

Textile works and dye works

Industry Profiles, together with the Contaminated Land Research Report series, are financed under the Department of the Environment's contaminated land research programme.

The purpose of these publications is to provide regulators, developers and other interested parties with authoritative and researched advice on how best to identify, assess and tackle the problems associated with land contamination. The publications cannot address the specific circumstances of each site, since every site is unique. Anyone using the information in a publication must, therefore, make appropriate and specific assessments of any particular site or group of sites. Neither the Department or the contractor it employs can accept liabilities resulting from the use or interpretation of the contents of the publications.

The Department's Contaminated Land Research Report series deals with information needed to assess risks; procedures for categorising and assessing risks; and evaluation and selection of remedial measures.

General guidance on assessing contaminated land and developing remedial solutions which is complementary to the Department's publications is provided by the Construction Industry Research and Information Association (CIRIA).

Acknowledgements

The Department of the Environment is grateful to the members of the Interdepartmental Committee on the Redevelopment of Contaminated Land (ICRCL), and the following individuals and organisations for assistance in the compilation of this profile:

Arup Environmental (Ove Arup and Partners)
Mr R Burrows (Belmont Bleach and Dyeing Company Limited)
Dr P Cooper (Courtaulds Textiles, British Apparel and Textile
Confederation Environmental Group)
Dr M Hewson (British Textile Technology Group)
Mr C Smith (Textile Finishers Association)
Mr H Wilson (British Carpet Manufacturers Association)

DOE Industry Profile

Textile works and dye works

	Page
Preface	(iii)
1. Background	1
1.1 History of textile manufacture	1
1.2 History of dyeing	1
1.3 Location	2
2. Textile manufacturing processes	3
2.1 Raw materials and delivery	3
2.2 Production of yarn and fabric	3
2.3 Treatments to fibres, yarns and fabric	4
3. Dyeing processes	8
3.1 Dye manufacture	8
3.2 Dyeing and printing	9
4. Wastes management	10
5. Ancillary activities	11
6. Contamination	11
6.1 Factors affecting contamination	11
6.2 Migration and persistence of contaminants	12
7. Sources of further information	13
Annex Potential contaminants	17
Table 1 Main groups of contaminants and their probable locations	20

This profile is based on work carried out by Ironside Farrar Limited, following earlier work by Dames and Moore International, and was prepared for publication by the Building Research Establishment.

Preface

DOE Industry Profiles provide developers, local authorities and anyone else interested in contaminated land, with information on the processes, materials and wastes associated with individual industries. They are not definitive studies but they introduce some of the technical considerations that need to be borne in mind at the start of an investigation for possible contamination.

Every site is unique. Investigation of a site should begin with documentary research to establish past uses. Information on the site's history helps to focus a more detailed investigation. This knowledge needs to be supplemented by information on the type of contamination that may be present and where on site it may be found. Profiles give information on the contamination which might be associated with specific industries, factors that affect the likely presence of contamination, the effect of mobility of contaminants and guidance on potential contaminants.

The date when industrial practices first commenced on a site and its location are important clues in establishing the types of operations that may have taken place, so each profile provides a summary of the history of the industry and its likely geographical spread within the United Kingdom.

Profiles should be read with the following reservations in mind:

- individual sites will not necessarily have all of the characteristics described in the profile of that industry;

- practices can vary between sites and change over time;

- as practices change, problems of possible contamination may also change;

- the profile may refer to practices which are no longer followed, and may omit current practices which avoid contamination.

The risks presented by contaminated sites depend on the nature of the contaminants, the targets to which they are a potential threat (such as humans or groundwater) and the routes or pathways by which they reach these targets. The current or proposed use of a site and its environmental setting are crucial in deciding whether treatment is necessary and if so, the methods to be used. Some sites may not need treatment.

The information in profiles may help in carrying out Control of Substances Hazardous to Health (COSHH) assessments for work on contaminated land - see Health and Safety Guidance Note HS(G) 66 *Protection of workers and the general public during the development of contaminated land*, Health and Safety Executive, 1991, and *A guide to safe working practices for contaminated sites*, Construction Industry Research and Information Association, 1995.

Note: the chemical names given to substances in this profile are often not the modern chemical nomenclature, but the names used historically for those substances.

Textile works and dye works

1. Background

The textile industry involves the spinning of a wide range of natural and synthetic fibres into yarn and the production of fabric from yarn. Spun yarns and fabrics may receive various treatments to improve their appearance, feel and performance and may be dyed or printed.

This profile describes the processes involved in the production of yarn and fabrics. The manufacture and application of dyes in the textile industry are also described.

The profile does not deal with the manufacture of synthetic fibres themselves. This is covered by the profile on organic chemicals manufacturing works (see Section 7).

1.1 History of textile manufacture

Textile production moved from a cottage industry to factory production with the Industrial Revolution. Inventions in the cotton industry from the middle of the 18th Century were later adapted for use in the woollen industry: John Kay's flying shuttle increased weaving speed, while mechanical spinners invented by Sir Richard Arkwright and Samuel Crompton led to the development of spinning machines.

The first power looms were installed in works at the beginning of the 19th Century. The initial power source of water was replaced by steam. Further improvements were made during the 19th Century and the volume and speed of production increased. By the 20th Century, fully automated systems were in operation.

Synthetic fibres provided new materials for the industry. Originally the synthetic fibre industry applied the knowledge gained from working with natural fibres but research has led to this part of the industry introducing new processes.

Over capacity and foreign competition have troubled the textile industry in the 20th Century. Many large works have closed. Census of Production data show that in 1924 there were almost 8000 works employing more than 10 people and just over 2000 employing 10 or fewer. In 1993 there were just under 5000 works of all sizes. The number of employees declined from almost 1.3 million in 1924 to 205 000 in 1994.

1.2 History of dyeing

Until the 19th Century, the colours used for dyes came from natural sources such as animals, plants, shellfish and minerals. Typical examples were cochineal, logwood, murex, purpura, indigo and madder. Earliest methods of dyeing involved mixing the colouring agent with water to make a dye bath, immersing the yarn or fabric and fixing the colour in the textile.

Early dyers found that if cotton or wool was treated before dyeing, the colour would more permanently fix to the textile. Different mordants (pre-treatments materials) used with the same dye produced different colours.

Synthetic dye manufacturing grew after William Henry Perkin discovered in 1856 that a purple dye could be obtained from reacting aniline (a chemical obtained from coal tar benzol) with potassium dichromate and extracting the dye with alcohol. Dyestuffs research concentrated on discovering new colourants which could be synthesised from coal tar hydrocarbons, studying the structure of synthetic dyes to improve their properties and finding synthetic routes for the bulk manufacture of natural dyes, particularly indigo.

Today, more than 7000 synthetic organic dyes are in commercial use. Few natural dyes are used commercially, but interest in these is increasing because of their reduced impact on the environment.

1.3 Location

Woollens

Some 95% of raw wool scouring in the United Kingdom is carried out in the Aire and Calder valleys of West Yorkshire. The mechanical processing of wool is more widely diffused, but there are heavy concentrations in the North West, West Yorkshire and the East Midlands. The Scottish Borders is also an important woollen manufacturing area.

Carpets

20% of carpets today are manufactured from wool. The main centres of manufacture are Yorkshire, Kidderminster, Lancashire, Scotland and Northern Ireland. Synthetic carpet manufacture is associated with areas of synthetic fibre manufacture.

Cotton

About 90% of cotton scourers and 70% of the mechanical processors in the United Kingdom are located in Manchester and Lancashire. The East Midlands is also important for cotton production.

Silk

Very little silk is produced or spun in the United Kingdom today. In the past it was located in places to which foreign silk workers fled to escape religious persecution, for example, Spitalfields in London, Macclesfield and several towns in East Anglia.

Synthetic fibres

The operations carried out on synthetic fibres to a certain extent mirror those carried out on cotton and for this reason cotton processors and finishers often treat synthetics as well. Thus 50% of the industry is still based in the North of England.

Other textiles

This category includes lace, rope, twine, net, elastomerics and felt and is geographically widespread across the country. Lace making developed in Nottingham and jute (sacking) weaving in Dundee. The weaving of asbestos fibres has taken place widely in the past.

Dyeing

As dyes are widely used in making textiles and carpets, dye manufacturing has tended to develop close to the textile industry. Dyes are also used in other materials including plastics, paper, leather, varnishes, lacquers and cosmetics.

2. Textile manufacturing processes

2.1 Raw materials and delivery

The raw materials delivered to textile works include natural and synthetic fibres. The origin of the various fibres are:

Natural fibres	Cotton	The white downy fibres clothing the seeds of the cotton plant.
	Jute	Fibre obtained from the bark of plants from India and Pakistan. Traditionally used in the production of sacking, mats and carpet backing.
	Flax	Blue flowering plant, the stems of which provide the fibres used to make linen.
	Wool	A fine, soft, wavy fibre with a scaly surface forming the fleece of sheep and goats.
	Silk	A strong lustrous fibre produced by the silkworm.
Semi-synthetic	Rayon	A semi-synthetic polymer made from cellulose, the main constituent of plant cell walls.
Synthetic fibres	Derivatives of oil	For example nylon (polyamide), polyester, polyacrylonitrile, polypropylene and polyvinyl derivatives.

Chemicals used in textile manufacture range from soaps and detergents to sizing agents and chemicals used to impart different properties such as water repellency, flame retardancy, crease resistance and easy care finishes. Examples are given in Sections 2.2 and 2.3. The delivery methods for chemicals vary considerably but include bulk tankers, 25-200 litre drums and kegs for liquids, and a wide range of bagged/palletised systems for granules and powders.

In the past, containment methods in case of spills were likely to have been rudimentary, with drums and other containers set on pallets without secondary bunding. Today, large bulk storage tanks are generally provided with bunding but smaller amounts of chemicals may still be stored in unprotected areas.

The transfer of chemical substances and raw materials within the plant is generally by fork-lift in the case of containerised liquids or palletised loads or by pipelines in the case of bulk storage liquids.

2.2 Production of yarn and fabric

Picking, carding and combing of fibres are carried out to remove vegetable or other impure matter before the fibres are spun into yarn.

Carding and spinning

Carding is the tearing of fibres using a series of machines with fine-pointed wire belts wound around large drums. The loose rope produced by carding is known as card sliver. Spinning is the drawing and twisting of card sliver to make yarn. After spinning, the yarn may be sent for dyeing before it is used to weave or knit a fabric.

Weaving

Weaving uses traditional flying shuttle looms to form the fabric from the yarn, but they may have special features like water jet systems or air pulsing to increase the output of woven fabric.

Knitting

Knitted fabrics are made by the intermeshing of one or more yarns to form loops and in order to form the loops the yarn must be bent in a number of directions. Knitting may be used to form garment sized pieces or whole garments. Residual oils present in wool fibres or fabrics and sizing agents (usually applied to cotton yarns) improve workability during knitting or weaving.

Other interlaced techniques for fabric production include net and lacemaking, braiding and pleating.

Carpets

Carpets consist of:

- a backing layer (woven jute or woven or non woven thermoplastic fabric)
- a stabilising adhesive (styrene-butadiene with a carbonate filler or polyvinyl chloride (PVC) or polyurethane)
- a stabilising layer (linen or jute end, cotton or thermoplastic)
- the pile (wool, wool blend or synthetic - 80% of carpets are manufactured from synthetics).

Different carpet types are defined according to the way the yarn is inserted and fastened to the backing, for example woven (Axminster and Wilton), tufted, needle-punched or fibre-bonded and flocked. After weaving, the carpet is machine brushed to remove loose fibre and yarn. Faults are repaired and missing pile is stitched in using a portable needle gun. The pile is then sheared to a uniform level and may be steamed to raise it and create a more aesthetic appearance.

2.3 Treatments to fibres, yarns and fabric

Mechanical and chemical processes may be applied to improve the workability or finish of fibres, yarn and fabric.

Treatments which involve some kind of chemical addition usually involve bath immersion or roller coating (padding). Many of the chemicals used are potential contaminants.

Anti-bacterial and anti-fungal finishes

Fabrics may be treated with compounds to prevent fungal or mould growth (for examples, see Annex).

Anti-static finishes

Clinging of synthetic fibres may be reduced by the application of anti-static agents during processing.

Beetling

A process in which linen, and cotton fabrics made to resemble linen, are crushed in a 'beetle' machine to produce a firm, flat, high lustre surface.

Bleaching

This is accomplished by oxidation or reduction. Cotton and other cellulosic fibres are treated with alkaline hydrogen peroxide. Sodium hypochlorite was used in the past but is now generally only used to bleach linen. Wool and other animal fibres are subjected to acidic reducing agents. Gaseous sulphur dioxide was used until the 1970s but treatment with mild hydrogen peroxide or sodium hypochlorite is used today. Synthetic fibres can be treated by either oxidation or reduction, depending upon their chemical composition. The treatment can be undertaken by immersion under pressure and high temperature, followed by rinsing and drying.

Burling and mending

Burling, removing foreign matter, loose threads, knots and slubs, mainly applies to woollen, worsted, spun rayon and cotton fabrics. Mending is the repairing of defects.

Calendering

A final process where heat and pressure are applied, imparting a flat, glossy, smooth surface. It is applied to linens, silks and man-made fabrics.

Carbonising

Unwanted animal matter mixed with animal fibres is eliminated by applying sulphuric acid (wet process) or gaseous hydrochloric acid (dry process) followed by heating.

Crabbing and heat setting

Crabbing is a process where heat is applied to set and dry the warp and weft of woven wools and worsteds. When it is applied to synthetic material it is known as heat setting.

Crepe

For a non-permanent crepe finish, the cloth is passed through embossed rollers. For permanent crepe, sodium hydroxide paste is rolled into the fabric in a patterned form or a resin paste is applied and the whole fabric is dipped in sodium hydroxide. The treated areas shrink, producing the characteristic punctured effect.

Decatizing

This is a method of improving the finish of fabrics and involves the application of steam and pressure. It is applied to woollens, particularly worsted, synthetic and blended fibre fabrics and various knits.

Drying

Excess water is removed mechanically by centrifuge squeezing and vacuum suction rolls. Remaining moisture is removed by passing the fabric or yarn through heated dryers under controlled temperature, humidity, drying time and dimensional stability.

Durable press

This confers shape retention, permanent pleating/creasing, smooth seams and the ability to shed wrinkles. Chemicals used to achieve durable press include urea formaldehyde, dimethyl-dihydroxy ethylene urea, carbamates, dimethyl-dipropylene urea and melamine formaldehyde.

Flameproof, fireproof and fire resistant finishes

Chemicals used include borax, borax acids, ammonium phosphate, tetrakis (hydroxymethyl) phosphonium chloride (THPC), zinc compounds (on wool), oils, waxes and resins incorporating organobromide compounds or based on phosphorus, antimony and titanium compounds. In the past, chlorinated and phosphorus compounds were used.

Fulling (felting or milling)

A process that increases the thickness and compactness of wool by subjecting it to moisture, heat, friction and pressure. Acid or soap is used.

Mercerisation

This process is applied to cotton and cotton blends to increase lustre and to improve strength and affinity for dyes. The treatment produces a swelling of the fibre. It can be applied at yarn or fabric stage and involves immersion of the material under tension in a sodium hydroxide solution followed by cold water spraying and then neutralisation with acid or by liquid ammonia treatment.

Moireing, embossing, glazing and polishing

These are all variations of the calendering process. Glazing achieves a smooth stiff, polished surface by applying starch, glue, shellac or resin and then passing the fabric through hot rollers.

Moth repellents

Moth attack of wool and silk can be prevented by the application of certain pesticides (for examples, see Annex). Moth resistant treatments are applied to carpets.

Napping, shearing and brushing

Napping is applied to woollens to raise a velvety soft surface. Shearing cuts the raised naps to a uniform height and it may be applied to create stripes. Brushing removes loose threads and short fibre ends.

Optical brighteners

Bleaching with optical brighteners, which contain fluorescent colourless dyes, gives the effect of great whiteness.

Scouring (washing)

Scouring removes, for example, grease, chemicals, dirt, suint (dried perspiration) from fleece, fibre, yarn or fabric. Aqueous scouring uses soaps and detergents while solvent scouring usually employs compounds such as tetrachloroethene, perchloroethylene (PCE), 1,1,1 - trichloroethane and trichlorethene. Surfactants are also used to assist cleaning. The fabrics are then washed in hot water to remove the scouring solutions. Effluents from washing are likely to contain sodium hydroxide or organic solvents. In the past, imported fibre, yarn or fabric may have been treated with pentachlorophenol, to prevent mildew forming in transit, and this chemical may have been present in the effluent from works using imported

materials. Today, safer rot-proofing materials are used. In the past, fleeces may have been contaminated with anthrax spores and sheep dip residues.

Singeing (gassing)

Singeing of yarns and fabrics produces an even surface by burning off projecting fibres, ends and fuzz. It is usually followed by wetting the material to stop smouldering.

Sizing and desizing

Sizing chemicals are applied to warp yarns (especially cottons) to enable them to withstand the stresses of weaving. Sizing chemicals include polyvinyl acetate (PVA), polyacrylic acid and carboxymethyl cellulose. These chemicals are removed by desizing, often achieved by applying solutions of enzymes such as malt diastase.

Softening

This involves the addition of agents such as glycerin, sulphonated oils, sulphonated tallow and sulphonated alcohol.

Soil release

Soil release treatments are used to remove stains from fabrics such as polyester and cotton blends and fabrics prior to durable pressing. Compounds used include organofluoro compounds, oxazoline derivatives or carboxymethyl cellulose.

Stabilising (shrinkage control)

Shrinkage of cotton and cotton blends is achieved by dampening the fabric and then drying it in a slack state to eliminate tensions and distortions. Rayon and rayon blends may be stabilised by the use of resins (for example organic chloride compounds or melamine formaldehyde) which impregnate the fibre or by adding acetyls to produce a chemical reaction. Polyesters and nylons are permanently stabilised by heat setting during finishing. Shrinkage of wools is controlled by treatment with chlorine or (less often) by coating with resins or enzymes.

Stentering

This is the process of drying or curing fabrics in an oven.

Water proofing and water repellence

Water proofing is achieved by the application of insoluble metallic compounds, paraffin waxes, bituminous materials and drying oils. Water repellent finishes are achieved by the application of wax and resin mixtures, aluminium salts, zirconium salts, organic silicones and organofluoro compounds.

Weighting

Weighting of silk involves the application of metallic salts to add body and weight. It is not permanent but can be repeated. Such salts can be iron (III) oxide, tin (IV) oxide and manganese (IV) dioxide.

3. Dyeing processes

3.1 Dye manufacture

Dyes are colourants soluble in a carrier, most commonly water or an organic solvent. Dyes are classified in two ways in the Colour Index (see Section 7): according to their chemical structure and method of application. Classification of dyes according to method of application is shown below, together with the types of textile fibre that can be commercially dyed by each method:

Basic	cationic dyes	wool, wool blends, silks, acrylic
Acid	anionic dyes	wool, silk and nylon
Direct	anionic dyes	cotton, linen, viscose
Chrome	anionic dyes that must be applied with sodium dichromate	wool
Azoic	insoluble pigments formed within the fibre initially by a soluble coupling compound and then a diazotized base	cotton, linen
Vat and sulphur	insoluble in water and converted into soluble colourless compounds by use of sodium hydrosulphite. Once they are absorbed they are oxidised to an insoluble coloured pigment	cotton, viscose, linen, silk
Disperse	non ionic dyes	polyester, triacetate, secondary acetate, nylon
Metal complex	anionic dye containing chromium	wool, nylon
Pigment	applied to the fabric surface with a resin bonding system	all types
Reactive	anionic dyes that combine covalently with the fibre	cotton, linen, viscose

Pigments may be produced for use in other industries, for example for paints, inks, lacquers, cosmetics, waxes. Dyes may be manufactured for use in other industries, for example for wood stains, varnishes, lacquers, inks, polishes, plastics. See Section 7 for relevant Industry Profiles.

Dyes are manufactured from a number of intermediate compounds which are themselves made from feedstocks obtained from elsewhere, for example benzene, toluene, aniline and naphthalene. Until the 1950s-1960s, intermediates were

obtained from the by-products of gas works, mainly coal tar and ammoniacal liquors, and dye works were often found adjacent to gas works.

After town gas production ceased, source compounds were, and continue to be, derived from crude oil refining (see Section 7). The intermediates are formed by processes such as sulphonation, nitration, halogenation, oxidation or Friedel-Crafts alkylation. These intermediates are combined to form the dye by processes such as condensation, coupling and diazotisation.

All types of dye may be used anywhere in the United Kingdom. Because the process technologies vary with the major categories of dye, manufacturers tend to specialise, producing a range of dyes based on one chemical group, for example the azo group of chemicals.

Most but not all colours are dried for sale. They may also be ground and mixed with additives and diluents in blending plants. Solids are packed in metal or plastic drums and 'big bags' (taking about 1 tonne of material). Liquids are packed in drums, intermediate bulk containers or road tanker for delivery.

3.2 Dyeing and printing

Fibre, yarn or fabric can be dyed in batches or in a continuous operation, depending on the type and quantity of goods required.

In batch dyeing, the items to be dyed are placed in a bath and the dye added in solution or suspension. There are many different machines for batch dyeing, all ensuring maximum contact between the dye and the goods, and having careful temperature control. Dye fixation is achieved either during dyeing or in a subsequent process such as steaming or baking. After dyeing, the spent liquor is drained off, there may be a further process or after treatment, and the goods are washed to remove any dye which has not 'fixed'.

For continuous dyeing, a long rope of fibres, yarn or fabric is pulled through each stage of the dyeing process. Fabric is also processed in open width. The tanks of dye are equipped with rollers which squeeze the material to control the amount of dye left in.

Another method of colouring textiles is by printing, ie applying patterns to the surface of fabric or carpets. There are five methods:

Hand block printing

A template made from wood, perhaps with copper inserts, designed with the required pattern. Colour is applied to the block and the pattern is stamped on the fabric or carpet. A separate block is required for each colour to be printed.

Engraved roller printing

This is used when a long run of the same pattern is to be applied to the fabric or carpet. Rollers which pick up the dye are engraved with the pattern and the fabric is passed under them. A separate roller is required for each colour.

Flat screen printing

Colour is applied to the fabric or carpet through a silk or, more commonly, polyester screen.

Roller screen printing

This is the application of colour through a cylindrical screen made of nickel. In both screen techniques, a separate screen is required for each colour.

Transfer printing

Paper is printed with the required pattern of volatile disperse dyes and the pattern is transferred to the fabric by passing both the paper and the fabric over a hot calendar.

Except for transfer printing, the dye is applied to the fabric in paste form, the necessary viscosity being controlled by the use of thickening agents which prevent dye migrating over the surface of the fabric or carpet. Examples are reagents such as starch, gum tragacanth, alginates, methyl cellulose, ethers and sodium carboxymethyl cellulose.

Most printing patterns are fixed by steaming. The fabric is then washed to remove loose dye and paste residue. Wool fabric may be chlorinated prior to printing. Cotton fabrics are bleached prior to printing and some are also mercerised.

4. Wastes management

The bulk of wastes from textiles and dyemaking are liquid effluents. Desizing removes the sizing agents and the resultant effluent may be at a high temperature and contain organic matter. Scouring can produce a near boiling alkaline brown coloured liquid which may contain pesticide. Bleaching produces effluent wastes which contain bleaching agents, ie sodium hypochlorite (less frequently used today) and hydrogen peroxide. Mercerising produces a cold/warm alkaline waste liquid. Dyeing and printing processes can result in an effluent containing typically 5% to 20% of the dye. Companies have recognised their responsibilities for the environment. Environmental option schemes are being organised by the Department of Trade and Industry and by national organisations such as the Textile Finishers Association and the British Textile Technology Group.

By far the most common route for the disposal of liquid effluents, both today and in the past, is discharge to a foul sewer directly or via a series of settling tanks. The effluent is treated by the local water company which charges the operator for the service. In the past effluents may have been discharged to local streams or rivers especially if there was no sewer available.

Segregation of discharges from individual unit process operations is uncommon. Thus large volumes of aqueous waste are discharged to sewer, generally with elevated biological oxygen demand (BOD), chemical oxygen demand (COD) and surfactant concentrations (as a result of the washing processes). This is particularly the case where facilities are involved in processing natural fibres.

About two thirds of companies undertake some primary treatment of their effluent, most commonly by pH control and heat exchange to reduce temperature of discharge. A few use secondary treatment such as the activated sludge process, chemical flocculation or flotation. Tertiary effluent treatment methods, for example ion exchange, reverse osmosis, activated carbon or chemical oxidation, are uncommon.

About two thirds of carpet manufacturers discharge to sewers. The remainder discharge to the sea or watercourse, use liquid waste contractors or use processes which do not produce liquid effluent.

5. Ancillary activities

A number of supporting activities are necessary for the running of the plant and production processes. The textile industry tended to make use of steam power which until the middle of the 20th Century was raised by coal fired boilers. This resulted in the generation of large quantities of boiler ash (containing heavy metals and sulphates) which will have required disposal. Depending on the location of the works, water for steam raising may have been stored in a reservoir or lodge adjacent to the works. More recent works may use gas or oil for fuel and may therefore have fuel storage tanks.

It is possible that plant buildings and infrastructure have been insulated with asbestos lagging. Asbestos cement sheeting may have been used in roofing or cladding.

Sites with their own electricity generators may have used polychlorinated biphenyls (PCBs) as dielectric fluids in transformers or capacitors.

6. Contamination

The contaminants on a site will largely depend on the history of the site and on the range of materials produced. Potential contaminants are listed in the Annex and the probable locations on site of the main groups of contaminants are shown in Table 1. It is most unlikely that any one site will contain all of the contaminants listed. It is recommended that an appropriate site investigation be carried out to determine the exact nature of the contamination associated with individual sites.

6.1 Factors affecting contamination

Ground contamination may result from the accidental spillage of chemicals in storage areas or during the various stages of manufacturing yarn, making dyes and dyeing textiles.

Off-loading areas, storage tanks and drum storage areas, pipework and surface water soakaways should all be considered likely areas of contamination. Older or upgraded works may have redundant underground tanks or pipelines containing chemical residues or wastes.

Effluents from washing fibres, yarn or fabric are normally discharged to the foul sewer but may be lost to the surrounding ground if the sewer leaks. There is the possibility that effluent may have contained pesticides such as lindane (g-hexachlorocyclohexane) and pentachlorophenol (PCP), particularly where imported fibres or fabrics have been used.

Finished or partly finished fabrics are a possible fire risk and, if there has been a fire, firefighting water may have spread contaminants over a wide area.

Many industries, including the textile industry, have in the past used solid waste to make up ground levels on site. Solid wastes may have been disposed of in on-site landfills.

Where asbestos has been used in buildings or pipework, decommissioning or demolition may result in local contamination. Asbestos pipework and boiler ash (containing heavy metals and sulphates) may have been disposed of in on-site landfills. Any organic infill has the potential to generate landfill gases, principally methane and carbon dioxide.

Contamination may also occur from PCBs where transformers or capacitors containing these have been refilled or decommissioned.

6.2 Migration and persistence of contaminants

6.2.1 Organic compounds

The fate of organic compounds, particularly solvents which have been lost to the ground, will depend on their solubility and volatility and on physical, chemical and biological factors. Volatile organic solvents will readily partition from the liquid phase to the vapour phase resulting in high concentrations in the soil pore space above the unsaturated zone. Close to the soil surface, some will be lost directly to the atmosphere by evaporation. Under favourable ground conditions, less volatile solvents of low aqueous solubility will tend to migrate to the water table, where those of a lower density than water will form layers on the water table surface. Compounds which are denser than water, for example chlorinated solvents, generally accumulate at the base of the water body. Although small quantities of the solvents will be dissolved and thus migrate in a manner consistent with general groundwater flow, the bodies of the free phase solvents may not.

The higher the natural organic matter and clay content of the soil, the greater the degree of adsorption of the organic contaminants and the greater the reduction of contaminant migration. Thus, the greater degree of mobility will occur in coarse-grained sands and gravels with little organic matter. The less soluble and therefore less mobile compounds which become adsorbed on to clay or organic matter may cause water pollution long after the original source has been removed, by continuing to desorb into the soil-water.

The more soluble organic compounds including the alcohols, for example methanol, will dissolve in water and readily migrate through the soil system, eventually reaching the ground water.

Widespread contamination by solvents may enhance the mobility of some organic compounds which, though of low aqueous solubility, may dissolve readily in organic solvents, for example adhesives, halogenated oils, flame retardants and some resins. The potential for groundwater contamination by organic compounds of low aqueous solubility may therefore be increased.

Organic compounds such as resins and solvents may present flammability risks and are potentially biodegradable, producing methane and carbon dioxide gases.

Biodegradation processes in soils can be influenced by a number of factors, namely moisture content, oxygen concentration and pH, acting separately or in combination. For example, low moisture content reduces microbiological activity, while high moisture content can reduce oxygen penetration and possibly lead to anaerobic soil conditions. Such conditions enhance the biodegradation of some

materials, for example chlorinated compounds, while aerobic conditions are needed to biodegrade many oils. Low pHs tend to reduce the bacterial population and encourage fungal activity; at pHs lower than 5 microbiological activity is much reduced. The presence of heavy metals also inhibits micro-organisms. As a result of these factors, at high concentrations in soil, even relatively non-persistent compounds may not biodegrade readily.

Partial degradation can produce intermediate breakdown products which are more mobile than the parent compound. Even potentially biodegradable compounds such as toluene, acetone and oil-related hydrocarbons may persist due to unfavourable conditions.

6.2.2 Metals

As with organic compounds, the transport of metals through the soil is significantly influenced by the presence of clay minerals and organic matter. The solubility of some metals (for example copper, zinc and lead) may increase under acidic conditions. In other cases the relationship is more complex, for example trivalent chromium is soluble under both acidic and alkaline conditions. Certain heavy metals may be taken up by plants and animals, thereby entering the food chain.

6.2.3 Inorganic compounds

A variety of inorganic compounds are used by the textile industry, particularly mineral acids, alkalis, bleaching agents and metal salts. The most significant effects resulting of the loss to ground of these compounds are acidic or alkaline ground conditions; raised chloride concentrations can result from some bleaching agents and metal chlorides. As most, if not all, of the compounds used are in an aqueous form, it can be assumed that, following loss to ground, they will readily migrate in groundwater and, depending on the attenuation properties of the underlying ground, may reach the underlying water table.

6.2.4 Other factors

Asbestos is neither soluble nor biodegradable and persists in the soil. Wind dispersion of contaminated soil may be a further transport mechanism of some contaminants such as asbestos fibres and metals. It is likely to be a significant factor only if there is gross surface contamination.

PCBs are very persistent, fat soluble and tend to accumulate in food chains. They are generally insoluble in water and do not readily migrate.

Pathogens such as anthrax spores can be long lived and may be potentially hazardous even after remaining in the ground for several decades.

7. Sources of further information

7.1 Organisations

For further information concerning the textile and dye industries in the United Kingdom, the following organisations should be consulted:

British Carpet Manufacturers' Association
5 Portland Place
London
W1N 3AA

The British Textile Technology Group (BTTG)
Shirley House
Didsbury
Manchester
M20 2RB

Chemical Industry Association Limited
Kings Buildings
Smith Square
London
SW1P 3JJ

Environmental Technology and Analytical Services
International Wool Secretariat
Development Centre
Valley Drive
Ilkley
West Yorkshire
LS29 8PB

Institute of Wastes Management
9 Saxon Court
St. Peters Garden
Northampton
NN1 1SX

Knitting Industry Federation
53 Oxford Street
Leicester
LE1 5XY

Textile Environmental Network (TEN)
Chelsea College of Art and Design
Lime Grove
London
W12 8EA

Textile Finishers Association
Reedham House
31 King Street West
Manchester
M3 2PF

7.2 Sources of information concerning the activities described in this profile

The colour index. Third Edition. The Society of Dyers and Colourists, The American Association of Textile Chemists and Colourists. Bradford, 1971 (Vols. 1-4) and 1975 (Vols 5-7).

Aspin C. *The cotton industry.* Shire Album Series, No. 63. Shire Publications Limited, 1981.

Aspin C. *The woollen industry.* Shire Album Series, No 81, Shire Publications Limited, 1982.

Austin G T. *Shreve's chemical process industries.* 5th Edition. McGraw-Hill, London, 1984.

Baines P. *Flax and linen.* Shire Album Series, No. 133. Shire Publications Limited, 1987.

Bush S. *The silk industry.* Shire Album Series, No. 194. Shire Publications Limited, 1987.

Dragun J. *The soil chemistry of hazardous materials.* Hazardous Materials Control Research Institute, Silver Spring, MD, USA. 1988.

Grierson S. *Dyeing and dyestuffs.* Shire Album Series No 229. Shire Publications Limited, 1989 (out of print but to be reprinted).

Heaton C A (Editor). *The chemical industry.* Chapter 2 Dyestuffs. Blackie and Son Ltd, Glasgow, 1986.

Textile industry: floor coverings and dyes and pigments. Encyclopaedia Britannica. Volumes 5, 7, 18.

Information on researching the history of sites may be found in:

Department of the Environment. *Documentary research on industrial sites.* DOE, 1994.

7.3 Related DOE Industry Profiles

Chemical works: coatings (paints and printing inks) manufacturing works
Chemical works: cosmetics and toiletries manufacturing works
Chemical works: fine chemicals manufacturing works
Chemical works: organic chemicals manufacturing works
Chemical works: soap and detergent manufacturing works
Gas works, coke works and other coal carbonisation plants
Sewage works and sewage farms
Timber products manufacturing works

7.4 Health, safety and environmental risks

The notes issued by the Chief Inspector of Her Majesty's Inspectorate of Pollution (HMIP) provide guidance for the processes prescribed for integrated pollution control in Regulations made under the Environmental Protection Act 1990. Of particular relevance is:

Her Majesty's Inspectorate of Pollution. *Textile treatment processes.* Chief Inspector's Guidance to Inspectors. Process Guidance Note IPR 6/6. London, HMSO, 1995.

The Control of Substances Hazardous to Health (COSHH) Regulations 1994 and the Management of Health and Safety at Work Regulations 1992 are available from HMSO. Information on relevant health and safety legislation and approved codes of practice published by HSE publications are available from Health and Safety Executive Books, PO Box 1999, Sudbury, Suffolk, CO10 6FS (Tel. 01787 881165), as well as HMSO and other retailers.

Information on the health, safety and environmental hazards associated with individual contaminants mentioned in this profile may be obtained from the following sources:

Howard P H. *Handbook of environmental fate and exposure data for organic chemicals*. Vols. I and II. USA, Lewis Publishers, 1990.

Sax N and Lewis R. *Hazardous chemicals desk reference*. New York, Van Nostrand Reinhold Company, 1987.

Verschueren K. *Handbook of environmental data on organic chemicals*. 2nd Edition. New York, Van Nostrand Reinhold Company, 1983.

7.5 Waste disposal and remediation options

Useful information may be obtained from the Department of the Environment series of Waste Management Papers, which contain details of the nature of industrial waste arisings, their treatment and disposal. A current list of titles in this series is available from HMSO Publications Centre, PO Box 276, London, SW8 5DT. Of particular relevance is:

Department of the Environment. *Special wastes. A technical memorandum providing guidance on their definition*. Waste Management Paper No.23, HMSO, London, 1981. New edition in preparation.

Publications containing information on the treatment options available for the remediation of contaminated land sites, prepared with the support of the Department of the Environment's Research Programme, can be obtained from National Environmental Technology Centre Library, F6, Culham, Abingdon, Oxfordshire, OX14 3DB.

A full list of current titles of Government publications on all aspects of contaminated land can be obtained from CLL Division, Room A323, Department of the Environment, Romney House, 43 Marsham Street, London, SW1P 3PY.

Advice on the assessment and remediation of contaminated land is contained in guidance published by the Construction Industry Research and Information Association (CIRIA), 6 Storey's Gate, Westminster, London, SW1P 3AU.

Annex Potential contaminants

The chemical compounds and other materials listed below generally reflect those associated with the industry and which have the potential to contaminate the ground. The list is not exhaustive, nor does it imply that all these chemicals might be present or that they have caused contamination.

Textile manufacture and dyeing

Metals, metalloids and their compounds

eg aluminium
antimony
cadmium
chromium
copper
lead
iron
manganese
mercury
tin
titanium
zinc

Other inorganic compounds

eg borates
free and complex cyanides
sodium dichromate
sodium hypochlorite
sulphide compounds
chloride compounds eg magnesium chloride
bromides
fluorides
phosphates eg disodium phosphate
mineral acids eg sulphuric hydrochloric
alkalis eg sodium hydroxide
ammonium salts eg ammonium phosphate

Chlorinated organic solvents

eg trichloroethene
tetrachloroethene (TCE)
perchloroethene (PCE)
1,1,1-trichloroethane

Sizing agents

eg polyvinyl acetate (PVA)
polyacrylic acid
carboxymethyl cellulose

Miscellaneous organic compounds

bonding agents eg dimethyl urea formaldehyde
melamine formaldehyde
urea formaldehyde
polyvinyl chloride
polyacrylates
polyurethanes

	stabilising agents eg acetyls
	durable press eg dimethyl-dihydroxy ethylene urea dimethyl-dipropylene urea
	acetic acid formic acid
	phenolic compounds including pesticides (see below)
Water repellents	eg organo silicon oxazoline
Fire/flame retardants	eg borax borax acids ammonium phosphate tetrakis (hydroxymethyl) phosphonium chloride (THPC) brominated organic compounds with metal oxides such as antimony and reactive phosphorous/ nitrogen derivatives
Soaps and detergents	eg soap glycerol sulphonated hydrocarbons alkylbenzene ethylene oxide products (see the relevant Industry Profile, Section 7, for more details)
Pesticides (anti-bacterial, anti-fungal treatments and moth repellents)	eg organo-phosphates organo-chlorine pesticides (including g-hexachlorocyclohexane) organo mercury chlorinated phenols pentachlorophenol pentachlorophenol laurate naphthalene sulcofuron permethrin flucofuron (reintroduced in 1989) cyfluthrin (banned outside United Kingdom in 1988) chlorphenylid (banned in 1988) dieldrin (banned in 1989).

Dye manufacture

Types of organic dyestuffs

basic
acid
direct
chrome
azoic
vat and sulphur
disperse
metal complex
pigment
reactive

Non-chlorinated organic solvents

eg acetone
toluene
benzene
aniline
naphthalene
xylene
methyl ethyl ketone (MEK)
methanol

General contaminants

Fuel

eg oil, coal

Boiler ash

heavy metals (see list of metal compounds)
sulphates

Mineral oils

Asbestos

Polychlorinated biphenyls (PCBs)

Anthrax spores

Gases

carbon dioxide/monoxide, methane

Table 1 Main groups of contaminants and their probable locations

Textile works and dye works

Contaminant	Location				
	Raw material delivery and storage	Process area	Waste storage/disposal	Fuel storage	Electrical substations and transformers
Metals, metalloids and their compounds					
Inorganic compounds					
Sizing agents					
Organic solvents					
Other organic compounds					
Polychlorinated biphenyls (PCBs)					
Dyes					
Pesticides					
Asbestos					
Anthrax spores					
Carbon dioxide					
Methane					

Shaded boxes indicate areas where contamination is most likely to occur

DOE Industry Profiles

Airports
Animal and animal products processing works
Asbestos manufacturing works
Ceramics, cement and asphalt manufacturing works
Chemical works: coatings (paints and printing inks) manufacturing works
Chemical works: cosmetics and toiletries manufacturing works
Chemical works: disinfectants manufacturing works
Chemical works: explosives, propellants and pyrotechnics manufacturing works
Chemical works: fertiliser manufacturing works
Chemical works: fine chemicals manufacturing works
Chemical works: inorganic chemicals manufacturing works
Chemical works: linoleum, vinyl and bitumen-based floor covering manufacturing works
Chemical works: mastics, sealants, adhesives and roofing felt manufacturing works
Chemical works: organic chemicals manufacturing works
Chemical works: pesticides manufacturing works
Chemical works: pharmaceuticals manufacturing works
Chemical works: rubber processing works (including works manufacturing tyres or other rubber products)
Chemical works: soap and detergent manufacturing works
Dockyards and dockland
Engineering works: aircraft manufacturing works
Engineering works: electrical and electronic equipment manufacturing works (including works manufacturing equipment containing PCBs)
Engineering works: mechanical engineering and ordnance works
Engineering works: railway engineering works
Engineering works: shipbuilding, repair and shipbreaking (including naval shipyards)
Engineering works: vehicle manufacturing works
Gas works, coke works and other coal carbonisation plants
Metal manufacturing, refining and finishing works: electroplating and other metal finishing works
Metal manufacturing, refining and finishing works: iron and steelworks
Metal manufacturing, refining and finishing works: lead works
Metal manufacturing, refining and finishing works: non-ferrous metal works (excluding lead works)
Metal manufacturing, refining and finishing works: precious metal recovery works
Oil refineries and bulk storage of crude oil and petroleum products
Power stations (excluding nuclear power stations)
Pulp and paper manufacturing works
Railway land
Road vehicle fuelling, service and repair: garages and filling stations
Road vehicle fuelling, service and repair: transport and haulage centres
Sewage works and sewage farms
Textile works and dye works
Timber products manufacturing works
Timber treatment works
Waste recycling, treatment and disposal sites: drum and tank cleaning and recycling plants
Waste recycling, treatment and disposal sites: hazardous waste treatment plants
Waste recycling, treatment and disposal sites: landfills and other waste treatment or waste disposal sites
Waste recycling, treatment and disposal sites: metal recycling sites
Waste recycling, treatment and disposal sites: solvent recovery works
Profile of miscellaneous industries incorporating:
Charcoal works
Dry-cleaners
Fibreglass and fibreglass resins manufacturing works
Glass manufacturing works
Photographic processing industry
Printing and bookbinding works

Copies may be purchased from:

Publications Sales Unit
Block 3, Spur 7,
Government Buildings,
Lime Grove,
Ruislip, HA4 8SF

Price £10

Cheques payable to DOE.