FEPA MONITORING AT DREDGED MATERIAL DISPOSAL SITES OFF THE TYNE

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ABSTRACT

The report reviews the results from FEPA monitoring activities at the dredgings disposal sites off the Tyne. It also addresses some questions related to a proposal to increase the quantity of contaminated dredged material from the Tyne being disposed of at the Souter Point and North Tyne disposal sites.

EXECUTIVE SUMMARY

- There is a historical legacy arising from earlier disposal activities off the Tyne; however, the effect of reductions in contaminants loading in response to regulatory action over the last 15 years or so, including the complete cessation of certain activities, has been one of net environmental improvement.
- There are several studies that show the extent of contamination (fly, ash, minestone, sewage sludge and dredging disposals) in the area. A historical overview of the benthic environment studies off the Tyne are given in section 1, 2 and appendix, while more recent studies are described in section 4.
- Benthic macrofaunal and meiofaunal communities reflects the different physical and chemical conditions (such as type of sediment and contaminant concentrations) created at the seabed by the disposal activity (section 1 and 4).
- Dredging disposal sites show high levels of contamination from TBT, PAHs (see section 4) which can be related to the disposal of dredged material from the Tyne estuary. Concentrations of trace metals show a gradual decrease from the Tyne to offshore (see section 3, for example on lead). The disposal of contaminated dredged sediments would enhance the flow or transfer process from the Tyne to the marine environment.
- The Tyne is one of the most contaminated estuaries in the UK (section 3). TBT and PAHs are well known to be hazardous to the marine environment, fauna and human health. TBT is hazardous substance because it is toxic, bioaccumulates and is persistent in the environment. The half-life of TBT is ½ - 1½ years in aerobic sediments and between 1 and >20 years in anaerobic sediments (Waldock *et al.*, 1993). The disposal of contaminated dredged material from the Tyne will have significant implications on the spreading of contaminants and incorporation into the food chain.
- The model simulating the TBT movement from the Tyne disposal site is useful (J.Aldridge, pers.comm.), however at the moment presents some limitations. There are several aspects that are important to consider and include such as the contaminants dispersing from the Tyne and the effects of dredging at the Tyne. The distribution of the sediments moving with the water movements will depend on the particle size. We do not have comprehensive impression of the particle size distribution throughout the North East coast, and therefore it is important to understand the footprint of the dredged material. Some effort should be dedicated to the definition of the footprint of the dredged material at the disposal site. This may be achieved for example using modelling techniques and real data from sediment transport and particle size distributions. Another important aspect to consider is the dispersal of contaminants through the water column.

- There is a large body of evidence accumulated over many years to indicate that the leaching of TBT has harmful environmental effects. For example, it was held responsible for the near collapse of commercial oysters farming in France, and the depletion of a variety of other invertebrate communities in the marine environment. The disposal of TBT contaminated material at sea has the potential to adversely affect local shell-fisheries (such as for *Nephros*), and could enhance the scope for TBT bioaccumulation in fish.

1. OVERVIEW OF BENTHIC ENVIRONMENTAL STUDIES OFF THE TYNE ESTUARY by Hubert Rees

Since 1974, the disposal of wastes to sea from ships in UK waters has been regulated under the Food and Environment Protection Act (1985) and its predecessor the Dumping at Sea Act (1974). Prior to this, sea disposal was the subject of voluntary (*i.e*., non-statutory) agreements. Until recently, the Souter Point site was divided into an inner and outer part for licensing purposes. The former received colliery waste until 1993, and fly ash from coal-burning power stations until 1990, while the latter received dredged material (principally maintenance dredgings) from the Tyne estuary. Both the Souter point site and the N Tyne site (some 10 km to the north) are currently used for dredged material disposal. Just to the east of the N Tyne site, a sewage-sludge disposal site was in use between 1978 until 1998, receiving some 500,000 wet t. p.a. in most years. Finally, some 5 km to the north of this site, liquid industrial wastes were discharged from ships until cessation of the activity in 1992.

The long history of sea disposal from ships to locations off the Tyne estuary, along with earlier unregulated discharges (including ballast and domestic rubbish) from shipping *en route* to the Tyne ports, led Buchanan (1963,1964) to define the entire inshore area surrounding the Tyne mouth as 'polluted', based upon the physical evidence from sampling, and the inhibitory effects of fly ash concretions on invertebrate recolonisation. Similar observations were made by Rees *et al.* (1985).

Investigations of the environmental effects of solid waste disposal off the NE coast were carried out in the 1970s by Eagle *et al.* (1979). The effects of the ongoing disposal of fly ash to a site to the north of the Tyne were investigated by Bamber (1984, 1990), while Herrando-Perez and Frid (2001) examined the progress of changes in the benthic fauna and sediments following cessation of the activity. However, the majority of benthic studies off the Tyne have been directed at the effects of sewage-sludge disposal. Although this activity only commenced in 1978, a recommendation to proceed had been taken several years previously and, as a consequence, a programme of 'baseline' investigations was initiated, which included systematic sampling across a grid of stations along with sampling at representative stations over time (*e.g*., Buchanan *et al*., 1974; 1978). Continuation of the latter effort has led to a number of important papers on long-term temporal trends in the marine benthos and their causes (*e.g.*, Buchanan and Moore, 1986; Austen *et al*., 1991; Buchanan, 1993; Frid *et al*., 1996). The outcome of transect and time-series studies on behalf of the regulator was reported in Rees *et al.* (1985, 1992) and Rowlatt *et al.* (1989, 1991); an annual sampling programme is still ongoing, in order to investigate changes following cessation of the activity. Accompanying this effort, monitoring immediately prior to disposal, and then at 3-yearly intervals thereafter, was carried out by the licensee (Northumbrian Water Authority) in a programme agreed with the regulator.

The prevailing natural substratum type in the vicinity of the Souter Point disposal site is muddy sand. However, sediments may be significantly modified at locations in receipt of dredged material, or in response to an earlier history of solid industrial wastes or other (unregulated) discharges inshore. The disposal site is located at about 40 m depth, but this shallows by up to 5 metres at the inshore end, as a result of historical accumulations of minestone and fly ash concretions (CEFAS, unpublished data). Tidal currents in the vicinity of the site are moderate in strength and run approximately parallel with the coastline, while the net residual drift, at least in surface waters, is southward (see Rees *et al*., 1992). These circumstances favoured the evolution of a straightforward transect sampling design in an earlier investigation of the effects of multiple inputs to this site (Rees and Rowlatt, 1994). The survey identified an impoverished fauna in the immediate vicinity of solid industrial waste disposal. Localised elevation in the concentration of mercury in sediment in the outer part of the Souter Point site appeared to be attributable to the disposal of maintenance dredgings from the Tyne estuary, while the distribution of tomato pips at and near to the site could also be ascribed principally to the disposal and subsequent dispersal of sewage-contaminated dredged material (see also Rowlatt *et al*., 1989).

It may be observed that, although there is still an historical legacy arising from earlier disposal activities off the Tyne, the effect of reductions in contaminant loadings in response to regulatory action over the last 15 years or so, including the complete cessation of certain activities, has been one of net environmental improvement. This has occurred both directly as a result of controls on the quality of deposited material, and indirectly associated with improvements to the water quality of the Tyne estuary itself. The outcome of more recent investigations are reported on the following section 4.

2. OVERVIEW OF THE AREA OFF THE NORHT-EAST COAST OF ENGLAND (Physical Aspect) AND WASTE DISPOSAL by Steve Rowlatt

The area off the Tyne and Tees on the north-east coast of England is deep and fairly quiescent; it has received waste from several sources over the last 20 years. Waste from coal-mining, power stations and dredging has been deposited at various designated sites offshore.
The effects on the environment have been studied by CEFAS and are summarised in appendix. Regarding the proposal to dump 163000 M^3 of dredging waste at sea some comments are included below.

2.1. The disposal of dredged material

Dredged material from the rivers in the north-east of England is dumped at sea in licensed areas.

TBT that remains with the sediment particles would exhibit a dispersal pattern similar to the particular matter.

The particular issue at present is the proposed disposal of 163000 M^3 of TBT-contaminated dredged material from the Tyne.

This issue is discussed in the following section.

2.2. The disposal of TBT contaminated dredged material

The rather limited dispersion of the bacteria at the sewage sludge disposal site indicates only limited movement of the sludge (which has a low density) and consequently it may be assumed that dispersion of dredged material will be even more limited.

Sediment transport in this area of the north-east coast is generally towards the south in line with the tidal residuals. The estimation of the effects of the waste deposited at sea can be made from knowledge of the waste transport in the area and the likely effects of the waste on biota.

The effects of the TBT will be severe on the local biota and the only immediately apparent suitable mitigation measures are to dump the waste elsewhere eg. on the land.
A survey of the sediments around the UK under the JMG show that the Tyne has high levels of Lead, and the levels decrease from the coast to offshore.

3. CONTAMINANTS IN SEDIMENTS AT DREDGING DISPOSAL SITES OFF THE TYNE

3.1.TRIBULTYL TIN (TBT)

Monitoring of a series of contaminants in sediments at dredgings disposal sites is routinely carried out by CEFAS in support of the FEPA licensing process. If any unexpected elevations are encountered, advice on appropriate action is provided in order to minimise the risk of any adverse consequences on the marine biota and including the risk of contaminant bioaccumulation and then transfer through the food chain. Prior to disposal, samples of dredged material have, for many years, been routinely screened for a range of contaminants, especially trace metals. The range has increased in recent years in line with tighter regulatory controls, and now includes determinations of TBT originating from anti-fouling paints (Murray *et al*., 1999). Depending on concentrations, TBT has sublethal or lethal effects to a wide range of organisms and is accumulated into the food chain. Occasionally, the concentrations in dredged material have been sufficiently high to preclude the sea disposal option, for example, in the case of sediments near to dry-dock facilities, where paint-stripping of ships' hulls takes place. Present guidance determines that a concentration in dredged material that exceeds 0.1mg kg^{-1} is considered unacceptable and a licence for disposal to sea is refused. However, some concerns still remain over the potential for adverse effects arising from an earlier history of TBT-contaminated sediments deposited at sea.

TBT concentrations in sediments at the two dredgings disposal sites off the Tyne were found to be elevated, with highest concentrations confined to within the licensed boundaries (Fig. 1). The highest values of TBT were found at the western edge of the Souter Point disposal ground, suggesting that disposal activity is concentrated there. Levels at the old sewage sludge disposal site (disused from 1998) were below the minimum detection limit.

A wider and ongoing survey of TBT concentrations at dredgings disposal sites around the England and Wales coastline did not show such elevated values elsewhere. Also, a remedial action has been taken with respect to the licensing of TBT-contaminated sediments from the Tyne.

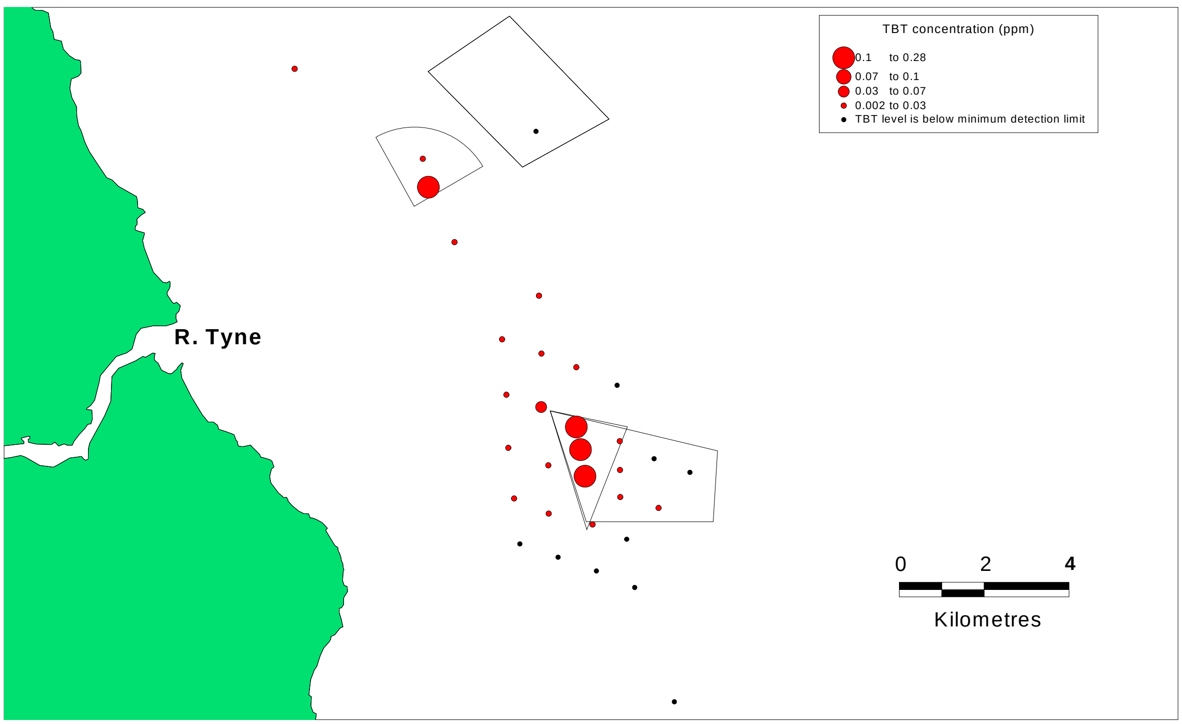

Figure 1: TBT content at the North Tyne and Souter Point dredgings disposal sites off the Tyne in 1999.

A survey in 2000 at the Souter Point disposal site showed similar concentrations to those found in 1999.

Occasional samples from the Souter Point site collectd in 1998 showed higher values of TBT than in 1999 and 2000, with maximum values of 0.6 and 0.8 ppm. This may be indicative of hot spots related to the presence of paint particles (Bryn Jones pers.comm.).

Further studies on the distribution of TBT in the sediments within the Tyne and Souter Point disposal site were conducted in 1999 using sediment cores (Jackie Reed et *al*. submitted)

72% of sites sampled in the Tyne estuary contained TBT concentrations > 1mg kg, with the highest concentrations of TBT associated with fine particles (<63µm) of the sediments. This was related to the large amount of TBT-coated paint particles within the sediment.

TBT:DBT ratios were 12:1 at Souter Point disposal site indicating fresh inputs of material with both high and low TBT concentrations. Highest concentrations were mainly confined to the disposal site although TBT concentrations were also elevated on the western edge of the disposal site, indicating either that disposal is concentrated on the land-ward margins of the site or there is localised migration of sediments (Fig 2).

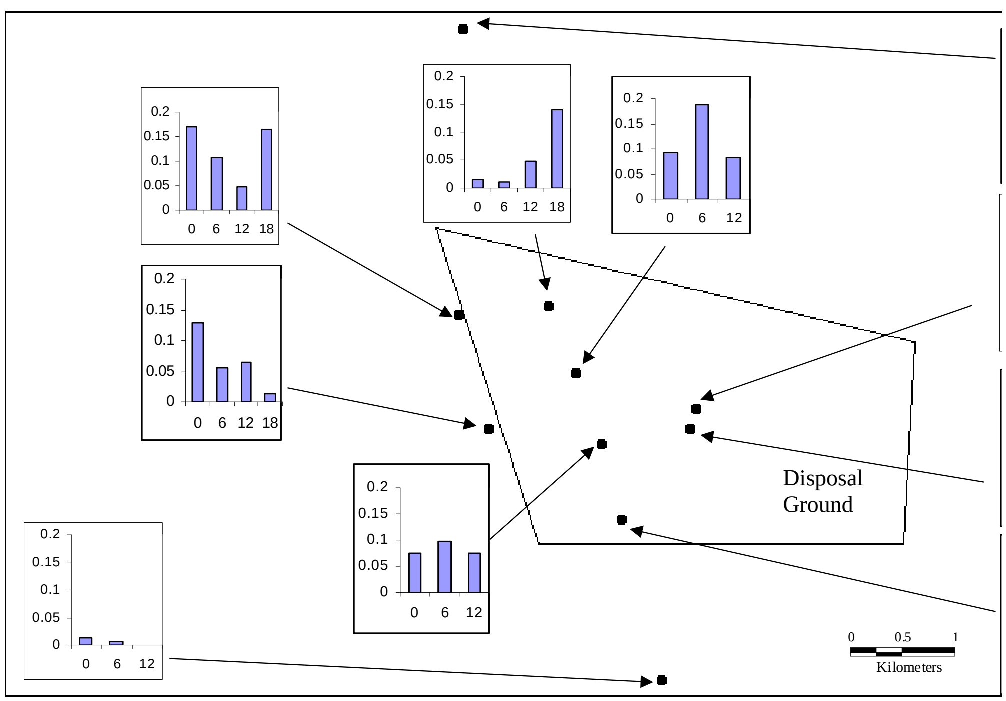

FIGURE 2. TBT Concentrations (mg/kg d/w) in sediment cores (cm) at Souter Point dredging disposal site (off the Tyne) in 1999.

The distribution of TBT observed in the core samples may be related to the history of disposals at the site, sediments mixing storm events, bioturbation effects and degradation or dispersion of TBT contaminated sediments at the surface of the seabed.

Behaviour and fate of paint-derived TBT within dredged material and during sediment removal were determined in the laboratory (DEFRA contract A0232) using a U-tube and flume to simulate UK offshore and estuarine conditions. The paint-derived TBT tended to be drawn to the surface (0-2cm) using both techniques. It was concluded that re-suspension events are likely to cause accumulation of TBT paint particles in the surface layers of the sediment.

Risk assessment of TBT associated with paint particles in sediments, based on a series of bioassays (DEFRA contract A0232) determined that sediment-bound TBT or free TBT is more acutely toxic than paint-derived TBT. Long term exposures to paint-derived TBT at concentrations >1mg kg caused adverse biological effects (mortality, reduced feeding/casting rates). TBT concentrations in the Tyne estuary sites were found very high (>10mg kg^{-1}). Long term impacts of paint derived TBT is a real problem in Tyne as TBT leaches from the paint particles in the sediment.

Caged dogwhelks deployed in the estuary of the inner estuary showed high levels of imposex after 6 months exposure. Comparative data for animals caged at the disposal site would be available on DEFRA contract C1035.

TBT contamination in sediments is widespread around England and Wales (DEFRA contract A0232). Some 2-12% of dredged material samples taken over the last decade contained elevated levels thought sufficient to cause widespread environmental impacts if disposed to sea. The Tyne shows the highest concentrations of TBT.
TBT in contaminated dredged material was found in the finer fraction (sediment bound) and light fractions (paint particles) the latter occurring in the samples containing the highest TBT levels.

After resuspension of sediments contaminated with TBT, paint flakes settled out with highest TBT concentrations at the surface (0-2 cm). This is likely to occur offshore as well as under estuarine conditions during disturbance events and points to a complex environmental fate for paint material. Sediment bioassays used for licensing dredged material showed toxicity of TBT at 1 mg kg^{-1} in acute toxicity tests (DEFRA contract A0232). Ecotoxicological studies have shown that TBT concentrations ≥1 mg kg^{-1} affects benthic communities (Matthiessen & Thain 1989, Austen & McEvoy, 1997) When presented as particulate paint material the assays underestimated potential toxicity in short term exposures but endpoints were similar for sediment bound and TBT in paint in chronic tests. Paint-derived TBT showed an adverse effect on the diversity and structure of meiofaunal assemblages living in highly contaminated sediments (Schratzberger et al 2002).

Separation techniques based on density and chemical differences in dredged material are promising methods to reduce TBT contamination. These techniques could be used operationally during dredging to provide cleaner sediment for disposal, or use. Current licensing conditions are restricting biological harm from TBT largely to within the boundaries of disposal sites.

TBT is a hazardous substance because it is toxic, bioaccumulates and is persistent in the environment. The half-life of TBT is ½ - 1½ years in aerobic sediments and between 1 and >20 years in anaerobic sediments (Waldock *et al*., 1993).

During resuspension events paint particles are therefore likely to accumulate in the surface layers of sediment and this is likely to provide a different fate for TBT particles compared with the rest of the sediment-bound TBT. This corroborates with the results from the remediation work (e.g. density separation) and can explain the presence of high TBT levels found in surface sediments from the River Tyne survey (see above). The latter case study illustrates the importance of disturbance on the remobilisation of historic inputs of TBT either by natural processes and/or by ship movements (e.g. propeller action from vessels or ship manoeuvring).

3.2. POLYCYCLIC AROMATIC HYDROCARBONS (PAHs) by Robin Law and Carole Kelly

Sediment samples collected from the Tyne disposal sites (North Tyne and Souter Point in 1999 were analysed for a suite of polycyclic aromatic hydrocarbons (PAH), including both parent and alkylated compounds. The results showed high concentrations of oil derived PAH at both disposal sites, of the same level of concentration to sediments from the River Tyne itself. Sediments sampled from the Souter Point disposal site contained total PAH concentrations between 23 and 49 ppm, and those from the North Tyne disposal site between 13 and 58 ppm. Samples from the dredged area in the River Tyne showed similar concentrations, ranging from 40 to 50 ppm.

The similarity of the concentrations of PAH in sediments both from the Tyne and from the disposal sites indicates both the regular disposal of PAH contaminated sediments, and that subsequent dispersion of the PAH contaminated sediments is not a rapid process. Further studies would be needed to clarify the timescale of this process, and the consequent spread of PAH contaminated sediments beyond the boundaries of the disposal sites.

Sediments in the River Tyne contain PAH at concentrations known to cause toxic effects to sediment-dwelling organisms (Woodhead RJ, Law RJ, Matthiessen P, 1999). Following a series of CEFAS studies the River Tyne was ranked as the second most biologically impacted river, with alkylated PAH (naphthalenes and fluorenes) being implicated in the acute toxicity to organisms (Matthiessen P, Law RJ, 2002). Presentation and assessment of PAH data is complicated as data are obtained for a large number of compounds and groups and, in addition, two separate toxic modes of action are of concern for these compounds. These are an acute toxic effect, mainly due to the smaller, low molecular weight PAH, and carcinogenicity (the initiation of cancers) which is specific to a number of the larger parent (non-alkylated) PAH, and also very dependent on molecular structure. In order to simplify the interpretation of the latter aspect, a system of toxic equivalents has been developed for PAH, similar to the TEQ approach followed for dioxins and furans. This sums the contribution of each of the carcinogenic PAH by presenting their concentrations as an equivalent concentration of the best known carcinogen, benzo[*a*]pyrene, which can all then be summed to yield a benzo[a]pyrene equivalent concentration (BaPE) for the whole sample. Although primarily developed for assessing contamination in shellfish the calculation of toxic equivalency values for sediments is useful as it provides a single-figure estimate of the total carcinogenic potential of the PAH mixture in each individual sample. The BaPE values for sediments at the disposal grounds were 600-1,500 ug kg^{-1} and those from the River Tyne ranged from 1400-2,400 ug kg^{-1}. Again, the values observed in the River Tyne and at the disposal sites are similar, and very high.

The conclusion must be that the dredging and disposal of the Tyne PAH contaminated sediments would impact the marine environment around the disposal sites, but currently we cannot predict the degree or scale of the impact.

4. RECENT STUDIES OF THE BENTHIC FAUNA AT THE SOUTER POINT DREDGING DISPOSAL SITE

4.1 Benthic macrofauna: 2002

Preliminary results from a survey of the benthic fauna at Souter Point conducted in 2002 (Paul Whomersle, pers. comm., DEFRA contract AA004) shows clear differences between benthic assemblages living inside and outside the dredgings disposal site.

Species within the disposal site are mainly deposit feeders and suspension feeders. Some are know to show tolerance to contaminated sediments. For example, a dominant polychaete worm (*Chaetozone setosa*) found within the dredgings disposal site is a typical early coloniser of defaunated sediment, and is also known to be a bio-accumulator of toxins such as certain trace metals. The assemblage outside the dredgings disposal site is dominated by predatory feeders. Bioturbating echinoderms (*Echinocardium cordatum*) were present within the dredgings disposal site, while filter-feeding echinoderms (*Amphiura filiformis*) were dominant outside. The observed differences in assemblage types reflect the differences in the prevailing physical and chemical conditions (i.e., type of sediment and contaminant concentrations).

A preliminary comparison of results from 2002 with those from 1992 shows changes in the dominant species and in the structure of assemblages with time. Further progress with the analyses of 2002 samples will allow a better definition of these changes.

4.2 Benthic meiofauna: 2000

In 2000 a meiobenthic survey was conducted along a transect from the outer Tyne estuary to the Souter Point (Michaela Schratzberger, pers. comm.: DEFRA contract A1026). A significant change in nematode assemblage structure was found at the disposal site. Changes were related both to high TBT concentrations and burial. The former resulted in a reduction in biomass (probably due to low juvenile survival and a reduction in adult reproduction) of those species that successfully coped with burial. Burial also restricted the colonisation of some species that were not able to withstand deposition. Laboratory studies confirmed that TBT concentrations >10mg kg significantly changes meiofaunal community composition. Thus, as with the macrofauna, the response of meiofauna depended not only on the level of TBT contamination but also on the physical disturbance associated with the disposal.

DISCUSSION

The area off the Tyne and Tees on the north-east coast of England is relatively deep and quiescent; it has received waste from several sources over many years. Thus waste from coal-mining, power stations, sewage and chemical treatment works and dredging has been deposited at various designated sites offshore. Presently, only dredged material is licensed for sea disposal. The reductions in waste inputs from ships to sea over the last 15 years or so, coupled with more rigorous controls on the quality of material licensed for disposal and improvements to the water quality of the Tyne estuary itself have resulted in a net enhancement in conditions at the seabed.

Regarding the present proposal to dispose of 163,000 M^3 of TBT-contaminated dredged material from the Tyne, it may be noted that TBT which remains associated with the sediment particles would be expected to exhibit a dispersal pattern similar to the particulate matter.

Sediments in the River Tyne contain PAH at concentrations known to cause toxic effects to sediment-dwelling organisms (Woodhead RJ, Law RJ, Matthiessen P, 1999). Following a series of CEFAS studies the River Tyne was ranked as the second most biologically impacted river, with alkylated PAH (naphthalenes and fluorenes) being implicated in the acute toxicity to organisms (Matthiessen P, Law RJ, 2002). It is important to note that dredging and disposal of the Tyne PAH contaminated sediments would impact the marine environment around the disposal sites, but currently we cannot predict the degree or scale of the impact.

Earlier studies at a sewage-sludge disposal site off the Tyne (Rowlatt et al., 1989) showed a rather limited dispersion of faecal bacteria. This in turn indicated only limited movement of the sludge (which has a low density) and consequently it may be assumed that dispersion of dredged material will be even more limited.

Sediment transport in this area of the north-east coast is generally towards the south in line with the tidal residuals. However we do not have a comprehensive impression of the particle size distribution of the particle size distribution throughout the north-east coast. Some effort on the study of sediment transport, particle size distribution and developing of modelling techniques would be useful. There are several aspects that are important to consider such as the contaminants dispersing from the Tyne, effects of dredging at the Tyne, the particle size distribution throughout the North East coast and dispersal of contaminants through the water column.

It may be concluded from the available evidence in this compilation that the effects of the proposed sea disposal of dredged material with high levels of TBT will be severe on the local biota and hence this option would appear to be environmentally unacceptable. Alternative solutions may be to dispose of the waste elsewhere, e.g., on land at suitable containment sites, or to apply treatment measures to dredged material prior to sea disposal in order to reduce concentrations.

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APPENDIX

The area off the North-east coast of England and waste disposal by Steve Rowlatt

The area off the Tyne and Tees on the north-east coast of England is deep and fairly quiescent; it has received waste from several sources over the last 20 years. Waste from coal-mining, power stations and dredging has been deposited at various designated sites offshore.
The effects on the environment have been studied by CEFAS and are summarised here in several studies. This is followed by a discussion of the proposal to dump 163000 M^3 of dredging waste at sea.

Minestone

Echosounder tracks in all years between 19871 and 1989 showed a significant mound at the inshore edge of the Wearmouth disposal site. A survey undertaken in 1989 (Fig. 4) provided the data for the 3D diagram shown in Fig.5. the volume of the mound is estimated as 2.3 x 106 m3 which, assuming a bulk density of 1.8, is equivalent to 4.2 x106 t of waste. The sidescan images produced in 1981 and 1988 indicate that the seabed is stony (Fig. 6a) while those in 1989 (Fig. 6b) showed widespread sand waves. The area of sand waves extended over the disposal site with sand ribbons to the east (Fig. 7). Sonar images from 1990 show less sand waves with a return to stonier conditions. Figure 8 shows typical particle size distributions of minestone and tailings samples. The minestone has a unimodal distribution with a mode at 8-11 mm. The available data for the tailings do not have any clearly discernible mode. Figure 9 illustrates particle size distributions for sediment samples collected at and to the north of the disposal site. A single population of particles with a mode of 1.4-4 mm dominates the sediment taken from the site while that from the north is bimodal with modes at 1.4-2 and 22-32 mm.

DISCUSSION
The weight of waste accumulated at the site is 4.2 x 106 t which is equivalent to only about five years of disposal at present rates. As deposition has occurred for over 20 years it is clear that much of the waste must have dispersed. It should be noted that disposal away from the site may account for some of the difference between deposition and accumulation, however this factor is likely to have been small, at least since the introduction of the Dumping at Sea regulations and could not account for the large observed difference. The majority of the waste disposed is minestone (Fig. 2) consisting of large particles (Fig. 8) which will not, as such, be transported to any great extent by the weak tidal currents in this area; 46 cm-s at springs. It is possible that storms will move some particles although the area is sheltered to a large degree from the prevailing south-westerly winds due to its close proximity to land (4 km).
Although the hydrographic conditions suggest limited mobility of the minestone it should be borne in mind that some of the particles contain coal; such particles will have lower density thus facilitating transport under extreme conditions. Two factors indicate that sand particles are mobile at the disposal site. Firstly, the presence of sand waves and sand ribbons in 1989 indicate that particle movement does take place. Secondly, the change in the nature of the seabed from sandwaves in 1989 to a more mixed substrate in 1990, indicates that sand particles were removed from the area. Three possible sources of these sand particles can be postulated. Firstly they were deposited as dredgings or tailings, secondly they were transported into the area by natural sedimentary processes or thirdly, they arose from the disintegration of minestone. The sandwaves could not be composed of dredgings as these are silts, neither could they be from tailings as only small quantities were deposited before the 1989 survey when the most widespread waves were observed. The possibility of a natural sediment influx to the area can also be discounted, because the sandwaves are centred on the disposal site with sand ribbons extending away, indicating that the sand originates at the site and are transported away from rather than to the site. Disintegration of minestone provides the only credible explanation of the sand material at the disposal site.

Minestone is formed during a vigorous excavation process, which fractures and unloads to rock particles resulting in physical changes, which can weaken them making them more susceptible to weathering and abrasion. Further support for a disintegration theory comes from a comparison of the particle sizes of the waste and disposal site sediments (Figs. 8 and 9) .The sediments have a smaller modal diameter (1.4-4 mm) than the stone from which they were derived (8-11 mm), indicating that the particles have, to some extent, broken down. Once the particle size of the minestone has decreased, storms and tidal currents will be capable of moving the material away from the site. The minestone products will then enter the natural sediment transport pathways and when the sandstone and shale fragments are fully disaggregated they will produce sand and clay particles and become indistinguishable from other marine sediments, a substantial proportion of which in this area are derived from cliff erosion.

CONCLUSIONS Wearmouth:

1. The accumulation of rock at Wearmouth accounts for a minor part of the total quantity of minestone deposited.
2. Most of the minestone is dispersed by natural sediment transport processes after it has broken down to smaller particles. As such the area affected is unlikely to increase in geographical scale or severity of effect unless the quantity disposed of increases.

The Tyne Sewage sludge disposal dite

The following section provides two examples of the approach to measuring change in sediment off the Tyne.

In order to improve the water quality of the Tyne estuary, changes were made in the Tyneside sewerage system in the late 1970s. Among these, the installation of new collection sewers and treatment facilities has resulted in the production of quantities of primary settled sewage sludge which is deposited at sea off the river Tyne (Fig. 3.4). The operation started at a low level in 1978 and increased to an annual deposition of approximately 500,000 wet tonnes in 1984, since when it has varied little.

The sea-bed at the sewage sludge disposal site consists of soft muddy sand and the water is 50 m deep. The tidal streams run approximately parallel with the coast with maximum velocities of 40 cm s^{-1}.

During the early stages of operation regular monitoring was undertaken with a view to detecting any effects of disposal as soon as they occurred. The monitoring programme was primarily aimed at assessing the condition of the sea-bed and its associated fauna, although the area was also examined for water and fish quality as part of nation-wide monitoring programmes. The present discussion deals with studies of spatial and temporal changes in surface sediment quality. The temporal component of this work has been carried out since 1987.

Fig.3.4. Distribution of E.coli in the sediments around he Tyne sewage-sludge disposal sites, 1988.

3.4.2 Methods

Sea-bed samples were collected in line with GCSDM guidelines. A 0.1 m^2 Day grab was used to sample the seabed. Immediately after collection a surface scrape of the sediment was taken for bacterial analysis. *E. coli* were enumerated using the membrane filtration procedure described by West (1988).

Sub-samples of the surface 0-1 cm of the sediment were stored frozen for later chemical and physical analysis. On return to the laboratory the sediments were defrosted and sieved at 63 μm to extract the fine fraction. The fines were subdivided and the carbon content of one sub-sample determined instrumentally, after pre-treatment with sulphurous acid to remove any carbonates present. Another sub-sample was digested with aqua regia and the metals mercury, copper, chromium, nickel, lead and zinc determined using atomic absorption spectrophotometry (Harper *et al*., 1989).

3.4.3 Results and Discussion

The area of sludge settlement as indicated by faecal bacteria is at and to the south-east of the disposal site (Fig. 3.4). This figure also shows areas of sediment impacted by the outflow of the river Tyne and coastal outfalls, both of which contain sewage bacteria. The zone of settlement at the sewage sludge disposal site is confirmed by the presence of significant quantities of tomato pips in the sediments.

The examples given in Figs. 3.5a-d show that there is a general reduction in trace metal and carbon concentrations with distance from the shore and that the outflow of the river Tyne affects sediment composition. However, with the possible exception of chromium, there is no evidence of accumulation of either metals or carbon at the disposal site. In the context of the riverine inputs to the nearshore zone it should be noted that the Tyne drains a catchment which includes the heavily mineralised Pennines as well as industrial sources of contamination and the elevated levels of metals cannot be ascribed wholly to man-made contamination.

In order to assess any changes in sediment quality with time a system has been set up based on a stratified random design (Fig. 3.6) in which sediment samples collected in different years can be compared. The samples are collected from an area centred on the zone of initial settlement defined by the faecal bacteria discussed earlier and is designed to detect changes in sediment quality brought about if there is an accumulation of sludge. This design meets the requirements of GCSDM for a 'no-change' standard. This sampling system supersedes an earlier design based on transect sampling which was liable to reflect a component of the general offshore trend of decreasing metal concentrations. For most elements there is little year to year variation in the results (Fig. 3.7a-d).

(a) **(b)**

Figure 3.5(a). Distribution of organic carbon (%) in the <63 μm fraction of sediments around the Tyne sewage-sludge disposal site, May 1988
Figure 3.5(b). Distribution of chromium (mg kg^{-1}) in the <63 μm fraction of sediments around the Tyne sewage-sludge disposal site, May 1988.

Figure 3.5(c). Distribution of zinc (mg kg^{-1}) n the <63 μm fraction of sediments around the Tyne sewage-sludge disposal site, May 1988.

Figure 3.6. Sampling grid used to assess temporal changes in sediment quality off the Tyne.

Figure 3.7. Time-series of concentrations (mg kg^{-1}) of (a) copper; (b) chromium; (c) lead; and (d) zinc in the <63 μm fraction of sediments collected at the Tyne sewage-sludge disposal site (mean concentration ± S.E.). Metals Task Team 'no-change' standards shown on chart.

The disposal of sewage sludge

INTRODUCTION

The dumping of primary-settled sewage sludge at a site 10 km off the River Tyne, UK, commenced in 1978, with a slow build-up in quantity to some 500,000 t wet weight in 1984. The site is licensed by ~1AFF under the Dumping at Sea Act, 1974. Sea disposal is a consequence of phased imple-mentation of new land-based treatment facilities in the Tyneside area (Norgrove and Staples, 1976). An important aim of this project is to improve water quality of the Tyne estuary. MAFF surveys in this region in the 1970's were concerned mainly with inshore sites for the disposal of solid wastes, especially colliery waste, fly ash and dredged spoil (Eagle ~ ~., 1979). The work identified a predominantly southward movement of sand-sized particles as bedload, with offshore transport by eddy diffusion and wind-driven currents being con- fined to very fine particles held in suspension in the upper water layers. Work by Buchanan and Warwick (1974), Buchanan, Kingston and Sheader (1974) and Buchanan, Sheader and Kingston (1978) addressed itself largely to temporal trends in the macrobenthos of regularly-monitored sites and was aimed in part at the provision of baseline information in connection with plans for future sewage sludge disposal, a task subsequently under- taken by the regional (Northumbrian) water authority. The present account deals mainly with a spatial comparison of the sediments and benthos sampled in and around the Tyne sludge disposal site in 1984. This forms part of a wider and continuing monitoring programme by MAFF in this area.

METHODS

(a) Field sampling

In February 1984, sea-bed samples were taken off the Tyne estuary, approximately along the 50 m contour, using a 0.1 m2 Day grab deployed from the MAFF research vessel RV CLIONE. Single samples were taken at 24 sites, for chemical analysis of the top 10 mm of sediment. A further 10 sites were each sampled 4 times and treated in the following manner: after measuring the depth of sediment at the centre of the closed buckets, contents of the first 3 hauls were individually washed through an 0.5 mm mesh sieve, and the retained bentbos was preserved in 5% buffered formalin with Rose Bengal for later laboratory analysis. The contents of the fourth grab were sub-sampled for enumeration 0{ faecal bacteria, by removing a portion of the surface 5 mm using a sterile spatula. A further sample of the surface 10 mm was removed and stored at -18°C prior to determination of particle size, organic carbon, and trace metal content. Reference will also be made to a grid of stations worked in 1982, using a 1 mm mesh sieve for extraction of benthos. This work will be more fully reported elsewhere (8. M. Rowlatt ~ ~. , in preparation).

(b) Laboratory analysis

Benthic macrofauna were identified to species level, as far as possible, and counted in the laboratory.

Counts of faecal coliforms and faecal streptococci were determined on board, by a most-probable-number technique involving a 3-decimal dilution, 15 tubes per dilution series. Azide Dextrose broth was used to isolate and enumerate faecal streptococci and modified-minerals-glutamate broth was the primary enrichment medium for faecal coliforms and !. ~. All tubes were incubated at 37°C and examined up to 48 h. Tubes with positive reactions were subcultured into media for confirmatory tests; faecal streptococci -KF streptococcus agar and then characteristic colonies taken to Bile-Aesculin-Azide Agar at 44°C; faecal coliforms -Brilliant Green Bile Broth at 44°C; !. -Brilliant Green Bile Broth and tryptone water for indole production at 44°C. An approximation of the MPN value was obtained from Thomas's short formula. After thawing, sediment samples were wet sieved using a 90 ~m sieve. The particle-size distribution of the > 90 ~m fraction was determined by dry sieving at 0.5 phi intervals. Organic carbon concentrations were determined in the < 90 IJ,m fraction using a Carlo Erba CHN analyser after removal of carbonates with 8O2 solution. Mercury, copper, zinc, lead and chromium were determined in an aqua regia extract of the < 90 ~m sediment fraction by atomic absorption spectrophotometry with background correction.

Although both the > 90 llm and < 90 ~m fractions of the sediments were analysed for metals, the present discussion relates to concentrations of

(a) Physical features

Water depths at the time of sampling ranged from 49 to 55 m. Sediments were predominantly fine sand, with appreciable quantities of material in the less than 90 ~m fraction, as shown in Table 1. Stations in the vicinity of the dumpsite were marginally coarser (median diameter 0.19- 0.20 mm) than further south. The most southerly site was noticeably finer (median = 0.11 mm). There was no systematic variation in grab sample volume, though the quantity retained at the dumpsite centre *was* on average lower than elsewhere.

(b) Metals and organic carbon

The concentrations of most sediment metals showed a decreasing trend away from the dumpsite centre. This is demonstrated using data for lead along the SSE transect (Figure 3); the superimposed plot gives three point running means.

Carbon values in the dumpsite at stations 1 and 2 were marginally higher than elsewhere, reaching 4.4%. While this may suggest an effect of sludge disposal, caution is required in interpretation, due to the expectation of high background variability, connected with the natural presence of significant quantities of coal (Buchanan and Longbottom, 1970).

(c) Benthos and faecal bacteria

The macrobenthos was diverse and dominated numerically by small poly— chaetes, especially by a capitellid (<u>Heteromastus</u> <u>filiformis</u>) and by two spionids of the genus <u>Prionospio</u> (Figure 4). Other major phyla – crusta— cea, mollusca and echinodermata – were sparsely represented by comparison. The proportional numerical contribution of these groups did not show appreciable variation between sites (Table 2). A feature of the plots of Figure 4 is the downward trend in numbers away from the dumpsite centre, with a peak at its southern edge. This peak corresponds with those for faecal streptococci and tomato seeds (Table 3), both of which can be considered as more stable indicators of sludge contamination.

High counts of faecal coliforms, and to a lesser extent E. <u>coli</u>, were found both in the dumpsite itself, and at site 6, some 6 km to the south. This recent faecal contamination may be explained by settling of fine material which was dumped earlier on the same day at the beginning of a south-east flowing flood tide, since the tidal excursion would approximate to this distance southwards from the dumpsite centre. Marginally elevated counts for benthos were found at this site, and it is of some interest to note that a similar distribution of bacterial counts was observed in 1985.

Ten minute beam trawl samples were taken from 3 sites as shown in Figure 2. Although a certain amount of sludge debris was evident in the dumping ground, a similar variety and number of taxa were recorded at all sites, and the same five species – 4 decapods and 1 mollusc – dominated the fauna numerically (Table 4). Allowing for field sampling error, this provided no indication of any adverse effects on the epifauna arising from sludge disposal.

DISCUSSION

1. <u>Metals</u>

A downward trend in concentrations of certain metals away from the dumpsite centre may be linked with sludge disposal, though contributions from an earlier history of dredged spoil disposal in the vicinity, and natural and anthropogenic inputs from riverine sources are probable. Work in progress should clarify any cause/effect relationship.

2. Bacteria

Non—spore forming faecal bacteria provided a sensitive indicator of recent contamination and were detected at all sites examined. Observed trends were consistent with settling and temporary accumulation of sludge components at the sea bed, though two other sources which might contribute to counts – especially south of the dumping ground – deserve consideration. First, the presence of faecal bacteria may be anticipated in dredged material originating from contaminated estuarine areas (Figure 2). Second, there is evidence from pre—sludge dumping surveys that low numbers of faecal bacteria from Tyne water efflux can reach the sea bed as far out as the 50 m contour line (P. A. Ayres – MAFF unpublished data).

3. Benthos

Elevated counts for benthos in the immediate vicinity of the dump— site, matched by certain other indicators of contamination, suggest there may be localised effects attributable to sludge dumping. However, these effects could not be considered severe when compared with classical models Eor changes in community structure in response to organic enrichment. (The presumption concerning enrichment at the Tyne site is based on the fact that the sludge is not heavily contaminated with potentially toxic substances such as certain trace metals, being derived largely from urban rather than industrial sources, and disposal in quantity has only recently commenced). Thus, there is no evidence for successional change in species composition at increasingly contaminated sites, which at higher levels might typically take the form of over—representation by opportunists, such as capitellid worms, at the expense of more sensitive groups. Evidently, these offshore Tyne assemblages naturally support a number of numerically important species which in other circumstances might be associated with anthropogenic inputs of organic matter (Pearson and Rosenburg, 1978).

Given the recent history of Tyne side sludge disposal, it may be inferred that the response of the local ecosystem has not yet stabilised, and the possibility arises of future changes of a less benign nature than those deduced from the present sampling study. Hence, continued monitoring of conditions in this area will be required.

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