4.0 CONTAMINATED DREDGED MATERIAL

4.1 Disposal of Contaminated Dredged Material

4.1.1 General

In 1989, 44 million tonnes of the U.K.'s maintenance dredged spoil were dumped at sea. According to British Ports Federation this volume of dredged material represented 144 separate offshore dumping licences, and entailed the bulk of maintenance dredged spoil for the U.K. in 1989. In general, very little dredged material is used for alternative on-land application, such as landfilling or brick making (BPF's evidence to the Environment Committee, 12.2.92). Contrary to U.K.'s offshore dumping practice of maintenance dredged material, over 90 percent of the total volume of dredged material in the USA is considered acceptable for disposal at a wide range of disposal alternatives (USACE, date unknown). However, the presence of contamination in some dredging locations has generated concern that dredged material disposal may adversely affect water quality and aquatic or terrestrial organisms. Since many dredged waterways are located in industrial and urban areas, some sediments may be highly contaminated with wastes from these sources. Such wastes are often differentiated into heavy metals, organic micro-pollutants and oils. In addition, sediments may be contaminated with chemicals from agricultural practices.

4.1.2 During open water disposal operations, the anaerobic sediments are mixed with aerated surface water and a complex chemical interaction occurs. Heavy metals such as cadmium, copper, chromium, lead and zinc which have been stabilised in oxygen-free sediments, form precipitates and coagulate in the presence of oxygen. Phosphorous and nitrogen can be temporarily released into the water column, while pesticides, and oils and grease are usually not very water soluble. However, all of these contaminants have the potential to affect a proposed beneficial use project.

4.1.3 When contaminated dredged material is placed on an onshore or terrestrial site, an increased degree of contaminant bioavailability is expected, due to a variety of chemical processes affecting contaminant mobility. Such processes are discussed further in Sections 4.3 and 4.4.

4.2 Subtidal (Offshore) Disposal and Changes in the Contaminated Sediment Characteristics

4.2.1 The presence of potentially toxic contaminants such as pesticides, organic wastes and heavy metals in dredged sediments causes concern that offshore (open-water) disposal of contaminated dredged material may result in deterioration of the aquatic environment.

Metabolic processes in aquatic ecosystems tend to concentrate potentially toxic contaminants in sediments. These contaminants are not very soluble in water under the conditions that normally occur in oxygenated uncontaminated surface waters. Therefore introducing high concentrations of these contaminants into aquatic ecosystems will generally result in an equilibrium condition where most of the contaminant will be sorbed (absorbed and adsorbed) by suspended particulate matter and then deposited on the bottom when the suspended material settles. The time necessary to achieve this equilibrium condition depends upon the physiochemical conditions in the aquatic system and the quantity and duration of contaminant introduction.

In reduced (oxygen-depleted) sediments, metal sulphides successfully bind potentially toxic metals. In oxygen-rich conditions sulphides react with oxygen to give sulphates while liberating the metals. Thus, as a typically reduced sediment is dispersed in oxygen-rich surface waters during open water disposal, there is some possibility that metal sulphides will become oxidised resulting in free metal ions. At the same time, however, in the presence of dissolved oxygen, other reactions may result in the formation of metal hydrous oxides which precipitate, thus removing metals from the water column and therefore reducing the risk of metal uptake by living organisms. On balance, therefore, the presence of oxygen rich waters reduces the "risk" of metal release in the water column thus reducing the contamination hazard.

4.2.2 Bioaccumulation of Contaminants Released in Water

Many chemicals are present in the aquatic environment in extremely low concentrations, frequently near to or below the threshold of readily detectable limits by routine analytical techniques. Living organisms, however, may accumulate these chemicals to levels greater than the ambient concentrations in their environment. Pollution and toxicology research indicates that persistent chemical residues from contaminated dredged material may accumulate within the tissues of aquatic plants and animals to dangerously high levels. As food becomes the primary source for contaminant accumulation, food-chain biomagnification is expected as the result of dietary intake of food (prey) by a consumer (predator). Extensive scientific work has indicated that the total amount of contaminants in dredged material is not representative of their potential environmental effects, and bioaccumulation therefore becomes the important parameter in assessing the environmental effects of open-water (offshore) disposal of contaminated dredged material (Verloo et al, 1989). Although well documented in terrestrial ecosystems, the occurrence and extent of biomagnification in aquatic ecosystems is still the topic of considerable debate (U.S. AEWES, 1985).

A series of technical notes prepared by the U.S. Army Engineer Waterway Experiment Station in 1989, outlines and describes the principal factors that determine uptake and retention of chemicals by aquatic organisms. These factors, which are related to the contaminants themselves, sediment, water, and biota characteristics are briefly outlined in Table 4.2.2.

Table 4.2.2 Bioaccumulation Potential of Contaminants in Relation to Contaminant, Sediment, Water and Biota Characteristics

Factor Determining Uptake and Retention	Consequence
Contaminant Characteristics	
Fugacity (L:fuga = flight)	Contaminant becomes bioavailable depending on its water or oil phase.
Hydrophobicity ("fear of water")	Hydrophobic contaminants leave the aqueous phase and associate themselves with animal lipids.
Water solubility	Bioaccumulation increases as water solubility decreases.
Stability	Risk of bioaccumulation increases as contaminants stability also increases.
Sediment Characteristics	
pH and Redox potential	During oxidation of reduced sediments, sulphides turn to sulphates and metals (previously bound to sulphides) are freed, and therefore bioavailable.
Sediment organic content	No simple relationship with bioaccumulation.
Oil and grease content	May concentrate organic chemicals if present in sufficiently high concentrations.
Particle physical interaction	Desorption of contaminants from sediment particulates is dependant on physical interactions among the particles during open water disposal.
Sediment particle size	Smaller particle size increases opportunities for adsorption of contaminants; suspension of fine particles during disposal increases potential for ingestion by marine fauna.
Water Characteristics	
Dissolved organic carbon (DOC)	DOC has a high affinity for hydrophobic contaminants, thus preventing them from becoming available to living organisms.
Water hardness	High concentrations of calcium and magnesium in water reduce the bioavailability of toxic metals but not of organic compounds.
Salinity	Increasing salinity decreases the water solubility of organic compounds, thus their bioaccumulation potential. The relationship of salinity to metal bioaccumulation is more complex and element specific.
Biota Characteristics	
Depuration mechanism	Some organisms are able to excrete contaminants thus reducing the risk of exposure to them.
Food intake	Recent studies assign a greater role to contaminated food as a major pathway for bioaccumulation of contaminants in aquatic organisms (assuming absence of depuration mechanism).
Feeding type	Predatory fish assimilate organic contaminants from food with much higher efficiency (about 65-95%) than deposit feeders (20-40%).

Factor Determining Uptake and Retention	Consequence
Metabolic rate	A high rate of metabolism is usually accompanied by increased rates of contaminant uptake from water, but this may be accompanied by a high excretion rate. The net effect on bioaccumulation depends on the favoured process.

Source: US, AEWES, 1991

When dredged material is unsuitable for unrestricted open water disposal because of its contaminant content, disposal followed by capping is considered as a mitigative measure. Capping of contaminated dredged material containing heavy metals (such as mercury, cadmium, and lead), and organic compounds (such as petroleum hydrocarbons and PCBs) with relatively uncontaminated sand and silt has been extensively studied by the Japanese and the U.S. Army Corps of Engineers. Possible beneficial uses for contaminated dredged material dumped offshore are discussed further in Section 4.6.1 where the main findings of an U.S. case study are presented.

4.2.3 Guidelines for Dredged Material Open-Water Disposal

The open-water dispersion of lightly contaminated maintenance dredged material is still temporarily permitted in industrially developed countries, provided that the quality of the underwater sediments in the receiving areas is not worsened. In the U.K., MAFF deal with applications for aquatic disposal of maintenance dredged material. Each case is considered on its own merits and MAFF subsequently grant or refuse dumping at an offshore licensed dumping site.

In the Netherlands, appropriate guidelines for aquatic dumping have been drawn up. Compliance with the appropriate thresholds allows unconfined offshore disposal in the North Sea and adjacent estuaries. A set of guidelines on dredged sediment quality have been formally adopted for use in the Netherlands since 1987. The set comprises three values for each parameter; the reference, testing and signalling values (see Appendix E). Sediments lying below or equal to the reference value can, in general, be deposited on the land or in fresh or sea water without restriction. When the parameter levels lie between the "reference value" and the "testing value", open water disposal is permitted under certain conditions. For instance one of these conditions concerns the chemical changes in the particular contaminants being disposed that may take place in sea water. If the dredged materials have contaminant concentrations higher than the "testing value" they must be disposed of in controlled containment facilities subject to constant monitoring (Davis et al, 1990). Moderately to highly contaminated dredged material is disposed of to two different depots in the Netherlands, the Slufter and Papegaaiebek depots respectively. These are further discussed in Section 4.8.2.

In addition to the above set of guidelines, another set of Dutch standards was presented in a paper at the 1989 International Seminar on the Environmental Aspects of Dredging Activities. These guidelines, however, concentrate on disposal in fresh water as opposed to offshore (salt water)disposal.

All the aforementioned sets of guidelines for the open water disposal of contaminated dredged material are listed in Appendix E.

4.3 Terrestrial (Upland) Disposal and Changes in the Contaminated Sediment Characteristics

4.3.1 As indicated in Section 2.2.2, concerns for the improvement and/or maintenance of water quality and the protection of aquatic nursery, spawning grounds, fish passage and migration, and feeding areas have been expressed in relation to offshore disposal of contaminated material. These concerns have contributed to significantly increased pressure for confined or up-land disposal options for contaminated dredged material.

Dredged material contamination characteristics reflect the population, industry and land uses of an area. In turn, the chemical constituents of dredged material determine the suitability of that material for a particular land use. Four potential problem areas exist depending on the presence of available chemical constituents in the dredged material and the post-disposal prevailing physiochemical processes: plant toxicity, animal toxicity, surface water contamination and ground-water contamination. Plant uptake of chemicals may also present problems if growth or reproduction potential of the plant is altered or if harmful chemicals are passed via the food web into higher organisms.

The land application of dry oxidised dredged material may increase the solubility and hence availability of heavy metals through the oxidation process of their reduced forms, in particular the metal sulphides. However, under oxidising conditions, certain processes such as metal oxide formations and pH changes become the important factors for the metal's availability.

4.3.2 <u>Processes Responsible for the Behaviour of Heavy Metals in Terrestrial Disposal of Contaminated Dredged Sediment</u>

The potential of a heavy metal to become a contaminant depends greatly on its form and availability rather than on its total concentration within a dredged sediment. For instance, reduced environments favour slower degradation of organics and the formation of structurally complex, large molecular weight molecules which are more effective in binding metals, therefore reducing their bioavailability.

Land application, for example behind embanked enclosures for disposal or for habitat development, offers considerably more opportunity for significant changes in the physiochemical parameters of the bulk solids to occur than offshore disposal. Whereas soluble substances in soil pore water may respond almost immediately to changes in oxidation levels in the case of open water disposal, chemically reactive components of the bulk solid phase may only slowly respond to a change in the oxidation-reduction environment during terrestrial disposal. However, such changes over extended time intervals would significantly affect chemical transformations regulating the bioavailability of toxic substances. Gradual oxidation of organic matter, possibly accompanied by release of heavy metals to plant available forms, may be particularly relevant to dredged sediments transported to terrestrial areas for disposal or habitat development where oxygen supplies are unrestricted and oxidation uninhibited.

Two particular categories of chemical reaction merit further discussion:-

- **pH and Redox Potential**

The pH and redox potential (degree of oxidation or reduction) of soils, sediments, and surface waters are two important physiochemical properties regulating the chemical forms of toxic metals and affecting their bioavailability. The pH and oxidation-reduction status of bottom sediments containing potential toxicants may be altered by dredging and dredged material disposal, and influence the mobilisation of sediment-bound toxic metals.

During oxidation changes in the sediment (following terrestrial disposal), moderate reductions in pH may be expected as a consequence of iron oxidation. Reduced soils and sediments (found in oxygen-starving conditions) typically contain several hundred to a few thousand parts per million (ppm) of soluble ferrous iron. As this iron is oxidized to insoluble ferric oxyhydroxides (in oxygen rich conditions), some release of hydrogen ions may occur resulting in moderate increases in acidity. A rather severe acid environment may also occur where an initially reduced sediment material containing several hundred ppm total sulphide becomes oxidized. As a consequence of sulphide oxidation, a weak sulphuric acid solution may form resulting in pH values as low as 2 to 4. Such a strong acid environment will almost certainly mobilise toxic heavy metals increasing their availability to organisms, as well as the movement of these metals into groundwater and adjacent surface waters.

For such reasons, highly acidic dredged material can severely limit beneficial use options unless acidity is mitigated against. The need for such mitigating measures is discussed further in Section 4.6.2.

- **Organic Matter**

Microbial activity in aerobic soils and sediments is reported to enhance the rate of organic matter degradation relative to anaerobic environments reducing the total levels of organic matter present (Gambrell et al, 1976). In addition, the structurally complex large molecular weight compounds, characteristic of humic materials in reduced environments, are reported to be altered to smaller, less complex molecules with less metal binding capacity as a soil or sediment is oxidised. As a result metals become liberated and available to plants.

4.3.3 Guidelines for Dredged Material Upland Disposal

To date, there are no U.K. standards for upland (terrestrial) disposal of dredged material. DoE guidelines on the redevelopment of contaminated land are mainly used to determine disposal options or other uses of land-based contaminated materials. In addition, DoE has prepared a set of standards for the application of sewage sludge to agricultural land. These two sets of guidelines could be used for interim decision making purposes with regard to acceptable disposal practices for dredged material on land.

In the U.S., until standards are set for upland dredged sediment disposal, guidelines must also be taken from other research areas such as on-land sludge disposal (Appendix E). The American experience in this field shows that, in most cases, the heavy metal contents of dredged material fall below the maximum allowable limits recommended in domestic sewage sludge applied to land (USACE, date unknown). If higher concentrations of chemical constituents are found in dredged material, it should not be used in a land improvement project without prior treatment to remove or reduce contaminants. Confined disposal is the alternative option. This is further discussed in Section 4.8.

4.4 Intertidal Disposal and Changes in the Contaminated Sediment Characteristics

4.4.1 Marshes are considered to be any community of plant and animal species that experiences periodic or permanent shallow inundation. The processes that affect the behaviour of contaminants in the dredged material used for man-made marsh or other intertidal systems, are therefore expected to be very similar to those encountered in either offshore or terrestrial disposal in accordance with the prevailing wet or dry condition.

4.4.2 Oxidation Changes in Contaminants

A study performed by Darby et al (1986) in a man-made estuarine marsh demonstrated characteristic effects of oxidation: iron and manganese oxide minerals precipitated whereas zinc, copper, lead and cadmium were mobilised and transferred into the effluent water during dumping of the sludge-water mixture. Such results demonstrate the problematic effect of dispersing anoxic waste materials in ecologically productive high-energy nearshore, estuarine and inlet zones.

Metal release from tidal river sediments has been studied on a site from the lower Elbe River in Germany, and has been interpreted as being due to an oxidation of the oxygen-starving fine-grained fluvial deposits which are subject to periodic drying and wetting. The sediment analysis indicated that the high proportions of mobile cadmium forms correlated with the reduction in total cadmium contents. The distribution of cadmium in the sediment cores suggested that the release of metals is controlled by the frequent down and upward flux of oxygenated surface water by tidal action. From the observed concentrations it would be expected that long term removal of up to 50% of cadmium from the sediment subsurface would take place by this process of oxidative pumping (Forstner, 1989).

4.4.3 Contaminant Transfer

Although considerable information is available from the agricultural literature on toxic heavy metal uptake by crop plants from contaminated or sludge amended soils, much less is known about factors influencing metal uptake by marsh plants from dredged sediments. Metals and chlorinated hydrocarbon compounds commonly associated with industrial, agricultural, and urban areas may be transferred to marsh plants from the water or marsh substrate. When contaminated dredged material is used for marsh development, the potential for contaminant transfer should be considered. Various studies in the U.S. have shown that plants grown in dredged material absorb heavy metals in varying degrees depending upon the plant species (USACE date unknown). In most cases, these contaminants are not generally translocated into the top shoots but are retained in the root systems. Potential danger is therefore limited to users of the root system, such as waterfowl that feed on plant tubers. However, research on plants grown in dredged material disposed on upland areas indicates a tendency to accumulate heavy metals in all plant parts, including stems and seeds, in contrast to to marsh plants. This differential uptake of metals is demonstrated through a case study in Section 4.6.4.

Many pesticides, chemical by-products, and petroleum products in dredged material have unknown biomagnification abilities. It is known that some pesticides have affected reproductive abilities of birds by causing egg-shell thinning and behaviour modification (Duffus, 1980). Petroleum products can smother small organisms, which are potential food for higher organisms . Fertilisers and sewage in dredged material alter the habitat where they accumulate by changing plant growth habits and species composition and by reducing dissolved oxygen levels in water. This in turn, may affect the intertidal fish population.

The potential beneficial uses of contaminated dredged material for marsh habitat creation and the associated environmental impacts are demonstrated in Section 4.6.3 through a case study.

4.5 Predicting the Uptake of Contaminants following Intertidal and Terrestrial Disposal of Dredged Sediments

4.5.1 Due to the qualitative diversity and quantitative availability of reactive constituents in soils and sediments, the speciation of metals and their availability to plants and other organisms in natural systems are extremely difficult to predict based on theoretical considerations. To further complicate matters, the fixation or release of metals induced by a change in soil pH and/or redox potential results from the composite influence of all the regulatory processes affected by these two parameters.

As already mentioned in 4.4.3, little is known about factors influencing metal uptake by marsh plants from wetland soils or dredged sediments. A strong pH influence on trace metal availability to plants is supported by the agricultural literature. Generally, an increase in acidity favours plant uptake of these metals. Relatively little is known about the influence of oxidation or reduction intensity on the plant availability of soil and sediment bound toxic metals to crop or marsh plants. It is, however, known that for marsh plants which become established on dredged sediments applied to land, a wide range in the pH and redox potential of the rhizosphere as well as changes in this environment with time is expected. Such changes determine whether or not a marsh plant will become subject to conditions where metals are bioavailable. The success of a habitat created on dredged spoil depends on whether or not these changes are considered. For instance, a marshland habitat managed as waterfowl feeding areas may not be a successful habitat because of the metal bioavailability and bioaccumulation hazard. Managing the same habitat as waterfowl roosting or nesting grounds could eliminate the risk of metal bioaccumulate through dietary intake, as discussed in Section 4.2.2.

4.6 Beneficial Uses of Contaminated Dredged Material

Section 3.1 outlined the main categories of potential beneficial uses of maintenance dredged material. When dealing with contaminated material, however the degree of contamination, as well as the expected chemical changes subsequent to disposal, will determine the preferred beneficial uses(s).

The following three subsections deal with case studies of beneficial use of contaminated dredged material for habitat creation and highlight the main observed environmental effects.

4.6.1 Subtidal (Offshore) Use - Habitat Creation Case Study

Approximately 5 percent of the material dredged annually from the New York/New Jersey Harbour is unsuitable for unrestricted ocean disposal and requires careful placing with capping as a mitigative measure. Clean dredged material is used for capping to ensure that contaminants are isolated from the marine environment (Coch et al, 1987).

New York District initiated the New York Bight Capping Project in 1980 to determine whether capping was a viable management technique for contaminated dredged material. Approximately 0.39 million cubic meters of fine-grained, contaminated material from New York Harbour was dumped offshore and capped with approximately 0.15 million cubic meters of less contaminated material. The entire experimental dump site was then capped with 0.84 million cubic meters of clean, fine-to-coarse sand varying from 0.5m to 1.6m deep. Within a year of placement of the cap, benthic organisms populated the site. A bioaccumulation study showed that mussels at the experimental dump site had not bioaccumulated higher levels of contaminants than those mussels at a control site, two years after placement and capping. A chemical study undertaken by the New York University Medical Centre two years after the completion of the capping showed that contaminant levels in the sand cap, as compared with the capped contaminated material, were greatly reduced. Therefore, contact of the contaminants with the water column was also greatly reduced. A study using predictive models, bathymetric survey and sediment areas indicated that the presence of the cap reduced contaminant food chain levels in the water column and in the marine environment (Coch et al, 1987).

4.6.2 Terrestrial (Upland) Use - Habitat Creation Case Study

In 1981, contaminated sediment was dredged from Black Rock Harbour, Connecticut, and placed in aquatic upland environments as part of the U.S. Army Corps of Engineer/EPA Field Verification Programme. Contaminant mobility and the progressive development of the upland ecosystem will be evaluated until September 1995.

To date, the contaminated dredged material has been evaluated only on a short-term basis. This has included laboratory tests before dredging and disposal operations and during the operational phases of some confined disposal facilities. Subsequent monitoring has demonstrated that the placement of Black Rock Harbour sediment in an upland disposal environment resulted in significant changes in the contaminated sediment. Following upland disposal, the dredged material dried and oxidized. Salinity dropped from a high of 29 to <1 mg/kg. The pH of the dredged material dropped from 7.6 in 1983 to 3.2 by the end of 1986. This substantial increase in the acidity of the dredged material enhanced the solubility and availability of the toxic metals zinc, cadmium, copper, chromium, nickel and lead.

After placement in an upland environment, control plots of unamended dredged material were barren of vegetation from 1985 through 1989 even after repeated attempts to establish acid tolerant, salt tolerant and metal tolerant plant species. Plots which were treated with lime, sand and gravel, and manure had the best established vegetative cover by 1985. By 1989 they were 97% covered with vegetation. The successful establishment of planted vegetation was followed by an abundance and diversity of animal species. No data is available to evaluate contaminant uptake by the animal species because too little biomass per species was available for chemical analysis. The contaminant uptake by plant tissues, however, has been evaluated and the main observations are shown in Table 4.6.2.

Table 4.6.2 Contaminant Uptake by Plant Tissue in Upland Environments

Zinc	Leaf tissue content within the normal range of 15-150 µg/g found in agricultural crops.
Cadmium	Concentrations equal to or slightly above the normal range and substantially below the critical content level of 8 µg/g.
Copper	Concentrations appear to be either in the normal range or slightly elevated above phytotoxic levels of 25-40 µg/g.
Nickel	Concentrations equal to or slightly above the critical content level of 11 µg/g.
Chromium	Concentrations above normal 1 µg/g in 1988 and three of the four amendments showed tissue content above phytotoxic levels of 20 µg/g in 1989.
Lead	Concentrations within or slightly above the normal range of 2-5 µg/g.
Mercury	Tissue concentrations were 1/10 of the only available reference levels of 1 µg/g in wheat kernels which is the action level for human foodstuff.

Table Adapted from: US AEWES, 1991

Notes:
1. Phytotoxic = plant killing
2. Critical content as defined by US AEWES, 1991.

4.6.3 Intertidal Use - Habitat Creation Case Studies

Nearly two decades of marsh development research in the United States has confirmed that marshes can be established in a wide variety of environments. Successful plantings have been made in sediments ranging from fine-grained materials to coarse-grained sands, and in salinity regimes from brackish to salt.

- **Black Rock Harbour Contaminated Dredged Material - Case Study**

In October 1983, contaminated dredged sediment from Black Rock Harbour, Connecticut, was used to create a wetland environment. The initial growth of Spartina alterniflora appeared to be slow up to 1983 but then in the years from 1987 to 1989 the vegetation on the created wetland gradually expanded until the planted side was covered by a dense stand. The 1988 and 1989 plant tissue concentrations of heavy metals were generally no greater than those measured in the naturally occurring Spartina alterniflora before wetland creation or those measured in nearby naturally occurring saltmarshes. Copper and chromium tissue concentrations tended to be higher than in the natural marsh, possibly indicating Spartina's ability to accumulate the bioavailable metals in the soil. The higher levels of copper and chromium, however, did not inhibit the plant growth as the success of the planted vegetation indicated six years later.

In 1988 and 1989 concentrations of copper, cadmium and mercury in the tissues of the snail Ilyanasa Obsoleta were less than the respective concentrations of the Field Verification Laboratory control snails. It was noted that Ilyanasa Obsoleta typically contained elevated levels of copper, possibly due to high copper concentration in the respiratory pigment haemogamin (Lee et al, 1991).

■ **Windmill Point Wetland Habitat Development - Case Study**

Windmill Point in the James River, Virginia, U.S., is one of a number of wetland sites built on contaminated dredged material during the Dredged Material Research Programme which began in 1974. Despite some subsidence and erosion, it has been both beneficial and successful in a number of ways. It has developed into a highly productive, rapidly evolving freshwater marsh which survived intact for over nine years in a high-volume river with strong spring floods and is slowly diminishing in emergent vegetation but increasing in shallow water fisheries habitat. It has also provided a basis for comparison of natural and man-made wetlands.

Five heavy metals (chromium, lead, zinc, cadmium and nickel) and fourteen PCBs, including DDE, were examined in soil and plant samples from Windmill Point. While several of these substances were found in the dredged material soil in the island wetland, only DDE was found to translocate to wetland plant shoots. The only apparent impact from the DDE would be to any wildlife eating shoots of island plants and from other contaminants, by any wildlife eating roots of these plants (Landin et al, 1987).

■ **Honga River, Maryland - Case Study**

Historically, the Baltimore District in USA has utilised the beneficial use concept in a variety of applications. In 1972, the District stabilised the excavated material dredged from the Federal Project at Honga River, Dorchester County, Maryland, by creating 1.6 hectares (4 acres) of <u>Spartina alterniflora</u> emergent wetlands using seeds. (Earhart, 1987).

4.6.4 <u>Differential Uptake of Metals in Dredged Spoil by Marsh and Terrestrial Plants - Case Study</u>

A series of plant bio-assays using the saltwater plant <u>Spartina alterniflora</u>, were conducted simulating flooding (marshland) and dry (upland) conditions. For the bio-assays dredged sediment from Black Rock Harbour, Connecticut, was used due to its extremely high concentration of zinc, cadmium, copper, chromium and lead (Folsom et at, 1985).

<u>Spartina alterniflora</u> grew well and had low heavy metal contents under flooded (reduced) conditions. The results of this bioassay were typical for contaminated saltwater sediment placed under a flooded condition, and the data compared well with levels observed in plants from natural saltmarshes. On the contrary, <u>Spartina alterniflora</u> did not grow well in the original air-dried (upland) sediment, and high metal concentrations were detected in the plant tissues indicating that metals were more biavailable in the air-dried sediment than in the flooded. The reasons for this difference were discussed in Sections 4.3 and 4.4.

4.7 TREATMENT OF CONTAMINATED DREDGED MATERIAL

4.7.1 Contaminated dredged material can be treated, prior to its end use, in order to reduce the impacts on the terrestrial or aquatic environment. The clean-up processes are physico-chemical, thermal, or biological and include those listed in Table 4.7.1.

Table 4.7.1 Clean-up Techniques of Contaminated Soil

Physical	Substrate (silt, sand) washing	Contaminated fine particles and organic matter are removed.
Chemical	Soil leaching	Chemical leaching to solubilize metals for subsequent removal by precipitation.
Chemical	Solvent extraction	Substrate is extracted with solvents (pressurised hydrocarbon gases) and the solvent is separated and recycled.
Thermal	Vapour extraction	Contaminated materials are fed into co-current fluidised bed and mixed with hot gas (160°C); contaminants forced into gas stream which is treated downstream.
Thermal	Thermal desorption (Low temperature)	Contaminated material is heated in a rotary dryer where water and organic contaminants are driven off and condensed for subsequent treatment.
Thermal	Soil incineration	Soil heated to 850-900°C resulting in desorption/incineration of contaminants.
Biological	Biological treatment	Naturally occurring bacteria are enhanced in a controlled manner in order to speed up the natural processes of degradation.

Source: Taylor et al, 1990

The overall cost of any disposal option involving removal of contaminated material from a site will reflect the costs of:

- dredging
- treatment method
- transport of the material to the disposal location

The minimum cost of physical treatment (for the removal of metals) is likely to be £50/m³. The cost for the removal of the organics by biological treatment is likely to be in the range of £50/m³ to £100m/³, whereas the incineration method for the removal of organics can cost up to £500/m³ (U.S., 1990 prices) (Taylor et al, 1990). In the Netherlands, however, the equivalent incineration technologies, more recently developed, cost up to £100/m³ (Taylor et al, 1990).

Transport costs in the U.K. are typically in the order of £0.2/m³ km (ibid), and beyond 50km the transport costs can be greater than the other disposal costs (£10-50/m³ in the U.K.) in licensed landfill sites.

4.7.2 The type of clean-up methods discussed above are, however, mainly used during the redevelopment of contaminated land. In the case of contaminated dredged material to be used for habitat creation in upland areas, the only remedial measures reported to be used are the mixing of the dredged material with lime to alleviate the increased acidity during the oxidation of sulphides after disposal, as discussed earlier and the application of manure to make up for the loss of organic matter and nutrients also during oxidation.

The case study discussed in Section 4.6.2, emphasises the usefulness of combining lime application with manure, as well as the addition of sand and gravel, prior to planting. Amending the dredged material with sand and gravel, in particular coarse limestone gravel, can provide the new habitat with a nontoxic microhabitat and a substrate for seed germination. In the Black Rock Harbour case study in Connecticut, coarse limestone gravel was placed on the surface to neutralise acid rainfall that might impact the plot, in addition to providing an acid-neutralising agent over the longer term.

4.8 Containment of Contaminated Dredged Material

4.8.1 An alternative option to the treatment of contaminated dredged material is its containment. If the dredged material contains such high contaminant concentrations as to make treatment uneconomic, confinement may be the only other option.

4.8.2 The Dutch Slufter and Papegaaiebek Disposal Facilities

Two disposal sites have been constructed for the disposal of dredged material from the Rotterdam area. For heavily contaminated dredged material, a 29 ha depot, the Papegaaiebek, has been constructed with a capacity of 0.9 million m^3. For the light to moderately contaminated material a depot covering 260 ha, the Slufter, with a capacity of 90 million m^3 has been created. Every two years a major campaign in which dredged material is sampled and analysed is carried out in the Port of Rotterdam. The results of these dredged material analyses lead to the disposal of the dredged material in the Papegaaiebek, the Slufter or in the open sea.

The Slufter depot is managed jointly by the Dutch Government, the Ministry of Transport and Public Works and the Municipality of Rotterdam. When the Slufter has been filled (according to the design calculations in 2002) it will be possible to use the site for recreational purposes.

The excess water from the Papegaaiebek depot passes through a settling basin before it is discharged. It remains for a minimum of three days, during which time the suspended matter which may be in the process water settles, so that the water that is discharged contains little or no contaminants. This is checked daily. A system has also been installed to monitor the soil under the depot. Under the sheeting lies a drainage system and via monitoring tubes water can be pumped up and then analysed, for monitoring purposes.

SECTION 5 METHODOLOGY FOR DETERMINING VIABLE BENEFICIAL USES

5.1 Beneficial Use Options

5.1.1 Critical Parameters

Section 3 demonstrates that there are a wide range of options for the beneficial use of clean dredged material, many of them related to habitat development. Section 4 indicates that, with careful controls, beneficial uses may also exist for some types of contaminated dredged material. Broadly speaking, the selection of a preferred option from a range of potential beneficial uses, will depend, inter alia, on some or all of the characteristics listed on Table 5.1.1. These characteristics are described in more detail in Appendix C.

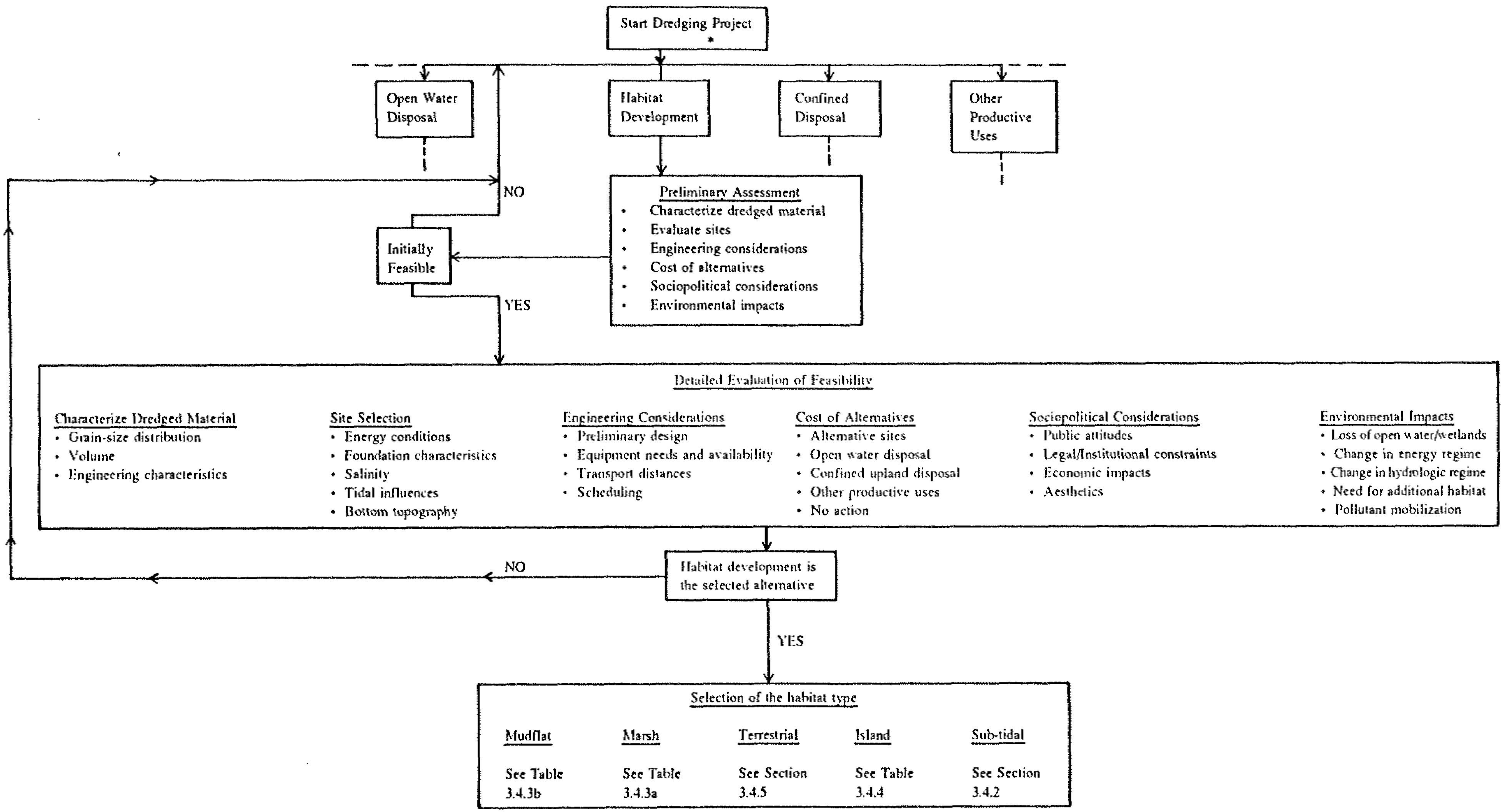
Table 5.1.1

Technical viability - sediment size - degree of contamination - effects on coastal processes - time scale of dredging activity - water quality	**Site details** - availability - size - suitability - proximity to dredging area - proximity to source of flora and fauna
Ecological desirability - existing wildlife interest at site - diversity and rarity - naturalness - long-term ecological trends - position on migration route	**Economic viability** - cost - cost of alternative options - sources of finance
Management implications - sustainability of habitat - vulnerability to disturbance - seasonal restrictions - degree of control over influencing factors	**Socio-political constraints** - education and research potential - amenity and recreation value - opposition from local groups

5.1.2 Methodological Framework

Ultimately, the selection of a suitable option or options will be very site specific and Figure 5.1.2 shows an example of a methodological framework for the selection of habitat development alternatives. This framework has been developed by the U.S. Army Corps of Engineers for use in North America. Rigorous scrutiny, however, indicates that the flowchart is entirely suitable for use in the U.K., given that the degree of contamination is known at the start of the dredging projects. Once the type of habitat has been selected, the tables in Section 3 provide guidance as to the specific requirements of various habitat types.

Figure 5.1.2 Procedural guidelines for selection of habitat development alternatives



* - Assess degree of contamination of sediment. If sediment is contaminated treat or dispose of it in a designated dumping site. If it is clean enough to use for habitat development proceed to next stage.

Source: U.S. Army Corps of Engineers, date unknown.

5.2 Survey and Monitoring Requirements

Before a successful habitat creation project can be initiated, it is necessary to know not only about the characteristics of the dredged material, but also the physical, chemical and biological characteristics of existing natural systems. For many coastal habitats this information exists, but in certain cases, only to a very limited extent (see Section 3.4.3ii).

Following site selection the physical, biological and chemical factors at the site must be monitored before, during and after the dredging and disposal operation to ensure that all requirements are met for successful habitat establishment. Such monitoring should enable the identification of potential problem and hence identify any remedial measures.

Prior to habitat creation a baseline assessment should be carried out. This should cover fisheries, wildlife, benthic characteristics, sediment and water quality, wave and tidal data, and coastal processes. The detail of the baseline survey should be as thorough as possible. The detail of subsequent monitoring may then be reduced if appropriate in the future.

During placement of material, water quality leaving the disposal area should be monitored for turbidity and chemical change. Any deterioration from ambient levels should be assessed in terms of potential impacts on the surrounding area, and if necessary mitigation measures should be considered.

Following placement of material, monitoring should be carried out to determine changes in soil structure and chemistry, vegetation (colonizing and planted species), fish and wildlife, benthos, and other selected chemical and physical parameters. It is useful if a nearby control site is also monitored to record any changes due to natural or external sources. The design of the monitoring programme should be determined in respect of individual sites. Site specific research should enable all interactions occurring between chemical, physical and biological parameters to be determined so that any changes are understood and identified. Careful planning is required so that sampling points, transects and parameters are compatible with the baseline assessment.

Many of the early beneficial use projects in the U.S. were not fully successful or failed because they did not have adequate planning, execution and/or follow up (Christoffers 1987). There is a definite need to select project sites carefully and provide sufficient funding to conduct the required pre-project and post-project studies, at least until habitat creation processes are more fully understood. Planning and implementation requirements are further considered in 5.3 below.

5.3 Planning and Implementation Requirements

The U.S. Army Corps of Engineers through their Dredged Material Research Programme initiated the long-term study and monitoring of eleven habitat development field sites built of dredged material (Landin et al, 1989). Ten major recommendations for habitat development and restoration using dredged material developed from this study, which are applicable to habitat creation in the U.K., included reference to:

i) Carefully plan habitat development projects, even if the dredging work has already taken place and the habitat development is to be on an existing habitat creation site.

ii) Examine nearby sites in the project vicinity to determine habitat needs and the likelihood of successful habitat creation initiatives.

iii) As with any biological project, be sure to take into account site variables, and allow some margin of error.

iv) Develop a set of criteria and objectives where the aims of habitat development are included during early project planning stages.

v) Remain flexible in these criteria and objectives, because a site may develop over time into a similar but equally important habitat because of unforeseen factors.

vi) Develop a contingency management plan in case alternate (undesirable) habitats should evolve over time on the dredged material.

vii) Provide careful instruction to contractors and inspectors whose responsibilities include seeing that construction specifications are adhered to.

viii) Follow up on projects to be sure that they are completed as specified.

ix) Monitor habitat development projects to determine success or failure and to document construction and site development activities.

x) Develop strategic management plans for dredging and placement that incorporate natural resource beneficial uses.

From these points, it is worth noting that the need for strategic plans (point x) will become increasingly relevant in the U.K. as beneficial use techniques are refined and as pressure for alternative sites for the disposal of dredged material increases.

SECTION 6 CASE STUDY: HOLES BAY, POOLE HARBOUR, DORSET

6.1 Background to Case Study

6.1.1 This case study concentrates on the south eastern corner of Holes Bay, an intertidal area owned by the Poole Harbour Commissioners. The aim of the case study is to determine possible viable beneficial uses for the material in this section of the bay if it were to be dredged.

6.2 Brief Description of Poole Harbour

6.2.1 Location and Designation

Poole Harbour, Dorset (see Figure 6.2.1) is a major south coast estuary extending for approximately 10 km from west to east. Water exchange within the harbour is greatly influenced by an atypical tidal regime and by the narrow harbour entrance. The tidal cycle is characterised by double high tides followed by a single low tide with a maximum tidal range of 1.7m. Fresh water inflow to the harbour is small.

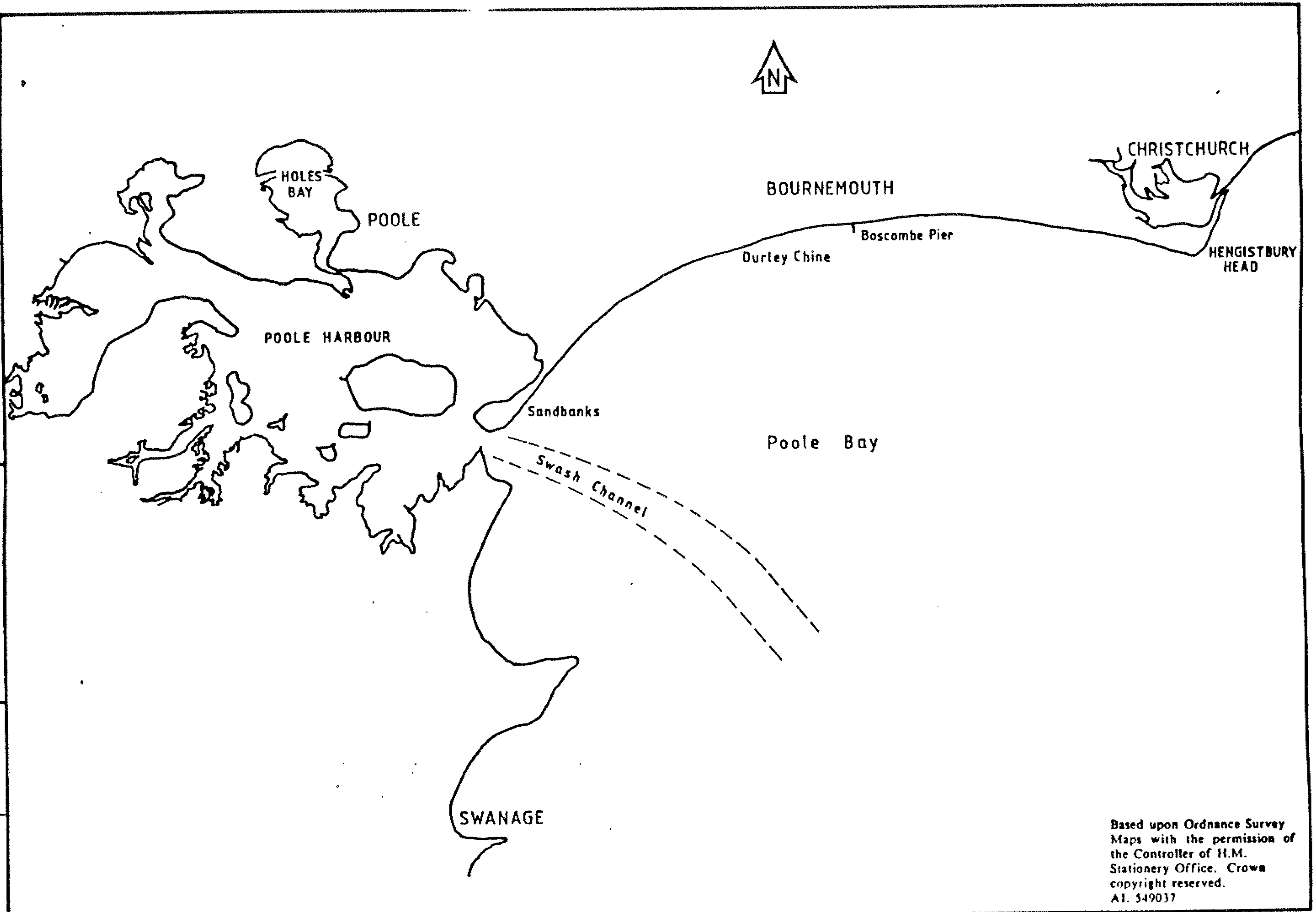
Poole Harbour is one of the largest natural harbours in the world, with a significant proportion (80%) of its area comprising inter-tidal, fine-grained mud, sand flats and marshes. The harbour contains ornithological, marine, floral and invertebrate features of substantial nature conservation interest.

In recognition of its importance, the harbour is designated as a Site of Special Scientific Interest by English Nature, under the 1981 Wildlife and Countryside Act. Part of the harbour is also designated as an Area of Outstanding Natural Beauty and Heritage Coast. Deep water channels within the Harbour, maintained by natural scour supplemented by dredging, are restricted.

6.2.2 Physical Status of Poole Harbour

The main physical properties of Poole Harbour are described below:

- Bed Sediment — The sediment types vary from mud to sand and gravel with the larger particle sizes (sand and gravel) generally being located towards the south and west and the finer (mud) at the north and east.



Title POOLE HARBOUR AND BOURNEMOUTH BEACH

CONSULTING ENGINEERS
POSFORD DUVIVIER

DATE FEB. 92	SCALE 1:100,000
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Figure 6.2.1

- **Bathymetry** — Generally Poole Harbour is shallow, with depths varying between 0.5m below and 2.5m above chart datum, (0.0m chart datum = -1.40m Ordnance Datum). Maximum depths in the harbour occur in the harbour mouth and are well over 10m below chart datum. There is a great variation in the wet area of the harbour between high and low tides and, as a consequence, a large proportion of the water in the harbour is flushed out each low tide through the harbour entrance. The tidal prism* ratio which is a measure of this flushing for Poole Harbour is equal to 0.45 and 0.22 for spring and neap tides respectively. This shows that the basin is much more efficiently flushed during spring tides.

*The tidal prism ratio is defined as:

$$\frac{\text{Volume of water in basin at high tide - volume of water at low tide}}{\text{Volume of water in basin at high tide}}$$

- **Dredged Channels** — The North Channel and the Middle Ship Channel are both regularly dredged to maintain their depths at 3.6 and 6.0m respectively below Chart Datum.

- **Tidal Currents** — Tidal currents in the harbour reach a peak of approximately 1m per second near the harbour entrance and in the channels, but velocities are very much smaller elsewhere.

- **Wind Conditions** — The dominant wind direction in the harbour is from the south to west. The maximum wind speed expected to occur yearly is approximately 25m/s as determined by a study undertaken by Hydraulics Research (HR).

- **Wave Climate** — The HR studies show waves in the harbour to be largely locally generated with a maximum expected annual wave height of less than 0.5m and a corresponding wave period of approximately 2 seconds. These wave heights only occur at high tide when the fetch (distance over which the wind blows) is at a maximum.

  In addition, some waves will penetrate the harbour entrance when the wind is from the south east. The long fetch associated with this direction gives rise to relatively large waves, but spreading of the waves into the harbour area results in a progressive reduction in the wave heights from this source.

A third source of waves is shipping movements. Little data is available on this but boatwash waves are not thought to be a problem. Studies elsewhere have shown that troublesome waves can be caused by small vessels travelling at excessive speed whilst larger ferries and naval ships did not cause problems.

- Tides — Poole Harbour has a relatively small tidal range. During spring tides the mean range between high and low tides is approximately 1.7m and during neap tides it is approximately 0.5m. The shape of the tide curve (how the tide level varies with time) is complex, due to the phenomenon of double tides.

6.2.3 Chemical Status of Poole Harbour

A study by Boyden (1975) investigated the distribution of heavy metals in Poole Harbour and in particular in sediments and water at sites in Holes Bay, Wareham Channel, Lift Bridge, Sandbanks and South-east Brownsea Island. General heavy metals, especially cadmium, nickel and zinc were shown to fluctuate widely in concentrations in the waters of a restricted region of Poole Harbour close to Poole town. Shellfish and algae were also bioassayed and elevated metal concentrations were detected in their tissue. In contrast, sediments in this region showed little evidence of any gross abnormality in distribution of metals (Boyden, 1975). In sediments, the highest concentrations of metals were recorded in samples collected from the upper region of Holes Bay. These sediments were also enriched with organic matter possibly indicating that the effluent from the sewage treatment works may have introduced the majority of these metals into the estuary. A gradual reduction in concentrations of most elements occurred towards the harbour mouth, possibly owing to dilution with marine sedimentary material.

With the exception of the uppermost portion of Holes Bay, the studies results showed no evidence of any gross contamination by heavy metals elsewhere within the harbour (Boyden, 1975).

6.2.4 Biological Status

Some species and communities of marine invertebrates which occur within the harbour are defined as being of conservation importance both in a national and regional context. Other species are of widespread distribution in the U.K.

Within Poole Harbour subtidal habitat diversity is low, and predominantly sedimentary in nature. The only hard substrate within the harbour is of anthropogenic origin, primarily harbour and jetty walls. The intertidal zone, comprising a majority of the harbour's area, also consists mainly of sedimentary habitats. These receive only limited exposure because of the harbour's double tide phenomenon. As a result, saltmarsh and other fringing habitats are confined to a relatively narrow band around the harbour edge.

Three brackish water species of national importance are known to occur within Poole Harbour. One of these, the honeycomb worm, Sabella pavonina, forms very extensive beds in Poole Harbour. Another nationally rare species is the sponge, Suberites massa, which was found at several locations and was common on artificial substrata within the Lower Holes Bay Zone. Two species of regional importance occur in Poole Harbour. Both of these are bryozoans (small, sessile colonial animals). These two species, Anguinella palmata and Farella repens, are rarely recorded, but are probably more common than data suggests (ie. they have not been recorded in all their localities as they are difficult to find and identify). The latter of the two species occurs in the subtidal channels of Holes Bay (Dyrynda, P. 1987).

The habitats in and around the harbour also support nationally and internationally significant numbers of wintering wildfowl and waders.

Fringing habitats of heathland, grassland and the islands provide additional interest, in turn supporting further scarce and restricted flora and fauna.

6.3 Current Dredging Process

6.3.1 Dredging Requirements

Under Section 22 of the Poole Harbour Act 1914 the Poole Harbour Commissioners (PHC) have a power to dredge for the purposes of, inter alia, maintaining navigation, removing obstructions and cleansing or scouring the harbour. Currently the work carried out by the PHC exclusively in the commercial shipping channels amounts to the removal through dredging of about 70,000 m^3 in an average year. There is also a growing requirement for some maintenance dredging to be carried out in the vicinity of existing boatyards and similar facilities, but the quantities of material involved are very small.

The anticipated future demands for capital dredging are difficult to determine as any future projects would only be initiated in response to a commercial stimulus. At present, capital work is being carried out to widen the Middle Ship Canal and enlarge the Hamworthy Shipping basin, involving the removal of 700,000m^3 of material. It may be necessary in the future to deepen the harbour approach and other associated channels to ensure that larger vessels have better access at all states of the tide. This could potentially result in capital dredging of up to approximately 3.4 million cubic metres although it is most unlikely that such schemes would be tackled on a single phase basis.

In addition to the above, capital dredging requirements may arise as a result of marina and boat haven schemes, both private initiatives and those promoted by the Commissioners in the harbour in a response to commercial needs. It is anticipated that such future maintenance dredging will not warrant more than 100,000 to 150,000 m^3 per year (including existing maintenance dredging) even if the majority of the proposed projects are carried out.