POLLUTION, SOLIDS

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Introduction

A very wide variety of solid wastes have been dumped at sea or discharged into the oceans via pipelines or rivers, either deliberately or as a consequence of other activities. The main solid materials involved are dredged material, particulate wastes from sand/gravel extraction and land reclamation, industrial wastes, including mining wastes and munitions, and plastics and litter.

Regulation

The London Convention 1972 has regulated dumping at sea of these materials on a global basis since it came into force in 1974 and at the time of writing it has 77 contracting parties. Regional conventions also regulate the dumping of these materials in some parts of the world, e.g. the OSPAR Convention 1992 for the North-East Atlantic, the Barcelona Convention 1995 for the Mediterranean, the Cartagena Convention 1983 for the Caribbean and the Noumea Convention 1986 for the South Pacific. Where materials are discharged into the oceans via pipelines or rivers, this usually falls under national regulation but regional controls or standards may strongly influence this regulation, e.g. within the countries of the European Union. When human activities introduce solid materials as a by-product of those activities, this is commonly subject only to national regulation, if any at all.

Impacts

All solid wastes have significant physical impacts at the point of disposal when disposed of in bulk. These impacts can include covering of the sea bed, shoaling and short-term local increases in water suspended solids levels. Physical impacts may also result from the subsequent transport, particularly of the finer fractions, by wave and tidal action and residual current movements. All these impacts can lead to interference with navigation, recreation, fishing and other uses of the sea. In relatively enclosed waters those materials with a high chemical or biological oxygen demand (e.g. organic carbon-rich) can adversely affect the oxygen regime of the receiving environment whereas sediments with high levels of nutrients can significantly affect the nutrient flux.

Biological consequences of these physical impacts can include smothering of benthic organisms, habitat modification and interference with the migration of fish or shellfish due to turbidity or sediment deposition. The toxicological effects of the constituents of these materials may be significant. In addition, constituents may undergo physical, chemical and biochemical changes when entering the marine environment and these changes have to be considered in the light of the eventual fate and potential effects of the material.

Dredged Material

Dredging

Dredging is undertaken for a variety of reasons including navigation, environmental remediation, flood control, and the emplacement of structures (e.g. foundations, pipelines and tunnels). These activities can generate large volumes of waste requiring disposal. Dredging is also undertaken to win materials, for example for reclamation or beach nourishment. Types of material dredged can include sand, silt, clay, gravel, coral, rock, boulders and peat. Mining for ores is considered further within the section on industrial wastes.

Most dredging activities but particularly hydraulic dredging generate an overspill of fine solid material as a consequence of the dredging activity. The particle size characteristics of this material and the hydrodynamics of the site will determine how far it may drift before settling and this will influence the extent and severity of any physical impact outside the immediate dredging site. The chemical characteristics of this material have to be taken into consideration in any risk assessment of the consequences to the environment.

Dredged Material

Waterborne transport is vital to domestic and international commerce. It offers an economical, energy efficient and environmentally friendly transportation for all types of cargo. Dredging is essential to maintain navigable depths in ports and harbors and their approach channels in estuaries and coastal waters (maintenance) as well as for the development of port facilities (capital). Maintenance dredged materials tend generally to consist of sands and silts whereas capital dredged material may include any of the materials mentioned above. Dredged material can be used for land reclamation or other beneficial uses but most of that generated in marine areas is disposed of in estuaries and coastal waters by dumping from ships or barges. The disposal of dredged material is the largest mass input of wastes deposited into the oceans. However, it does not follow that dredged material is the most environmentally significant waste deposited in the ocean, since much dredged material disposal is relocation of sediments already in the marine environment, rather than fresh input.

London Convention data indicate that Contracting Parties dumped around 220 million tonnes dredged material in 1996. However, not all coastal states have signed and ratified the Convention and less than half of the Contracting Parties regularly report on their dumping activities. Data from the International Association of Ports and Harbours indicated that in 1981 around 580 million tonnes of dredged material were being dumped each year and that survey only had data from half the countries contacted. Thus, it would seem likely that actual quantities of dredged material dumped in the world's ocean could be up to 1000 million tonnes per annum.

Regulation

The Dredged Material Assessment Framework (DMAF) of the global London Convention 1972 is widely accepted as the standard guidance for the management of dredged material disposal at sea. Regional conventions will often have their own guidance documents that will usually be more specific to take account of local circumstances, e.g. The Guidelines for the Management of Dredged Material of the OSPAR Convention last revised in 1998.

Characterization

Dredged material needs to be characterized before disposal as part of the risk assessment procedure if environmental harm is to be minimized. This will usually require consideration of its physical and chemical characteristics and may require assessment of its biological impacts, either inferred from the chemical data, or directly through the conduct of tests for toxicity, bioaccumulation etc. The physical properties and chemical composition of dredged materials are highly variable depending on the nature of the material concerned and its origin, e.g., grain-size, mineralogy, bulk properties, organic matter content, and exposure to contamination.

Impacts

In considering the impacts of dredged material disposal, a distinction may be made between natural materials and those sediments that have been contaminated by human activities. Although physical, and associated biological, impacts may arise from both types of materials, chemical impacts and their associated biological consequences are usually of particular concern from contaminated sediments.

In common with the other materials covered in this article, the physical impact of dredged material disposal is most often the most obvious and significant impact on the aquatic environment. The sea bed impacts can be aggravated if the sediment characteristics of the material are different from that of the sediment at the disposal site or if the material is contaminated with debris such as pieces of cable, scrap metal and wooden beams.

Most of the material dredged from coastal waters and estuaries is, by its nature, either uncontaminated or only lightly contaminated by human activity (i.e. at, or close to, natural background levels). Sediments in enclosed docks and waterways are often subject to more intense contamination, both because of local practices, and the reduced rate of flushing of such areas. This contamination may be by metals, oil, synthetic organics (e.g. polychlorinated biphenyls, polyaromatic hydrocarbons, pesticides) or organometallic compounds such a tributyl tin. The latter has been a major concern in recent years due to its previous widespread use in antifouling paints, its consequential occurrence in estuarine sediments in particular, and its wide range of harmful effects to many marine organisms. However, it is generally the case that only a small proportion of dredged material is contaminated to an extent that either major environmental constraints need to be applied when depositing these sediments or the material has to be removed to land for treatment or to specialized confinement facilities.

Beneficial uses

Dredged material is increasingly being regarded as a resource rather than a waste. Worldwide around 90% of dredged material is either uncontaminated or only lightly contaminated by human activity so that it can be acceptable for a wide range of uses. The London Convention DMAF recognizes this and requires that possible beneficial uses of dredged material be considered as the first step in examining dredged material management options. Beneficial uses of dredged materials can include beach nourishment, coastal protection, habitat development or enhancement and land reclamation. Operational feasibility is a crucial aspect of many beneficial uses, i.e. the availability of suitable material in the required amounts at the right time sufficiently close to the use site.

Sand/Gravel Extraction

Introduction

Sand and gravel is dredged from the sea bed in various parts of the world for, among other things, land reclamation, concreting aggregate, building sand, beach nourishment and coastal protection. The largest producer in the world is Japan at around 80–100 Mm^3 per year, Hong Kong at 25–30 Mm^3 per year, the Netherlands and the UK regularly producing some 15–20 Mm^3 per year and Denmark, the Republic of Korea and China lesser amounts.

Reclamation with Marine Dredged Sand and Gravel

In recent years, some very large land reclamations have taken place for port and airport developments particularly in Asia. For example, in Hong Kong some 170 Mm^3 was placed for the new artificial island airport development with another 80 Mm^3 used for port developments over the period 1990–1998. Demand projections indicate a need for a further 300 Mm^3 by 2010. Also, in Singapore the Jurong Island reclamation project initiated in 1999 was projected to require 220 Mm^3 of material over 3 years.

Regulation

National authorities generally carry out the regulation of sand and gravel extraction and they may have guidance on the environmental assessment of the practice. There is currently no accepted international guidance other than for the Baltic Sea area under the Helsinki Convention, although other regional conventions such as OSPAR do plan to develop guidance.

Impacts

The environmental impacts of sand and gravel dredging depend on the type and particle size of the material being dredged, the dredging technique used, the hydrodynamic situation of the area and the sensitivity of biota to disturbance, turbidity or sediment deposition. Screening of cargoes as they are loaded is commonly employed when dredging for sand or gravel to ensure specific sand : gravel ratios are retained in the dredging vessel. Exceptionally, this can involve the rejection of up to five times as much sediment over the side of the vessel as is kept as cargo. When large volumes of sand or gravel are used in land reclamation, the runoff from placing the material may contain high levels of suspended sediment. The potential effects of this runoff are very similar to the impacts from dredging itself.

Physical impacts The most obvious and immediate impacts of sand and gravel extraction are physical ones arising from the following.

- Substrate removal and alteration of bottom topography: trailer suction dredgers leave a furrow in the sediment of up to 2 m wide by about 30 cm deep but stationary (or anchor) suction dredgers may leave deep pits of up to 5 m deep or more. Infill of the pits or furrows created depends on the natural stability of the sediment and the rate of sediment movement due to tidal currents or wave action. This can take many years in some instances. A consequence of significant depressions in the seabed is the potential for a localized drop in current strength resulting in the deposition of finer sediments and possibly a localized depletion in dissolved oxygen.
- Creation of turbidity plumes in the water column: this results mainly from the overflow of surplus water/sediment from the spillways of dredgers, the rejection of unwanted sediment fractions by screening and the mechanical disturbance of the seabed by the draghead. It is generally accepted that the latter is of relatively small significance compared to the other two sources. Recent studies in Hong Kong and the UK indicate that the bulk of the discharged material is likely to settle to the seabed within 500 m of the dredger but the very fine material (< 0.063 mm) may remain in suspension over greater distances due to the low settling velocity of the fine particles.
- Re-deposition of fines from the turbidity plumes and subsequent sediment transport: sediment that settles out from plumes will cover the seabed within and close to the extraction site. It may also be subject to subsequent transport away from the site of deposition due to wave and tidal current action since it is liable to have less cohesion and may be finer (due to screening) than undredged sediments.

Chemical impacts The chemical effects of sand and gravel dredging are likely to be minor due to the very low organic and clay mineral content of commercial sand and gravel deposit and to the generally limited spatial and temporal extent of the dredging operations.

Biological impacts The biological impacts of sand and gravel dredging derive from the physical impacts described above and the most obvious impacts are on the benthic biota. The consequences are as follows.

- Substrate removal and alteration of bottom topography: this is the most obvious and immediate impact on the ecosystem. Few organisms are likely to survive intact as a result of passage through a dredger but damaged specimens may provide a food source to scavenging invertebrates and fish. Studies in Europe on dredged areas show very large depletions in species abundance, number of taxa and biomass of benthos immediately following dredging. The recolonization process following cessation of dredging depends primarily on the physical stability of the seabed sediments and that is closely related to the hydrodynamic situation. Significant recovery towards the original faunal state of the benthos depends on having seabed sediment of similar characteristics to that occurring before dredging. The biota of mobile sediments tends to be more resilient to disturbance and able to recolonize more quickly than the more long-lived biota of stable environments. Generally, sands and sandy gravels have been found to have recovery times of 2–4 years. However, recovery may take longer where rare slow-growing animals were present prior to dredging. The fauna of coarser deposit are likely to recover more slowly, taking from five to ten years. Recolonizing fauna may move in from adjacent undredged areas or result from larval settlement from the water column.
- Creation of turbidity plumes in the water column: as these tend to be limited in space and time, they are not likely to be of great significance for water column fauna unless dredging takes place frequently or continuously.
- Re-deposition of fines from the turbidity plumes and subsequent sediment transport: deposition of fines may smother the benthos in and around the area actually dredged but may not cause mortality where the benthos is adapted to dealing with such a situation naturally, e.g. in areas with mobile sediments. The deposited fines may be transported away from the site of deposition and affect more distant areas, particularly if the deposited sediment is finer than that naturally on the seabed as a result of screening.

Industrial Solids

Introduction

Industries based around coasts and estuaries have historically used those waters for waste disposal whether by direct discharge or by dumping at sea from vessels. Many of these industries do not generate significant quantities of solid wastes but some, particularly mining and those processing bulk raw materials, may do so.

The sea may be impacted by mining taking place on land, where waste materials are disposed into estuaries and the sea by river inputs, direct tipping, dumping at sea or through discharge pipes. Examples include china clay waste discharged into coastal waters of Cornwall (southwest England) via rivers, colliery waste dumped off the coast of northeast England, and tailings from metalliferous mines in Norway and Canada tipped into fiords and coastal waters. Alternatively, mining may itself be a waterborne activity, such as the mining of diamonds in Namibian waters or tin in Malaysian waters, with waste material discharged directly into the sea.

Fly ash has been dumped at sea off the coast of northeast England since the early 1950s, although this ceased in 1992, and has been going on since 1988 off the coast of Israel in the Mediterranean Sea. Fly ash is derived from 'pulverized fuel ash' from the boilers of coal power stations but is mainly 'fly ash' extracted from electrostatic filters and other air pollution control equipment of coal- and oil-fired power stations. This fine material is mainly composed of silicon dioxide with oxides of aluminum and iron but may carry elemental contaminants condensed onto its surfaces following the combustion process.

Surplus munitions, including chemical munitions, were disposed of at sea in various parts of the world in large quantities after both World War I and World War II. In addition, a number of countries have made regular but smaller disposals at sea since 1945. In earlier times much of this material was deposited on continental shelves but since around 1970 most disposals have taken place in deep ocean waters.

Regulation

The London Convention 1972 has regulated the dumping of industrial wastes at sea since it came into force in 1974. Annex I of the Convention was amended with effect from 1 January 1996 to ban the dumping at sea of industrial wastes by its Contracting Parties. However, not all coastal states have signed and ratified the Convention and less than half of the Contracting Parties regularly report on their dumping activities. In 1996 Japan dumped some 3 million tonnes of solid industrial wastes into the sea. Other Contracting Parties reportedly dumped only very small amounts.

Characterization

Like dredged material, these materials need to be characterized before disposal can be permitted to ensure that significant environmental harm is not caused as a result of its disposal.

Impacts

The impacts of the disposal of solid industrial wastes into the sea is as described in the introduction, although chemical and biological impacts may be more significant than for some other solid wastes due to the constituents of the materials. However, physical impacts are usually dominant due to the bulk properties of these materials. Fly ash has a special property (pozzolanic activity) that causes the development of strong cohesiveness between the particles on contact with water. This leads to aggregation of the particles and the formation of concretions that may cover all or part of the sea bed.

Beneficial Uses

Beneficial uses can often be found for these materials but depend strongly on the characteristics of the material and the opportunities for use in the area of production. Inorganic materials may be used for example for fill, land reclamation, road foundations or building blocks and organic materials may be composted, used as animal feed or as a fertilizer.

Plastics and Litter

Introduction

There has been growing concern over the last decade or two about the increasing amounts of persistent plastics and other debris found at sea and on the coastline. Since the 1940s there has been an enormous increase in the use of plastics and other synthetic materials that have replaced many natural and more degradable materials. These materials are generally very durable and cheap but his means that they tend to be both very persistent and readily discarded. They are often buoyant so that they can accumulate in shoreline sinks.

Regulation

A number of international conventions including the London Convention 1972, MARPOL 73/78 and regional seas conventions ban the disposal into the sea of persistent plastics. Annex V of the International Convention for the Prevention of Pollution from Ships 1973, as modified by the 1978 Protocol (known as MARPOL 73/78) states that 'the disposal into the sea of all plastics, including but not limited to synthetic ropes, synthetic fishing nets and plastic garbage bags, is prohibited'. An exception is made for the accidental loss of synthetic fishing nets provided all reasonable precautions have been taken to prevent such loss. This Annex came into force in 1988. Guidelines for implementing Annex V of MARPOL 73/78 suggest best practice for waste handling on vessels. Many parties to MARPOL 73/78 have installed additional waste reception facilities at ports and/or expanded their capacity in order to encourage waste materials to be landed rather than disposed of into the sea. Annex I of the London Convention 1972 prohibits the dumping of 'persistent plastics and other persistent synthetic materials, for example netting and ropes, which may float or remain in suspension in the sea in such a manner as to interfere materially with fishing, navigation or other legitimate uses of the sea'. All land-based sources of these materials fall under national regulation.

Impacts

Persistent plastics and other synthetic materials present a threat to marine wildlife, as well as being very unsightly and potentially affecting economic interests in recreation areas. They are a visible reminder that the ocean is being used as a dump for plastic and other wastes. These materials also present a threat to navigation through entangling propellers and blocking of cooling water systems of vessels. In 1975 the US Academy of Sciences estimated that 6.4 million tonnes of litter was being discarded each year by the shipping and fishing industries. The debris that is most likely to be disposed of or lost can be divided into three groups.

Fishing gear and equipment Nets that are discarded or lost can continue to trap marine life whether floating on the surface, on the bottom or at some intermediate level. Marine mammals, fish, seabirds and turtles are among the animals caught. In 1975 the UN Food and Agriculture Organization estimated that 150 000 tonnes of fishing gear was lost annually worldwide.

Strapping bands and synthetic ropes These are used to secure cargoes, strap boxes, crates or packing cases and hold materials on pallets. When pulled off rather than cut, the discarded bands may encircle marine mammals or large fish and become progressively tighter as the animal grows. They also entangle limbs, jaws, heads etc. and affect the animal's ability to move or eat. Plastic straps for four- or six-packs of cans or bottles can affect smaller animals in a similar way.

Miscellaneous other debris This covers a wide variety of materials including plastic bags or sheeting, packing material, plastic waste materials and containers for beverages and other liquids. There are numerous studies of turtles, whales and other marine mammals that were apparently killed by ingesting plastic bags or sheeting. Turtles appear particularly vulnerable to this type of pollution, perhaps by mistaking it for their normal food, e.g. jellyfish. A potentially more serious problem may be the increasing quantities of small plastic particles widely found in the ocean, probably from plastics production and insulation and packing materials. The principal impacts of this material are via ingestion affecting animals' feeding digestion processes. These plastic particles have been found in 25% of the world's sea bird species in one study and up to 90% of the chicks of a single species in another study.

See also

Anti-fouling Materials. Pollution Control. Benthic Organisms Overview. Pollution: Effects on Marine Communities. International Organizations. Law of the Sea. Marine Mammal Overview. Marine Policy Overview. Seabirds as Indicators of Ocean Pollution.

Further Reading

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POLYNYAS

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Introduction

Polynyas are large, persistent regions of open water and thin ice that occur within much thicker pack ice, at locations where climatologically, thick pack ice would be expected. Polynyas have a rectangular or oval aspect ratio with length scales of order 100 km; they persist with intermittent openings and closings at the same location for up to several months, and recur over many years. In contrast to polynyas, leads – another open water feature – are long, linear transient features associated with the pack ice deformation, are not restricted to a particular location, and generally have a much smaller area than polynyas. Polynyas occur in both winter and summer. Given that their physical behavior in winter is more complicated than in summer, we begin with the winter case, then follow with a shorter description of their transition to summer.

Polynyas can be classified into coastal and open-ocean polynyas. Coastal polynyas form where the winter winds advect the adjacent pack ice away from the coast, so that sea water at temperatures close to the freezing point is directly exposed to a large negative heat flux, with the resultant rapid formation of new ice. This new ice is advected away