

Pollution of UK estuaries: historical and current problems

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ABSTRACT

Britain's estuaries have traditionally been attractive sites for industry due to their perceived powers to assimilate and disperse industrial effluents. Regulation is by a system of environmental quality objectives and standards. Increasingly, however, the concept of assimilative capacity is being superseded by an environmental protection philosophy based upon the precautionary principle. This is generally interpreted in terms of staged reductions of identified, listed priority pollutants.

There are two major problems in conforming to such an approach. The first problem is historical, resulting from past discharges. It is illustrated by reference to high levels of PCBs and mercury in biological samples from the Liverpool Bay area. Some of the sources of these are identified and control implications considered.

A second problem relates to the effluents currently discharged by industry. The complexity of effluents routinely discharged is discussed in relation to the effectiveness of their control.

Given the difficulties of present approaches, the alternative of clean production, linked to a commitment to zero discharge within a structured time frame, is proposed as a more effective means of environmental protection.

INTRODUCTION

The first legislation passed to prevent water pollution in the UK, the Gas Works Clauses Act of 1847, prohibited discharge of coal gas liquors into surface waters. Successive legislation led to the modern provisions of the Control of Pollution Act (1974). Much of this was not brought into force by regulation until the mid-1980s and was superseded by the Water Act (1989). This adopted the control framework developed over the preceding century, creating the National Rivers Authority (NRA) to be responsible for consenting, monitoring and enforcement of industrial discharge standards. These obligations were integrated with those of maintenance and improvement of general riverine and estuarine quality through the achievement of

environmental quality objectives (EQOs). While the environmental quality standards (EQSs) which underpin the objectives are to be accorded statutory status only as of 1992, the broad principles (Gunn, 1984) have been informally established for some years.

The system of EQOs/EQSs evolved from early UK pollution control initiatives to reduce biological oxygen demand (BOD) imposed upon waters by industrial and sewage discharges (see Pentelow, 1952; Isaac, 1957). Coupled to a concept of 'assimilative capacity', this strategy resulted in a spectacular improvement in biological quality of the River Thames over three decades (Wood, 1982), albeit at the expense of emplacing a permanent, highly interventive management system (Ellis, 1989). This concept with its basic underlying assumption that natural ecosystems can assimilate a certain loading of otherwise harmful material without loss of structural or functional integrity, was eventually adopted in the formulation of international environmental policy regulating chemical discharges as well as BOD (see, e.g. GESAMP, 1986).

At the same time, some of the limitations of the approach were becoming clear. Cairns (1989) points out that the validity of the concept of assimilative capacity will probably never be established, but that lack of validation appears to be acting as a barrier to the development of adequate methodologies in the field of ecotoxicology. He notes that methods have changed little in 45 years. Single species toxicity test results remain a primary tool of decision makers despite the serious problems inherent in the extrapolation of results to the prediction of effects in natural systems (Cairns, 1984, 1986). Simply, ecotoxicological methods are not sophisticated enough to identify undesirable changes reliably, a point emphasised by Johnston and Stringer (1989).

Recently, a list of 36 chemicals was published with the intention that it form the framework for pollution reduction in the North Sea (MINDEC, 1990). This and priority pollutant lists such as the US EPA list, the EEC 'black' and 'grey' lists and the UK 'redlist' contain those substances for which an unqualified assimilative capacity approach is perceived to be inappropriate in order to facilitate their regulation (Byrne, 1988; DoE, 1988). While such lists are attractive to decision makers, there are important limitations. Firstly, the compilation process is heavily reliant on results from single species toxicity tests and uses estimates of environmental half-life and bioaccumulative potential rather than empirical values (DoE, 1988; Johnston and MacGarvin, 1989). Secondly, as noted by Johnston and Stringer (1989), the scientific demonstration of direct causal effect in the wider environment is often difficult and inevitably retrospective. Consequently, the identification of an ecotoxicological problem generally takes place long after damage has been caused and remediation has become impossible. Lists can also become unwieldy with

respect to the research and monitoring effort required to evaluate fully chemical fate and effects in aquatic environments. Indeed, the UK Department of the Environment justifies the 'redlist' in terms of improved utility, insofar as it considers only 26 substances rather than the 129 materials of the EEC 'blacklist' to which it is compared (DoE, 1988). Nonetheless, all lists are restricted and do not consider the many hundreds of substances known to be entering the aquatic environment and the hydrocycle (Waggot, 1981).

A growing appreciation of the difficulties of adequate ecotoxicological evaluation has led, in turn, to an apparently more precautionary environmental philosophy being embraced in a growing number of scientific and political fora. Precaution, underpinned by techniques of clean production and technology, is considered by some authorities as axiomatic to future environmental protection (Baas et al., 1990). At present, however, the precautionary principle seems simply to be a commitment to a staged reduction of priority pollutants, illustrated well by the recent North Sea Ministerial Declaration (MINDEC, 1990). This is effectively only a widening of the EQO/EQS concept to achieve 50–70% contaminant reductions over a larger area. Difficulties engendered by reliance on single species toxicity tests are still present. The priority pollutant list largely reflects retrospective rather than prospective wisdom concerning the relatively few considered chemicals. Further, as a result of the wider field being 'managed', wide confidence limits attach to estimates of contaminant inputs from UK and other estuaries (Grogan, 1984; DoE, 1987; Johnston et al., 1987). This has many implications for control and verification procedures.

This paper illustrates the above difficulties in the context of new data relating to the problems of PCB and mercury contamination in the Liverpool Bay area and the complexity of some effluents currently discharged to the tidal Tees. In the former case, it is clear that the assimilative capacity approach has suffered a major failure with serious long-term implications. In the latter example, a simple evaluation of effluent quality demonstrates that an extremely large variety of compounds is discharged to the aquatic environment and that no listing system is able to account fully for such complexity without entailing prohibitive monitoring costs.

METHOD AND MATERIALS

Samples of tissue were obtained from four grey seal (*Halichoerus grypus*) carcasses found in the region of Liverpool Bay and from specimens of eels (*Anguilla anguilla*) caught by line from the Mersey estuary in the region of Albert Dock (Fig. 1a,b). These were analysed for mercury and organochlorine compounds. Sediment samples obtained from the Weston Canal, Merseyside, were analysed for mercury, and volatile and semivolatile chlorinated

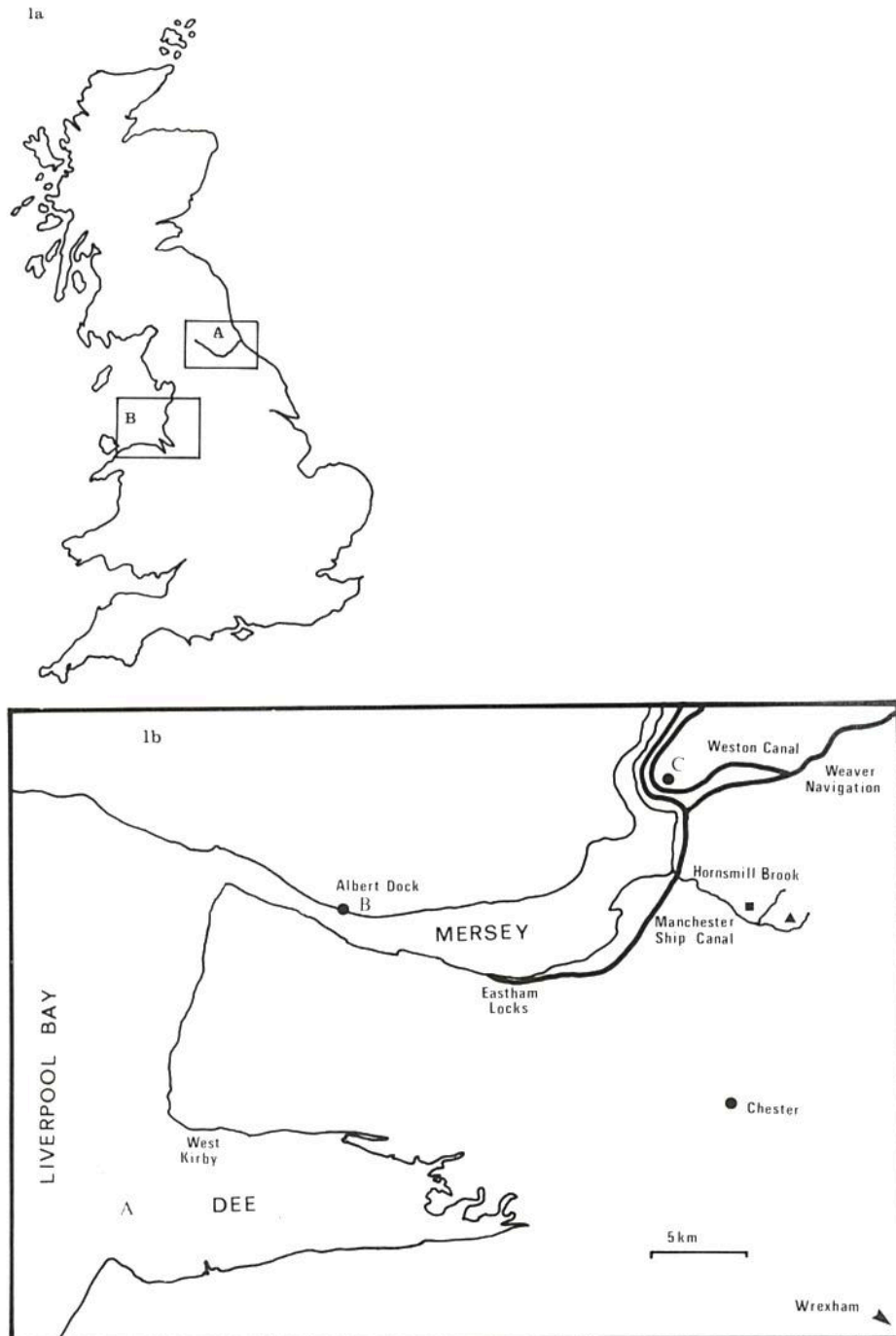


Fig. 1. (a) Map of Great Britain showing the areas studied. (A) The River Tees. (B) Liverpool Bay. (b) Map of the Mersey and Dee estuaries showing locations from which samples were taken. (A) Grey seal haul-out sit. (B) Albert Dock, eel samples. (c) Weston Canal, sediment samples. (■) Helsby landfill; (▲) Alvanley landfill, both known to contain PCBs.

compounds. Sediment samples taken close to known landfill sites in the Mersey area were analysed for PCBs. Effluent samples obtained from discharges to the Tees estuary (Fig. 1a) were screened for their content of organic chemicals. Analysis was according to the methods given below.

Mercury analysis

Approximately 2 g of material was dried to constant weight over 72 h at 85°C. The dried sample was cold acid digested for 12 h in 10 ml of analytical grade nitric acid, then brought to boiling for a final period of 1 h. Digest volumes were made up to 25 ml and analyses conducted by cold vapour generation according to the method of Hatch and Ott (1968). Measurements were made on a Thermo-electron 151 atomic absorption spectrophotometer fitted with background correction. Normal quality control procedures were performed to check accuracy and precision of the results obtained. Detection limits were established at 4 ppb wet weight.

Organochlorine analysis

Approximately 0.7 g of tissue was homogenised using a mixture of acid-washed sand and anhydrous sodium sulphate as a grinding agent. Both reagents were previously baked at 700°C for 5 h. Homogenates were allowed to soak overnight in a 1:1 mixture of acetone and hexane, both of pesticide analysis residue grade. Samples were extracted with repeated washings of solvent mixture into a final volume of 50 ml. Extracts were shaken and allowed to stand overnight after which 25 ml was pipetted into a preweighed universal and evaporated to constant dry weight giving the lipid value for the sample. The lipid sample was then redissolved in 5 ml hexane and shaken occasionally for 1 h.

Sample clean-up was carried out by passing 1 ml of extract through a packed column containing aluminium oxide previously held at 800°C for 4 h and deactivated by tumbling for 1 h after the addition of 5% distilled water. The column was eluted with 1 ml aliquots of hexane until 5 ml of cleaned-up extract was obtained. Analysis was performed on a Varian 3400 GC fitted with electron capture detection (ECD). A 30 m DB210 capillary column was used at a programmed temperature of 190°C. Identification and quantification were carried out by comparison with a standard pesticide mixture and a PCB standard of Aroclor 1254. The following pesticides and derivatives were analysed for: hexachlorobenzene, dieldrin, γ -hexachlorocyclohexane (Lindane), DDT and the DDT metabolites TDE and DDE. Polychlorinated biphenyls were determined for all samples. Recoveries were tested on spiked samples and normal quality control procedures employed. Detection limits

for the organochlorines were: hexachlorobenzene and γ -hexachlorocyclohexane, $0.005 \mu\text{g g}^{-1}$; DDE, DDT, TDE and dieldrin, $0.01 \mu\text{g g}^{-1}$; PCBs, $0.05 \mu\text{g g}^{-1}$.

Broad spectrum effluent analysis

One litre samples of effluent were taken directly from discharge pipelines into glass bottles, previously acid-washed and rinsed with pesticide residue analysis grade hexane. Samples were back extracted with two 5 ml aliquots of hexane. The sample was acidified to 0.5% with Aristar nitric acid between extractions to facilitate removal of acidic species. Emulsions were removed by centrifugation of the extract. Chromatography was carried out on a Hewlett-Packard 5890 gas chromatograph with a 5970 mass selective detector and a 25 m Ultra-1 column programmed from 35 to 260°C. Solvents used were evaluated before use and blank and control tests routinely carried out. Compound identification was by computer matching mass spectra of analytes against the NBS mass spectral library. Integration threshold and other parameters were kept constant in order to allow the results to be broadly compared. Matches at > 90% probability and < 90% but > 50% probability were recorded.

Sediment analysis

Aliquots of wet sediment were acidified, by the addition of nitric acid, to 10% by volume. After addition of 100 volumes of hydrogen peroxide solution, they were incubated overnight at 60°C. Analysis for mercury was by cold vapour method using a Varian Spectra AA40.

Solvent analysis was conducted according to the static headspace method equilibrated at 85°C. A Sigma 3 gas chromatograph fitted with a 25 m BP5 column and connected to a Finnegan ITD 700 ion trap detector was used for the analysis. Initial temperature was 40°C held for 2 min, then ramped to 120°C at a rate of $10^\circ\text{C min}^{-1}$. Quantitation was against an external standard of dichloromethane. Semivolatile compounds were wet extracted into toluene and analysed using the same equipment. In this case, an initial temperature of 120°C was ramped at $10^\circ\text{C min}^{-1}$ to a final temperature of 270°C. Quantitation was carried out against an internal standard of deuterated naphthalene added prior to sample extraction.

RESULTS AND DISCUSSION

Results of analysis of samples from the Liverpool Bay area are reported in Table 1. Values are given as micrograms per gram wet weight except where

TABLE 1

Levels of mercury and chlorinated compounds determined from samples taken in the Mersey and in Liverpool Bay. *n* denotes number of samples analysed. Values given are in micrograms per gram wet weight except where a dry weight value is indicated.
(Key: HCB, hexachlorobenzene; HCL, lindane; DDE and TDE, DDT metabolites; HEOD, dieldrin; PCB, polychlorinated biphenyls; ND, not detected; -, not analysed; (), one standard deviation about the mean; [], range of values)

Sample	<i>n</i>	Hg	HCB	HCH	DDE	TDE	HEOD	PCB
Seals								
Blubber	4	1.24 (0.71) [0.56-2.16]	0.055 (0.097) [ND-0.21]	ND	3.59 (2.56) [1.17-7.22]	-	0.39 (0.28) [0.16-0.77]	44.64 (33.25) [9.6-80.99]
Liver	2	597.3 (373.4) [333.3-861.4]	0.01 (0) -	ND	0.24 (0.12) [0.16-0.33]	-	0.14 (0.04) [0.11-0.17]	4.81 (0.45) [4.49-5.13]
Eels								
Muscle	30	0.90 (0.26) [0.61-1.30]	0.007 (0.009) [ND-0.04]	0.09 (0.08) [ND-0.31]	0.02 (0.02) [ND-0.13]	ND	0.09 (0.06) [ND-0.24]	7.38 (6.69) [2.03-34.91]
Sediments								
Weston Canal ^a	4	11.76 (17.28) [13.4-94.5]	65.25 (123.20) [1.0-250]	-	-	-	-	-
Alvanley	1	-	-	-	-	-	-	6.3
Hornsmill Brook	1	-	-	-	-	-	-	280.0 ^b

^a The following chlorinated compounds were also found in these samples: trichloromethane [ND-60.0]; tetrachloromethane [ND-300.0]; dichloroethane [trace]; hexachloroethane [trace]; trichloroethene [trace]; tetrachloroethene [ND-30.0]; hexachlorobutadiene [ND-6.0].

^b Dry weight value. Appears to be largely Aroclor 1242.

indicated. It is clear that while mercury inputs to the Mersey estuary and Liverpool Bay from the chlor-alkali process have been reduced, and are due to be reduced further (Dickson, 1987), the results from the Weston Canal confirm that there are still significant inputs to the public waterways in the area. Langston (1986) notes that water leaving the interconnected Weston Canal/Manchester Ship Canal through the Eastham Locks to the Mersey carries with it some 2.5 kg day^{-1} of mercury. The high mercury levels found in marine organisms in the Liverpool Bay system (Langston, 1986; Dickson, 1987; Franklin, 1987) undoubtedly reflect both historical and present inputs. Overall, it is admitted that some fish consumers from the locale exceed World Health Organisation (WHO) limits for mercury intake. Concentrations of mercury recorded in the eels sampled were, without exception, in excess of the EQS defined by the European and Paris Commissions of 0.3 mg kg^{-1} wet weight. Although they are consumed locally, eels are not reported in the Ministry of Agriculture, Fisheries and Food (MAFF) monitoring scheme for the area (see Franklin, 1987).

The serious degree of contamination of the system as a whole is reflected in the extremely high values (333.3 and 861.4 mg kg^{-1} wet weight) found in the livers of two of the seals from the area. These are amongst the highest ever recorded. Seals, as top marine predators, are particularly vulnerable to contaminants biomagnified through the food chain (Holden, 1978). It has become quite clear that the concept of assimilative capacity does not apply to mercury discharges and given the scale of present problems caused by past, persisting inputs, it is difficult to see how continued industrial-scale input can be justified.

Industry situated on the Weston Canal also appears to be acting as a source of several other priority pollutants including chlorinated solvents (Table 1). Due to their volatility and consequent relatively short evaporative half-lives in water it is unlikely that wider aquatic systems will be seriously impacted. However, the receiving water itself is designated as Class 4, the worst possible category (DoE, 1986). Moreover, chlorinated solvents are known ozone depleters with substantial atmospheric lifetimes (Simmonds et al., 1988).

The semivolatile compound hexachlorobenzene, a by-product of industrial chlorine chemistry (Courtney, 1979), was found at extremely high concentration (250 mg kg^{-1} wet weight) in one sediment sample. Since absolute discharge levels are not known, it is impossible to evaluate the contribution this source has made to body burdens in biota relative to other inputs and pesticidal use. The overall levels recorded in the biological samples analysed are low. It is likely, however, that the Weston Canal acts as an important local source of this organochlorine pollutant. Levels of the banned pesticide dieldrin in the eels examined are close to or exceed the legislative limits imposed for consumed fish in a number of countries (EPA, 1989).

Polychlorinated biphenyl levels recorded in the eels analysed exceed most of the national proscriptive limits reported by EPA (1989). PCBs have not been produced since 1977 in the UK (DoE, 1984), but the voluntary ban on manufacture came after some 30 years of production during which time these chemicals were widely and diversely used. Recent estimates (OECD, 1987) suggest that, in the UK alone, there are some 12 000 tonnes of primary PCB wastes and in the EEC as a whole, in excess of 250 000 tonnes. The inventories are incomplete and these figures must be regarded strictly as minimum estimates. No authorised discharges of PCBs direct to the Mersey or Dee estuaries are recorded on the public register established under the Control of Pollution Act (1974). This, however, does not rule out discharges to sewer, details of which are not publicly available under the terms of the regulatory legislation, namely the Public Health Acts (1936, 1937 and 1961).

Analyses of sediments taken from streams in the vicinity of landfills known to contain PCBs at Alvanley and at Helsby show high loadings of these chemicals. Both receiving waters ultimately debouch to the Mersey. Fine sediments from West Kirby in the Dee are also known to contain elevated levels of PCBs, possibly as a result of input from contaminated land in the vicinity of Wrexham (R.J. Law, MAFF, personal communication, 1990). The readiness with which such sources can be identified in this industrialised area implies that they are common. Certainly, this seems to be reflected in the higher levels of PCBs found in Liverpool Bay seal tissues compared with seals from elsewhere in the UK not apparently subject to such inputs (Law et al., 1989). These problems are of continuing concern given the assessment by Tanabe (1988) that some 60% of the PCBs originally produced are localised in dumps and landfills and the view of Cummins (1988) that if global PCB emissions are not completely restricted then the extinction of marine mammals is inevitable. The Liverpool Bay seals are seemingly already threatened. Recently, Baker (1989) has described abnormalities in the reproductive tracts of female seals from the area which were previously only known from highly PCB- and DDT-contaminated seal populations from the Baltic (Reijnders, 1980).

These problems have resulted from the philosophy of assimilative capacity applied on a wide scale in the Liverpool Bay system. Mercury, already identified as a considerable local problem, continues, under consent, to be legally discharged. Polychlorinated biphenyls, although nominally regulated by a production ban and increasingly stringent legislation (DoE, 1984; MINDEC, 1990), are a growing global problem. The numerous local sources, resulting from past permissive discharge and disposal practices, inhibit control through existing national legislative instruments and international conventions. Undoubtedly, both the mercury and the PCB problems in the Liverpool Bay area are beyond the scope of simple remedial measures. They

serve as a reminder of the inadequacies of an environmental protection strategy which operates through the retrospective detection of environmental effect.

A further aspect of the inadequacy of the assimilative capacity approach with particular reference to inadequacy of listing procedures relates to the complexity of industrial effluents. This is illustrated in the Tees estuary, which, for much of its lower part, is classified as poor or bad (DoE, 1986). From the discharge consent data on the public register relating to the larger industrial discharges, it is apparent that less than 20 physico-chemical determinands are routinely controlled. This may result from legislative exemption of many discharges to the river until late 1987 when they were 'deemed' to be consented under the 1974 legislation to bring them within the terms of the Act. These deemed consents are eventually due to be determined fully and properly controlled as part of a continuing scheme to improve water quality of the Tees. Almost $0.5 \times 10^6 \text{ m}^3$ of effluents are discharged daily to the Tees estuary

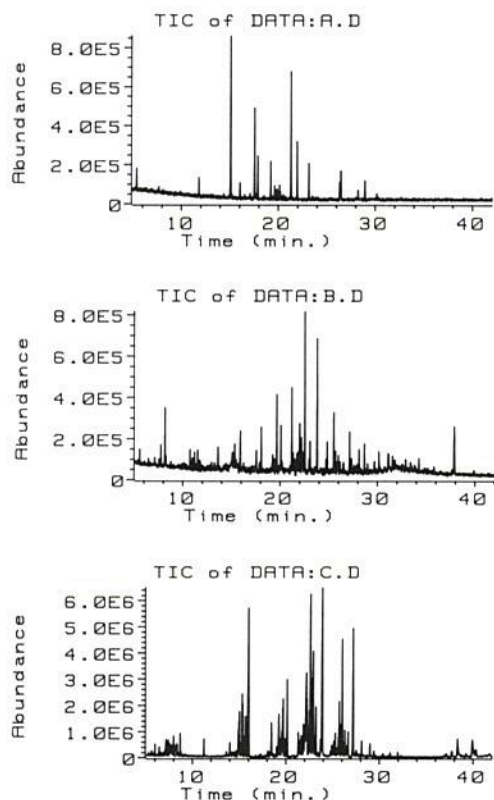


Fig. 2. Traces derived from the analysis of industrial effluents discharged into the tidal River Tees. These correspond to the details given in Table 2. Trace A: Steel manufacture. Trace B: Combined sewage/industrial. Trace C: Chemical/agrochemical.

with three major industrial sites contributing around three-quarters of the total.

The smaller discharges are nonetheless of importance. Significant chromium input results from a $2000 \text{ m}^3 \text{ day}^{-1}$ discharge at the upstream tidal limit. A small factory processing sheepskins is consented for organochlorine pesticides imported with the skins and leached out by washing. The larger discharges from steel and bulk chemical manufacture, however, contribute the greatest quantities of contaminants to the Tees and best illustrate the complexity and changeability of effluent character. Figure 2 shows three traces obtained by the broad spectrum analysis of effluents discharged to the Tees. Figure 3 shows three traces from the analysis of an effluent from a single chemical complex sampled on three different occasions. Table 2 records the number of peaks resolved on each trace using the same analysis and integration parameters, together with the results of probability based matching of mass spectra with the US National Bureau of Standards Spectral Library.

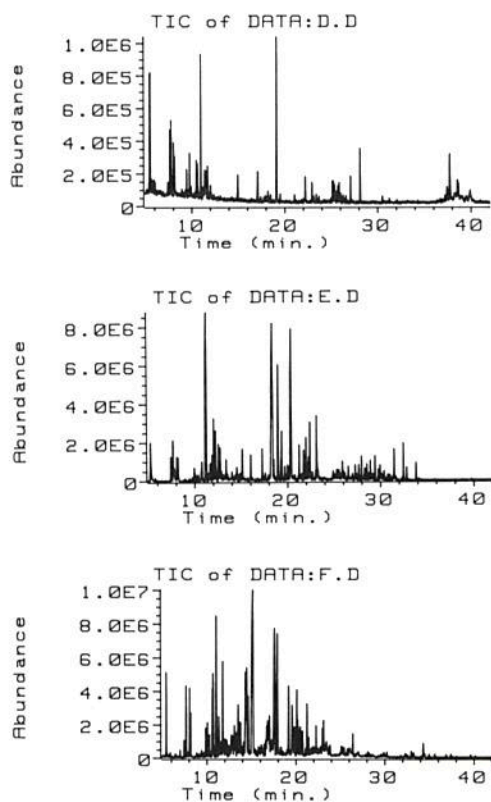


Fig. 3. Traces (D-F) derived from the analysis of three separate effluent samples taken from a single manufacturing complex at different times. Further details may be found in Table 2.

TABLE 2

Peaks resolved under identical conditions of sample preparation and machine settings from effluent samples taken from the Tees estuary. Peaks matched against the US NBS spectral library at the 90 and 50% level are recorded with the percentage remaining unmatched at each probability. Sample designations match those in Figs 2 and 3

Sample	Industrial sector	Peaks resolved	Matched > 90% (% not matched)	Matched > 50% (% not matched)
A	Steel	9	4 (55.6)	4 (11.2)
B	Mixed sewage/industrial	22	3 (86.4)	13 (27.8)
C	Chemical/agrochemical	108	8 (92.6)	46 (50.0)
D	Combined chemical	30	6 (80.0)	16 (26.6)
E	Combined chemical	131	20 (84.7)	46 (49.7)
F	Combined chemical	158	36 (77.3)	79 (13.5)

The figures presented in Table 2 underline the difficulty of characterisation of effluents on the river. Few compounds are identified to a high level of probability. For each trace, numbers of individual peaks broadly correspond to the numbers of chemicals present, although as the trace becomes more complex the chances that each peak may represent more than one compound due to co-elution increases. This further complicates the identification procedure. The pitfalls of automated GC-MS analysis of environmental samples are reviewed by Millington and Norwood (1986). Apart from possible chromatographic inadequacies, the standard of spectra held in the computer library and the algorithms used for matching can result in a high potential for false-negative and false-positive identifications. Only by lowering the probability threshold is it possible to report high match levels in the case of effluents analysed here. Full, precise characterisation then, presents a difficult prospect, would require a considerable amount of analytical effort and result in costs well in excess of the \$900-2000 per sample already estimated as normal for quantitative routine multi-component analysis (EPA, 1989).

Examination of the traces in Figs 2 and 3 shows also that effluent components vary considerably according to source. Sample A contained several polynuclear aromatic hydrocarbons which can be relatively easily identified as a result of the highly characteristic molecular ion produced and recorded in GC-MS analyses. Sample B contains many nitrogenated compounds from methyl-methacrylate manufacture which proved not to be amenable to analysis. In the case of sample C, the sewage component contains a large number of biogenic and oil-derived compounds which have a confounding effect upon the analysis. The traces A, B and C all show a high degree of individuality, but give no indication of possible changes with time. Traces D,

E and F (Fig. 3) suggest that such variability may be considerable even in effluents derived from integrated manufacturing complexes where process consistency is likely. The principal components, largely substituted benzenes, polycyclic aromatic hydrocarbons and alkanes, appear to vary widely both qualitatively and quantitatively. Surprisingly, despite the organic materials present in these samples there is no regulation either specifically or by group parameter of any of them, with the exception of oils, grease, cyanide and phenols through the discharge consents granted by the NRA. On average, less than four determinands are routinely monitored for each discharge.

The analytical difficulties underscore the problems of regulating such effluents. Firstly, if it is not possible to identify components of the mixture reliably, then it is simply not possible to estimate the environmental significance of the discharges. Evaluation of ecosystem effect is impossible other than in the simplest terms due to the complexity of the effluents and by possible constituent changes with time. These limitations are illustrated well by the US Environmental Protection Agency scheme (Schimmel et al., 1989) where complex effluents are evaluated using single species toxicity tests based on three organisms. This approach is also recommended for regulation of complex effluents in the UK (NRA, 1990). It is neither economically possible nor technically feasible to predict the whole ecosystem effect of discharged effluents. It follows that an assessment of notional assimilative capacity in the receiving system for these effluents is not possible either.

The historical problems of pollution in UK estuaries, then, exemplified by the Mersey/Liverpool Bay system, and the current problems of inadequate regulation of highly complex and variable effluent streams as on the Tees, make it clear that a more productive, more protective strategy is required for the future. The increasing tendency to rely upon pollutant lists is simply an index of the failure of regulation using present approaches. Use of lists is unlikely to result in resolution of current aquatic environmental problems nor to offer future protection against new difficulties. There are extensive and obvious shortcomings with respect to determination, control and enforceability. Simply, if no reliable figure for inputs of a substance exist, then there is no way to assess and quantify the effects of an applied control strategy based on stepwise reduction. Continuing commitment to present philosophies will fuel a need for increasingly sophisticated analysis and monitoring. There is no guarantee that deleterious changes will be identified while still reversible. This in turn will come to consume a disproportionate amount of the resources available for environmental protection without actively addressing the underlying problems. Under the circumstances what is surprising is not that permissive approaches to discharges and assimilative capacity have failed to protect the environment on occasions, but that conspicuous failures have not been more frequent.

Against this background, the adoption of a zero-discharge policy becomes conceptually attractive. In order to avoid simply transferring contamination from one medium to another, clean technology must be used to address the generation of wastes at source. A commitment is needed to a precautionary policy formulated with zero discharge and clean production techniques as keystones. If implemented within a clearly designated time period, this would constitute a viable and more robust alternative to the failure-prone permissive approaches to environmental protection based upon assimilative capacity.

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