MERSEY ESTUARY (U.K.) BIRD MORTALITIES — CAUSES, CONSEQUENCES AND CORRECTIVES

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ABSTRACT

In late 1979 there was an extensive mortality amongst the newly arrived over-wintering populations of waders, wildfowl and gulls in the Mersey Estuary. Mortalities on this scale were unprecedented in the area and there was no obvious cause although circumstantial evidence collected during the months following the incident indicated the probability of acute poisoning by trialkyl lead compounds.

The principal source of trialkyl lead compounds was the discharge to the Manchester Ship Canal from a factory producing tetraalkyl lead petroleum additives. Under certain conditions of freshwater flow and tidal movements appreciable concentrations of trialkyl lead could occur in the adjacent waters of the Mersey Estuary. The persistence of trialkyl lead in the estuarine waters provided a suitable source for its up-take by benthic fauna and subsequently birds in amounts similar to those shown to be acutely toxic in laboratory experiments.

Simple empirical models were used to calculate an appropriate effluent quality standard to protect waders and wildfowl. Full co-operation was received from the factory concerned and the levels of trialkyl lead discharged have been reduced to the standard. Levels of alkyl lead in the water and in estuarine fauna have fallen in line with the reduced discharge. No bird mortalities attributable to alkyl lead have been observed since the lower discharge levels have been consistently achieved.

KEYWORDS
Alkyl lead; bird mortalities; bioaccumulation; EQS; estuary; discharge standards

INTRODUCTION

Although mass mortalities or 'wrecks' of seabirds have been reported from around the coasts of the UK for at least 100 years (NERC, 1971) large-scale mortalities of estuarine birds are virtually unknown. The mortalities of waders, wildfowl and gulls which occurred in the Mersey estuary in 1979, 1980, 1981 and 1982 were a cause of considerable concern as they occurred at a time when the water quality and biological status of the estuary were thought to be improving, following a prolonged period of severe pollution.

The grossly polluted state of the Mersey estuary and its causes have been well documented (Porter, 1973; Gouge et al., 1977). Although it is only recently that it has been possible to implement a comprehensive scheme to reduce the pollution load discharged directly to the estuary (Dixon, 1985) substantial reductions in the polluting load entering the estuary via its grossly polluted tributaries have been achieved, particularly during the period 1970 to
Over this period the peak counts of wildfowl and waders using the estuary as a feeding or roosting area increased dramatically, from less than about 10,000 to more than 70,000 (Buxton, 1978; G.E. Thomason, personal communication). Comparable data regarding the numbers of invertebrates and fish found in the estuary are less extensive but again indicate a considerable improvement.

THE 1979 AND SUBSEQUENT MORTALITIES

During the period from September to December 1979 some 2,400 birds were found dead or dying in the middle reaches of the estuary (see Fig. 1). As with any incident of this nature only a proportion of the casualties are discovered and the figure of 2,400 represents a minimum estimate of the birds actually involved. The severity of the mortality caused widespread concern amongst organizations with conservation and shooting interests in the estuary and resulted in a co-ordinated investigation to try to discover the cause. Full details of this investigation are given by Head et al. (1980). The 1979 incident was peculiar in many respects. Mortalities occurred over several weeks; numbers affected fluctuated throughout the period, possibly associated with high tides; many bird species and other animals were reported affected.

Fig. 1 Mersey estuary location map
The majority of dead and dying birds were dunlin (Calidris alpina) with lesser numbers of blackheaded gulls (Larus ridibundus), redshank (Tringa totanus), teal (Anas crecca), curlew (Numenius arquata), mallard (Anas platyrhynchos), herring gulls (Larus argentatus) and common gulls (Larus canus). A total of 26 species was collected (Table 1). Affected birds captured alive exhibited distinctive symptoms including a marked muscular tremor, inability to fly, lack of co-ordination and green droppings. Investigations of tissues from affected birds for disease and a range of the most commonly occurring contaminants revealed only elevated levels of lead. This lead was initially thought to be inorganic but subsequently shown to be in the trialkyl form. A limited survey of water and biota from the estuary indicated the presence of trialkyl lead compounds. From the small amount of information available at the time and some broad assumptions it seemed that the levels of trialkyl lead in the tissues of affected birds were consistent with their feeding on prey items contaminated by trialkyl lead. However, at that stage the involvement of other factors could not be ruled out.

<table>
<thead>
<tr>
<th>TABLE 1 Composition of bird mortalities</th>
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</thead>
<tbody>
<tr>
<td>Gulls</td>
</tr>
<tr>
<td>Waders</td>
</tr>
<tr>
<td>Wildfowl</td>
</tr>
<tr>
<td>Unidentified</td>
</tr>
<tr>
<td>Others</td>
</tr>
<tr>
<td>TOTAL</td>
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Investigations at the time of the incident revealed no evidence of any spillage or accidental discharge of lead or any other toxic material although the potential for such an event on this highly industrialized estuary did certainly exist. The only discharge of alkyl lead compounds near to the estuary was from a factory manufacturing tetraalkyl lead antiknock additives for petrol. The discharge from this factory was not directly to the estuary but to the Manchester Ship Canal (MSC) at a position some distance from the area where the affected birds were recovered. There was a smaller discharge to the R. Weaver catchment, ca 20 km inland.

Smaller but significant mortalities occurred on the estuary during the Autumn of 1980, 1981 and 1982. The birds affected during these incidents exhibited symptoms similar to those observed in 1979 but the mortalities differed in that they affected proportionately more gulls and involved very few waders and wildfowl (see Table 1). Chemical analysis of birds recovered during these incidents indicated elevated levels of trialkyl lead in many of the wildfowl and waders but only in some of the gulls. Botulism toxin was found to be present in the blood of gulls recovered during the 1980, 1981 and 1982 incidents and botulism was almost certainly the cause of death in gulls, at least, in these years. Details of the analyses carried out during the 1979, 1980 and 1981 incidents are given by Bull et al. (1983) and of investigations into the occurrence of botulism by Smith et al. (1982).

Although there were potentially other causes for the mortality in 1979, at the time poisoning by alkyl lead seemed the most likely explanation. The major source of the alkyl lead was probably the discharge to the MSC though other potential sources such as the natural alkylation of lead in sediments (Harrison and Laxen, 1978) and seepage from dredgings deposited locally could not be discounted. Accordingly, investigations were put in hand to examine the fluxes of alkyl lead in the estuarine system.

ALKYL LEAD IN THE MANCHESTER SHIP CANAL AND MERSEY ESTUARY

The pattern of water movements in the MSC is extremely complex. Part of the freshwater run-off from the R. Mersey and all of that from the R. Weaver catchment (a total of ca 4 500 km²) enter the tidal section of the canal at Latchford Locks and at Weston Point near Runcorn, respectively. The majority of the R. Mersey flow enters the estuary at Howley Weir, Warrington. To maintain the Statutory Water Level (SWL) in the canal (8.9 m above Chart Datum 1975 at Liverpool) water may be discharged, if necessary, via subsurface outlets at Weaver Sluices.
During most spring tides, high water at Eastham exceeds SWL (so called "levelling" tides) and the lock gates at Eastham are fully opened for about one hour to prevent wave damage. Movement of water into the canal at Eastham can affect water levels as far upstream as Latchford, with appreciable upstream flows on very high tides. Tides exceeding 9.2 m at Liverpool can also overtop Weaver Sluices providing an additional input of saline water to the middle reaches of the canal. When the tide begins to ebb, the lock gates are closed and excess water is returned to the estuary by opening the requisite number of gates at Weaver Sluices, with a consequent draw-down from both upstream and downstream. This process is so vigorous that the water level in the canal returns to normal within a few hours of high water in the estuary. On tides less than 8.9 m there is no intrusion of estuarine water and losses from the canal during routine locking in and out of ships are compensated by inflows, principally from the R. Weaver.

These periodic and episodic events have a profound influence on the build-up and loss of pollutants discharged to the canal, their transport either in solution and/or suspension from the discharge points, and their ultimate input to the estuary. At the time of the 1979 mortality it was evident from our limited knowledge of the complexities of the system (D'Arcy and Wilson, 1978) that a very carefully planned programme would be necessary to investigate possible causes and to monitor the dynamic changes in concentrations that could be expected. Data from a limited number of surveys in the canal and estuary during 1980 were used to plan an intensive programme of sampling and analysis during 1981 and 1982. Water samples were collected from 20 stations along the canal and a similar number in the estuary from offshore to the normal tidal limit at Warrington. Generally these were taken in the canal prior to a "level" and in the estuary at the end of a levelling period; in both cases to obtain what were expected to be the maximum concentrations in the water. On two occasions, the gradual build-up and movement of alkyl lead through the system was monitored by more frequent sampling prior to, during and after levelling. Regular collection of effluent, estuarine sediment and biological samples (Macoma and Enteromorpha) was also carried out. All samples collected during 1980 and subsequently were analysed using established electroanalytical methods (Hodges and Noden, 1979) to provide data on the concentrations of alkyl lead. Preliminary investigations had established that alkyl lead in aqueous and biological samples from the MSC and estuary was present in the polar trialkyl (predominantly) and dialky forms; tetraalkyl lead was only rarely detected, then only at trace levels. Some examples of the results obtained are given in Fig. 2 which shows the build up of alkyl lead in the MSC during an interlevelling period, and in Fig. 3 which clearly demonstrates the effects of the intermittent, pulsed releases from the canal superimposed on a much smaller regular input from lockages on water concentrations in the estuary. It is interesting to note that, because of their polar nature, unlike many metals in natural waters, these alkyl lead species apparently are not scavenged by particulate material (indeed no evidence was found of their presence in the sediments) and that they behave conservatively in solution (Riley and Towner, 1984). The slope of the ideal mixing line (Liss, 1976) was found to vary considerably, apparently in response to fluctuations in freshwater run-off.
Mersey Estuary bird mortalities

In addition to the water and biological sampling regular counts of waders and wildfowl on the estuary were carried out and any dead and sick birds collected. Levels of alkyl lead and total lead were determined in selected tissues of dead and sick birds and those shot specifically for analysis.

ENVIRONMENTAL FLUXES OF ALKYL LEAD

From the data collected during this intensive programme it is possible to describe, in quantitative terms, the movement of alkyl lead through the canal/estuarine system, as shown schematically in Fig. 4. Thus during an interlevelling period the mass of alkyl lead in the MSC increases at a rate largely proportional to the discharged load to a total determined by the duration of the interlevelling period. Generally these periods are longer during solstices, and longer in summer than in winter. This pattern can be modified by the freshwater flows to the canal and the quantity of water lost by lockages such that particularly in dry summers there is a greater net loss of water, and alkyl lead, at Eastham during interlevelling periods.

When sluicing operations at Weaver Sluices, associated with levelling tides, begin the alkyl lead load in the canal is rapidly reduced to an extent dependent on the height and number of consecutive sluicing tides (a tide may level but not be accompanied by sluicing). During equinoctial spring tides this results in the virtually complete flushing of the section of canal between Eastham and Weaver Sluices; during the summer, only partial flushing occurs, leaving a substantial alkyl lead load to be added to during the next interlevelling period. In the summer months when there is generally less freshwater run-off and fewer levelling tides, concentrations in the MSC tend to increase accordingly.

The loss of alkyl lead during levelling causes a rapid rise in the alkyl lead load (and concentration) in the estuary. Thereafter throughout the subsequent interlevelling period the estuary load declines, as alkyl lead is flushed to the Irish Sea at a rate principally determined by the freshwater flow into the estuary. In general, residence times tend to be greatest during the drier months of summer.

The concentration of alkyl lead in estuarine organisms, taking Macoma as an appropriate model, follows the fluctuations in concentration of the overlying water although the exact relationship is not clear. Sedentary infauna are exposed to a wide range of alkyl lead concentrations as the overlying water moves past them through the tidal cycle and the concentration accumulated by the organisms may be a function of the maximum, mean, or minimum water concentration or some complex integration of ambient concentrations. From field data, experience during initial cleansing of biological material and from experimental data (Maddock and Taylor, 1980) it was found that alkyl lead appeared to have a relatively low concentration factor (ca 10 X) and a relatively short half-life (of about 3 days) in Macoma. It is postulated that the birds accumulate alkyl lead from their invertebrate prey, at a rate which will be affected by predator and prey species, feeding rates, and assimilation and elimination efficiencies. The effect shown by the birds will depend on the type and rate of detoxification mechanisms. Thus as the levels in prey increase so levels in bird tissues could be expected to increase, possibly to levels which could intoxicate or kill.
Fig. 4 Schematic representation of alkyl lead fluxes through the environmental compartments of the Manchester Ship Canal and Mersey Estuary.

Hydrographic and other circumstances will tend to result in maximum loads and highest concentrations of alkyl lead occurring after the autumn spring tides, at the very time when the migratory birds are starting to arrive on the estuary to overwinter.

TOWARDS A DISCHARGE STANDARD FOR ALKYL LEAD

The total amount of lead in the discharge to the MSC had been subjected to control for many years and indeed during that period there had been a steady decline in the levels of lead discharged. However the 1979 incident clearly called for separate control on the amount of alkyl lead discharged, but to what extent? There was no information in the literature to indicate what discharge levels would be appropriate to protect the various environmental compartments or their uses. Drastic restrictions could unnecessarily penalize the company and threaten its viability; insufficient action could lead to further risk to environment and/or public health.
On the basis of the scheme outlined above the pathway of alkyl lead through the environmental compartments of the MSC and estuary can be represented thus:

\[
\text{discharge} - \text{MSC water} - \text{estuary water} - \text{biota} - \text{birds} - \text{man}
\]

Man has been included because birds are shot during winter on the estuary and taken for food.

Initially we attempted to define the quantitative relationships between the various environmental compartments by establishing a mass-balance model for the aquatic phases and using what were thought to be appropriate uptake and loss kinetics to model concentrations in Macoma, and thence birds. Owing to the difficulties of modelling the extremely complex water movements in the MSC in particular, it was not possible to produce a reliable model of load and concentration changes in the MSC and the attempt to establish mass balances was abandoned. Following this a second approach was made, using observed data to establish empirical relationships between the amounts or concentrations of alkyl lead in the various compartments and to use these in a predictive mode to determine the impact of discharges of different loads. The only model tested was the simple linear regression as this was found to give statistically significant results. Examples of resultant relationships are shown in Table 2.

### TABLE 2 Relationships between levels of alkyl lead in different environment compartments.

For all regressions of \( y = ax + b \), \( p < 0.005 \)

<table>
<thead>
<tr>
<th></th>
<th>( x )</th>
<th>( y = ax + b )</th>
<th>( r )</th>
<th>( n )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration in MSC</td>
<td>Discharge level</td>
<td>( y = 66.6x - 23.4 )</td>
<td>0.76</td>
<td>27</td>
</tr>
<tr>
<td>Concentration in Estuary</td>
<td>Discharge load</td>
<td>( y = 0.0034x - 3.8 )</td>
<td>0.87</td>
<td>48</td>
</tr>
<tr>
<td>Concentration in Macoma</td>
<td>Discharge load</td>
<td>( y = 0.00024x - 0.14 )</td>
<td>0.65</td>
<td>288</td>
</tr>
<tr>
<td>Concentration in Macoma</td>
<td>MSC concentration</td>
<td>( y = 0.00346x + 0.29 )</td>
<td>0.42</td>
<td>223</td>
</tr>
<tr>
<td>Concentration in Macoma</td>
<td>Estuary concentration</td>
<td>( y = 0.0056x + 0.20 )</td>
<td>0.68</td>
<td>288</td>
</tr>
<tr>
<td>Concentration in bird liver</td>
<td>Discharge load</td>
<td>( y = 0.0031x - 5.1 )</td>
<td>0.50</td>
<td>58</td>
</tr>
<tr>
<td>Concentration in bird liver</td>
<td>Concentration in Macoma</td>
<td>( y = 7.46x - 1.38 )</td>
<td>0.45</td>
<td>62</td>
</tr>
<tr>
<td>Number of dead birds (all)</td>
<td>Discharge concentration (monthly mean)</td>
<td>( y = 65.0x - 485 )</td>
<td>0.71</td>
<td>17</td>
</tr>
<tr>
<td>Number of dead birds (all)</td>
<td>Discharge concentration (mean previous month)</td>
<td>( y = 56.5x - 413 )</td>
<td>0.81</td>
<td>17</td>
</tr>
<tr>
<td>Number of dead birds (all)</td>
<td>Concentration in Macoma (mean previous month)</td>
<td>( y = 739.1x - 292 )</td>
<td>0.90</td>
<td>14</td>
</tr>
<tr>
<td>Number of dead birds (excluding gulls)</td>
<td>Discharge concentration (monthly mean)</td>
<td>( y = 48.7x - 361 )</td>
<td>0.56</td>
<td>17</td>
</tr>
<tr>
<td>Number of dead birds (excluding gulls)</td>
<td>Discharge concentration (mean previous month)</td>
<td>( y = 42.6x - 338 )</td>
<td>0.77</td>
<td>17</td>
</tr>
</tbody>
</table>

The more statistically significant of these models were run using a variety of discharge conditions equivalent to discharge levels of between 4 and 12 mg l\(^{-1}\) soluble lead (the concentration of soluble lead in the discharge had been found to bear a constant relationship with the alkyl lead concentration).

Peak concentrations of alkyl lead in the estuary water predicted at all discharge levels between 4 and 12 mg l\(^{-1}\) soluble lead, would not be expected to give rise to direct toxic effects on fauna in the estuary on the basis of acute toxicity data reported by Maddock and Taylor (1980). In the MSC however concentrations of alkyl lead in the vicinity of the discharge could exceed acutely toxic levels at discharge levels greater than 6 mg l\(^{-1}\) soluble lead. Similarly calculated peak concentrations would not, assuming concentration factors of 10-100 \( X \), result in lead tissue concentrations in excess of the limits of 2 and 10 mg kg\(^{-1}\) in fish and shellfish, respectively, laid down in The Lead in Food Regulations (1979). Only at discharge levels greater than 12 mg l\(^{-1}\) soluble lead would levels accumulated in birds exceed the statutory limit of 10 mg kg\(^{-1}\) for lead in game and game paté.
All relationships predicted an increasing risk of bird mortalities at a discharge in excess of 6 mg l\(^{-1}\) soluble lead, and similar levels would be expected to give rise to alkyl lead concentrations in bird livers greater than 0.5 mg kg\(^{-1}\), the maximal level advocated by Osborn et al. (1983) to prevent sublethal intoxication in birds. These levels were associated with levels of 0.4 mg kg\(^{-1}\) alkyl lead in Macoma. The protection of birds therefore appeared to be the critical element in the pathway. Accordingly the relationships between discharge loads and bird mortalities (including sick birds) were examined more closely, in particular to take account of seasonal factors, such as low freshwater flows and long interlevelling periods in summer, and variations in the numbers of birds on the estuary. The relationship between the number of affected birds and discharge load was modified in two ways. Firstly the monthly numbers of affected birds were taken to include only those species, mainly ducks and waders, where analytical or other evidence suggested alkyl lead was the primary cause of illness, and those numbers were then expressed in terms of the total bird population estimated to be present in the estuary that month (ie. death rate). Secondly, for each corresponding month an "effective" alkyl lead load was computed from the monthly discharge load by applying a "sluicing" factor, related to the effect of the levelling tides on the MSC, and a "flushing" factor related to the estuary retention time i.e. the freshwater flow. These modifications produced the following relationship:

\[
y = 0.00021 x - 0.0374. \quad (r = 0.850, n = 29, p = < 0.0005)
\]

This relationship was then used to predict the effects of different discharge loads under adverse tidal and river flow conditions, and with bird populations the size of the mean 1979-82 values. The results are summarized in Fig. 5.

This clearly demonstrates that the critical period for estuarine bird populations is September/October as a result of the progressive accumulation of alkyl lead in the MSC from May till July being flushed to the estuary by the high spring tides of August/September. It follows that birds feeding on the MSC are at greatest risk in July and August.

**THE RESULT OF APPLYING THE DISCHARGE STANDARDS.**

Although the relationship described above was based on a number of assumptions, the Authority used the conclusions in 1983 as a basis for establishing a standard for alkyl lead for the discharge, in addition to the previously applied standard for total lead. Shortly after the bird mortality of 1979 the manufacturer had already taken steps to progressively reduce the discharge of alkyl lead to the MSC and since 1979 it had expended considerable resources on measures to reduce levels to comply with the new standard. The results of these efforts can be seen in Fig. 6.
Mersey Estuary bird mortalities

Fig. 6. Changes in the concentrations of alkyl lead in the environmental compartments of the Manchester Ship Canal and Mersey Estuary since 1980

The reductions in discharged loads have been followed by lower levels of alkyl lead in water and in Macoma. Significantly, since 1982 when compliance with the new standard was consistently achieved no birds have been reported suffering from alkyl lead poisoning.

CONCLUSIONS

It is probable that the bird mortalities were, in a perverse way, the consequence of the general improvement in quality in the estuary, as a result of which the unforeseen effects of a specific pollutant, hitherto swamped by the gross pollution load, became manifest. As further improvements in water quality occur the effects of other specific pollutants may appear and become significant. It seems likely that the bird mortalities of 1979 were the result of an unusual coincidence of extreme circumstances. The relatively dry summer and low tides gave rise to long interleveling periods which, with the typical effluent discharge conditions characteristic at the time, resulted in high levels of alkyl lead in the estuarine environment. This, together with an unusually high invertebrate biomass that summer and the possible early arrival of overwintering birds, resulted in acute poisoning of some birds. Field and experimental data subsequently collected have demonstrated this as one of the most striking examples of pollutant transfer in the aquatic environment producing demonstrable and quantifiable effects in top predators. Equally the detailed investigations have illustrated how critical path analysis and the setting of environmental quality objectives and standards can be used for the protection of the environment.

ACKNOWLEDGEMENTS

The work reported here is a summary of extensive investigations and collaboration between organizations. In particular we wish to acknowledge the contribution of our many colleagues in North West Water; the Associated Octel Company; British Association Shooting and Conservation; British Trust for Ornithology; Frodsham Wildfowlers; ICI (Brixham); Institute of Terrestrial Ecology; Liverpool University; MAFF Veterinary Investigation Centre,
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