Acquisition and use of data for assessment of the environmental impact of colorants

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The Notification of New Substances Regulations 1982 require information about new chemicals to be submitted to the national competent authority prior to placing them on the European Community market. The information must be of sufficient quantity and quality to allow an assessment to be made of the new chemical's impact on the environment. The data given in the notification need to be supplemented with information about the use, release and behaviour of the new chemical. For dyes this was collected during a survey of the industry, to produce estimates of environmental concentrations. These are compared with the concentrations at which adverse effects have been recorded in ecotoxicity tests, to make an initial assessment of the effect of manufacturing and using the new chemical.

INTRODUCTION

The assessment of the environmental impact of a chemical takes account of the hazards it might pose to the environment and to man as a consequence of its release to air, water and soil. The increasing use of chemicals and the damage caused to the environment by some of them has contributed to public concern over their effects. The UK Department of the Environment (DOE) is contributing to international and European programmes assessing the environmental impact of some of the thousands of chemicals currently in use. However, most assessments are carried out on new chemicals notified under the Notification of New Substances Regulations 1982 [1]. These implement the Sixth Amendment of the EC Directive on Classification, Labelling and Packaging of Dangerous Substances [2] and provide a mechanism for the early identification and assessment of potential hazards of new substances. Manufacturers and importers are required to supply basic data about the new chemical to the Health and Safety Executive (HSE) and to the DOE, which jointly have the role of competent authority. Generally a notification made in a member state is assessed on behalf of the European Community as a whole. A summary of the notification data is then made available by that member state to the European Commission and all the other national competent authorities.

The Notification of New Substances Regulations are concerned with the provision of information about chemicals and have no direct role in chemical management as far as the environment is concerned. In the event of a substance having properties dangerous to human health, steps can be taken by HSE under the Health and Safety at Work, etc. Act 1974 to control its manufacture and use. However, if the chemical is unlikely to affect human health but does pose a hazard to the environment, with the permission of the notifier, the DOE advises water and waste disposal authorities. They can control discharges using the powers available to them under the Control of Pollution Act 1974.

To date colorants have formed the bulk of substances notified to be manufactured or imported in Great Britain in quantities of more then 1 tonne per year and so it is understandable that the whole procedure of notification is of interest to the industry. This paper describes the

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environmental assessment of new substances, using dyes as examples. Considerable data are required to make these assessments; some are provided in the notification but these are limited in scope. The Building Research Establishment has carried out a survey of all aspects of the manufacture and use of dyes in the UK [3] for the DOE, which has added to the information available. In this paper examples are given of calculations and assessments which have been made using the data collected in the survey.

ENVIRONMENTAL ASSESSMENT

The assessment of environmental impact of any chemical is not a precise procedure, as it depends on the nature of the chemical. The likely maximum concentration of a substance is estimated for each environmental compartment – soil, water and air – and then compared with those concentrations which it is judged may cause harm. In the UK waste chemicals are commonly released through discharge to rivers, either directly or after biological treatment in a sewage works. As a result it is usually the likely concentration in rivers that is compared with the concentrations of the new chemical that produce adverse effects in aquatic organisms.

The concentration of a new chemical in soil, air or water will not be known; it is also unlikely that many measurements will have been taken for existing chemicals. Consequently, for most environmental assessments, concentrations in the environment are predicted from estimates and calculations. This is now an accepted part of all assessments of environmental impact; the Organisation for Economic Cooperation and Development (OECD) has collected together information on many different methods used throughout the world [4]. The first stage in making a prediction about a chemical is to consider how it will enter the environment both during its manufacture and as a result of its use. Some chemicals, such as those in cleaning materials, are entirely released to waste water in use. Others, such as colorants, are usually permanently fixed to a substrate so that significant quantities may be released only during manufacture and during the colouring processes. When the coloured items are discarded they will usually be part of domestic waste, which is most commonly disposed of by land filling.

With insoluble pigments, waste material is likely to remain in solid form at the manufacturing or processing site and is disposed of with other solid wastes. However, because dyes are both manufactured and used in solution or dispersion, releases through wastage are likely to join the waste water from the production plant or dyehouse.

For all predictions of environmental concentrations it is essential to use realistic values for the quantity of chemical released to each environmental compartment over a finite period of time. For chemicals, such as dyes, that enter waste water, information about the discharge of that waste water is also required. Is it likely to be discharged to rivers? Will it be treated before discharge? Or is it more likely to be discharged to the sewer and treated in a sewage treatment works before discharge to the river?

This information can then be used, together with other basic data about the chemical, to predict its fate. Other factors to be considered are degradation, both during biological treatment and in rivers, the identity of breakdown products and the likelihood of adsorption onto sewage sludges and river sediments. In the prediction method used by the competent authority, the effects of these processes are considered and then dilution equations are used to take account of the diluting effects of all the other effluent in the sewage treatment works, and of the water in the streams and rivers which receive the discharge.

Clearly one estimate of the dye concentration for one river does not give an adequate picture of its use, wastage and environmental fate. The aim is to define the worst case situation, a combination of maximum releases and poor breakdown, adsorption or dilution, which lead to an estimate of the maximum likely concentration of that chemical in rivers.

In making an assessment, this predicted maximum concentration is compared with the concentration at which the chemical has demonstrated adverse effects. This information is generated from the results of the toxicity tests on fish and other aquatic and soil organisms given in the notification and from information about the chemical's likely persistence and potential to accumulate in fish and animal tissues. If there is a factor of at least 100 between the two concentrations, the chemical is judged to be unlikely to cause harm. If the difference between them is less, the competent authority may ask the notifier for more information about the use of the chemical and the quantities that are likely to be released so that the predictions of environmental concentration may be refined. In addition more tests may be required to determine the chemical's toxicity to a wider range of species.

SOURCES OF INFORMATION

A major problem in making an assessment of the environmental impact of a new chemical is obtaining sufficient information about its properties, releases and likely behaviour in the environment to ensure that, right from the start, the predictions about environmental concentrations are realistic. This information comes from a number of sources and, for dyes in particular, is now fairly substantial.

The starting point is the physico-chemical and toxicity data that the manufacturer provides in the notification [1]. The work of the Ecological and Toxicological Association of the Dyestuffs Manufacturing industry (ETAD) has provided large quantities of data on the safety of using dyes and the effects of dyes on the environment. This is very useful; if a new dye has physical and chemical properties similar to those exhibited by the vast majority of existing dyes, then it is likely to behave in a similar fashion when it is both used and discharged to waste.

Because the notification gives little information about the quantities of a new chemical that will be released to the environment, estimates must be made at this first stage in predicting environmental concentrations. In most industries new chemicals are introduced in such a way as to replace existing ones gradually. This is particularly so for colorants, which must be capable of application to substrates using current methods and equipment. It is now generally agreed that information about the patterns of use and release of chemicals from a particular industry provides valuable data that can be incorporated into estimates for new chemicals. In the USA, where there is a longer experience of hazard assessments, the Environmental Protection Agency has reported on worker exposure and releases from dyeing and printing textiles [5]. Prediction of releases of dyes in the UK has been aided by data collected in the survey of the dye industry [3].

The data available in the notification, from ETAD's work and from the industry survey, are described in more detail in the following sections.

Data from the notification

The information about a new substance required to be submitted to the competent authority by the Notification of New Substances Regulations is listed in Table 1. Data about toxicity to man are also required but are not shown here; they are considered by the Health and Safety Executive in its assessment of the safety implications of the production and use of a new chemical.

The ecotoxicological information shown in Table 1 is required for all chemicals that come within the requirements of notification. If more than 10 tonnes per year are likely to be produced or imported, then the competent authority can require further toxicological studies to be carried out; similarly, if it is expected that more than 100 tonnes will be produced or exported, more extensive tests on the chemical's toxic, carcinogenic and teratogenic effects are required. Individual dyes are rarely produced in large quantities and so most require only the results of the 'base set' studies on notification. However, once the total quantity of a substance sold reaches 50 tonnes (with further triggering points of 500 and 5000 tonnes) the competent authority must be informed and can again require further studies to be done. When looking at the test programme at any level, the competent authority takes account of the current information about a substance, its known and planned uses and the results of tests carried out at previous levels. Some of the dyes first notified, when the regulations came into force in 1982, are now reaching the triggering total of 50 tonnes sold and will need to be reviewed.

The measurements of fish and daphnia toxicity are the major indicators of the concentrations of the chemical in water at which adverse effects would be expected to be observed. During the assessment it is these figures that provide the basis for comparison with the predicted environmental concentrations. For dyes, as with other chemicals where toxicity has been extensively investigated and reported, these figures in the notification also indicate whether or not the new chemical is typical of similar types.

The information about degradability is likely to confirm that the new dye's properties are those expected of other dyes. In calculating environmental concentrations, one of the most important considerations is whether the chemical remains intact after release to the environment or whether it is broken down; if it is then the breakdown products are of interest and concern. Most waste water containing released chemicals is subjected to aerobic biological treatment before discharge to a river or when it passes through the local sewage treatment works. Complex organic molecules, e.g. dyes designed to be 'fast' under stringent conditions of use, rarely degrade, either chemically or biologically. It would be expected that a new dye would behave like most other dyes and generally not be aerobically biodegraded in treatment works [6]. However, work by ETAD members Brown and Labourer [7] has indicated that dyes do break down in anaerobic conditions, either during the anaerobic digestion of sludge carried out at many sewage works, or within the sludges and sediments on the river bed.

TABLE 1

Data provided by the notifier

Identity of the substance
Name(s), trade name(s), CAS number if allocated
Empirical and structural formulae
Composition:
- Degree of purity
- Nature of impurities
- Spectral data

Methods of detection and determination

Information on the substance
Proposed uses
- Types of use (function of the substance and its desired effects)
- Field of application with approximate breakdown between (a) industry, (b) farmers and skilled trades, and (c) public at large

Estimated production and/or imports for each of the anticipated uses or fields of application
Overall production and/or imports in order of tonnes per year: 1, 10, 50, 100, 1000, 5000:
- During first 12 months
- Thereafter

Recommended methods and precautions concerning handling, storage, transport, fire and other dangers
Emergency measures

Physico-chemical properties of the substance
Melting point
Boiling point
Relative density
Vapour pressure
Surface tension
Water solubility
Fat solubility
Partition coefficient n-octanol/water (log P_{ow})
Flash point
Flammability
Explosive properties
Anti-flammability
Oxidising properties

Ecotoxicological studies
'Base set' data for all substances produced and/or imported at a level of more than 1 tonne per year:
Acute toxicity to fish:
- LC_{50}
- No effect concentration

Acute toxicity to daphnia:
- LC_{50}
- No effect concentration

Degradation:
- Ready biodegradability
- Abiotic degradation (hydrolysis as a function of pH)
- BOD
- COD
- BOD/COD ratio

It is a major concern of water authorities and those who operate treatment plants that dyes, and other chemicals that are not degraded by aerobic biological treatment, do not have an inhibitory effect on this process. The notification should include the results of a screening test for assessing the possible inhibitory effect of dyes on aerobic waste water bacteria. This test, based on measurement of the respiration rate of activated sludge, was devised by ETAD and has now been adopted as a standard test method by OECD and the European Community. Brown, Hitz and Schäfer [8] have summarised the results for 202 different dyes in seven ETAD laboratories and found that, for all but 18 basic dyes, concentrations of more than 100 mg/l are required to inhibit respiration.

The information in the notification gives other clues to the chemical's behaviour after its release. Complex dye molecules are probably sorbed by organic compounds during sewage treatment, either in the primary settlement stage or when mixed with micro-organisms at biological treatment. To what extent this occurs is difficult to predict. ETAD gives a range of 20–90% adsorption for dyes in sewage works and points out that the actual figure is dependent on the conditions prevailing at the time, especially pH [9]. Research using a simple test method to gauge the tendency of a dye to be removed by adsorption during treatment by the activated sludge process has produced broad generalisations about the behaviour of each major dye class [10]. The notification should include details of the dye's application class as well as its chemical class so that these generalisations can be used. The data given on the dye's solubility and its n-octanol/water partition coefficient also give a rough guide as to how readily it will be adsorbed and be carried into the sewage works' sludges.

Dyes that are not adsorbed are carried out into the river in the sewage works' final effluent. To make assessments, dye concentrations in both the sewage works' effluent and river water are calculated from the predicted behaviour of the released dyes. However, it is likely that ultimately dyes are sorbed by humic acids and other organic materials and are carried into river sediments, where they are degraded anaerobically [9]. Monitoring excercises in the Rhine and other rivers to which dyes have been discharged in large quantities over the years have failed to detect significant concentrations of dyes in sediments [9].

The dye's n-octanol/water partition coefficient (log P_{ow}) and its solubility characteristics are useful indicators of its tendency to accumulate in fish and animal tissues. Anliker [9] has summarised investigations which show, typically, dyes do not bioaccumulate. This is the case even when log P_{ow} values are high, which Anliker suggested is due to the large molecular size of these dyes and their tendency to aggregate.

Data from the survey of industry

The aim of the survey of the dye industry was to collect as much information as possible about both the manufacture and use of dyes in the UK. Reviews and papers about practical aspects of the subject were studied but much of the most useful data were obtained through talking to people within the industry about the activities of their companies. I am grateful to all those who gave their time to help in this way. Much of the information received is confidential and will remain so but it has been very valuable in allowing a realistic overall picture of the industry to be built up.

The review of dye manufacture has resulted in a list of all major sites in the UK where dyes are produced, some indication of the size of typical batches and estimates of the quantities of waste dye released to waste water. There is also information about the treatment process employed before waste water is discharged, usually to sewer but also from some sites to estuaries or surface water.

General information was collected about the use of dyes for a number of substrates: leather and paper as well as textiles. However, it was only for the textile industry that sufficiently detailed data were obtained on the amounts of dye used and discharged to build up a realistic picture of dyehouse practice. The different aspects on which the data were collected were:

- Use of the different application classes of dye for particular fibres
- Average and maximum quantities of fibre or fabric dyed with one colour in both continuous and batch dyeing operations
- Ratios of dye to goods for full range of depths of shade
- Dye lost in spent baths and rinsing water through lack of fixation
- Fate of waste water from dye works.

In making predictions of environmental concentrations, account is taken of both the average situation and the rare combination of events, termed worst case, that represent the maximum impact the chemical may have on the environment. Using the information from the survey, it was possible to produce estimates for the average and maximum amounts of dye released during both batch and continuous dyeing using a number of combinations of dye class and fibre. Some examples of these estimates for batch dyeing are shown in Table 2.

The first step was to use the information on dyehouse practice to estimate the likely weight of goods dyed with one colour in one 24 h period. Assuming that the active substance constitutes 50% of the dyestuff, the weight of dye used was calculated for both medium (average) and dark (maximum) shades. Ranges of loss through lack of fixation to the substrate typical of each dye class were published by the OECD in 1977 [11]. The lower limit of each range was used to calculate the average amount of dye released, α, for each scenario, while the upper limit was utilised for the maximum release. For continuous dyeing, account was also taken of the dye remaining in the machine at the end of the dyeing process.

Brown [12] has indicated that 80% of customers for textile dyes buy 200 kg or less of active substance per year. The estimated amount of dye used in a 24 h period has been divided into 200 kg to give an indication of the number of days in a year when a particular dye might be released.

The survey showed that most UK dyehouses discharge their waste water without pretreatment to the sewer. The dye released into this waste water is carried along with all the other dyehouse effluents to the local sewage treatment works. Any dye not adsorbed by sludge is likely to pass through the works unchanged and be discharged to a river or other surface water in the final effluent from the works. In both the sewage works and the river, the concentration

TABLE 2

Calculated estimates of dye released in batch dyeing (i.e. weight of one dye released in 24 h)

Substrate	Scenario[a]	Wt of goods dyed (kg)	Wt of dye used (kg)	Dye class	Proportion of unfixed dye (%)	Wt of dye released to waste, α (kg)	No. of days each year
Polyester loose stock	Average	800	8	Disperse	8	0.6	25
	Maximum	2500	87.5		20	17.5	2
	Major incident	800	8			8	
Wool yarn	Average	800	8	Levelling acid	7	0.6	25
	Maximum	2500	87.5		20	17.5	2
	Major incident	800	8			8	
Cotton fabric	Average	400	4	Reactive	20	0.8	50
				Direct	5	0.2	50
				Vat	5	0.2	50
				Sulphur	30	1.2	50
	Maximum	3200	112	Reactive	50	56	2
				Direct	20	22.4	2
				Vat	20	22.4	2
				Sulphur	40	44.8	2
	Major incident	400	4			4	

(a) Average release: average weight of goods dyed to a medium shade (i.e. 1% dye:goods ratio), fixation loss at lower limit of range for each dye class
Maximum release: maximum weight of goods dyed in 24 h to a dark shade (i.e. 3.5% dye:goods ratio).fixation loss at upper limit of range for each dye class
Major incident: release of all the dye in an average dyebath

of dye is reduced through the diluting effects of mixing with other effluents and with river water; the extent to which this occurs depends on the capacity of the sewage works and the flow of the river. It is possible to take an average figure for both these volumes to cover UK conditions but this does not provide minimum values for worst case estimates. The sewage treatment works in the UK can vary quite widely in their capacities and the rivers receiving discharges also have a wide range of flow values. Clearly it is important to take account of the situation where dye-containing wastes are treated in low-capacity sewage works that discharge to a river of low volume. The survey included a study of those sewage treatment works in the dye-using areas of England that receive dye wastes from textile dyehouses. Water authority staff provided data that were analysed to produce values to use in calculations. These are shown in Table 3.

For the volume of waste dealt with by the sewage works (V_w) the same figure can be used for both average and worst case values in all three areas quoted in Table 3. There is a considerable difference in the volumes of rivers receiving discharges (V_r) between the Yorkshire and the Lancashire and Cheshire areas on the one hand and the dye-using areas of the East Midlands on the other. If a dye is limited to a particular use, e.g. dyeing wool fleece in Yorkshire, then a representative scenario can be produced that incorporates the figures for V_r for the Yorkshire area. If this is not possible, the lowest figure (for the East Midlands) should be used.

When the volume of the river is significantly larger than the volume discharged from the sewage works, it may not be necessary to include a value for V_w in calculations. When making similar estimates of dye concentrations in rivers, Brown [12] pointed out that his calculations are independent of the size of the sewage works. However, when the volumes of the rivers are relatively low, as they are in the East Midlands, considerable inaccuracy would occur if the volume of the effluent carrying the dye waste were ignored.

The survey also considered the treatment facilities at the works that receive dye-containing wastes. Because the degree of adsorption of a dye by solids may depend on the amount of sludge with which it comes into contact [10], the number of sewage works that incorporate activated sludge plants was recorded. Of the hundred sewage works identified as dealing with dye-containing wastes, only one-third have activated sludge plants: the remainder use biological filters for the biological treatment process.

TABLE 3

Volumes for use in estimating environmental concentrations of dyes

Textile dye-using area	Average[(a)]		Worst case[(b)]	
	V_w (m^3/day)[(c)]	V_r (m^3/day)[(d)]	V_w (m^3/day)[(c)]	V_r (m^3/day)[(d)]
Yorkshire	1×10^4	4.5×10^5	4×10^3	4.4×10^4
Lancashire and Cheshire	1×10^4	1.4×10^5	4×10^3	3.2×10^4
East Midlands	1×10^4	3.0×10^4	4×10^3	4.2×10^3

(a) The median values of V_w and V_r; half the sewage works in each area deal with daily volumes and discharge to rivers with volumes lower than these.
(b) The 25 percentile values of V_w and V_r; 75% of sewage works deal with daily flows and discharge to rivers with volumes higher than these
(c) The volume of sewage dealt with each day by the dye-receiving sewage treatment works
(d) The volume of the river upstream of the discharge point of the dye-receiving sewage works

TABLE 4

Examples of calculated estimates of dye concentration in river water as a result of dye release by the textile industry

Scenario	Wt of dye released α(kg)[(a)]	Adsorption on sludge in sewage works (%)[(b)]	Concn (C_w) of dye in sewage works effluent (μg/l)[(c)]	Concn (C_r) of dye in receiving river (μg/l)[(d)]	No. of days each year
A levelling acid dye used to batch dye wool yarn by a hypothetical company, using Yorkshire dilution values					
– Average	0.6	0	56	1.2	25
	0.6	50	28	0.6	25
– Worst case	17.5	0	4 375	364	2
	17.5	50	2 187	182	2
– Major incident	8	0	800	17.4	
	8	50	400	8.7	
A reactive dye used to batch dye cotton fabric by a hypothetical company, using Lancashire dilution values					
– Average	0.8	0	80	5.3	50
– Worst case	56	0	14 000	1555	2
– Major incident	4	0	400	26	

(a) Average: average release of dye, α, discharged to sewage works and rivers with average values of V_w and V_r
Worst case: maximum release of dye, α, discharged to sewage works and rivers with worst case values for V_w and V_r
Major incident: release of all the dye prepared for an average batch to sewage works and rivers with average values for V_w and V_r
(see also Tables 2 and 3)
(b) Experimental work by Hitz, Huber and Reed [10] suggested that acid dyes show variable adsorption but reactive dyes are poorly adsorbed
(c) $C_w = \alpha/V_w$
(d) $C_r = \alpha/(V_w + V_r)$

The survey has provided sufficient information to produce scenarios representing the use and release of particular classes of dyes, the effect of adsorption of sewage and the diluting effect of total sewage works' effluent and river water. The number of combinations of dye class, fibre type, and dyehouse practice and location is high. The scenarios for two of these are set out in Table 4, together with calculated concentrations of dye in sewage works' effluent and in the receiving river. It is difficult to predict the proportion of the discharged levelling acid dye that may be adsorbed by sludge [10], so concentrations are calculated assuming both no adsorption in the sewage works and 50% adsorption.

A significant proportion of sewage sludge in the UK is disposed of by spreading it on land. The competent authority uses a number of assumptions to estimate the concentration of a new organic chemical in soil. The results of applying these assumptions to the levelling acid dye adsorbed by sludge are shown in Table 5.

TABLE 5

Calculated estimates of dye concentration in soil as a result of dye release from the textile industry

	Concentration of dye in soil (mg/kg)	
Scenario[a]	Arable land	Grazing land
Average[b]	0.3	2.2
Worst case[b]	24.3	162

(a) A levelling acid dye used to batch dye wool yarn by a hypothetical company. 50% adsorption of released dye to sludge

(b) For average and worst case situations, the capacities of sewage works (V_s) are those given in Table 3 and the quantities of dye released to waste (α) are those given in Table 4, otherwise the assumptions are the same as are made by the competent authority: sludge is spread on land at 1 kg/m², ploughed to a depth of 20 cm for arable land and spread to a depth of 3 cm on grazing land

USE OF CALCULATED CONCENTRATIONS FOR ASSESSMENTS

Using general data on the toxicity and adverse effects of dyes from the literature, it is possible to draw some conclusions from these figures similar to those made during environmental assessments.

Brown, Hitz and Schäfer [8] showed that most dyes must be at a concentration above 100 mg/l to have an inhibitory effect on the biological activity of a sewage works. It is only estimates of releases under worst case conditions that result in concentrations which would cause concern if the safety factor of 100 were strictly applied.

Anliker has [9] reported work by ETAD members on the toxicity of dye products to fish, which showed that only 2% of 3000 colorants available commercially have LC_{50} values less than 1000 µg/l. Brown [12] stated that, while dye concentrations of 1000 µg/l may colour clear water, a concentration of 100 µg/l will probably have no visible effect. So the concentration of 1000 µg/l has some significance for the effects of dyes on rivers. Again, it is the release of maximum likely quantities of a dye to a small capacity sewage works discharging to a low volume river that results in estimated concentrations close to this value. Unlikely and infrequent though this combination of events may be, the possibility of its occurring must be considered by the competent authority in relation to the full toxicity data for a dye.

Another ETAD study [12] investigated the effects of three dyes in soil on the germination and growth of sorghum, sunflower and soya. Some effects on growth were observed at soil concentrations of 1000 mg/kg, though none were observed at 100 mg/kg and below. The estimates made here suggest that, when maximum quantities of dye are released, soil concentrations could be more than 100 mg/kg.

CONCLUSIONS

When the competent authority receives a notification of a new dye it now has a considerable quantity of information available to aid the assessment of the dye's environmental impact. In addition to the data supplied in the notification and summaries of published studies on the ecotoxicological effects of dyes, the survey [3] of the manufacture and use of dyes in the textile industry provides estimates of the quantities of particular dyes released to waste water and of their concentrations in sewage works' effluent and river water. It is true that some of the data to make such predictions could be provided by the notifier, but its ready availability to the competent authority should prevent unnecessary queries.

The information in the survey describes dyeing techniques in use now. If a dye that is notified is to be used on a new substrate or applied by a significantly different method from those included in the survey, it will be necessary to obtain data about its release pattern.

There are areas in which shortage of data has made predictions difficult. For example, more complete information about the amounts of dyes used and released in continuous dyeing would be useful. Prediction of the adsorption of dyes to sludge relies on one laboratory study that mimicked the conditions in a sewage works. These predictions have been used to estimate the concentrations of dyes which could arise in soil after dye-containing sludges have been spread on the land. In view of the closeness of some of the calculated concentrations to those shown to effect the growth of plants, more studies on all aspects of dye adsorption on sludge and its eventual disposal will aid assessments of environmental impact.

In his paper on the effects of colorants Brown [12] gave an example of a dilution calculation for a dye released into river water, similar to those described here. A combination of average values produced a concentration of 1 µg/l for a single dye in a typical river. This is useful to illustrate how calculations may be carried out but it is important that an estimated value like this does not become a standard. The strength of the scenario approach adopted in this study is that a number of different situations are considered and a range of values produced. Clearly there are occasions when dye concentrations in rivers are higher than 1 µg/l; this study has gone some way to identifying them.

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