ISSN 0308 - 5589

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD
DIRECTORATE OF FISHERIES RESEARCH

FISHERIES RESEARCH TECHNICAL REPORT

No. 52

The composition of dredged spoils dumped at sea from England and Wales

LINDSAY A MURRAY
and M.G. NORTON

LOWESTOFT, 1979

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD
DIRECTORATE OF FISHERIES RESEARCH

FISHERIES RESEARCH TECHNICAL REPORT
NUMBER 52

The composition of dredged spoils dumped at sea from England and Wales

LINDSAY A. MURRAY and M.G. NORTON

LOWESTOFT 1979

The authors:

Lindsay Murray, BSc PhD is a Higher Scientific Officer and M.G. Norton, BSc PhD is a Principal Scientific Officer in the Aquatic Environment Protection Division of the Directorate of Fisheries Research. Both are stationed at the Fisheries Laboratory, Burnham-on-Crouch.

Fish. Res. Tech. Rep., MAFF Direct. Fish. Res., Lowestoft, (52) 10 pp.

CONTENTS

FISHERIES RESEARCH TECHNICAL REPORT NUMBER 52

THE COMPOSITION OF DREDGED SPOILS DUMPED AT SEA FROM ENGLAND AND WALES

by

Lindsay A. Murray and M.G. Norton

1. Introduction

Large quantities of spoil are generated by the dredging of ports, harbours, rivers and approach channels around many coastal states including the United Kingdom. Although in some areas such spoils can be used for local land reclamation or can be disposed of on land, the majority are deposited at sea.

The local physical effects of depositing dredged spoil in the marine environment, such as the smothering of sedentary organisms and interference with fishing, have long been recognised and steps have been taken to select dumping sites where such effects are minimised. In recent years, however, discussion has taken place on the extent to which the chemical contamination of certain dredged spoils may lead to adverse effects on the receiving area over and above those associated with the physical effects of uncontaminated spoils (e.g. Lee, 1976). Aspects which have received attention, particularly by the US Corps of Engineers' Dredged Material Research Program, include the impact of chemical contamination of dredged spoil on water quality and the biological availability of metals contained in spoils. In the USA, test protocols have been designed to deal with these aspects (US EPA, 1973a, 1973b; US EPA, 1977). In England and Wales, studies of the impact of dredged spoil disposal on some of the more important dumping areas have been conducted by the Ministry of Agriculture, Fisheries and Food (MAFF) as part of its statutory programme, under the Dumping at Sea Act (Great Britain, 1974), to assess the environmental impact of dumping wastes at sea (Norton and Rolfe, 1978).

Attention has also been given by UK authorities during the last few years to monitoring the concentrations of certain metals in samples of water, fish and shellfish taken from areas covered by the two international conventions which deal with the pollution of the North Sea and north-east Atlantic. These are the Oslo Convention, which controls dumping of wastes from ships, and the Paris Convention, which controls disposal of waste from land-based sources. These monitoring programmes, parts of which are coordinated by the International Council for the Exploration of the Sea, have included estimates of the inputs of certain substances from all sources into coastal waters (ICES, 1978).

In order to provide a more reliable estimate of the quantities of potential pollutants derived from dredge spoils from England and Wales, a survey of their chemical compositions has recently been concluded by MAFF. The results of this survey together with a general discussion of the environmental significance of these inputs are presented in this paper.

2. Methods

2.1 Sources of samples

The dumping of dredged spoil at sea from England is regulated by MAFF through licences issued under the Dumping at Sea Act, 1974. Until 1 April 1978 MAFF was also the licensing authority for Wales. As part of the licensing procedure, samples of spoil from dredging operations involving 10 000 $t\ a^{-1}$ or more of spoil were collected for analysis. This survey thus covered the majority of the $28 \times 10^6\ t\ a^{-1}$ of spoil currently dumped in some 70 designated spoil grounds around the coasts of England and Wales.

Samples of spoil dredged from approximately 130 sites round the coast from Berwick-on-Tweed in the north-east to Workington in the north-west were provided by the dredging contractor or relevant port or harbour authority. Where a large port was being dredged, samples were taken from several berths or dredged channels, but only single samples of spoil were taken from some of the smaller ports. The analyses carried out at the Fisheries Laboratory, Burnham-on-Crouch over the period 1975-1977 included measurements of the metals mercury, cadmium, copper, chromium, zinc, lead and nickel. In some cases the non-saponifiable (i.e. 'persistent') oil content was also measured.

2.2 Metals analysis

Unsorted spoil samples were analysed for metals using a rigorous extraction technique designed to extract the majority of the metal present. Approximately 2 g of dried sediment (dried at 100-105°C to constant weight) were digested by 5-10 ml of an equal mixture of nitric acid and hydrogen peroxide, gently heated for about 12 h until the mixture nearly reached dryness. The residue was reheated almost to boiling point with 20 ml of 5% nitric acid g^{-1} dry weight of sediment, then cooled, decanted and centrifuged. Cadmium, chromium, copper, nickel and zinc were analysed directly on the resultant centrifugate by flame atomic absorption spectrophotometry (on a Perkin Elmer 306 instrument) using deuterium correction where necessary. Lead was determined by the same technique after a concentration step involving complexing with ammonium pyrollidene dithiocarbamate and extraction into methyl isobutyl ketone. Mercury was determined by flameless atomic absorption spectrophotometry (on a Baird Atomic 3600 instrument) using the automated method of Kirkwood (1976) and Koirtyohann and Khalil (1976). Prior to the work of Van Loon *et al* (1977), which showed that mercury losses from sediment dried at < 105°C were insignificant, mercury was determined on wet spoils using the same extraction and determination procedures.

TABLE 1 Results of metals analysis of dredged spoils

		Concentration mg kg^{-1} dry weight													
		Mean							Range*						
Dredged Area	No. of Sites Sampled	Hg	Cu	Zn	Cd	Pb	Cr	Ni	Hg	Cu	Zn	Cd	Pb	Cr	Ni
BERWICK ON TWEED	1	0.15	63	200	1.0	80	70	48							
BLYTH	6	0.14	90	143	1.4	86	23	37	<0.07 - 0.2	8 - 190	64 - 360	1.1 - 2.2	30 - 140	7 - 36	22 - 80
RIVER TYNE	3	2.03	133	1370	8.2	633	43	93	0.5 - 4.0	100 - 180	1300 - 1400	4.5 - 12.0	550 - 740	18 - 80	90 - 100
SUNDERLAND	6	0.37	60	353	1.9	373	36	49	<0.06 - 0.6	10 - 90	90 - 670	<0.2 - 5.1	48 - 680	48 - 65	15 - 60
SEAHAM	1	0.10	34	140	<0.2	60	90	30							
HARTLEPOOL	1	0.80	56	120	<0.2	95	42	40							
RIVER TEES	13	7.02	234	766	3.6	325	493	40	0.5 - 20.0	22 - 700	72 - 3000	<0.2 - 13.0	50 - 850	13 - 1500	20 - 65
SCARBOROUGH	2	0.44	35	122	0.3	85	28	28	0.07 - 0.8	10 - 61	82 - 162	<0.2 - 0.4	52 - 118	7 - 50	17 - 39
BRIDLINGTON	1	N.D.	75	240	<0.2	130	10	<20							
HUMBER PORTS	12	0.70	81	375	1.0	184	106	82	<0.06 - 1.0	11 - 106	50 - 470	<0.2 - 2.0	25 - 240	10 - 150	16 - 106
BOSTON	2	0.14	19	108	<0.2	50	18	25	0.07 - 0.2	12 - 26	70 - 145	All <0.2	39 - 61	10 - 25	16 - 33
KINGS LYNN	2	0.50	27	125	0.4	76	22	36	0.2 - 0.8	22 - 32	102 - 145	<0.2 - 0.6	65 - 86	19 - 25	32 - 39
GREAT YARMOUTH	3	1.54	21	79	0.2	30	4	7	<0.2 - 0.5	4 - 35	45 - 140	<0.2 - 0.5	7 - 47	<1 - 8	<5 - 13
LOWESTOFT	3	0.60	49	91	<2	54	17	27	0.11 - 0.2	23 - 81	72 - 110	All <2	40 - 69	13 - 20	22 - 34
FELIXSTOWE	1	0.25	36	112	<0.2	67	45	40							
IPSWICH	1	2.50	150	350	1.0	220	38	55							
HARWICH	1	0.26	21	62	<0.2	67	7	<20							
THAMES ESTUARY WHARVES	4	0.78	46	220	1.8	93	39	50	0.3 - 3.5	7 - 120	48 - 450	<0.2 - 4.8	13 - 250	5 - 85	17 - 82
DOVER	5	0.52	23	94	0.8	59	22	27	0.3 - 1.0	16 - 33	65 - 130	<0.2 - 1.1	46 - 70	17 - 27	21 - 34
NEWHAVEN	3	0.09	7	43	<5	33	4	<10	0.02 - 0.15	3 - 10	24 - 63	All <5	20 - 40	1 - 8	All <10
BRIGHTON	1	<0.07	8	16	0.5	65	10	30							
SHOREHAM	1	0.20	24	58	<2	38	15	22							

LANGSTONE	1	0.17	30	85	0.4	55	21	30							
PORTSMOUTH	1	<0.07	10	53	<0.2	21	36	29							
LYMINGTON	1	0.90	48	118	<0.2	72	40	30							
POOLE	3	0.70	29	167	1.2	43	12	18	0.3 - 1.0	75 - 163	11 - 400	<0.2 - 3.5	<5 - 100	2 - 22	<10 - 30
WEYMOUTH	1	0.20	12.5	170	<0.2	33	8	15							
PLYMOUTH	2	1.70	103	166	1.2	150	21	20	0.2 - 3.2	6 - 200	11 - 320	<0.2 - 2.3	10 - 290	12 - 29	5 - 35
FOWEY	1	0.20	100	150	<0.2	80	19	35							
AVONMOUTH/PORTISHEAD	5	0.80	46	304	0.8	120	44	51	0.6 - 1.0	43 - 54	270 - 370	0.5 - 1.5	110 - 145	39 - 49	47 - 59
NEWPORT	3	0.27	37	267	<2	76	42	45†	0.2 - 0.3	27 - 40	190 - 320	All <2	13 - 140	38 - 48	
CARDIFF	2	0.47	52	290	<2	122	51	55†	0.44 - 0.5	44 - 60	270 - 310	All <2	120 - 125	41 - 62	
PORT TALBOT	2	0.86	63	275	<2	170	51	55†	0.32 - 1.4	50 - 75	250 - 300	All <2	120 - 220	38 - 63	
SWANSEA	2	0.89	97	675	9.9	390	36	60†	0.88 - 0.90	45 - 150	250 - 1100	1.8 - 18	130 - 650	28 - 43	
MILFORD HAVEN	1	N.D.	11	60	0.3	<20	10	N.D.							
HOLYHEAD	2	0.33	125	218	0.4	162	21	80†	0.30 - 0.36	60 - 190	195 - 240	<0.2 - 0.6	115 - 210	13 - 29	
MERSEY DOCKS	11	3.20	115	490	1.9	198	75	48	0.3 - 5.9	60 - 150	200 - 580	1.0 - 3.5	150 - 260	22 - 100	38 - 55
MERSEY RIVER	5	1.06	34	234	0.3	64	23	22	0.3 - 1.8	10 - 46	63 - 350	<0.2 - 0.9	25 - 80	3 - 31	10 - 25
MANCHESTER SHIP CANAL DOCKS	5	20.7	155	686	1.9	5080	126	67	3.8 - 29.6	120 - 220	490 - 880	1.1 - 2.9	310 - 12 000	83 - 230	50 - 95
PRESTON	2	0.55	12	88	<2	9	9	6†	0.01 - 0.1	4 - 20	52 - 125	All <2	7 - 10	7 - 13	
FLEETWOOD	2	1.9	33	150	<0.2	70	22	N.D.	1.3 - 2.5	20 - 45	60 - 240	All <0.2	40 - 100	14 - 30	
LANCASTER	1	N.D.	20	120	<5	50	20	N.D.							
HEYSHAM	1	0.30	15	72	<0.2	36	9	N.D.							
BARROW	3	0.11	9	60	1.0	30	10	13	<0.06 - 0.2	2 - 16	23 - 85	0.6 - 1.2	15 - 45	4 - 15	5 - 17
WHITEHAVEN	1	0.14	45	95	<5	40	17	N.D.							
WORKINGTON	1	0.03	12	56	<0.2	44	8	N.D.							

---

* Where more than one sample analysed

† Determined on one sample only

N.D. Not determined

2.3 'Persistent' oil determinations

The concentration of non-saponifiable (i.e. 'persistent') oil was determined in a number of spoil samples. Weighed samples of approximately 100 g of dredged spoil were rendered as mobile and homogenous as possible by the addition of water and the destruction of any lumps with a glass rod. These suspensions were extracted twice with 50 ml hexane by shaking in a large conical flask. The hexane extracts were combined and evaporated to dryness, heated with 25 ml of a 1N solution of KOH in ethanol in a steam bath for 2 h, then diluted with water and re-extracted. This extract was evaporated to dryness on a steam bath in a previously dried and pre-weighed beaker. The beaker was allowed to cool and dry in a desiccator. The weight of the remaining material was assumed to be 'persistent' oil.

3. Results

3.1 Trace metals

The results of the metals analyses are presented in Table 1 and expressed as mg kg^{-1} dry weight. The solids content of the spoils varied from 33 to 83% with a mean of 51%. The highest concentrations of metals were generally encountered in dredgings from areas of intense shipping activity and heavy industry, such as the Tees, Tyne and Mersey estuaries. The lowest concentrations occurred in samples dredged from ports or rivers in less industrialised areas, such as the Rivers Bure and Yare in the Great Yarmouth area. Comments on the geographical variations in the concentrations of each metal analysed follow.

3.1.1 *Mercury*

Using the average concentrations shown in Table 1, and the amounts of spoil from each area licensed for dumping, the weighted mean concentration of mercury was 1.2 mg kg^{-1}. This is similar to the weighted mean concentration of 0.9 mg kg^{-1} reported by Meuller *et al* (1976) for dredge spoils dumped in the New York Bight. The mean concentrations in Table 1 suggest some degree of contamination of many of the spoils compared with non-polluted near-shore sediments, for which typical concentrations of mercury are <0.1 mg kg^{-1} (Dept. of the Environment, 1976). Nevertheless, in several of the samples used in the study the mercury concentration was below the detection limit of the method (generally 0.06 mg kg^{-1}): these included some from areas with shipping and industrial activity, e.g. Hull and Sunderland. The highest mercury concentrations, which were found in samples from docks in the Manchester Ship Canal and from the River Tees (average 20.7 and 7.0 mg kg^{-1} respectively), were over an order of magnitude higher than the concentrations found in spoils from other areas. The concentration of mercury in spoil from the Mersey docks was similar to that reported for silty sediments in the Mersey by Craig and Morton (1976), but the spoils from docks on the Manchester Ship Canal contained significantly higher concentrations than did those from docks situated in the estuary itself.

3.1.2 *Cadmium*

The concentrations of cadmium ranged from a maximum of 18 mg kg^{-1} in one sample from Swansea docks to below the detection limit of (usually) 0.2 mg kg^{-1} in many areas. The high Swansea levels are consistent with the samples taken by Bloxam *et al* (1972) from Swansea Bay. Other industrialised areas exhibiting elevated concentrations of cadmium were the River Tyne (average 8.2 mg kg^{-1}) and the River Tees (average 3.6 mg kg^{-1}); these concentrations are similar to those reported for a variety of contaminated estuarine or inshore marine sediments by Greig and McGrath (1977). MAFF surveys have indicated that the cadmium concentration of marine sediments unaffected by obvious anthropogenic inputs or away from known geological sources is generally below the detection limit employed (0.2 mg kg^{-1}) (Eagle *et al.*, 1978, 1979). Similarly, several of the dredged spoils from uncontaminated areas contained no detectable cadmium.

3.1.3 *Zinc, copper and chromium*

The highest concentrations of zinc, copper and chromium were encountered in spoils from the River Tees, although the River Tyne and Manchester Ship Canal spoils also contained high concentrations of some of these metals. The zinc concentration of 3000 mg kg^{-1} found in a sample from the Tees may be compared with a low value of 11 mg kg^{-1} found in spoils from Poole and Plymouth. Zinc and copper concentrations in spoils from docks on the Mersey (average 490 and 115 mg kg^{-1}) were similar to or a little below those in Liverpool Dock sediments reported by Bellinger and Benham (1978).

The chromium concentration varied from 1 mg kg^{-1} in a spoil from Newhaven to 1500 mg kg^{-1} in a single sample from the River Tees. Most samples from the latter area contained high concentrations of chromium, the average of 493 mg kg^{-1} being an order of magnitude higher than elsewhere. The only other areas where more than 100 mg kg^{-1} of chromium occurred were in the Humber (range 10-150, mean 106 mg kg^{-1}) and the docks on the Manchester Ship Canal (range 83-230, mean 126 mg kg^{-1}).

3.1.4 *Lead*

The highest lead concentrations were found in samples from docks in the Manchester Ship Canal, where samples from four of the five docks sampled contained more than 3000 mg kg^{-1}, with the average of all samples being 5080 mg kg^{-1}. Spoils from the Tees, Tyne, Sunderland, Poole and Swansea areas had average lead concentrations in the range 320-640 mg kg^{-1}, while concentrations in all other spoils were below 300 mg kg^{-1}, averaging less than 80 mg kg^{-1}.

Measurements of the lead concentrations in a variety of near-shore sediments (Taylor, 1974; Chester and Stoner, 1975) indicate that lead concentrations of 20-65 mg kg^{-1} are typical of unpolluted sediments, although Bryan and Hummerstone (1971) report levels of up to 300 mg kg^{-1} in sediments from estuaries in mineralised zones, some of which drain areas of earlier mining activity but which are otherwise relatively free of industrial pollution. Samples taken in the present study from locations characterised by lead concentrations over 300 mg kg^{-1} are thus likely to be contaminated by lead from a variety of industrial sources including dock-yard processes (for example, from the lead-based anticorrosive paints and primers used to protect vessels), from industrial discharges, or from atmospheric fallout.

Spoils from four docks on the Manchester Ship Canal contained lead concentrations an order of magnitude higher than in the other spoils taken in this survey; the concentrations were also greater than those found by Bellinger and Benham (1978) in dock sediments from Liverpool, Tilbury and Manchester, suggesting a local input additional to that derived from normal dock-yard processes.

TABLE 2 'PERSISTENT' OIL CONTENT* OF DREDGED SPOILS, mg kg^{-1} wet weight

DREDGED AREA	No. of Samples	Mean	Range†
Blyth	1	110	
River Tyne	1	165	
Sunderland	6	58	15-140
Hartlepool	1	50	
River Tees	2	135	105-165
Humber Ports	5	36	10- 50
Kings Lynn	1	20	
Lowestoft	1	115	
Ipswich	1	55	
Dover	1	95	
Poole	2	268	50-485
Plymouth	1	150	
Avonmouth/Portishead	5	70	30- 95
Newport	1	25	
Cardiff	1	35	
Port Talbot	1	50	
Swansea	1	25	
Milford Haven	1	30	
Mersey Docks	5	163	35-520
Manchester Ship Canal Docks	5	290	60-735
Heysham	1	60	
Whitehaven	1	265	
Workington	1	10	

* See page 4 for details of analytical procedure for 'persistent' oil.

† Where more than one sample analysed.

3.1.5 *Nickel*

Nickel concentrations varied little between sites, the mean concentrations in the majority of spoils being in the range 10-60 mg kg^{-1} which is typical of near-shore sediments (Greig and McGrath, 1977; Carmody *et al*, 1973; Chester and Stoner, 1975; Wedepohl, 1960). The only spoils having mean concentrations above 60 mg kg^{-1} were those from the Tyne, the Humber, Holyhead and the Manchester Ship Canal.

3.2 'Persistent' oil

The results of the 'persistent' oil determinations are presented in Table 2 and expressed in mg kg^{-1} wet weight. These analyses were restricted to about 30% of the samples, so the results can only be used to give an indication of the range of concentrations to be expected in dredged spoils.

The highest concentrations were associated with dock sediments, a maximum concentration of 755 mg kg^{-1} being recorded at an oil-loading berth on the Manchester Ship Canal. All samples analysed contained detectable amounts of oil (average 130 mg kg^{-1}), the lowest concentrations being 10 mg kg^{-1} in samples from Workington and Grimsby.

4. Discussion

4.1 Sources of contamination

The spoils dredged from docks, harbours and navigable channels arise from accumulations of particulate matter from several sources. In estuaries, accumulation of sediment may result from near-bed landward movement of marine sediments and settlement of matter brought down the river. Discharges of effluent containing particulate matter may also contribute to such accumulations. In docks or harbours, these silting processes are probably supplemented by material from ships, by docks debris or by lost cargo, particularly where bulk solid cargoes such as coal or iron ore are off-loaded. These processes are continuous and lead to 'maintenance' dredging, which is carried out on a regular basis. In addition, capital works (e.g. deepening of berths or approach channels), which are carried out as required, may generate large quantities of spoil, such as boulder clays, differing markedly from more superficial marine or estuarial sediments in the area.

It is therefore to be expected that both the sediment type and the extent of contamination of the spoil will vary widely. Although the sediment particle-size distribution was not determined in this study, the spoils included a wide range of sediment types, such as capital spoils of chalk or boulder clay and maintenance spoils ranging from sandy sediments to fine silts and muds. Since the potential of metals to become associated with sediments is related to the available surface area of the sediment particles, differences between the particle-size distributions of the sediments from the ports may account for some of the variability in metal concentrations. However, recent MAFF surveys of marine sediments around England and Wales have shown that the fine (<90 µm) sediment fraction contained metal concentrations in excess of those shown in Table 3 only when an anthropogenic source of that metal could be identified (e.g. by dumping or discharge of effluent). The coarse (>90 μm) fraction of the sediment contained concentrations of metals substantially below those shown in Table 3. Thus spoils containing concentrations of metals higher than those shown in the table are likely to contain sediments or debris enriched with metals from anthropogenic sources.

TABLE 3 Range of metal concentrations found in silt-clays (<90 μm sediment fraction) in marine sediments unaffected by waste disposal [Eagle *et al*, 1978; 1979; R.S. Nunny, pers. comm.]

Concentration (mg kg^{-1})

Hg	Cu	Zn	Cd	Pb	Cr	Ni
0.04-0.13	5-18	30-115	<0.2	10-90	17-50	30-45

One common source of metals in berth and dock-yard sediments is the anti-fouling paints and primers which are rich in copper, zinc and lead: spoils from such sites were generally found to contain elevated levels of these metals. Bellinger and Benham (1978), in a survey of sediments near dry-docks at three English ports, found that substantial elevations of these metals tended to be restricted to areas close to the dry-dock itself; thus the extensive enrichment of sediments which occurred in some of the areas in this survey is likely to be derived from other sources, among them industrial discharges. Examples of such very significant elevations of metals are lead and mercury in regions of the Manchester Ship Canal; mercury, chromium and zinc in the River Tees; zinc and cadmium in the River Tyne; cadmium in Swansea sediments.

4.2 Inputs of metals to the marine environment from dredged spoils

The quantities of dredged spoil dumped at sea are known from returns made to MAFF under Dumping at Sea Act licences; thus estimates of the amounts of metals contained in dredged spoils dumped around England and Wales may be calculated. From the dumping returns for 1977 and using the data from Table 1, an estimate of the total metals dumped in dredged spoils has been made (Table 4). Due to the uncertainty inherent in characterising large quantities of spoil by only a few chemical analyses these figures can only be taken as an order of magnitude estimate. Nevertheless, it is evident that, in terms of *chemically* extractable metals, dumped dredged spoils do represent a major input of metals to the marine environment, the mass loads being substantially higher than the total input to the seas around England and Wales from the dumping of industrial wastes and sewage sludges shown in Table 5. However, it would be inappropriate to deduce from the comparison of mass loads that the input of metals through the dumping of dredged spoil was the most environmentally significant source, because the figures may not represent inputs from primary sources. Indeed, in many areas a proportion of the dumped spoil may be subject to landward movement and may lead to the recycling of the sediments including contaminating metals. In some instances a significant amount of dumped spoil returns to the area of dredging (Davies, 1974).

TABLE 4 Quantities of metals in dredged spoils dumped off England and Wales in 1977 (t)

Total quantity of spoil dumped	Total solids	Hg	Cu	Zn	Cd	Pb	Cr	Ni
27.7 x 10^6	14.1 x 10^6	17	860	3760	17	1770	910	750

TABLE 5 Quantity of solids and metals (t/a) involved in various types of wastes licensed to be dumped at sea from England and Wales January 1976 (from Norton, 1976)

Waste	Solids	Hg	Cu	Zn	Cd	Pb	Cr
Sewage sludges	252 614	4	260	761	13	196	210
Industrial wastes	38 620	0	41	70	0	2	7
Fly ash	750 000	0	40	30	0	20	14

4.3 Environmental significance of contamination of dredged spoils

The physical effects of dredged spoil disposal have been well documented through field studies of a number of spoil sites. The primary effect of disposal of clean spoil depends on the rate of dumping and the nature of the spoil. Where the quantity dumped is not large and the sediments are similar in nature to those in the receiving area, some benthic organisms may survive the initial deposit of spoil by burrowing to the surface (Saila *et al*, 1972), or recolonisation of the deposited spoil may take place by animals from the surrounding area. Such processes can be quite rapid, for instance recolonisation over the period of 3-13 months was reported by the National Marine Fisheries Service (1976). However where the spoil is not favourable for recolonisation by local benthic fauna, much longer recovery times may be involved or recovery may not take place at all or only to a limited extent (Windom, 1976).

Where the tipping frequency is such as to make recolonisation ineffective, areas of the sea bed are depleted of benthos. In MAFF's own surveys, one area used for the deposition of quantities of boulder clay showed no evidence of recolonisation by benthic organisms several years later. In addition to the effects on benthos, trawling may be obstructed by the sea-bed irregularities which often result from the dumping of spoil. It is important to bear these factors in mind when considering other more subtle effects which may arise from the dumping of a spoil contaminated with metals or other substances.

It is possible that chemically contaminated spoils may cause an adverse environmental impact by release of pollutants into the water column, direct toxicity to or inhibition of recolonisation by benthos, biological uptake of pollutants from contaminated sediments and the induction of disease in marine species. Each of these is now considered.

4.3.1 *Release of metals into the water column*

The release of metals into the water column from sediments immersed in sea water has been the subject of several investigations, e.g. Chen *et al* (1975), Serne and Mercer (1975), Lindberg and Harris (1977). While initial release of trace elements into the water column has been demonstrated in laboratory experiments, this appears to be temporary. Lindberg and Harris (1977) have suggested that any temporary release of mercury from the sediments into the surrounding water is followed by readsorption onto suspended clays, by precipitation and then by scavenging by iron released from the sediments. Chen and Wang (1976) have concluded that only very low levels of metals are released to the water column on resuspension of sediments, while Lee *et al* (1976) have reported experiments carried out on various dredged sediments in the United States which indicate that only manganese is released in significant amounts, the other metals being either rapidly readsorbed onto the particulate material or released either in small amounts or not at all.

Thus it would appear that the majority of the metals in dumped spoils are likely to remain with the particulate material, and that significant adverse effects on water quality at the disposal site are unlikely either during or after dumping.

4.3.2 *Inhibition of recolonisation by benthos*

Spoils grossly contaminated with metals, oils or other pollutants may not allow the recovery of the dumping area at the same rate as would a cleaner sediment. This was shown by Engler (1976) who reported that sediments highly contaminated with metals and chlorinated hydrocarbons were generally toxic to benthic organisms. Such sediments have also been shown to be highly toxic to fish and planktonic fauna in contact with them (Prater and Anderson, 1977). In one area which was surveyed by MAFF and which received highly contaminated spoils, little evidence of recolonisation of the spoils themselves was found, but sand from an adjacent mobile sand deposit had created a surface layer in which benthic organisms were found. Thus the extent of recolonisation can depend on factors other than the nature of the spoil.

4.3.3 *Uptake of pollutants from contaminated sediments*

It is possible that metals incorporated in the sediment might be taken up by benthic organisms either by ingestion of sediment or from metal-rich interstitial waters of the sediment (Bryan, 1976). The bioavailability of metals in dredged spoil may be low due either to strong complexation with organic material or, particularly where spoils are anaerobic, to the presence of sulphides or other inorganic species. Bellinger and Benham (1978) estimated the concentration of loosely bound metals by extracting with 1M ammonium acetate and found that only a small fraction (0.3-6.4%) of those released by acid digestion were released under these conditions. They suggested that these lower concentrations might be more representative of the amounts of metals biologically available. Hetherington and Harvey (1978), however, showed that the proportion of metals extracted by acetic acid and hydroxylamine hydrochloride was greater in an organically enriched sediment taken from a sewage sludge dumping ground than in an adjacent uncontaminated sediment, indicating that metals may be more readily leached from the more contaminated sediments.

Even though it might be expected that those readily leached components of contaminated sediments could lead to increased concentrations of pollutants in the tissues of the animals living in or on the sediment, studies of spoil disposal areas indicate that such an effect is not widespread.

Engler (1976) stated that studies of animals living on highly contaminated sediments showed accumulation of manganese and zinc but not of other toxic metals; he noted, however, that other studies have shown that animals placed on sediment containing high levels of metals accumulated metals in their tissues. Laboratory studies of a deposit-feeding clam *Macoma balthica* by Luoma and Jenne (1975), have demonstrated the uptake of cadmium from the sediment, but these authors concluded that sediment ingestion presented a relatively inefficient mode of cadmium uptake, the principal uptake route being from solution. Teeny and Hall (1977), in a study of dredged spoil disposal in Puget Sound, found that the disposal operation had no apparent effect on mercury and cadmium concentrations in the five species studied, whereas Thompson and Paton (1978) who studied the echinoderm, *Molpadia intermedia*, were not able to demonstrate any elevation of the metal content in animals from the Point Grey dump site. Even where sediments were contaminated with mercury from an organically-rich sewage sludge discharge, Eganhouse *et al* (1976) found that elevated concentrations of mercury in sediments were not transmitted to the benthos. The limited evidence of metal accumulation in animals from dredged spoil dump sites may, however, reflect the limited number of observations made and the difficulties involved in sampling and analysing the infauna.

4.3.4 *The induction of disease in marine species*

Polluted sediments have been implicated in studies of both fish and shellfish disease. A high incidence of diseased fish showing erosion of the fins has been recorded in areas of dredged spoil and sewage sludge disposal (Ziskowski and Murchelano, 1975; Mahoney *et al*, 1973). Some species of Crustacea from areas where dumping of sewage sludge and dredged spoil occurs also exhibit diseases of their gills and exoskeleton (O'Connor, 1976; Young and Pearce, 1975). These diseases have been induced by contact with contaminated sediments under laboratory conditions.

Although the above and other studies have established empirical links between the incidence of disease and contaminated sediments, no single causative factor has been identified and it is possible this may be due to elevated bacterial, organic, metal, hydrocarbon or pesticide levels acting either alone or in combination. Sindermann (1977) in a review concluded that the higher incidence of these diseases is characteristic of those degraded habitats where the animals are exposed to environmental stress through elevated levels of toxic chemicals, low dissolved oxygen and high bacterial populations. Thus it is not possible to deduce from the chemical composition of dredged spoil presented in this paper whether any of the spoils would be likely to induce such effects in the area in which they are dumped.

5. Conclusions

This survey of the composition of dredged spoils dumped at sea around England and Wales shows that wide variations of the concentrations of metals and 'persistent' oil occur between different sites. Some spoils from industrialised estuaries which are heavily used by shipping contain concentrations of metals up to 500 times greater than those in sediments from the least contaminated estuaries or ports.

The presence of metal and 'persistent' oil contaminants may lead to environmental effects over and above those associated with the physical impact of spoil dumping, through effects on the water column and on biota in contact with the sediment. Although laboratory and field studies have suggested that effects on water quality and metal uptake by biota are likely to be only of minor significance, the contamination of spoils may also reduce the likelihood of recolonisation of the dumped sediment by the benthos. The association in some areas of deposition with certain diseases of fish and shellfish is less certain. The nature of the receiving area will, however, determine the extent to which these effects occur. Field studies in specific dumping areas are thus required to establish in greater detail whether the chemical contamination of dredged spoils leads to an adverse environmental impact.

References

BELLINGER, E.G. and BENHAM, B.R., 1978. The levels of metals in dockyard sediments with particular reference to the contributions from shipbottom paints. Environ. Pollut., *15* : 71-81.

BLOXAM, T.W., AURORA, S.N., LEACH, L. and REES, T.R., 1972. Heavy metals in some river and bay sediments near Swansea. Nature, Lond., *239* : 158-159.

BRYAN, G.W., 1976. Heavy metal contamination in the sea. pp 185-302. In: R. Johnston (Editor) "Marine Pollution", Academic Press, London, 729 pp.

BRYAN, G.W. and HUMMERSTONE, L.G., 1971. Adaptation of the polychaete *Nereis diversicolor* to estuarine sediments containing high concentrations of heavy metals. 1. General observations and adaptation to copper. J. Mar. biol. Ass. UK, *51* : 845-863.

CARMODY, D.J., PEARCE, J.B. and YASSO, W.E., 1973. Trace metals in sediments of the New York Bight. Mar. Pollut. Bull., *4* : 132-135.

CHEN, K.W., GUPTA, A.Z., SYCIP, J.C.S., KNEZEJIC, M. and CHOI, W.W., 1975. Research study on the effect of dispersion, settling and resedimentation on migration of chemical constituents during open-water disposal of dredged material. Contract Report D-76-1. Prepared for US Army Waterways Experiment Station, Vicksburg, Miss., 221 pp.

CHEN, K.Y. and WANG, C.C., 1976. Water quality evaluation of dredged material disposal from Los Angeles harbour. Marine Studies of San Pedro Bay, California: Part II, Environmental Engineering Program, Univ. S. California, 155-186.

CHESTER, R. and STONER, J.H., 1975. Trace elements in sediments from the lower Severn Estuary and Bristol Channel. Mar. Pollut. Bull., *6* : 92-95.

CRAIG, P.J. and MORTON, S.F., 1976. Mercury in Mersey Estuary sediments, and the analytical procedure for total mercury. Nature, Lond., *261* : 125-126.

DAVIES, C.M., 1974. Location of spoil grounds in sedimentary systems. Dock Harb. Auth., *55* : 120-124.

DEPT. OF THE ENVIRONMENT, CENTRAL UNIT OF ENVIRON. POLLUT., 1976. Environmental mercury and man. Report of an Inter-departmental Working Group on Heavy Metals. Her Majesty's Stationery Office, London, 92 pp. (Pollution Paper No. 10).

EAGLE, R.A., HARDIMAN, P.A., NORTON, M.G. and NUNNY, R.S., 1978. The field assessment of effects of dumping wastes at sea. 3: A survey of the sewage sludge disposal area in Lyme Bay. Fish. Res. Tech. Rep., MAFF Direct. Fish. Res., Lowestoft, (49) 22 pp.

EAGLE, R.A., HARDIMAN, P.A., NORTON, M.G. and NUNNY, R.S., 1979. The field assessment of effects of dumping wastes at sea. 4: A survey of the sewage sludge disposal area off Plymouth. Fish. Res. Tech. Rep., MAFF Direct. Fish. Res., Lowestoft, (50) 24 pp.

EGANHOUSE, R.P., JOHNSON, J.N., YOUNG, D.R. and McDERMOTT, D.J., 1976. Mercury in Southern California waters: inputs, distribution and fate. Southern California Water Research Project, 1500 East Imperial Highway, El Segundo, California 90245, 57 pp.

ENGLER, R.M., 1976. Environmental impacts of the aquatic disposal of dredged material: fact and fancy. pp. 220-235. In: J.B. Herbich (Editor) "Proc. 8th Dredging Seminar", Texas. Texas A & M University, Sea Grant Program, Report No. TAMU-SG-77-102, 248 pp.

GREAT BRITAIN – Parliament, 1974. The Dumping at Sea Act 1974. Her Majesty's Stationery Office, London, 13 pp.

GREIG, R. and McGRATH, R., 1977. Trace metals in sediments of Raritan Bay. Mar. Pollut. Bull., *8* : 188-196.

HETHERINGTON, J.A. and HARVEY, B.R., 1978. Uptake of radioactivity by marine sediments and implications for monitoring metal pollutants. Mar. Pollut. Bull., *9* . 102-106.

ICES, 1978. Inputs of Pollutants to the Oslo Commission Area. Coop. Res. Rep. Int. Coun. Explor. Sea, (77) 57 pp.

KIRKWOOD, D., 1976. Determination of mercury. A modification of the static vapour technique for flameless AAS. Lab. Pract., *25* : 233.

KOIRTYOHANN, S.R. and KHALIL, M., 1976. Variables in the determination of mercury by cold vapour and atomic absorption. Analyt. Chem., *48* : 136-139.

LEE, G.F., 1976. Recent advances in assessing the environmental impact of dredged material disposal. pp. 554-578. In: "Dredging; environmental effects and technology". Proceedings of WODCON VII, San Francisco, 1976. Published by World Dredging Conference, Wodcon Association, San Pedro, California, 1156 pp.

LEE, G.F., LOPEZ, J.M. and MARIANI, G.M. 1976. Leaching and bioassay studies on the significance of heavy metals in dredged sediments. Univ. Texas, Center for Environ. Studies, Dallas, 68 pp.

LINDBERG, S.E. and HARRIS, R.C., 1977. Release of mercury and organics from resuspended near-shore sediments. J. Wat. Pollut. Control Fed., *49* : 2479-2487.

LUOMA, S.M. and JENNE, E.A., 1975. The availability of sediment bound cobalt, silver and zinc to a deposit feeding clam. US. Geological Survey, Menlo Park, California, 34 pp.

MAHONEY, J.B., MIDLIGE, F.H. and DEUEL, D.G., 1973. A fin rot disease of marine and euryhaline fishes in the New York Bight. Trans. Am. Fish. Soc., *102* : 596-605.

MEULLER, J.A., JERIS, J.S., ANDERSON, A.R. and HUGHES, C.F., 1976. Contaminant inputs to the New York Bight. NOAA Technical memorandum ERLMESA-6, Marine Ecosystems Analysis Program Office, Boulder, Colorado, 340 pp.

NATIONAL MARINE FISHERIES SERVICE, 1976. Survey of effects of dredging and spoil disposal, New London, Connecticut, 6th Quarterly report. US Dept. of Commerce. NOAA, National Marine Fisheries Service, Northeast region, 108 pp.

NORTON, M.G., 1976. The operation of the Dumping at Sea Act, 1974. Chemy. Ind., (19) 629-634.

NORTON, M.G. and ROLFE, M.S., 1978. The field assessment of effects of dumping wastes at sea. 1: An introduction. Fish. Res. Tech. Rep., MAFF Direct. Fish. Res., Lowestoft, (45) 9 pp.

O'CONNOR, J., 1976. Contaminant effects on biota of the New York Bight. Proc. Gulf Caribb. Fish. Inst., *28* : 50-63.

PRATER, N.L. and ANDERSON, M.A., 1977. A 96 hour sediment bioassay of Duluth and Superior Harbour basins (Minnesota) using *Hexagenia limbata, Asellus communis, Daphnia magna, Pimephales promelas* as test organisms. Bull. Environ. Contam. & Toxicol., *18* : 159-169.

SAILA, S.B., PRATT, S.D. and POLGAR, T.T., 1972. Dredge spoil disposal in Rhode Island Sound. Mar. Tech. Rep. Univ. Rhode Island (2) 48 pp.

SERNE, R.J. and MERCER, B.W., 1975. Characterisation of San Francisco Bay dredge sediments – crystalline matrix study. Appendix F – Dredge disposal study. US Army Engineer District, San Francisco, LA., 215 pp.

SINDERMANN, C.J., 1977. Recent data on possible association of coastal/estuarine pollution with fish and shellfish diseases. ICES CM 1977/E:14, 33 pp (mimeo).

TAYLOR, D., 1974. Natural distribution of trace metals in sediments from a coastal environment, Torbay, England. Estuar. Coastl. mar. Sci., *2* : 417-424.

TEENY, F.M. and HALL, A.S., 1977. Aquatic disposal field investigations, Duwamish waterway disposal site, Puget Sound, Washington, Appendix C. Dredged Material Research Program Tech. Rep. D-77-24. Prepared for Office, Chief of Engineers, US Army, Washington DC, 23 pp.

THOMPSON, J.A.J. and PATON, D.W., 1978. Heavy metals in benthic organisms from Point Grey dumpsite, Vancouver. A preliminary report. Pacif. Mar. Sci. Rep., Inst. Oceanogr. Sci., Patricia Bay, Sidney, B.C., 78-11, 18 pp.

US EPA, 1973a. US Environmental Protection Agency. Ocean Dumping Criteria. Federal Register, *38* : 12872-7.

US EPA, 1973b. US Environmental Protection Agency. Ocean Dumping Final Criteria. Federal Register, *38* : 28610-21.

US EPA, 1977. Ecological evaluation of proposed discharge of dredged material into coastal waters. Implementation Manual for section 103 of Public Law 95-532, July 1977. Environmental Effects Laboratory, US Army Engineer, Waterways Experiment Station, Vicksburg, Mississippi, 93 pp.

VAN LOON, J.A., RADZUIK, N., KAHN, N., LICHWA, J., FERNANDEZ, F.J. and KERBER, J.D., 1977. Metal speciation using atomic absorption spectroscopy. At. Absorp. Newsl., *16* : 79-83.

WEDEPOHL, K.H., 1960. Spureanalytische Untersuchungen an Tiefseetonen aus dem Atlantik. Geochim. Cosmochim. Acta, *18* : 200-231.

WINDOM, J.L., 1976. Environmental aspects of dredging in the coastal zone. CRC Crit. Rev. Environ. Contr., *6* : 91-109.

YOUNG, J.S. and PEARCE, J.B., 1975. Shell disease in crabs and lobsters from New York Bight. Mar. Pollut. Bull., *6* : 101-105.

ZISKOWSKI, J. and MIRCHELANO, R., 1975. Fin erosion in winter flounder. Mar. Pollut. Bull., *6* : 26-29.