be a shift from short-term, static and point-based monitoring towards catchment-scale environmental quality programmes, underpinned by a sound understanding of river basin sediment system dynamics.

Cost-benefit assessments can be used to evaluate different management and mitigation approaches so that risks to ecosystem and human health are reduced to acceptable levels.

Reuse

The next stages of the waste hierarchy, if prevention is not possible, are to reuse or recycle the waste material. This is the focus of the USAR pilot projects. This section will look more generically at some of the options for beneficial use of sediment, under the following categories: agriculture, construction, habitat creation and flood defence.

Agriculture

When sediment is dredged from watercourses to maintain the water quality or navigability, a simple solution is to spread the sediment on adjacent parcels of land. In many regions of the Netherlands, the landowners next to the river are obliged to receive dredged sediment, based on the assumption that this land is where the sediment originated. In the past, dredging sludge was seen as a useful product, as it can improve soil structure and fertility and can be used to level land parcels.

In more recent years, concerns have arisen around the quality and potential contamination of the sediment, making landowners less willing to accept the sediment onto their land. This makes local beneficial use more challenging, and sediment managers may end up having to look further down the waste hierarchy for a way of dealing with their waste - sometimes leading to the disposal of sediment rather than reuse.

However, due to legislation and policy changes, water and sediment quality is generally improving. For example, in the Krimpenerwaard in the Netherlands, approximately 90% of sediment nowadays is not contaminated and may be suitable to be distributed across the land.

There are several key considerations for sediment to be used on agricultural land:

- Sediment must be from freshwater rather than saline sources, or must have had the salinity reduced during the dewatering process, for example by being exposed to rainfall for several months
- Sediment will need to have a suitable water content in order to be incorporated into existing soil
- Sediment will need to be sampled and analysed to ensure it is not contaminated
- Soil is made up of organic matter as well as minerals like sand and silt. Dredged sediment typically contains more of the mineral element, as some of the organic matter may have been broken down or washed away. In addition, sediment dredged from a certain area may only contain a certain size of sediment particles, depending on where in the river system it has been sourced from. Therefore, it may need to be combined with other materials or other waste products in order to improve it for use as soil.

It is also important that the 'image' of sediment changes, back to being seen as a useful product rather than waste. Making use of sediment close to its source is convenient and saves some of the costs and CO_2 emissions associated with the transport of large volumes of bulky sediment. Clear policy and effective sampling and monitoring systems are vital to help bring about the necessary change of mindset, especially as there are multiple benefits to be gained from a change of approach.

Construction

Extensive dredging operations may produce suitable quantities of sediment for use in civil engineering and construction. There are some issues which will need to be taken into consideration for sediment to be reused for these purposes:

- The sediment will typically need to have a low water content and/or be dried before use.
- For dredged sediment to be suitable for use in civil engineering and public infrastructure work, the organic matter content must be less than 3% of the total dry mass. The presence of organic material can disturb and delay the setting of hydraulic binders (for example cement or lime). This reduces the durability of the final products such as concrete, mortar and road materials. To be used effectively, sediments must therefore be pre-treated to reduce their water and/or organic matter content (see pg 10).
- To make sediment more suitable for use in construction, mineral granular correctors often need to be added. This could be sand, or a number of 'waste products' are also suitable. Substances such as ground-granulated blast-furnace slag (GGBS) or bottom and fly ash are often added to concrete as a supplementary cementitious material (see box to the right).

Ground-granulated blast-furnace slag (GGBS) is made from waste produced during iron and steel production. It can be added to concrete as a partial replacement for cementitious material. Concrete containing 30% to 70% has increased durability - it sets more slowly but continues to gain strength over a longer period.

Bottom ash is the non-combustible residues left in a furnace after extraction. It is commonly sold as a lightweight aggregate for use in concrete blocks.

Fly ash is also known as pulverized fuel ash and refers to the residues that are driven out during the combustion processes and removed from the exhaust gases.

The following are some examples of construction applications for dredged sediment:

Roads

Due to their availability, mineralogical composition and geotechnical characteristics, dredged sediments can be a suitable substitute for aggregates used in road construction. However, treatment is often required to deal with high initial water and organic matter content. The addition of mineral granular correctors such as sand, blast furnace slag or bottom and fly ash and hydraulic binder treatment is usually recommended. In lab studies, it has been suggested that up to 40% of road materials could be substituted with sediment. However, this may not be a high enough content to make it a viable or attractive option on a large scale.

Several examples of sediment use in large-scale road projects have emerged in recent years. One such example is a 600m stretch of road in Dunkirk Harbour. A full-scale test road was built using marine dredged sediments in order to test the compatibility with standard construction methods.

Concrete

Concrete is a composite mineral material formed from a mixture of aggregates (sand/gravel) and hydraulic binders (substances that encourage setting when mixed with water). Concrete is the most widely-used building material in the world and is the mineral material second most commonly-used by humans, after water.

The natural resources used as aggregates tend to be non-renewable, and there is a need to find alternative materials going forward. The beneficial use of dredged sediment in concrete presents an opportunity for economic and environmental improvements in the production of concrete. Depending on their physico-chemical characteristics, sediments can be used as a replacement for cement or natural sand. Several research studies have shown that it is feasible to replace up to 20% of natural aggregates with sediment and up to 10% of the volume of binders. In particular, there is potential to use dredged sediment as an alternative to some of these typical aggregates:

- Lightweight aggregates - these are used in lightweight concrete products such as concrete block, structural concrete, and pavement. Dredged sediments have been mixed with fly ash and cement to produce lightweight aggregates to be used in the formulation of lightweight concrete (in accordance with the lightweight concrete standard EN 13055).
- Backfilling grout - grout is a mixture of water, cement and sands and is used in construction projects to fill gaps around pipes and sewers, and can be used to backfill trenches. Sediments can be used as part of the grout mix alongside cement (around 10%) and other supplementary cementitious material.

Permeable paving

Permeable paving allows rainfall and runoff to infiltrate paved surfaces. It has a high mechanical resistance and is resistant to frost, abrasion and hydrocarbons, ensuring the durability of the roadway. This system reduces the compaction of soils, reduces the risk of flooding and helps to clean up the water draining through the pavement.

Ceramics

In several research programmes, sediments have been used in place of natural clay for the manufacture of fired bricks. Subsequent tests have shown that the resulting products have suitable properties in terms of their mechanical resistance, water absorption and chemical composition.

[refs. 9 - 16]

Habitat Creation

Sediment arising from dredging projects can be beneficially used in certain situations for habitat enhancement, creation or reinstatement. Coastal habitats in particular are an opportunity for the beneficial use of sediment, with the potential for multiple additional benefits. Habitats such as saltmarshes, mudflats and shingle ridges, are important for species such as seabirds and fish, but are at risk of being 'squeezed' between development on the land and rising sea levels. These habitats are also important defences against coastal flooding, reducing the power and impact of storm surges, and reducing the size and cost needed for artificial flood defences. In addition, opportunities for bird watching and walking provide value through tourism and recreation and benefits for visitors health.

Habitats are, by their very nature, unique and complex, and their characteristics will be partly shaped by the land beneath them. This means that when using sediment for habitat creation or reinstatement, the physical and chemical characteristics of the sediment, the receiving site, and the habitat to be created, must be carefully considered and assessed for compatibility. In addition, a clear understanding of the ecological requirements and of the constraints of the surrounding environment and climate is essential before attempting to create or re-create a habitat.

The following are some examples, drawn from the RSPB SEABUDS report[17], of the types of habitat which can be restored or created through beneficial use schemes for dredged sediment, and the types of sediment suitable for each:

- Saltmarsh and mudflats: fine, muddy dredging materials can be used to stabilised eroding saltmarshes, particularly if placed in confined areas where the muddy sediments can dewater and solidify over time.
- Silt lagoons: storing silty material within bunded areas can create silt lagoon habitats. The combination of shallow water and mud attracts waterbirds and provides habitat for a variety of rare invertebrates. The initial stages of succession tend to be the most interesting for wildlife, so ongoing creation of these habitats will be of benefit to biodiversity.
- Dredging islands: bunded areas can also be created in shallow coastal waters and filled with fine material. The material will gradually dry and firm up to form islands, which can then be managed to create a variety of habitats.
- Offshore berms and sacrificial bunds: Stable berms of rock or clay can be created to provide coastline protection, or so-called 'sacrificial' bunds can be made of sand or shingle and used to gradually disperse sediment onto eroding coastlines.
- Shingle ridges: coarser dredged sediments can be used to build up shingle ridges, which provide habitat for nesting shoreline birds and act as a coastal defence.

A recent report by PIANC[18] highlights the following key considerations if dredged sediment is to be used for ecological purposes:

- The placement of the sediment needs to be based on a good understanding of local conditions, to avoid adversely altering local hydrodynamics. The best option may be to place the sediment strategically so that existing currents transport the material at a more natural rate, allowing time for species to adjust to the additional sediment.
- The physical sediment characteristics must meet the requirements of local wetland vegetation and fauna, as grain sizes influence community structure.

Backfilling of brushwood enclosures with dredged sediment alongside the saltmarsh at Brightlingsea Harbour

Flood Defence

Flood defence schemes often make use of a combination of techniques, which may include controlled flood areas, managed realignments to restore natural wetlands, and more engineered features such as dykes. Dykes can be created using dredged sediments, and may even be a suitable use for contaminated sediments.

Dykes are embankments used across low-lying areas such as Belgium and the Netherlands to protect urban areas from flooding, particularly along tidal rivers. On these tidal rivers, the dykes must be constructed to withstand daily movements of large quantities of water, placing the dykes under considerable pressure, without deforming. The dykes must also be able to withstand storm surges, which occur several times a year during the October to March storm season.

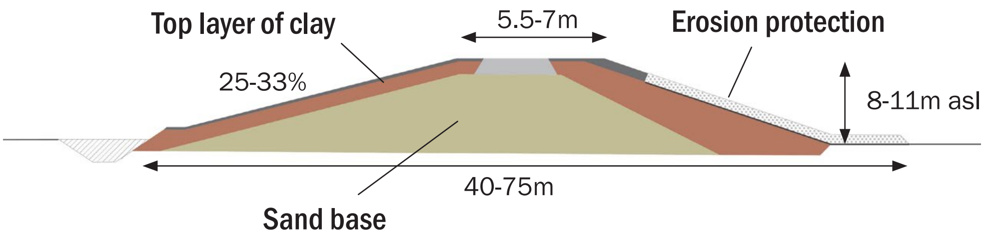
Features of dykes

Dykes consist of three main materials:

- Sand core - sand can be easily compacted, to provide a stable core
- Clay top layer - to make the dyke waterproof
- Quarry stone or similar material - to prevent erosion, ensuring the upper layer of the dyke is not worn down by waves colliding with the embankment

All of these elements can be constructed using recycled materials, such as dredged sediment. Within the USAR project, Flemish Waterways are investigating ways to reuse the sand and clay present in the sediment, but it would be beneficial for future projects to examine the potential to also produce the erosion protection materials from sediment.

Flood protection dykes in the Scheldt estuary, Belgium, typically have a crest width between 5.5 and 7 meters and a footprint that is 40 to 75 meters wide. The gradient of the slopes generally varies between 25 and 33%. The crest is 8 to 11 meters above sea level.



Advantages and limitations of the use of sediment in flood defence

The use of sediment offers numerous advantages:

- There is potential to use sediment dredged from a river or waterway to build the dykes on the banks of the same river. This would require very little transport, and would therefore reduce the associated costs and emissions.
- It is resource efficient, as a secondary material can be used in place of a primary raw material. It creates a market for sediment which would otherwise be wasted.
- There is less need for sediment disposal or landfill sites, which are often unpopular due to the associated dust, odours and road traffic.

However, there are also limitations to the use of sediment, involving various issues:

- As described above, dykes need to be both stable and waterproof. This does not pose an issue with the ‘classic’ raw materials - primary, geologically-deposited sand compacts well and provides sufficient stability, and raw clay is waterproof. Dredged sediment often does not necessarily immediately possess these characteristics, as it is composed of different particles. Therefore, significant preparatory work must be undertaken on a case-by-case basis, as both the composition of sediment and the design of the dykes is rarely the same each time. Such research has costs associated with it, but by saving on transport, the economic cost of both approaches can be similar.
- An additional difficulty is timing. In order to use dredged material to construct dykes, without the need for large amounts of transport and storage, the timing of dredging and constructing the dyke needs to more or less coincide.
- A last hindrance is the decontamination of the sediment. The use of mobile installations to decontaminate the sediment on the site is usually preferable, as it avoids the need for transportation to a separate treatment centre.

Storage & Transport

Transportation of sediment

The transportation of sediment can be undertaken using many of the standard transport options. However, the volume, weight and fluidity of the sediment tends to make certain forms of transport more efficient and less disruptive than others. The table below assesses the advantages and disadvantages of various forms of transport:

Transport Type	Advantages	Disadvantages
Trucks/ Heavy Goods Vehicles (HGV)	▶ The infrastructure (roads) is usually already in place	▶ Road networks, especially in rural areass, may not be able to cope with HGV traffic ▶ Trucks have a relatively small capacity (approx. 30 tonnes) - this means a large number of trucks will be needed ▶ Road traffic causes a nuisance to local communities ▶ The carbon emissions from many truck journeys will be high
Rail	▶ Efficient ▶ Potential for high capacity	▶ Railway needs to be near to sediment source and receptor in order to avoid truck use ▶ Carriages may need to block track during loading/unloading
Pipelines	▶ Suitable for long distances ▶ Pumping into pipelines makes little noise and so is not a nuisance for local people ▶ Efficient and low emissions ▶ Most dredging projects produce large quantities of sediment, so installation of a pipeline may be cost-effective	▶ Requires significant installation, so best suited to large projects (see also advantages)
Conveyor belts	▶ An alternative to pipelines for shorter distances (e.g. crossing a road)	
Barges	▶ High capacity - 650 tonnes (the equivalent of more than 20 trucks) ▶ Can be used to connect to pipelines ▶ Less disruptive than road or rail transport	

PRISMA

An example of successful sediment transportation

For the Interreg 2 Seas project PRISMA, Flemish Waterways needed to transport 100,000m^3 of sediment from the River Scheldt to a flood control area in Dendermonde, where it was used to build a compartment dyke. During the project, they avoided transport over land, and instead used barges to move the sediment 35km along the river, where it was processed on the banks of the river. This avoided more than 12,000 truck movements, improving the efficiency and sustainability of the project.

Storage

The storage of dredged sediment may be useful in order to coordinate supply and demand within sediment reuse projects, particularly in large-scale projects. Storage may also be necessary for sediments which need to go through several stages of treatment before use.

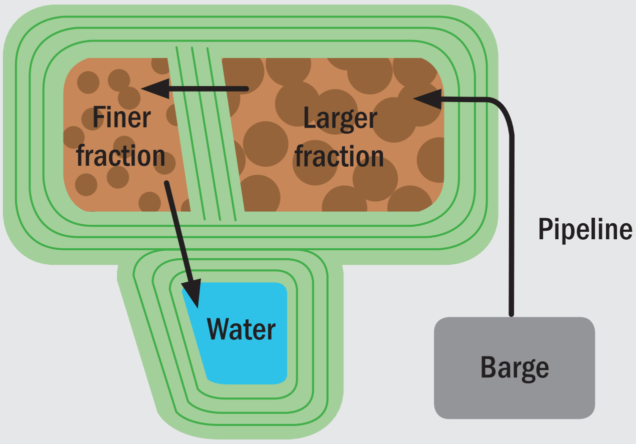
Several key considerations for the storage or stockpiling of dredged sediment for beneficial use are suggested in the report 'The Processing and Beneficial Use of Fine-Grained Dredged Material: A Manual for Engineers'[18]:

- If the sediment has been dewatered and is being 'stockpiled', it needs to be stored in a way which allows rainfall to runoff and not re-hydrate the sediment - piles of sediment need to be shaped to shed rainwater and should be at a sufficient distance apart to prevent ponds forming between the piles.
- There needs to be some control over the water which is released from the sediment, to protect the wider environment. This water could be directed into drainage swales leading to a detention pond, or a system for collecting leachate could be used to then allow appropriate treatment or disposal. Some projects working with contaminated sediment have lined storage areas with low permeability soil to prevent groundwater infiltration.
- Long term storage may affect the characteristics of the sediment, such as its strength or permeability. These processes of change may be slower during the winter months. Nonetheless, it is suggested that the condition of the sediment may need to be checked regularly if it is to be stored for more than a few weeks.

Sandstock De Bunt

An example of sediment storage

Flemish Waterways have used a 'lagooning' method to both store and separate out different sizes of sediment in order to reuse dredged sediment for the creation of a flood-protection dyke. The sediment is taken from a barge on the waterway, through a pipeline and is then sprayed into large lagoons. By spraying the sediment, gravity allows the larger sediment to be deposited in the first basin, finer sediment then drops out into the second basin, and the resulting water ends up in a third basin.



Advantages of 'lagooning' method

- Low consumption of raw materials
- Low level of transport, especially on the roads

Disadvantages of 'lagooning' method

- Needs space
- Takes time
- Not all of the sediment can be reused

Storage lagoons in Hamme, Belgium

Supporting Tools

The Institute of Mines and Telecommunications (IMT) is developing two key tools to help sediment managers to understand opportunities for the beneficial use of their sediment.

Inventory catalogue

Inventory catalogue of potential applications of sediment as a resource

For this tool, a team of academics will undertake a desk study and series of working group sessions to compile, analyse and compare practical examples and promising concepts for using and recycling sediment. These examples will be compiled into an inventory catalogue, alongside experiences of water managers and research institutes and previous projects from the 2 Seas region and beyond. Water and sediment managers will be able to use the inventory catalogue to make informed choices based on state-of-the-art and emerging applications for sediment.

Operational Sediment Management System

IT tool for water managers to make business cases and management decisions for recycling of sediment

This tool will allow users to feed regional sediment data, such as soil type, pollution and volume, into the system, which will then use this data to suggest suitable options for the use, and the end-users, of the recycled sediment. It will also suggest some of the specific needs to enable this beneficial use such as processing specifications, need for additives, storage and transport requirements, and costs.

It will be an open-source IT system which can be freely accessed and operated independently by water managers across Europe, and will allow the stakeholders involved in water management and dredging to quickly identify the most suitable and cost effective option for sediment recycling in their specific regional context.

Maintenance dredging on the tidal River Durme (copyright @Vilda)

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More information

The following reports and websites provide further reading around the subject:

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Optimizing the Use of Fly Ash in Concrete
cement.org/docs/default-source/fc_concrete_technology/is548-optimizing-the-use-of-fly-ash-concrete.pdf

Preparing a Waste Prevention Programme (EC)
ec.europa.eu/environment/waste/prevention/pdf/Waste%20prevention%20guidelines.pdf

MMO public register of marine licence applications
gov.uk/check-marine-licence-register

Classification of Waste - Soil, contaminated soil, stones and dredging spoil
gov.uk/how-to-classify-different-types-of-waste/construction-and-demolition-waste


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