CLEAN PRODUCTION:A NEW PARADIGM FOR ENVIRONMENTAL PROTECTION IN IRELAND

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INTRODUCTION

At present, Ireland stands at a developmental crossroads. Its rich cultural past will ensure that tourism remains an integral contributor to the economy. Agriculture is of key importance. The manufacturing industry sector, though, seems set for a large scale expansion. All these three areas of economic activity have implications for environmental management policy. The interests of one sector have to be reconciled with the others and high environmental quality is, in any case, axiomatic to recreational and agricultural interests.

Ireland and industry are no strangers to each other. History has led to the north part of the island having the greatest concentration of heavy industry. The best known is probably the now hugely contracted shipbuilding industry. In the less industrially developed south of the island, there is a substantial specialist chemical manufacturing industry, and heavy industry is represented by aluminium extraction from imported ore.

In comparison to the rest of Europe, however, the scale of this industry is relatively minor. Nonetheless, there are some spectacular examples of historical environmental degradation. PCB and heavy metal levels in Belfast Lough sediments are at the high end of the range of reported values. Mining activity in the south has caused widespread land despoilment. By and large, however, the cleanliness of the environment continues to impress visitors.

The whole island is now part of the European Community, and with this comes a uniformity of imposed legislation in the form of EC Directives. Many of these relate to the environment and are designed to impose uniform standards and promote an improvement in environmental quality over the Community at large. Concomitantly, foreign industry has sought to invest extensively in Ireland, encouraged by favourable tax regimes. These investment plans have thrown into sharp relief the potential conflict of interests between the various economic sectors. Not surprisingly, one concern most often articulated is the relevance of imposing standards originally designed to regulate economies where widespread environmental degradation already exists.

This is a pertinent observation given that major development projects have sought to secure environmental permits based upon the EC standards or the national standards applied in EC countries. Often pollution control is underpinned by the concept of Best Environmental Practice Not Entailing Excessive Costs (BATNEEC). As can be seen in the new EPA bill just passed by Parliament. It can be argued that specifically in the case of Ireland, such approaches are a license to pollute and will inevitably cause environmental degradation.

This in turn has been reflected in wide community concern about environmental protection and waste disposal practices. The instruments of the regulatory authorities have been and continue to be developed much along the lines of other European countries. Accordingly the emphasis hitherto has been very much upon pollution control rather than pollution prevention.

Such strategies, based on a permissive philosophy towards discharges, attempt to apply strict limits to the discharge of dangerous chemicals to aquatic environments. Due care is taken to limit the loading of the receiving system with oxygen demanding substances. The idea that this constitutes adequate protection of the aquatic environment is intuitively attractive and widely believed. Similarly, in aerial environments, emission control, rather than prevention and elimination, is widely perceived as an adequate way of protecting the wider environment. The failures of the regulations and hence the regulatory systems vary in consequence.

Local and regional degradation extend in some cases to global threat.

Clean production methods provide a potentially powerful mechanism whereby true environmental protection may be achieved and represent a strategy based on a new philosophy: the precautionary approach to environmental protection. Simply, there is a reduced scope for the failure of environmental protection strategies. This paper discusses some of the weaknesses of current regulatory systems, particularly with reference to the aquatic environment, and the importance of cleaner production methods in eliminating these. At present, Ireland has a unique opportunity to develop a plan of environmental protection based upon the concept of cleaner production.

THE EVOLUTION OF CLEANER PRODUCTION

Baas (1991) describes the evolution of the concept of cleaner production in terms of the theories of T.S.Kuhn. He notes that pollution problems are still largely being treated within a paradigm of production that was developed when adverse environmental effects were not yet recognised. The growing awareness of environmental problems, however, demands new practices and a new paradigm. This can be seen as a parallel of the situation in the natural sciences where new paradigms emerge after a period of contradictions and eventually a period of crisis. A revolutionary breakthrough leads to a new paradigm and a new period of "normal" science. Hence, Baas (1991) believes that cleaner production represents a new paradigm of environmental management.

The analogy used by Baas (1991) is intriguing and is one which invites further scrutiny. Close examination, using primarily European examples, makes it clear that at best we are at an advanced stage of contradiction, at worst in a period of crisis. It is easily demonstrated that there are widespread failures of the regulatory systems based upon a permissive approach. In turn these are attributable to the comprehensive failure of the concept of assimilative capacity to translate to a viable legislative framework. It is convenient to examine this in relation to where the legislators, enforcers and scientists currently stand in the process of evolving pollution control and this can be explored by examining regulatory systems currently in use.

LEGISLATION

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). In the most recent legislative change, portions of the Water Act (1989) have been moved and incorporated into the Environmental Protection Act (1990) as part of a UK Government commitment towards integrated pollution control.

This most recent legislation has assumed the control framework developed over the preceding century, creating the National Rivers Authority (NRA) to be responsible for consenting, monitoring and enforcement of industrial and other 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 1993 (ENDS 1991; NRA 1991a), the broad principles (Gunn 1984) have been informally established for some years. The regulatory instruments defined by the legislation are the consents or permits to discharge materials to the aquatic environment and the aim of the system is to control environmental quality in the local environment over a comparatively wide field.

The system of EQOs/EQSs evolved from early UK pollution control initiatives to reduce biological oxygen demand (BOD) imposed upon receiving waters by industrial and sewage discharges (see: Isaac 1957; Pentelow 1952). Coupled to a concept of "assimilative capacity", this strategy resulted in spectacular improvements 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). The strategy, with its basic underlying assumption that natural ecosystems can assimilate a certain loading of otherwise harmful material without loss of structural or functional integrity, has been adopted in the formulation of international environmental policy regulating chemical discharges as well as BOD (see: eg GESAMP 1986).

Another regulatory approach, also based upon assimilative capacity, adopted in Europe involves the use of fixed emission limits (FELs). This is exemplified by the Belgian system where industrial discharges are regulated according to manufacturing type or sector. Overall, progress has been somewhat impeded by the by the existence of three distinct administrative regions but national sectoral conditions are now used in the formulation of regional discharge permits. The system is based around a general discharge regulation based upon seven parameters, supplemented with additional parameters for each sector of industry (Smout & Heyman (1987). The Belgian system thus consists of a discharge quality framework but with no commitment to control of local environmental quality. The FEL approach has been widely criticised for this and undoubtedly leads to wholly inappropriate discharge strategies. Considerable debate has been generated around the relative merits of the fixed emission limit and environmental quality objective approaches. In the EC context, an argument frequently articulated is that EQOs adopted by the UK competitively advantage industry due to the much higher assimilative capacity of UK waters.

On a regional basis, the same principles have also been applied but there has been a growing awareness of the difficulties in controlling all components of discharges. This has led to the formulation of lists. Recently, a list of 36 such 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 difficulties are evident in defining "safe" limits and for which an unqualified assimilative capacity approach is inadequate. The list is designed to facilitate their regulation. (Byrne 1988; DoE 1988).

In the case of the North Sea list, the 36 listed chemicals are projected to be reduced by between 50 and 70% over a defined time frame. This may be seen as an EQO Based approach, albeit one which extends over a much wider area than the single rivers and estuaries covered by the UK system. An uneasy compromise between the FEL and EQO approach is nowhere more evident than in the series of EC Directives on water quality (CEC 1987). Here, the regulations are written in terms of both approaches although the UK is, conspicuously, the only country in Europe using the EQO approach.

The historical legislative trend is clear. It is consistently one of pollution control rather than one of pollution prevention. There is a preoccupation with "end-of pipe" controls as regulatory instruments underpinned by the concept of assimilative capacity. The framework is regarded as mature in historical terms and as highly evolved but capable of further evolution. It is also undeniably complex. More detailed examination reveals a number of serious flaws which reduce the effectiveness of the legislative instruments. These act to impede adequate enforcement and represent a first stratum of the contradictions predicted from the analogy of Baas (1991).

ENFORCEMENT

a) Local limitations

A primary limitation on enforcement of the UK system is exerted at the local level and arises from the fact that UK law does not act retrospectively. Accordingly, many discharges which had existed prior to the enactment of the COPA 1974 regulations were not covered by its provisions. Indeed, many direct discharges had escaped the provisions of legislation enacted in the 1950's and 1960's. These were known as "exempt discharges" prior to 1984 when they were then deemed to have consents for their existing discharges. They then became known as "deemed discharges" and a period of five years was set during which they were to be subjected to a process of positive determination and control and given a formal consent to discharge. Some of these discharges are only now being brought under formal control.

Unsurprisingly, the NRA inherited a system that was somewhat chaotic and lacking in realistic control. Current numbers of active consents are estimated at 139,00 in the UK of which about 12,000 are regularly sampled. In addition there are common excedences of consent limits by discharges which were sampled regularly. This led to the regulatory authorities operating an informal "understanding" from the mid 1980's onwards. This entailed no recourse to prosecution if dischargers complied limits on a 95 percentile basis. The "understanding" appears to have been a direct result of the opening of the public register of monitoring data in 1985 (ENDS 1990). The cumulative effect of these failings may be gauged from the specific example of the UK River Tees (INSERT 1). The Environmental quality objectives set are extremely low, while there is inadequate regulation of the industrial effluents. In turn these are more complex than is acknowledged by the terms of the consents. Overall, within the current pollution control framework, it is worth noting that UK rivers have declined in quality over a period of ten years as evidenced by the results of the 1985 and 1990 river quality surveys (DoE 1986; NRA 1991b).

Similarly, the Belgian fixed emission limit system has not proven to be robust. Sectoral conditions were originally intended to act as maxima, but the legislation holds provision for higher limits to granted, for example, on economic grounds. A crucial problem is that only the sectoral limits are published while the permits themselves are confidential. There is thus no way to evaluate the translation of national law to the regional level. Such data as are available indicate there may be widespread problems (INSERT 2).

Based on 20 permits from the Antwerp Harbour area, it is found that very few reflect the exact conditions of the relevant sector. Discharges are often permitted in excess of the sectoral limits which are clearly intended as maxima (OSPARCOM 1984) while a large number of permits have determinands extra to those laid down. The end result is that Belgium has a higher proportion of poor quality waterways than any other country in Europe (see: IHE 1986).

b) Scientific Instruments

The wholesale application of local legislative strategy to the regional level is illustrated by the current initiatives for a 50-70% reduction of selected chemicals to the North Sea. Again, the underlying philosophy is permissive based upon notional assimilative capacity. The regulatory instrument is the list of 36 chemicals agreed by the North Sea states (MINDEC 1990). It is at this stage that the scientific basis for pollution control strategies becomes subject to acute and obvious uncertainties. Priority Pollutant lists are attractive to decision makers because they provide a relatively simple regulatory instrument. There are, however, important limitations to this approach.

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 & 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 fully evaluate chemical fate and effects in aquatic environments. Indeed, the UK "redlist" is partially justified 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) (INSERT 1).

The priority pollutant list thus 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 broad implications for control and verification procedures. Agg & Zabel (1990) note that while little is known about levels of red list substances in surface waters, knowledge of loadings is crucial to the success of a reduction strategy based on listing procedures. They indicate the difficulties with analysis procedures, a problem explored in some detail by Johnston & Stringer (1991) and identified as a critical problem.

There are also potential problems with conducting a statistically reliable sampling programme. Agg & Zabel (1990) consider that with an economically affordable sampling frequency of 12 samples per annum at a site it would not be possible to show with reasonable certainty that a significant reduction in the input of a particular chemical has been achieved. This in itself undermines the whole approach of a programme of environmental control based upon reductions in the input of specified listed chemicals.

1) Assimilative capacity

The local and regional difficulties can be seen as constituting a wholesale failure of the regulatory instruments. This in turn must raise questions concerning how robust the underlying philosophy of permission actually is. In fact this is not a new debate. At the same time as assimilative capacity was being developed as an instrument of environmental protection. Some of the limitations of the approach were becoming clear. Indeed, 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.

Cairns (1989) 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 reliably identify undesirable changes resulting from environmental discharges of chemicals, a point emphasised by Johnston & Stringer (1989) and Johnston & MacGarvin (1989). These aspects of the overall problem are described comprehensively by Johnston *et al.* (1991) for the Mersey and Tees estuaries in the UK.

On a theoretical basis, Jackson (1991) has pinpointed the major drawbacks of the concept of assimilative capacity. The concept itself borrows some heuristic justification from the idea of environmental carrying capacity of ecological systems. When equated with a "dilute and disperse" philosophy however, the concept falls into conflict with the acknowledged, but poorly understood, complexity of natural systems. In addition, there is no way to distinguish between a finite, exhaustible buffering capacity in the wider environment from a sustainable capacity based on regenerative capabilities.

The most serious practical drawback, however arises from the need of an assimilative capacity based system to prove the "null hypothesis". Assimilative capacity relies on being able to prove the absence of causally related harm. As Jackson (1991) notes, the validity of the statement "There exist no harmful effects" cannot be established universally from resource limited observation. Added to this are the difficulties engendered by the complexity of ecosystems and organismal responses (See: Johnston & MacGarvin 1989). Inevitable simplifications are introduced by the choice of critical pollutant pathways for analysis. The weakness of the approach becomes clear. In practice what has tended to happen is that the assimilative capacity approach assumes the validity of the null hypothesis in the absence of proof to the contrary. This in turn elevates the burden of proof to play a critical role in the operation of the concept and this has resulted in delayed action in response to many problems of environmental protection.

Obviously, these failings strike at the heart of the scientific method, and considerable effort has been directed at defending assimilative capacity as a workable concept. Nonetheless, the concept may be seen to be central to a second stratum of contradiction with critical implications for environmental policy.

2) The Precautionary Approach

The widespread failure of legislative and regulatory instruments in effective environmental protection may be attributed therefore to a failure of the underlying concept of assimilative capacity. A growing appreciation of the difficulties of adequate ecotoxicological evaluation has led, in turn, to a more precautionary environmental philosophy being embraced in a growing number of scientific and political fora. The precautionary approach grew out of the German "Vorsorgenprinzip" introduced at the First International Conference on the Protection of the North Sea in 1984. At the second Conference in 1987, the final Ministerial Declaration (MINDEC 1987) agreed to:

> ".. accept the principle of safeguarding the marine ecosystem of the North Sea by reducing polluting emissions of substances that are persistent, toxic and liable to bioaccumulate at source by the use of best available technology and other appropriate measures. This applies especially when there is reason to assume that certain damage or harmful effects on the living resources of the sea are likely to be caused by such substances, even when there is no scientific evidence to prove a causal link between emission and effects (the principle of precautionary action)." Paragraph VII

and also:

> " Accepting that, in order to protect the North Sea from possibly damaging effects of the most dangerous substances, a precautionary approach is necessary which may require action to control inputs of such

> substances even before a causal link has been established by absolutely clear scientific evidence." Paragraph XVI.I

The principle was subsequently adopted by a number of other international fora, and was embraced by the UNEP Governing Council in 1989 at the 15th Session of the UNEP Governing Council, Decision 15/27.

Essentially, the precautionary principle acts to reverse the burden of proof required by an assimilative capacity approach. The practical aspects of this are outlined by Stairs & Johnston (1991):

> "The essence of a policy based upon precautionary action is simply an acknowledgement that, if further environmental degradation is to be minimised and reversed, precaution and prevention must be the overriding principles of policy. Application must ensure significant reduction and elimination of contaminants, especially persistent toxic substances, even where there is inadequate or inconclusive evidence to prove a causal link between emission and effects.
>
> Simply, the burden of proof should not be laid upon protectors of the environment to demonstrate conclusive harm but rather in the prospective polluter to demonstrate no likelihood of harm."

Johnston & Simmonds (1990) noted that:

> "....compared to present scientific methodologies for the evaluation of toxic effects in aquatic systems, one incorporating the precautionary principle has considerable rigour. Simply, it protects against initiating discharges of potentially harmful substances in the absence of adequate information. Current practices can only be effective as part of a process of damage limitation."

These ideas are developed in a further discussion (Johnston & Simmonds 1991):

> "In the wake of this reversal of the burden of proof in environmental studies, it follows that scientific inquiry will need to answer very different questions in the future. In turn this will require far reaching changes in the way we fund and prioritise our science."

This latter point has generated a spirited debate, with questions being directed at the scientific plausibility of the precautionary principle. For example, Gray (1990) considers that the precautionary principle should be applied within the existing statistical and monitoring frameworks, essentially a no-change option. Lawrence & Taylor (1990), seek to relegate the principle to the realms of the purely political in order to construct a case for notional commercial benefit to play a role. As the basis for an environmental protection strategy, they consider the principle to be scientifically unsound. Nonetheless the precautionary principle continues to be embraced by international fora. The most recent example is the adoption of the approach by the Contracting Parties to the London Dumping Convention who agreed by consensus the following language within a resolution on environmental protection: (LDC.44 [14]).

> ....that the quantity, diversity and complexity of chemical compounds entering the environment make it difficult to determine the overall threat to the environment,..... that existing pollution control approaches, under the London Dumping Convention, have been strengthened by shifting the emphasis from a system of controlled dumping based on assumptions of the assimilative capacity of the oceans to approaches based on precaution and prevention....."

The scientific debate continues but the intricacies of the argument and the potential for a third stratum of contradiction are effectively cut through by the LDC consensus and the decision reached by the 2nd Special Session of the UNEP Governing Council No: SS.II.4B in 1990. This further endorsed the concept of the precautionary principle and identified Clean Production as a means of implementing a precautionary approach to environmental protection.

Precaution, underpinned by techniques of clean production and technology is considered by some authorities as axiomatic to future environmental protection (see: Baas et al. 1990) and this has been further elaborated by the UNEP Governing Council in 1991 in decision 16/30B which calls for:

> "...cleaner production methods, including raw material selection, product substitution and clean production technologies and processes as a means of implementing a precautionary approach..."
>
> ....Governments and International and intergovernmental organisations to develop national and regional strategies based on a) Cleaner production programmes, including environmental audits to be carried out at all stages of production....and identifying appropriate cleaner production substitutes; b) accelerated work on reducing the use and emission of hazardous substances that are toxic persistent and bioaccumulative with the ultimate aim of phasing out those uses which cannot be adequately controlled, and by 1992, agree regional timetables for such phasing out."

Hence, the philosophy of assimilative capacity has been largely superseded, at least in principle, by one based on precaution, prevention and product bans. One paradigm of environmental protection has been replaced by another.

PHILOSOPHICAL CHANGES

Cleaner production is a concept which, as a key feature, promotes the switching of emphasis away from waste disposal to waste avoidance. This excludes measures that simply divert or dilute polluting waste streams. A toxic-use audit at the manufacturing stage identifies waste streams which may be eliminated directly by technical solutions but also indirectly by process or raw material substitutions. A wide approach is implied embracing the whole manufacture/ use/disposal cycle (Baas *et al.* 1990). It removes some of the limitations upon what can be achieved by use of the economically driven "end of pipe" solutions, exemplified by the "best available technology" (BAT) approach. It implies the design of durable, reusable, products which are easily dismantled for reconditioning or for the recovery of raw material for reintroduction to the manufacturing process. Given necessary regulatory and educative changes, such a philosophy promises to provide a workable framework through which far reaching changes in industry may be evenhandedly effected.

The development of such production frameworks require that simple questions be answered for each production process concerning (1) the waste streams generated; (2) the quantities and hazardous components of these; (3) fugitive losses of raw materials and (4) the efficiency of conversion of raw materials to final products.

Failure to consider such criteria, for example under (1) above may result in losses of considerable economic as well as environmental significance and there is huge variation in wastes generated by different companies producing the same products. Three examples from a US survey (Sarokin *et al.* 1985), illustrate the potential advantages of pollution prevention alone. In one case loss surveillance at the 1% level on a mass balance basis failed to identify a 0.06% loss, due to a faulty valve, of raw material used in phenol manufacture. Yet this represented 180 tonnes y^{-1} of material with a value of $100,000. In another case, records from two companies using phenols as raw materials showed that one using 2500 tonnes y^{-1} lost 0.08% as waste while another using 1600 tonnes y^{-1} lost 17%. Finally, of two plants each using 900 kg y^{-1} of formaldehyde one lost all in the waste stream, the other only 0.5%. There is obviously great scope in this one area alone for wholesale reductions to be achieved always supposing that the products of such processes conform to cleaner production criteria in the first place.

Application of these principles through a project carried out in Landskrona in

Sweden (Backman *et al. 1989*) has shown that environmental quality and economic profitability are compatible. In this case a number of problem industries worked with the University of Lund to explore the possibilities for pollution prevention in their respective industrial sectors. Researchers, in contact with equivalent industries outside Sweden, carried out audits and suggested options, which were then evaluated in detail by the companies concerned.

Some simple solutions were found in previously troublesome areas. Mineral oils used in metal working were substituted by vegetable based oils, halogenated solvent degreasers by mild detergents and solvent based paints replaced by powder based materials. Annual savings by this company were in excess of $400,000. A requirement to reduce solvent emissions was met by substituting solvent based inks at a printing works while another company losing 3% of its product in the effluent found that this represented an annual loss of $340,000 (See also INSERT 3). Similar collaborative work between industry and universities is now being carried out in Denmark and the Netherlands (Baas 1990). INSERT 4 shows a schematic of production under the old and the new paradigms.

The concept of cleaner production is now subject to formal definition and endorsement by UNEP and is as follows:

1: What is Cleaner Production?

Cleaner production means the continuous application of an integrated PREVENTIVE environmental strategy to processes and products to reduce risks to humans and the environment.

For production processes cleaner production includes conserving raw materials and energy, eliminating toxic raw materials, and reducing the quantity and toxicity of all emissions and wastes before they leave a process.

For products the strategy focuses on reducing impacts along the entire life cycle of the product from raw material extraction to the ultimate disposal of the product.

Cleaner production is achieved by applying know-how, by improving technology, and/or by changing attitudes.

2: How Is Cleaner Production Different?

Much of the current thinking about environmental impacts focuses on what to do with wastes and emissions after they have been generated. The goal of cleaner production is to avoid generating waste in the first place.

3: Why is Cleaner Production Important?

In the long run cleaner production is the most effective way to operate processes and to develop and produce products. The costs of wastes and emissions in addition to negative environmental and health impacts, can be avoided by applying the cleaner production concept from the beginning (See: INSERT 3).

CLEAN PRODUCTION

An even more comprehensive approach endorsed by Greenpeace is known as clean, rather than cleaner, production. In its totality, the definition represents a new paradigm of industrial production. The scale of these philosophical changes and paradigm shifts is considerable. This becomes clear when a definition of clean production is considered. There are substantial differences between the concept of cleaner production and that of clean production. Axiomatic to the definition of clean production is a consideration of the societal need for a product, implemented at the design stage. Further, other societal criteria are applied to cover the full product life cycle from extraction of raw materials to finished item. It also encompasses minimisation of inputs of renewable raw materials and energy, not just conserving inputs and moreover does not endorse disposal technologies. Rather, it attempts to close the cycle of non-toxic material use (See Insert 4).

The definition of clean production adopted by Greenpeace contains elements designed to promote the necessary societal changes:

"Systems of clean production are also planned to involve workers and community residents and to take into full account their health, environment, economic and cultural make up. Details of proposed inputs, local and imported resources and the expected outputs must be made public and remain open to public inspection."

Further:

Goods produced or grown in this type of system are compatible with ecosystems and biological processes throughout the entire life cycle, taking into account:

* product conceptualisation, design and material selection,
* raw materials extraction, processing and use,
* product manufacture or cultivation,
* packaging for display and handling,
* commercial and non-commercial use,
* final fate of products

Hence, clean production represents a true paradigm shift involving not only the materials and technologies of production, but also the societal and institutional processes are made to act within a broader social context. It therefore comprises more than a simple set of guidelines for technological redesign, it also implies a shift in the way producers think about production and the way in which consumers evaluate the products that they consume. Importantly, the emphasis is shifted even further away from waste minimisation and disposal practices to focus on not generating the waste in the first place. Under the clean production definition, the design and need for a particular product requires rationalisation as a prime consideration.

A number of factors operate against a favourable climate for clean production initiatives. The existence and development of waste disposal technologies is an obvious example. The proliferation of incineration plants, for example, provides no incentive to eliminate waste arisings. The possibility, too that hazardous waste and even hazardous products may be shipped to developing countries is another barrier. The most iniquitous recent example of this is the EC proposal to deregulate wastes for export on the basis of the fundamentally unscientific axiom of "non dispersibility". This ignores the fact that many of these wastes are toxic, should be eliminated from production processes and not recycled at all.

IMPLICATIONS OF CLEAN PRODUCTION

A major obstacle to widespread application and use of clean production is the lack of defined policy on the part of national governments and international regulatory bodies. In addition, lack of public accountability together with an approach based on negotiated agreements between legislators and industry will inevitably contribute to delay implementation of clean production. In the latter case, a mechanism which is not backed by a legislative system can lead to widespread environmental abuses. Even though legislators may espouse the principle of precaution, application of it is still within an assimilative capacity framework and traditional reliance on disposal technologies such as land fill and incineration. Until they state clearly that the priority must be given to avoiding the creation of waste, industry will not fundamentally rethink the way it operates. It is clear that failure to consider these methods will competitively disadvantage companies and not only those currently using resources in a profligate way. Clean production is not a threat to those companies who anticipate, and act upon likely changes already at an advanced stage on the political agenda.

All can and should play a part in breaking down resistance to the needed changes. The educated consumer can choose between products that are harmful and those that are not. In other words there needs to be a change in the way in which they evaluate the products that they consume, assuming that they are given a choice. Engineers can widen their scope and consider clean production techniques when designing new plant. Governments can change economic and regulatory structures to remove the fiscal impediments to clean production. More importantly, Governments need to ensure that mandatory, full public access to industrial environmental and production information is granted. What is needed also is an acknowledgement that a primary goal of clean production should be zero discharge of polluting substances. Polluting, toxic substances may be defined as those which are poisonous, which endanger human and/or environmental health in the long or short term, which are not naturally occurring. Even if they are actually found in nature, the volume or concentration from human activities must not endanger human or environmental health. This is widely regarded by industry as a naive stance yet it is a concept attracting increasing support from environmental scientists. J.B Sprague (1991), an eminent toxicologist, states:

> "The objective of regulations for controlling industrial water pollution is to protect natural communities of organisms. If done, that will include protection of humans as part of the general ecosystem. The ideal and ultimate goal must be no discharge of effluent, since plants and animals in the natural communities are adapted through millennia to conditions without human industrial input. On the other hand humans are now part of the system and cannot live without producing some sort of waste. Hence, any regulation of industrial discharges will always be a compromise between the ideal and whatever is possible at the moment. Regulations should be considered as temporary resting places on the road to a goal of zero discharge."

By closing product life cycles and removing toxic materials from the production process clean production facilitates this process. Indeed, recognition must come that zero discharge is the only way in which to ensure environmental protection given the inadequacies of current regulatory strategies and ecotoxicological methodologies. This fundamental change in philosophy needs to be encouraged by enlightened legislation and a clear target date by which all polluting discharges to aquatic environments should end. Clean production provides a means whereby this could be achieved.

The goal of zero discharge has one extremely important implication. If clean production processes are fully developed, some substances will need to be phased out and banned. This possibility has recently been recognised by UNEP in decision 16/30B at the 1991, 16th session of the UNEP Governing Council. This provides for the phase out of substances for which there can be no adequate control. Both UNEP and the Bergen Ministerial Declaration on Sustainable Development in the ECE Region (1990) have undertaken to:

> "... accelerate work on reducing the use and emissions of hazardous substances that are toxic persistent

and bioaccumulative with the ultimate aim phasing out those uses which cannot be adequately controlled and by 1992 agree regional timetables for such phasing out.

PHASE-OUTS

As noted by Johnston & Stairs (1991) and Jackson (1991), the auditing process is a key process in establishing a clean production regime. Industry must be made subject to clean production audits which encompass the qualitative and quantitative identification of toxic materials in routine use together with a programme for a phase out. The database resulting from these audits applied on an industrial sector basis, should be fully accessible to the public.

In some cases the audit will reveal that certain substances in use are not able to be adequately controlled. A good topical example is furnished by the chlorinated solvents, which are currently undergoing a review at the EC level in order to determine the optimum strategy for wastes. Insert 5 shows the potential mobilisation of chlorinated solvents through the environment. Due to the solvent nature of these compounds they are used in applications where they are designed to escape to the wider environment. Even when solvent recycling is employed, eventual complete loss is inevitable. In Europe current usage is estimated at between 667,000 and 800,000 tons per annum (CEC 1991).

The environmental effects of solvent use are varied ranging from the well known global problem of ozone depletion by CFCs 11 and 12 to the lesser understood involvement of chlorinated solvents in regional forest die-back (Franke 1991). In order to simplify this perspective the case of perchloroethylene will be considered to illustrate briefly why chlorinated solvents cannot be a component of clean production.

PERCHLOROETHYLENE

Perchloroethylene (PERC) is a common chlorinated solvent. In the USA for example, it is the most widely used halogenated solvent where 555 million gallons are consumed annually. Of this 56% is used in dry cleaning and 24% in the textile processing industries. It has come into use because of its stability an non-flammability. 10% is used in metal degreasing operations and it is also used as an intermediate in the production of the fluorocarbon F-113 (NDC 1988).

PERC is the most common dry-cleaning solvent and wastes are generated in the form of still residues or spent filter cartridges. In the USA it has been estimated that up to 45 gallons of solvent containing wastes are generated each month and most are disposed of as domestic waste. Due to its volatility, PERC is a common air contaminant and has the ability to contaminate fatty foodstuffs. Levels of PERC between 100-1000ppb have been found in butter bought from supermarkets near to dry-cleaning plants (Fawell & Hunt 1988; Miller & Uhler 1988). Residents of accommodation above dry-cleaning shops have shown elevated levels of PERC exhaled on the breath, an indication of cutaneous absorption (Verberk & Scheffers 1980).

Recent studies have drawn correlations between PERC in the atmosphere and forest decline in Europe (Frank (1991) due to degradation to trichloroacetic acid, a powerful herbicide. In addition PERC is a common groundwater contaminant and accidental spillages which cause such contamination appear to be increasing. This represents a serious form of pollution in that a few litres of solvent could in theory contaminate many thousands of litres of groundwater which then becomes unfit for potable use (Lawrence and Foster 1987).

As a result of recent studies there are growing health concerns, particularly related to reproductive capacity (van de Gulgen & Zielhuis 1989; Lindbohm *et al.* (1990). In a 1989 study in Finland it was found that 3,000 women who had been exposed to PERC at the beginning of their pregnancy showed an increase risk for spontaneous abortion of some 3-4 times above controls (Kyyrone *et al.* 1989) this result was later corroborated by a US study (Windham 1991).

Other studies have identified neurological disorders associated with inhaling organic solvents, including PERC. These include personality changes, depression headache and lassitude (Hartman 1988). A recent Danish study has found evidence of brain damage in exposed workers. (see: Gade *et al.* 1988). In addition there is evidence that PERC is a carcinogen (CEC 1986).

There is ample evidence from these and other published studies, of deleterious environmental and human health effects, certainly enough to justify application of the precautionary principle. Due to the fugitive nature of solvents such as PERC, it is unrealistic to expect to be able to prevent environmental release, or even to substantially slow it down. The Swedish Government has recognised this and has targeted PERC for phase out by 1996.

THE ROLE OF CLEAN PRODUCTION

In the case of PERC the clean production paradigm underpinned by a precautionary approach firstly identifies the need to phase out this chemical and indeed the whole group of chlorinated to which it belongs. The approach also provides a means for disseminating information to the public to exert change at the consumer level. The provision by the fashion industry of washable rather than dry clean only fabrics would help the phase out. The development of alternative cleaning methods will be required and in fact these are already underway and involve cleaning fluids extracted from plant material coupled with steam cleaning. Clearly the changes will be far reaching and necessary over several sectors of industry. Against the cost of these changes would be set the lowered risk to worker health and the environment.

CONCLUSION

Current methods of pollution control, based upon an assimilative capacity approach are prone to extensive failure. Clean production methods provide a means whereby pollution can be prevented. In many cases there are positive economic benefits to adopting such methods in addition to achieving environmental protection. Ultimately, clean production will lead to a phase out of certain chemicals for which adequate controls are not possible. This will require changes on the part of industry, consumer and government if clean production is to assume a position as a new paradigm of industrial production.

REFERENCES

Agg, A.R. & Zabel, T.F. (1990) Red list substances: Selection and monitoring. J. IWEM February 1990, 4: 44-50

Baas, L., Hofman, H., Huisingh, D., Huisingh, J., Koppert, P. & Neumann, F. (1990). Protection for the North Sea: Time for Clean Production. Publ. Erasmus Centre for Environmental Studies, Erasmus University, Rotterdam. Report No.11 79pp.

Baas, L.W. (1991). Cleaner water by cleaner production: theoretical reflections on case studies. In: Nath, B. & Robinson, J.P. (eds) Proceedings of the International Conference on Environmental Pollution. Volume II Publ. Inderscience, Geneva. pp857-865.

Backman, M., Huisingh, D., Persson, E. & Siljebratt, L. (1989) Preventative environmental protection stategy: First results of an experiment in Landskrona, Sweden. Publ. TEM/ University of Lund, Sweden 36pp

Byrne, C.D. (1988) Selection of substances requiring priority action. In: Risk Assessment of chemicals in the environment. Ed. Richardson, M.L. Publ. Royal Society of Chemistry pp 414-434

Cairns, J. (1984) Are single species toxicity tests alone adequate for estimating environmental hazard? Environ. Monitor. Assess. 4:259-273

Cairns, J. (1986a) The Myth of the Most Sensitive Species. Bioscience 36 (10):670-672

Cairns, J. (1989) Applied Ecotoxicology and Methodology. In: Aquatic Ecotoxicology: Fundamental Concepts and Methodologies. Ed. Boudou, A. & Ribeyre, F. Publ CRC Press, Boca Raton pp276-289.

CEC (1986) Organochlorine solvents, Health Risks to Workers. Chapter 9: Perchloroethylene. Publ Royal Society of Chemistry pp191-224

CEC (1987) European Community Environmental Legislation 1967-1987. Volume 4: Water Report No: XI/989/87 Publ. Commission of the European Communities 229pp.

CEC (1991) Information Document: Chlorinated Solvents, Second Draft. Reprt No: R3178129.KO4/JWN. Prepared by TAUW Infraconsult for the Commission of The European Community, Deventer, January 1992.

DoE (1986) River quality in England and Wales 1985. Department of the Environment Publ. HMSO, London 41pp

DoE (1987) Quality Status of the North Sea: A report by The Scientific and Technical Working Group to The Second International Conference on the Protection of the North Sea. UK Department of the Environment 87pp.

DoE (1988) Inputs of dangerous substances to water: Proposals for a unified system of control. The Governments consultative proposals for tighter control over the most dangerous substances entering the aquatic environment (The Red List). Publ. Department of the Environment UK July 1988 25pp & Annexes

Ellis, D. (1989) The Thames Estuary, a managed ecosystem. Mar. Poll. Bull. 20 (4): 151-152

ENDS (1990) Tidying up the mess of Britain's discharge consent system. ENDS Water Management Report No: 56. Publ. Environmental Data Services, London, Vol. 186 pp17-24.

ENDS (1991) Statutory water quality objectives: using the law to clean up Britains' waters. ENDS Water Management Report No: 62. Publ. Environmental Data Services, London, Vol. 203 pp10-12.

Fawell, J.K. & Hunt, S. (1988) Environmental toxicology: organic pollutants Publ: Ellis Horwood Ltd. 440pp

Frank, H. (1991) Airborne chlorocarbons, photoxidants and forest decline. Ambio 20 (1): 13-18

Gade , A., Mortensen, E.L. & Bruhn, P. (1988). "Chronic painters syndrome" A reanalysis of psychological test data in a group of diagnosed cases, based on comparisons with matched controls. Acta. Neurol. Scand. 77: 293-306

GESAMP (1986) Environmental Capacity: An approach to marine pollution prevention. Report No: 30, Joint Group of Experts on the Scientific Aspects of Marine Pollution. Publ. FAO Rome, 49pp

Grogan, W.C. (1984) Input of contaminants to the North Sea from the United Kingdom. Report to the UK Department of the Environment by The Institute of Offshore Engineering, Heriot Watt University 203pp

Gray, J.S. Statistics and the precautionary principle. Mar. Poll. Bull. 21 (4): 174-176

Gulgen, van de, J.W.J. & Zielhuis, G.A. (1989) Reproductive hazards related to PERC: A review. Int. Arch. Environ. Health 61: 235-242

Gunn, J.A.L. (1984) The UK Approach- Environmental Quality Standards In: Environmental protection: Standards, Compliance and Costs. Ed. Lack, T.J. Publ. Ellis-Horwood pp181-188

Hartman, D. (1988). Neuropsychological Toxicology Chapter IV: Neuropsychological toxicology of solvents. Publ. Pergamon Press pp108-156

IHE (1986) Carte de la qualite biologique des cours d'eau en Belgique bilan pour 1985. Institute d'Hygiene et d'Epidemiologie, Brussels.

Isaac, P.C.G.(1957) (Editor) The treatment of trade waste waters and the prevention of river pollution. University of Durham, Kings College. 311pp

Jackson, T. (1991). Towards Clean Production: concepts and principles for guiding technological choice towards sustainable development. Discussion Document for a Seminar on: The Principles of Clean Production, Stockholm April 23-24 1991. Publ.Stockholm Environment Institute, London 43pp.

Johnston, P.A., Booth, A.M. & Thorpe, B.G. (1987) Monitoring programmes, consented discharges and environmental effect in estuaries and coastal waters. In: 3rd Report from the Environment Committee, Minutes of Evidence, Pollution of Rivers and Estuaries. Publ. HMSO London, pp196-210

Johnston, P.A. & MacGarvin M. (1989) 0-2000: Assimilating lessons from the past. Greenpeace 3rd North Sea Conference Report No: 28. Greenpeace International, Amsterdam 32pp

Johnston, P.A. & Simmonds, M.P. (1990). Precautionary Principle. Mar. Poll. Bull. 21: 402.

Johnston, P.A. & Simmonds, M.P. (1991) Green Light for Precautionary Science. New Scientist, August 3 1991, p4.

Johnston, P.A. & Stairs K.C. (1991) The precautionary action approach to environmental protection. In: Nath, B. & Robinson, J.P. (eds) Proceedings of the International Conference on Environmental Pollution. Volume II Publ. Inderscience, Geneva. pp473-479.

Johnston, P.A. & Stringer, R.L. (1989) Complexity, entropy and environmental effect. In: Wheeler, D., Richardson, M.L. & Bridges, J. (Eds.)., Watershed 89: The Future for Water Quality in Europe Vol II. Pergamon Press, London pp283-291

Johnston, P.A. & Stringer, R.L. (1991) Analytical difficulties in the full characterisation of industrial effluents. Anal. Proc. 28: 249-250.

Johnston, P.A., Stringer, R.L. & French M.C. (1991) Pollution of UK estuaries: historical and current problems Sci. Tot. Env. 106: 55-70

Kyyronnen, P., Taskinen, H., Lindbohm, M.-L., Hemmiki, K. & Heinonen. O.P. (1989). Spontaneous abortions and congenital malformations among women exposed to tetrachloroethylene in dry cleaning.. J. Epidemiol and Comm. Health. 43: 346-351.

Law, R.J., Fileman, T.W. & Matthiessen, P. (1991) Phthalate esters and other industrial organic chemicals in the North and Irish Seas. Wat. Sci. Technol. 24 (10): 127-134.

Lawrence, A.R. & Foster, S.S.D. (1987) The pollution threat from agricultural pesticides and industrial solvents: a comparative review in relation to British aquifers. Hydrogeological Report of the British Geological Survey, No. 87/2

Lawrence, J. & Taylor, D. (1990) Statistics and the Precautionary Principle. Mar. Poll. Bull 21 (12): 477

Lindbohm, M.-L., Taskinen, H., Sallmen, M. & Hemminki, K. (1990) Spontaneous abortions among women exposed to organic solvents. Am. J. Ind. Med. 17: 449-463.

Miller, L.J. & Uhler, A.D. (1988) Volatile halocarbons in butter: elevated tetrachloroethylene levels in samples obtained in close proximity to dry-cleaning establishments. Bull. Environ. Contam. Toxicol. 41: 469-474

MINDEC (1987) Ministerial Declaration of the 2nd International Conference on the Protection of the North Sea 24-25 November 1987, London.

MINDEC (1990) Final Declaration of the Third International Conference on the Protection of the North Sea. The Hague, March 1990 36pp.

NDC (1988) Treatment technologies for solvent containing wastes. Pollution Technology Review No: 149 Publ. Noyes Data Corporation, Chicago.

NRA (1991a) Proposals for statutory water quality objectives. Water Quality Series No.5 Publ. National Rivers Authority, UK 100pp.

NRA (1991b) The quality of rivers, canals and estuaries in England and Wales: Report of the 1990 survey. Water Quality Series No.4 Publ. National Rivers Authority, UK 64pp

OSPARCOM (1984) The Oslo and Paris Commissions, The First Ten Years. Publ Oslo and Paris Commissions, London pp40-56

Pentelow, F.T.K. (1952) River Purification: A Legal and Scientific View of the Last 100 Years. E.J. Arnold, London 63pp

Sarokin, D.J, Muir, W.R., Miller, C.G. & Sperber, S.R. (1985) Cutting chemical wastes: What29 organic chemical plants are doing to reduce hazardous waste. Publ. Inform, N.Y. 535pp.

Smout, L. & Heyman, G. (1987) Wetboek Afval & Water in Vlaanderen. VZW Water, Energie en Leefmilieu, 463pp

Sprague, J.B. (1991). Environmentally desirable approaches for regulating effluents from pulp mills. Wat Sci. Technol. 24 (3/4): 361-371

Verberk, M.M. & Scheffers, T.M.L. (1980) Tetrachloroethylene in exhaled air of residents near dry cleaning shops. Environ. Res. 21: 432-437

Waggot (1981) Trace organic substances in the River Lee. In: Cooper, W.J. (Ed.)., Chemistry in Water Re-use Vol 2. Ann Arbor Science, Ann Arbor MI, pp 55-99

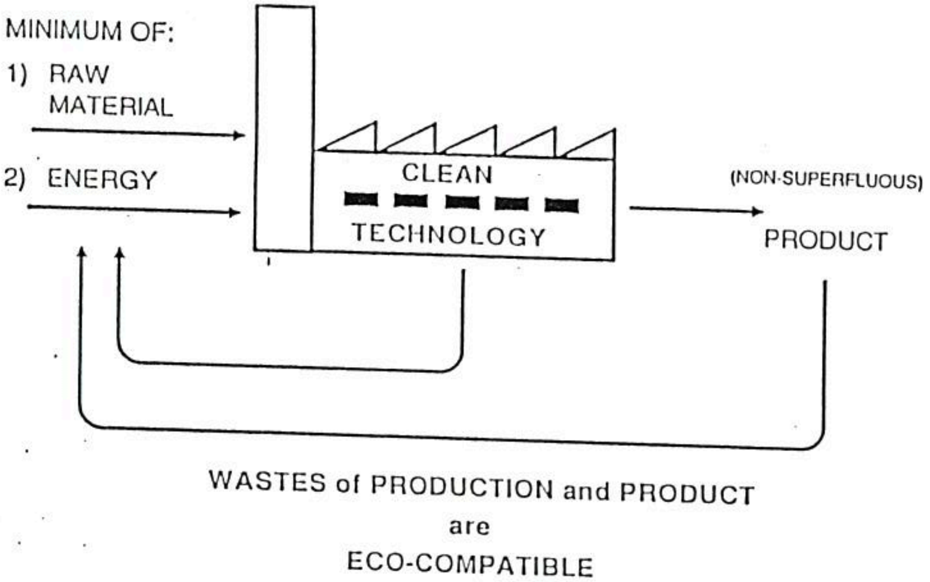
Windham G.C. (1991) Exposure to organic solvents and adverse pregnancy outcome Am. J. Ind. Med. 20: 241-259

Wood, L.B. (1982) The Restoration of the Tidal Thames. Adam Hilger, Bristol 202pp

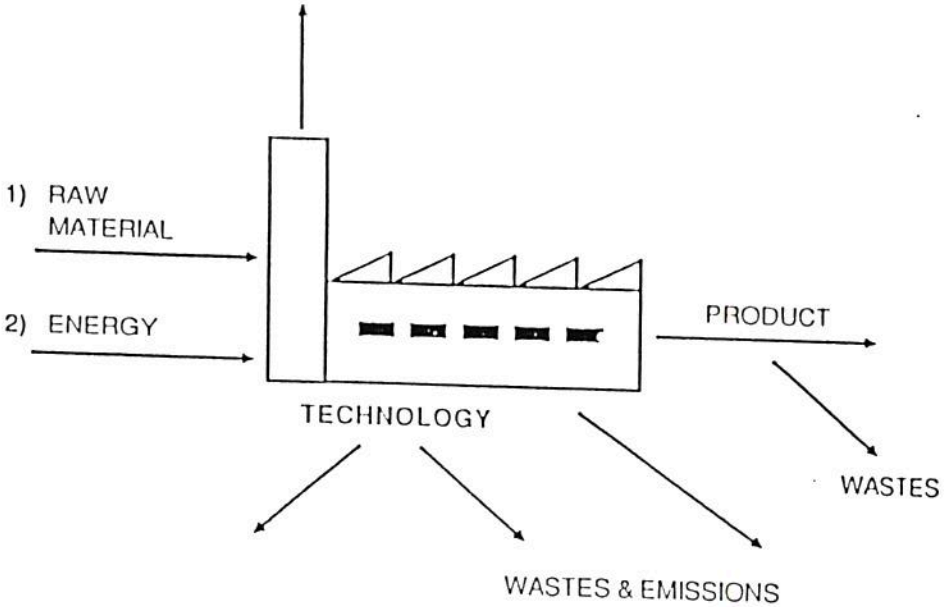
INSERT 4

A PICTORIAL COMPARISON OF NORMAL AND CLEAN PRODUCTION

CLEAN PRODUCTION



CURRENT INDUSTRIAL PRODUCTION



This insert shows schematics for the production under current methods and under a regime of clean production. Current production results in the environmental release of wastes, use of non renewable energy sources. The system is open to the environment and final prioducts ar enot likely to be eco-compatible. This can be compared to the clean production regime which utilises renewable energy sources. There is a minimum input of raw material and energy and all production wastes are eco-compatible and may be recycled into the production process. The product is itself eco-compatible and societally justifiable. It is long lived and at the end of its useful life may be recycled into the production process.

INSERT 2: The Belgian System

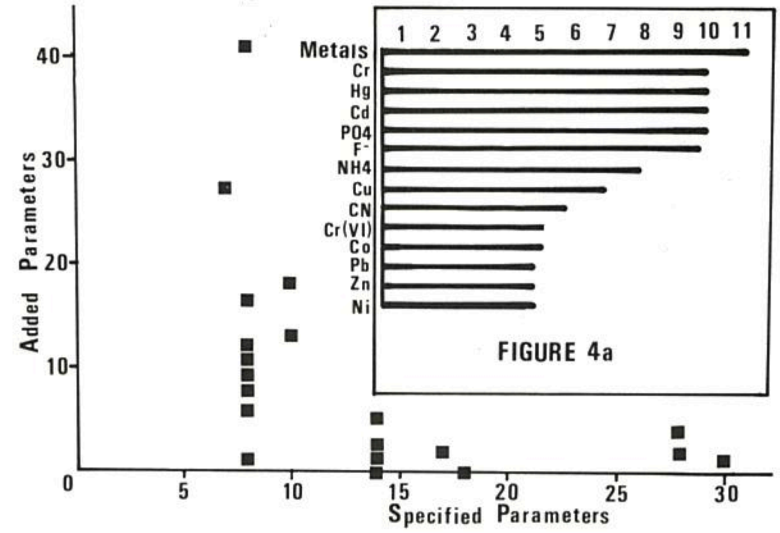


FIGURE 4a

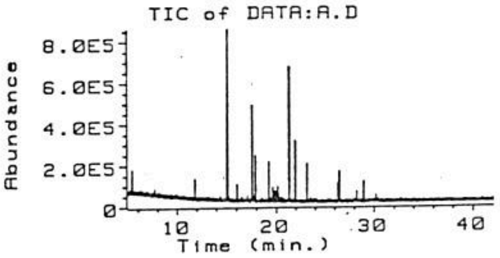
This figure shows a represenatation of data taken from 20 Antwerp Harbour discharge permits. The outer figure shows, on the horizontal axis, the number of controlled determinands specified by the sectoral conditions. The vertical axis shows the number of parameters which have been addede to the national conditions to regulate the factories concerned. The inset figure shows a breakdown of common determinands added to the consents. The horizontal axis shows the number of consents to which particular parameters have been added. Since the permits are generally unavailable for outside scrutiny, on a national basis the declared sectoral norms do not accurately represent the true situation.

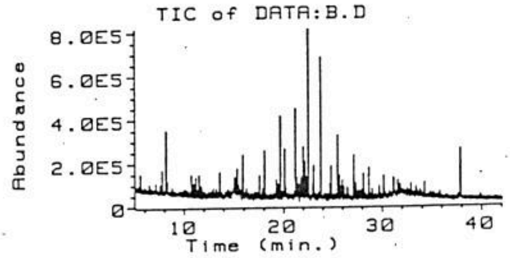
Few compounds are identifiable to a high level of probability and with the more complex traces, each peak may represent more than one compound due to co-elution. Chromatographic complications aside, the standard of spectra held in the computer library and the matching algorithms used can result in both false negative and false positive identifications. Precise characterisation, then, presents a difficult prospect, requiring considerable effort and resources.

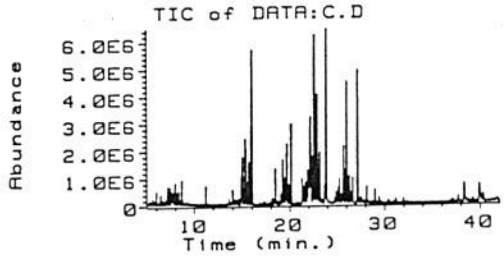
The traces indicate considerable variation according to source. Sample A contained several easily identified polynuclear aromatic hydrocarbons. Sample B, of effluent from methyl methacrylate manufacture, contained many unidentifiable compounds. In the case of sample C, the sewage component was a further cause of chromatographic difficulties. Traces D,E & F suggest that qualitative and quantitative variation with time may be considerable for any one discharge.

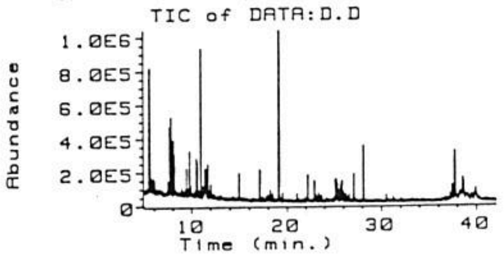
The discharge giving rise to traces D,E & F has been made the subject of a 1991 statutory consent. Only four organic group parameters were controlled through the deemed consent given by the NRA. There is a specified but flexible flow rate of 150,000 cubic metres daily to allow a power station to discharge cooling water to the same drainage system. Of the 11 determinands statutorily consented, only two organic substances, chloroform and phenols are controlled. The process effluent is derived from the manufacture of organic chemicals including nylon, polythene, ethylene dichloride and paraxylene. Recently (Law et al. 1991) a number of the chemicals identified in this discharge have been detected offshore. These workers note that there are insufficient data to assess the environmental hazard.

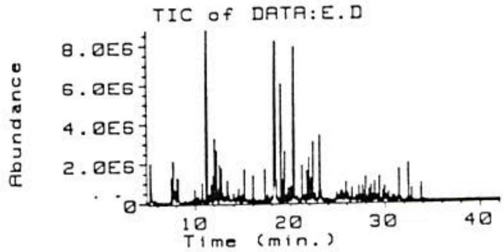
The analytical difficulties underscore the problems of regulating these effluents. If it is not possible to characterise the mixture reliably, then it is not possible to estimate the environmental significance of the discharge. Evaluation of eco-system effect is not possible and it follows that an assessment of notional assimilative capacity of the receiving system for these effluents is not possible either. This is more fully discussed by Johnston & Stringer (1991).

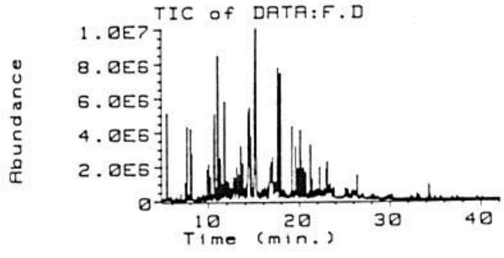












Traces A,B & C are derived from the broad-spectrum analysis using GC-MS on a hexane extract of the effluent. All traces were obtained under identical conditions of extraction and analysis. Sample designations are as given in the Table. A: Steel manufacture. B: Combined sewage/industrial effluent. C: Chemical and agrochemical.

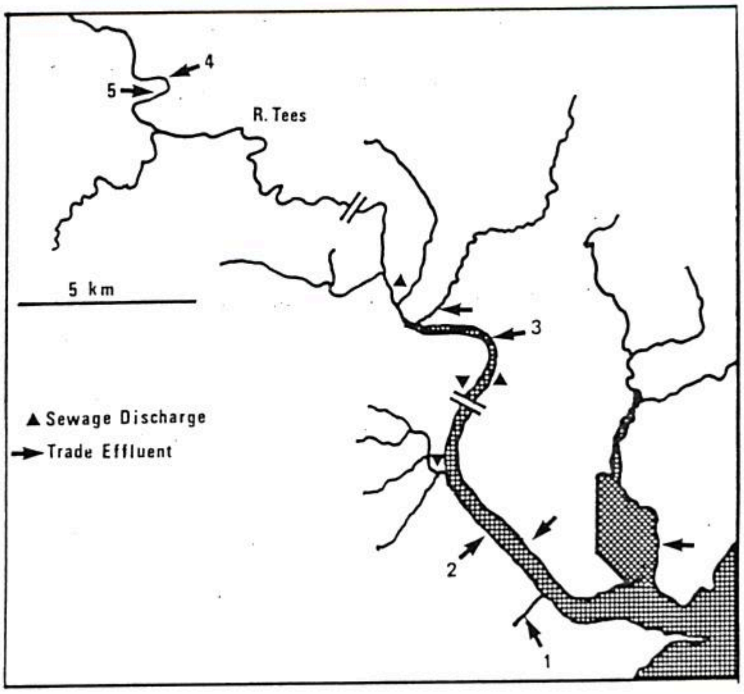
Traces D,E & F are derived from the broad spectrum analysis of effluent samples taken at different times from the same combined chemical complex.

INSERT 1: THE RIVER TEES

The River Tees is heavily industrialised in its lower, tidal reaches, with current EQOs set simply for abatement of visual and smell nuisance by eliminating visible sewage solids and maintenance of 10% oxygen saturation. Around 0.5 million cubic metres of industrial effluents are discharged daily to the Tees Estuary with three sites contributing around three quarters of the total volume. Sewage effluents are discharged after simple screening and/or primary treatment only.

From inspection of the data on the public register relating to the industrial discharges, it is apparent that less than four physico-chemical determinands are routinely controlled per discharge on average. Some twenty determinands are considered overall on the estuary. This results in part from legislative exemption of many discharges until late 1987 when they were "deemed" to be consented in order to bring them within the terms of the law. These deemed consents are eventually due to be fully determined and controlled as part of the Tees improvement scheme. Mercury and cadmium are regulated by EEC Directive.

The smaller discharges are of some importance. Significant chromium input results from a 2000 m^3 discharge at the upstream tidal limit (4) but is due to be eliminated by recycling and recovery. A small factory processing imported sheepskins is consented for organochlorine pesticides leached out by washing (5). The larger discharges however, contribute the greatest quantities of contaminants to the Tees and best illustrate the complexity and changeability of effluents (FIGURES 2 & 3). The figures in the table underline the difficulty of characterisation of effluents on the river analysed under identical conditions and compared using probability based matching of mass spectra with the US National Bureau of Standards Spectral Library.



Map of the River Tees system showing major industrial and sewage discharges. Locations 1-3 are responsible for 75% of the total volume of industrial discharges. 4 & 5 denote locations referred to in the text.

SAMPLE	INDUSTRIAL SECTOR	PEAKS RESOLVED	MATCHED > 90% (%UNMATCHED)	MATCHED > 50% (% UNMATCHED)
A	Steel(2)	9	4 (55.6)	4 (11.2)
B	Mixed sewage/industrial	22	3 (86.4)	13 (27.8)
C	Chemical/Agrochemical (3)	108	8 (92.6)	46 (50.0)
D	Combined chemical (1)	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)

Peaks resolved under identical conditions of sample preparation and machine settings from simple hexane extracts of effluent samples discharged to 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.

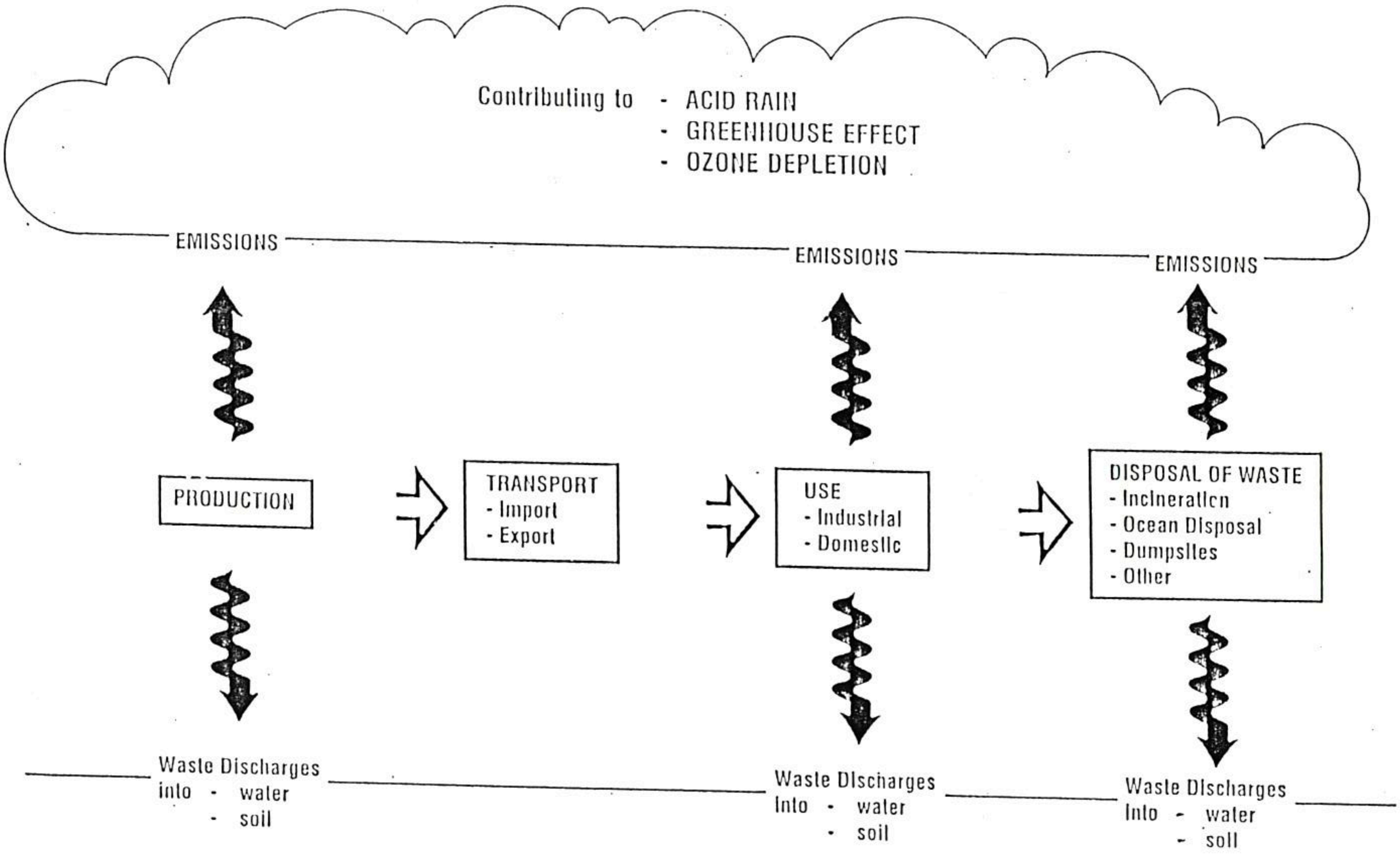


Figure showing the generalised solvent chain, from manufacture through use and disposal. The scope for environmental contamination is indicated at each stage.

INSERT 5: THE SOLVENT CHAIN