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EMISSION SCENARIO DOCUMENT ON PULP, PAPER AND BOARD INDUSTRY

IOMC
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EXPLANATORY NOTES

Purpose and background

This OECD Emission Scenario Document (ESD) is intended to provide information on the sources, use patterns and release pathways of chemicals used in the pulp, paper and board industry, in order to help estimate releases of chemicals into the environment. This ESD covers the use of chemicals in the making of paper and board and the recycling of paper and board. The main processes considered are paper-making and paper recycling.

This ESD may be periodically updated to reflect changes in the industry and new information available, and extended to cover the industry area in countries other than the lead (the United States). Users of the document are encouraged to submit comments, corrections, updates, and new information to the OECD Environment, Health and Safety Division (env.riskassessment@oecd.org). The comments received will be forwarded to the OECD Task Force on Environmental Exposure Assessment, which will review the comments every two years so that the lead country can update the document. Submitted information will also be made available to users within the OECD web site (www.oecd.org/env/riskassessment).

How to use this document

The user of this ESD needs to consider how the information contained in the document relates to the situation for which they wish to estimate releases of chemicals. The document could be used as a framework for identifying the information needed, or the approaches in the document could be used with the suggested default values to provide estimates. Where specific information is available, it should be used in preference to the defaults. At all times, the values inputted and the results generated should be critically reviewed to assure their validity and appropriateness.

Coverage

The main processes considered in this document are the production/preparation of recycled fibre (paper recycling) and the paper-making process, which is applicable to both recycled and virgin fibres. The document does not consider emissions from wood pulping processes involved in the production of virgin fibres/pulp (bleached or unbleached sulphate (kraft) pulping, sulphite pulping, semi-chemical pulping and mechanical pulping). Information on pulping can be found in OECD (2006a).

The industry categories, use categories and biocidal product types relevant to this document are as follows:

Industry category	Use category	Biocidal product type
12 – Pulp, paper and board industry	8 – Bleaching agents 10 – Colouring agents 23 – Flotation agents 31 – Impregnation agents 39 – Biocides, non-agricultural 43 – Process regulators (coagulants, defoamers, retention aids) 45 – Reprographic agents 50 – Surface-active agents 0 – Other (dry strength additives, wet strength additives)	11 – Preservatives for liquid-cooling and processing systems 12 – Slimicides

How this document was developed

An ESD for the pulp, paper and board industry is included in the EU Technical Guidance Document on Risk Assessment. This existing ESD was based on, amongst other sources, a report entitled *Paper recycling industry: review of processes and effluent composition*, which was produced in 1991 by PIRA International. Since that time, a large amount of relevant data have become available regarding the pulp, paper and board industry in the UK, in particular from submissions to the Environment Agency under Integrated Pollution Prevention and Control (IPPC) legislation. As a result of this, and in order to update the existing ESD, WRC-NSF produced a report for the Environment Agency entitled *National R&D project P2-203: Development of emission scenario documents for use in environmental risk assessment – pulp, paper and board industry* (September 2002). This document was produced in consultation with trade associations and sections of the industry, based mainly in the UK (giving the report a UK focus), and included scenarios for both paper-making and paper recycling. Following the production of this report, the Environment Agency identified a need to update and expand the scope of the emission scenario for paper recycling to the European situation. This led to the Building Research Establishment Ltd producing a report entitled *Emission scenario document – paper recycling* (October 2003) for the Environment Agency.

The current ESD has been produced by the Building Research Establishment for the Environment Agency by combining the two reports detailed above, and overseen by the OECD Task Force on Environmental Exposure Assessment. This document was circulated to the paper industry in the UK and Europe for consultation in early 2005. In addition, a meeting was held with stakeholders in June 2006 and further comments and information were provided after this meeting. A number of changes to the ESD were made following this consultation. Where possible, the paper production/consumption figures have been updated to 2004, representing the most recent figures available at this time (February 2006). Some information gathered for risk assessments of substances under the European Union Existing Substances Regulation has also been incorporated (in particular from the assessment of bisphenol A in relation to thermal paper). As a result of the consultation, further examples and guidance have also been added relating to the use of the document for low-tonnage substances. Information for the original reports was largely provided by industry practitioners with a wide breadth of knowledge and experience. Published sources are cited where appropriate, but most of the information did not come from such sources and was based on the knowledge and experience of consulted experts. Unless a specific source is cited for a piece of information, it should be assumed that it is derived from the experience of those experts. The information for the original reports was collected over the period 2000–03. The sources of additional information and revisions have been included as far as possible. It should be noted that some of the sources used to develop this ESD were the same as those used to develop the original ESD given in the EU Technical Guidance

Document for Risk Assessment. This version of the ESD was published by the Environment Agency of England and Wales in 2007 (Environment Agency, 2007a).

The draft ESD was circulated to and discussed by the OECD Task Force at its 15th meeting in December 2007. Comments from member countires were requested by the end of February 2008. Canada provided comments with regard to reference to the published ESD on Kraft Pulping and Integrated Paper Mills (OECD Series on Emission Scenario Document No.15, ENV/JM/MONO(2006)7) etc., which were incorporated as appropriate to this ESD. The final draft was approved by the Task Force at its 16th meeting in October 2008.

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1. OVERVIEW OF THE PULP, PAPER AND BOARD INDUSTRY

1.1 Introduction

The UK pulp and paper industry has several trade associations, including The Paper Federation and the Confederation of Paper Industries. The majority of mills are members of these associations, which allow sharing of information and effort and have provided data for this emission scenario document (ESD).

The pulp and paper industry consists of a variety of manufacturing operations that produce different forms of paper and board for different sector uses. All of the paper and board that is produced comes from either virgin wood pulp (domestic production or imports) or recycled fibre. Water is added to this pulp, along with chemicals and additives, to form a composite, which is then processed and rolled out into sheets. The end uses of the manufactured material determine the specific processes and additives used by the individual companies and mills, and so there is some variation across the industry. Some of the products, such as de-inked pulp (as a raw material) or other fibre sources within the recycling process, may be transferred between mills involved in the production of different grades of paper.

For the purpose of this document, the pulp, paper and board industry has been divided into two main processes.

- Fibre production processes. Wood fibres are the raw material for paper-making, with these fibres produced from either recycled paper (recycled fibre) or wood pulping (virgin fibres or pulp). For the UK, fibre production from recycled paper predominates (see Section 1.1.1).

- Paper-making processes. These are the processes by which the wood fibres are converted to paper and are similar for both recycled and virgin fibres.

The paper-making process can be integrated with the fibre production process (integrated mills) or the two processes can be carried out at separate sites (non-integrated mills).

1.1.1 Scope of this document

The main processes considered in this document are the production/preparation of recycled fibre (paper recycling) and the paper-making process (which is, in principle, applicable to both recycled and virgin fibres). The document does not consider emissions from wood pulping processes involved in the production of virgin fibres/pulp (bleached or unbleached sulphate (kraft) pulping, sulphite pulping, semi-chemical pulping and mechanical pulping). This reflects the fact that this ESD was developed from an earlier document, which was concerned with the UK situation. In the UK, domestic wood pulping is of a relatively minor importance in terms of the percentage of the total fibres used in paper-making. However, wood pulping is a much more important process in some European countries, notably Sweden and Finland. Information on pulping can be found in OECD (2006a).

The main products of the paper industry can be grouped into a number of different sectors:

- newsprint
- printings and writings
- liner, flutings and corrugated case materials
- folding carton board
- tissue
- speciality.

These products are made from different combinations of recycled and virgin fibres.

1.2 Raw materials: wood pulp and recycled fibre

1.2.1 Forestry and wood pulp supply

Information on the usage of different fibrous raw materials in the UK for 1989, 1999 and 2004 is presented in Table 1.1.

Table 1.1 UK fibrous raw material usage, 1989, 1999 and 2004

Material	% usage		
	1989	1999	2004
Domestic pulp	11	8	6
Imported pulp	36	26	25
Recovered (waste) paper	52	65	68
Other fibres and pulp	1	1	1

Source: Paper Federation of Great Britain 2000/May 2001; CPI 2006.

Only 10 per cent of UK land is forested and use of home-grown timber for paper production is limited to four mills. This domestic production has remained fairly stable at between 500,000 and 600,000 tonnes per annum for the last 10 years, accounting for around 15 per cent of the domestically-produced timber.

The import of wood pulp, which is predominantly used in the printings and writings sector (with some used in tissue and speciality paper), has remained fairly stable since 1986, at 1.5–1.6 million tonnes per annum. In contrast, the use of raw pulp has decreased, as more recovered fibre has been used (CPI 2000).

The majority of pulps used in the UK are sourced from Europe and North America.

Within Europe, the annual production of wood pulp is in the order of 35 million tonnes. The main types of wood pulp produced in Western Europe in 1996 were bleached sulphate pulp (40.8 per cent), mechanical and semi-chemical pulp (38.3 per cent), unbleached sulphate pulp (12.7 per cent) and sulphite pulp (7.5 per cent). In Western Europe, there are around 67 mills producing sulphate pulp, mostly located in Finland and Sweden but also in Spain, Portugal, France and Austria. Sulphite pulp production is carried out at around 24 mills, mostly located in Sweden, Germany, Austria and France, but also in Italy and Portugal. Mechanical pulp is produced at around 101 mills, mainly located in Finland, Germany, Sweden, France, Italy and Norway. Semi-chemical pulp is produced at around 23 mills, mainly located in Sweden, Finland, Norway and Italy (BREF 2001).

The emissions of chemicals to the environment from wood pulping processes are not considered in this ESD.

1.2.2 Recovered/recycled (waste) paper

Recovered paper plants are almost always integrated with a paper mill (BREF 2001), although some of the production may be further treated and marketed to other mills as ‘de-inked pulp’ (DIP).

The CEPI (Confederation of European Paper Industries) publish annual statistics on the amounts and types of paper recycled in Europe as a whole. The 2004 data (CEPI 2005a,b) are summarised in Table 1.2 and Table 1.3. The data relate to CEPI member countries[1], rather than to the EU. The total amount of recovered paper used in 2004 was 46,475,000 tonnes, an increase of 4 per cent on 2003, while the total amount of paper consumed was 86,466,000 tonnes. The recycling rate[2] was 53.7 per cent in 2004, up from 52.8 per cent in 2003 (the industry has set a target recycling rate of 56 per cent, to be reached by 2005). Recovered paper use by the different sectors in the UK for 1999 and 2000 is shown in Table 1.4.

CEPI (2002a) indicated that virgin fibres need to be continuously introduced into the recycling system and that the actual make-up of the raw materials used depends on the availability of raw materials and the paper grades being produced.

The packaging sector (which produces case materials, carton boards, wrappings and other packaging materials) is currently the biggest consumer of recovered paper and board in Europe, utilising almost two-thirds of Europe’s recovered paper (CEPI 2002a). As a result of this, utilisation rates3 are very high in the packaging sector (greater than 90 per cent for case materials). Of the other paper types, newsprint has a utilisation rate of around 80 per cent, and household and sanitary papers have utilisation rates of around 59 per cent, whereas printing and writing papers (which account for around 37 per cent of the total paper and board production) use only limited amounts of recovered paper. Based on the figures reported in Table 1.3, overall mixed grades account for 19.7 per cent of recovered paper, corrugated and kraft account for 40.8 per cent, newspapers and magazines account for 27.9 per cent and high grades account for 11.5 per cent.

There was a net export of recovered paper from CEPI countries in 2004 of 5,300,000 tonnes. Hence, the total amount of recovered paper collected was 51,775,000 tonnes (CEPI 2005b).

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[1] CEPI member countries: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, the Netherlands, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, UK.

[2] The recycling rate in a country is defined as the percentage of recovered paper utilisation (collection minus exports plus imports) compared to the total paper consumption in that country.

[3] Utilisation rate is defined as the percentage of recovered paper utilisation compared to the total paper production.

Table 1.2 Paper recycling figures in Europe in 2004

Country	**Recovered paper utilisation (1,000 tonnes)**	**Utilisation rate**	**Collection rate**	**Recycling rate**
Austria	2,141	44.1	68.4	100.9
Belgium	921	47.1	60.7	26.2
Czech Republic	447	46.9	43.1	33.7
Denmark	410	107.9	56.7	27.9
Finland	740	5.3	71.1	66.1
France	5,942	58.0	57.9	53.6
Germany	13,219	64.8	73.6	68.1
Greece	345	67.6	37.4	29.0
Hungary	370	63.9	49.7	46.6
Ireland	47	109.3	76.7	10.5
Italy	5,474	56.6	49.2	48.3
Netherlands	2,380	68.8	72.6	70.9
Norway	478	20.6	72.1	56.2
Poland	979	38.6	36.1	31.1
Portugal	297	17.8	36.5	24.7
Slovak Republic	208	27.1	49.3	47.7
Spain	4,474	81.0	54.6	62.2
Sweden	2,009	17.3	70.0	93.7
Switzerland	969	54.0	70.0	58.2
UK	4,625	74.1	56.9	36.5
Total CEPI countries	**46,475**	**46.7**	**59.9**	**53.7**

Source: CEPI 2005b.

Table 1.3 Use of recovered paper by sector in Western Europe in 2004

Paper type	**Amount of recovered paper used (1,000 tonnes)**				**Total use of recovered paper (1,000 tonnes)**	**Total paper production (1,000 tonnes)**	**Utilisation rate**
	Mixed grades	**Corrugated and kraft**	**Newspapers and magazines**	**Higher grades**			
Newsprint	190	-	8,656	155	9,001	11,265	79.9
Other graphic papers	115	133	2,242	808	3,298	38,509	8.6
Total newsprint and other graphic papers	**305**	**133**	**10,898**	**963**	**12,299**	**49,774**	**24.7**
Case materials	4,532	15,493	214	641	20,860	23,032	90.7
Carton boards	1,644	543	410	774	3,371	8,117	41.5
Wrappings, other packaging paper	1,824	1,543	429	609	4,410	8,146	54.1
Total packaging papers	**8,000**	**17,854**	**1,053**	**2,024**	**28,661**	**39,297**	**72.9**
Household and sanitary	528	81	935	2,080	3,624	6,146	59.0
Others	323	1,175	102	291	1,891	4,271	44.3
Total	**9,156**	**18,973**	**12,988**	**5,358**	**46,475**	**99,488**	**46.7**

Source: CEPI 2005a.

Table 1.4 UK recovered (waste) paper utilisation by sector, 1999, 2000 and 2004

Sector	**Utilisation rate (%)**		
	1999	**2000**	**2004**
Newsprint	103	110	129
Printings and writings	18	10	11
Corrugated case materials	105	105	104
Packaging papers	66	72	66
Packaging board[a]	72	65	63
Tissue[b]	78	79	56
Other	78	79	

Source: Paper Federation of Great Britain 2000; CPI 2006.

Notes: Utilisation rates above 100 per cent are possible because 1 tonne of recovered paper yields on average only 850kg of fibre.

a) 2004 figure includes Other category.

b) Category includes household and sanitary in 2004.

The amount of recovered paper used by UK paper mills as a proportion of their total output (utilisation rate) is around 74 per cent (see Table 1.2), which is one of the highest in the world. With the present mix of products, this figure is very close to the maximum achievable.

Although near the top of the European scale for utilisation, the UK's recovery/collection rate of around 57 per cent is average for the EU and CEPI countries. The highest collection rate is in Germany, with a rate of around 74 per cent (see Table 1.2). Recovery rates for different types of paper are variable; for example, a mixed office waste recovery rate of 22 per cent (based on data for London; Davies 2002) has been reported. A major review of the use of recycled paper in UK mills has been published by the Waste and Resources Action Programme (WRAP 2002).

Recycled fibre has been – and will continue to be – a major raw material for the paper and board industry. The main drivers for the use of recycled fibre are: economic pricing; environmental legislation and voluntary agreements; and efficient de-inking and other recovered fibre processing technologies. However, the use and application of recovered paper is not universal and is limited by:

- performance requirements;
- deteriorating fibre quality through increased recycling;
- the balance between paper production and consumption, which will affect availability;
- and technological problems in certain applications.

In 1998, recovered fibre accounted for 43.5 per cent of the total fibre used in paper-making world-wide. This proportion is likely to continue to increase at a rate of 3.6 per cent per annum through to 2005, at which point approximately 174 million tonnes of recovered paper are forecast to be used. Utilisation rates are expected to approach 50 per cent by 2005.

The liner and fluting grades of paper used in case-making materials are the most important end use application for recovered fibre and these grades show the highest utilisation rates for recovered fibre, particularly in Europe. Newsprint is one of the fastest growing applications for recovered fibre. Globally, recovered fibre has increased its share of the fibre used for newsprint from just over 20 per cent in 1990 to nearly 39 per cent in 1998. This can be expected to increase further, to around 47 per cent, by 2005. Printing and writing grades are still relatively modest users of recovered fibre. Many tissue-based products use recovered fibre as the predominant component. Globally, it accounts for over 50 per cent of the average tissue fibre used, with many grades containing 100 per cent recovered fibre.

One factor that could affect operations using recycled fibre in Europe is the possibility of EU legislation for a minimum recycled content in graphic grades.

The final end use and market acceptance of a product depends on its fitness for purpose and cost. The quality of recycled fibre pulps is a function of the recovered paper grades, the processing techniques applied and the operating mode of the processing plant. Depending on their end use, recycled fibre pulps are subject to certain strength requirements and can only contain controlled amounts of filler. Recycled fibres need to be free of adhesive contaminants (stickies) and have appropriate optical properties when used to produce graphic paper.

Currently, such criteria are being met and the resultant recycled fibre-containing products have market acceptance in many grades. Such acceptance may, however, become increasingly difficult to meet as end user demands become more stringent, incoming raw materials become more difficult to recycle and/or fibre properties deteriorate.

1.3 Product sectors

The main product groups relevant to the pulp, paper and board industry are discussed below. Products can be made from virgin fibre, recycled fibre or a combination of both. The paper-making processes involved are in principle similar regardless of which type of fibre raw material is used.

1.3.1 Newsprint

Domestic UK production of newsprint was approximately 1,118,000 tonnes in 2004 (CPI 2006), compared with 696,000 tonnes in 1990. There are three UK mills producing newsprint: two use 100 per cent recovered newspapers and magazines as raw material, while the other one adds a proportion of wood pulp produced on site from UK timber.

Within Western Europe (CEPI countries), newsprint accounted for around 11 per cent (11,265,000 tonnes) of the total paper production in 2004 (CEPI 2005a). Newsprint production has historically been centred in Finland and Sweden, but the increase in use of recycled fibres in newsprint production has seen the location of the industry shift to large consumer centres.

1.3.2 Printings and writings

Domestic UK production of paper destined for printing and writing – comprising uncoated and coated mechanical grades, and uncoated and coated wood-free grades – was 1,516,000 tonnes in 2004. The wood-free grades are currently made by 20 companies operating 32 mills in the UK. Mechanical grades, which are used for large circulation, low-priced magazine and brochure publishing, are manufactured by just one mill.

Production of printing and writing papers in CEPI countries accounted for around 39 per cent (38,509,000 tonnes) of the total paper production in 2004 (CEPI 2005a). The main producers of printing and writing papers are located in Germany and Finland, followed by Sweden, France, Italy and the UK.

1.3.3 Liner, flutings and corrugated case materials

Domestic UK production in this sector was 1,873,000 tonnes in 2004. With the exception of one operation in the UK, all of the manufacture is of recycled fibre grades.

Within Western Europe, the major producers of liner and flutings are located in Germany and France (BREF 2001). The total Western European (CEPI countries) production of packaging (all types) accounted for around 39 per cent (39,000,000 tonnes) of the total paper production in 2004 (CEPI 2005a).

1.3.4 Folding carton board

In the UK, 60 per cent of the board consumed by carton makers is from virgin material – a much higher figure than for mainland Europe, where more recycled material is included.

1.3.5 Tissue

Domestic tissue production in the UK was 805,000 tonnes in 2004 and used approximately 454,000 tonnes of recovered paper (two-thirds of this was recovered office papers). There are currently 11 companies manufacturing soft tissues in the UK. The larger mills/converters supply most of the consumer products sold through well-known retailers, with the largest five accounting for 75 per cent of consumer supplies.

Within Western Europe, tissue production accounted for around 6 per cent (6,146,000 tonnes) of the total paper production in 2004 (CEPI 2005a). Four countries (France, Germany, Italy and the UK) account for over 70 per cent of the total European tissue production. There are around 60 companies producing tissue in Europe, but the market is dominated by three large multinational companies.

1.3.6 Speciality (including sensitised papers)

There are many types of speciality paper manufactured in the UK. Examples include artists' papers, furniture papers, paper for tea bags, bank notes, medical papers, battery separators and filter grades. One of the major types of speciality paper is 'sensitised paper', which has coatings applied that allow images to be produced in response to stimuli such as pressure and heat. Measured in tonnage terms, the speciality paper sector does not appear to be a large sector, accounting for perhaps less than 5 per cent of the total production tonnage of paper and board in the UK. Exact figures are difficult to assess due to the overlap between speciality paper and many printing and writing grades.

UK paper industry statistics indicate that the UK consumed a total of 246,100 tonnes of speciality paper, of which 145,204 tonnes were described as 'other sensitised thermal and carbonless copy paper'

(Paper Federation 2002). UK carbonless copy paper consumption is approximately 50,000 tonnes per annum (Arjo-Wiggins 2002a).

2. PROCESSES AND SUBSTANCES USED IN THE PULP AND PAPER INDUSTRY

The processes and substances used in the pulp and paper industry can be subdivided to a certain extent depending on whether they are involved in paper recycling or paper-making. Although many of the substances are common to both, this distinction has been made through the following section to make it easier to delineate between the sources of substances when estimating releases to the environment. This section considers paper-making first, followed by paper recycling. In reality, the actual order of the processes carried out at individual sites will depend on whether the paper is being made from virgin fibres or recycled fibres.

2.1 Paper-making

Virgin fibres (derived from wood pulp) and recycled fibres (derived from recovered paper) are the main raw materials used during the production of paper. The selection of fibre is critical to the type and quality of the final product. The composition of other raw material (such as filler and coatings) used in the paper-making process also has a major affect on production costs, product quality and the overall environmental impact of the process.

While there is considerable variation in the paper products made and the processes used, most paper-making processes can be grouped into the following categories.

1) Stock preparation (preparation of fibres for introduction to the paper machine; see Section 2.2 for recycled fibres).

2) Stock approach system.

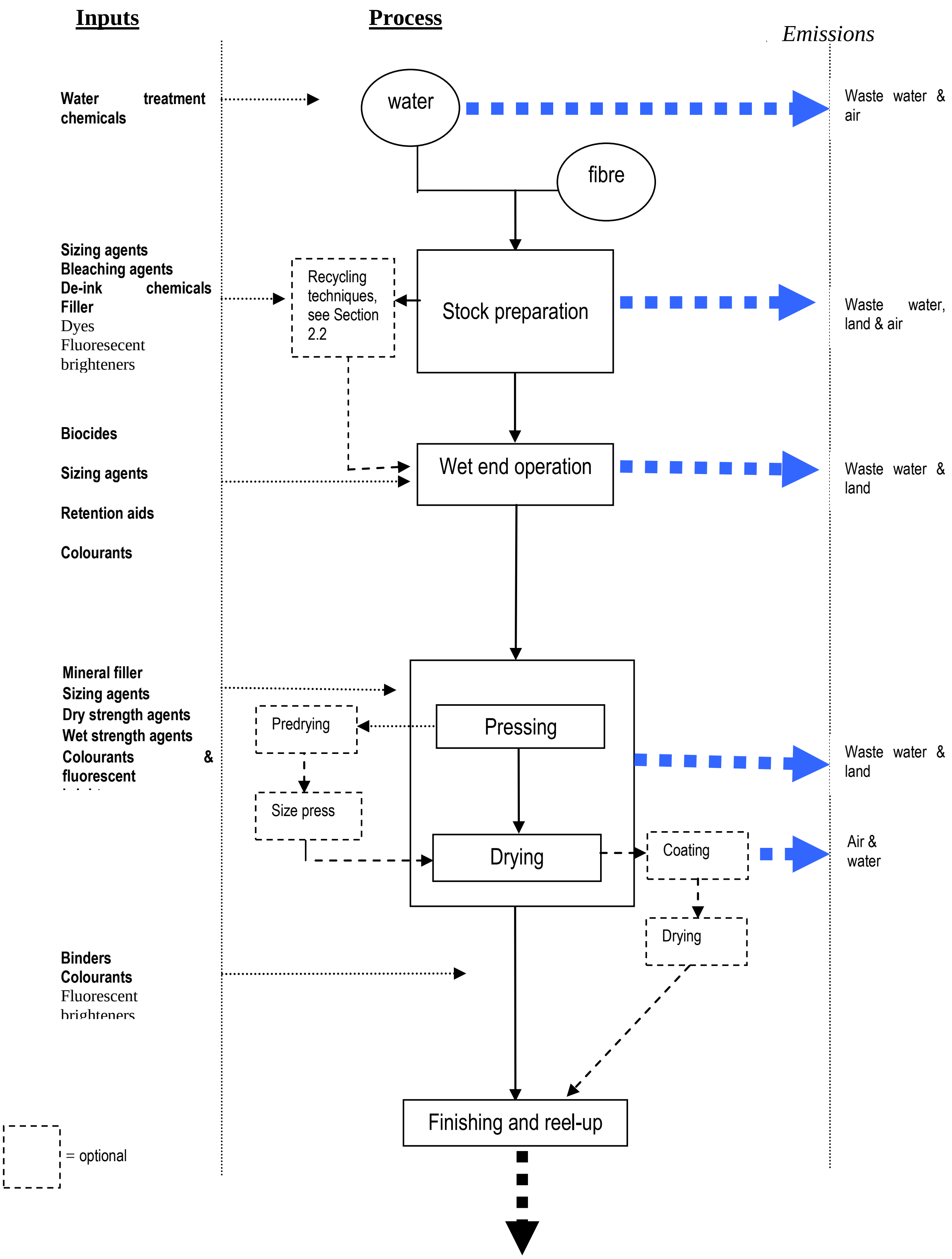
3) Paper machine, which consists of:

    - headbox – introduces the suspension of fibres to the wire;
    - wire section – drains paper so that it contains 12–20 per cent solids;
    - press section – removes more water from the web and increases solids content to 50 per cent;
    - drying section – removes the rest of the water by heating the web with drying cylinders;
    - reeler – reels the paper web into a roll.

4) Optional additional (finishing) process units such as calenders and coaters.

The key processes, chemicals added and likely releases to the environment during paper-making are shown in Figure 2.1.

Figure 2.1 Key processes, chemicals and releases in paper-making



2.1.1 Stock preparation

In stock preparation, virgin fibre (usually as imported dried pulp), recovered paper (usually as bales of waste paper) or a suspension of fibres (for integrated mills) are pulped and cleaned to remove contaminants (see Section 2.2 for preparating recovered paper; wood pulping is not considered in this document). Refining may be carried out to increase the bonding strength of the fibre. Chemicals such as resins, dyes and fillers may be added to improve the final quality of the paper. The pulp is stored in mixing chests to allow continuous operation.

2.1.2 Paper machine

The suspension of fibres is introduced to the headbox and metered uniformly onto a moving mesh that retains the fibre as a paper web and facilitates water drainage. Chemicals such as sizing agents and dyes may be added at this stage. The fibre slurry at the wet end of the paper machine is typically 0.2–1.5 per cent wet weight (w/w). Water is removed from the web along the mesh, achieving a solids content of 10–20 per cent. At this solids content, the web can be transferred to the pressing and drying section.

2.1.3 Sizing (optional)

Starch or synthetic sizing agents are added directly to the furnish in some grades (internal sizing) to reduce the natural absorbency of the paper or applied to the fibre surface (surface sizing). Typical synthetic sizing agents include alkyl ketene dimer (AKD) and polymers based on acrylic esters, maleic acid esters and acrylonitrile. The typical amounts used in paper-making are summarised in Table2.1.

2.1.4 Coating (optional)

Paper and paperboard are coated to reduce surface roughness and improve printing properties. Coatings – typically water-based emulsions of white pigments, binder and various additives – are applied to one or both sides of the paper using either equipment that is an integral part of the paper machine (on machine) or separate coating equipment (off machine). Typical coated paper grades include art paper, machine coated papers, lightweight coated papers (such as for magazines) and folding boxboard. The typical amounts used in paper-making are summarised in Table 2.1.

2.1.5 Dyeing of paper (optional)

To obtain coloured papers and boards, dyes are added to the paper stock or to the paper surface as part of the sizing operation. Dyes, pigments and optical brighteners are either added batchwise to the pulper or added continuously into the stock flow. Fixing agents may be added to improve dye fixation and reduce releases to water. Various types of dyes and other substances can be used in colouring paper (Kirk-Othmer 2001).

Table2.1 Quantity of inks and coatings applied to papers

	Quantity applied to paper	
	% w/w	kg/tonne (M_s)[a]
Substances applied after the paper-making process		
Inks applied to:		
Newspapers	0.5–5	5–50
Magazines	1–7	10–70
Books	0.5–1	5–10
Computer paper	0.3–0.8	3–8
Continuous stationery	1–3	10–30
Coatings (temperature sensitive and carbonless copy paper):		
Temperature sensitive	7–10	70–100
Colour former – bottom surface sheets A and B	5–8	65
Reactive coating – upper surface sheets B and C	8–12	100
Non-impact printed toner (Xerography)	0.5–2	5–20
Substances applied during the paper-making process		
Colourants and optical brighteners (newsprint, tissue and printing and writing paper):		
Organic paper dyes and optical brighteners		0.001–8.3 (80-100% to paper)
Inorganic pigments		0.003–40 (75% to paper)
Dye fixative		0.08 (100% to paper)
Drainage and retention aids (liner, corrugate and fluting, newsprint and printing and writing paper):		
Coagulants		0.3–1.8 (80% to paper)
Polymeric retention aid		0.1–11 (98% to paper)
Clay		1.0–1.8 (75% to paper)
Soluble inorganic		5.6 (60% to paper)
Dry strength agents (liner, corrugate and fluting):		
Soluble inorganic		0.3-0.6 (50% to paper)
Organic polymers		0.03-47 (90% to paper)

	Quantity applied to paper	
	% w/w	**kg/tonne (M_s)[a]**
Wet strength agents (tissue):		
Resins		0.1–48 (80-95% to paper)
Soluble inorganic		- (50% to paper)
Sizing agents (printing and writing paper):		
Sizing agents		0.33–28 (70-90% to paper)
Surface coatings (tissue):		
Resins and pre-polymers		0.1–40 (99% to paper)
Soluble organic and inorganic		0.02–2.25 (50% to paper)

Source: BRE (1993), updated through consultation (EPCG 2005, AEMCP 2005).
Note: a) The figures in kg/tonne refer to the mass of the substance (Ms) used to produce a tonne of paper or, in the case of substances applied after the paper-making process, the mass of substance present in a tonne of recovered paper. The percentage figures refer to the fraction of the substance added during paper-making that remains in the final paper ($F_{papermaking\_paper}$ = percentage/100) and allow the mass of substance in the final paper to be estimated. Further information on this topic is reported in Table 3.2 and Table 4.3.

2.1.5.1 Basic dyestuffs

Basic dyestuffs have a high affinity for mechanical and unbleached pulps with a large amount of acid groups in the fibre. The cationic dyestuff reacts with these acid groups to produce, by salt formation, very stable lakes that are insoluble in water. In contrast, bleached pulps cannot be dyed satisfactorily, as the pulp contains few acid groups after bleaching. Although most basic dyestuffs stain ligneous pulps, the addition of alum (with or without sizing) offers advantages, depending on the depth of shade and the type of paper required.

Basic dyestuffs usually have brilliant shades with high tinctorial strength. On ligneous pulps, they have good fastness to water, steam, and calendering and produce clear backwater. Basic dyestuffs have poor ‘lightfastness’ and, because of their poor affinity for bleached pulps, have a strong tendency to mottle and/or granite in blended furnishes with ligneous pulps. Basic dyestuffs are usually used for dyeing unbleached pulp in the mechanical pulp used for wrapping paper, kraft paper, box board, news and other inexpensive packaging papers. Their strong and brilliant shades also make them suitable for calendar staining and surface colouring, where lightfastness is not critical.

2.1.5.2 Acid dyestuffs

Acid dyestuffs have no affinity for vegetable fibres, either as bleached or ligneous pulps. This lack of affinity has the advantage that acid dyestuffs do not mottle in blended furnishes and produce level shades – and even appearance – when properly fixed by fixing agents, rosin size and papermaker's alum (aluminium sulphate). Acid dyestuffs are precipitated on the fibres by these materials, which form a linkage between the cationic-treated fibres and the dyestuff molecules. Sizing improves the retention of lake particles by forming aluminium resinate. Because of poor affinity and good solubility, acid dyestuffs have poor ‘bleedfastness’ – they lose colour when wet, forming coloured backwater, and are therefore suitable for paper that does not require this fastness, such as construction grades. Acid dyestuffs are most suitable for calendar staining or surface colouring, due to their solubility and brightness of shade.

2.1.5.3 Direct dyestuffs

The difference in the affinity of direct dyestuffs for ligneous and bleached pulps is considerably less than that of basic dyestuffs, but direct dyes are able to colour bleached pulps more evenly because they are easily wetted and penetrate rapidly. Direct dyestuffs generally have a high affinity for cellulose fibres and are therefore the most useful dyestuff for unsized or neutral pH dyeings. Their bonding ability to non-ligneous pulps and excellent fastness properties to light and bleeding make them useful for all fine papers. The shades of direct dyestuffs are not as bright as those of acid or basic dyestuffs and in blended furnishes (bleached-ligneous pulps) mottling or graniting may occur.

2.1.5.4 Pigments

Synthetic organic pigments are replacing the use of some inorganic pigments for ecological reasons. The conditions of dyeing are quite different for pigments than for soluble dyestuffs. Pigments do not react chemically with the fibre, but are fixed physically and are dependent on filtration, absorption, occlusion and flocculation. Papers dyed with pigments have good fastness properties, but pigments have poor affinity and low tinctorial strength. In addition, two-sidedness problems limit their application to paper.

2.1.5.5 Fluorescent whitening agents (optical brighteners)

These are fluorescent substances that transform invisible ultraviolet light into visible blue light. Fluorescent whitening agents change the appearance of paper in two ways: by emitting light and therefore increasing the luminosity (brightness); and by changing the shade from yellowish white to bluish white. They are unfavourably influenced by factors such as light with a low ultraviolet content and by the high absorption of ultraviolet light by pulps, chemicals and fillers. They can be used in the wet end, as a surface colorant, or in combination to obtain the greatest efficiency or yield.

2.1.5.6 Amounts used for dyeing of paper

Dyes and optical brighteners are added in the paper-making process during the preparation of printing and writing grades, as well as tissue and newsprint grades. Dyes are applied at concentrations as little as 0.005 per cent (w/w) or less for very pale shades and tints, or as much as 10 per cent (solid) to 20 per cent (liquid) for dark shades and blacks (Ros and Berns 1988). Optical brighteners are typically used at rates of 0.02–0.3 per cent, although a maximum value of 1.2 per cent has been reported (Baumann and Herberg-Liedtke 1993). These previously published data agree well with more recent data (see Appendix 1; Table A1.4) showing that the rate of use of dyes and optical brighteners in UK paper mills ranges from <0.005 per cent to 0.8 per cent (w/w). The typical amounts used in paper-making are summarised in Table2.1.

2.1.6 Printing inks and toners

In addition to the coatings applied at paper mills, coatings such as printing inks, dyestuffs and toners are applied elsewhere. These types of substances will be present on the paper when recycled and can be released to the environment during the recycling process. Typical quantities of inks and other coatings applied to paper are shown in Table2.1.

Printing ink is a mixture of colouring matter (colourant) dispersed or dissolved in a vehicle or carrier, forming a fluid or paste that can be printed onto a substrate and dried. The colourants used are generally pigments, toners and dyes, or combinations of these materials, which are selected to provide the desired colour contrast with the paper material. The vehicle acts as a carrier for the colorant during the printing operation and, in most cases, also serves to bind the colorant to the substrate. There are four principal classes of printing ink, which vary considerably in physical appearance, composition, method of application and drying mechanism. These classes also fall into two general types of consistency or viscosity: paste and liquid. The classes are: letterpress and lithographic (litho) inks, which are called paste inks; and flexographic (flexo) and rotogravure (gravure) inks, which are called liquid inks (Kirk Othmer 2001). Information on the processes and substances used for printing is available in an ESD produced on the printing industry (Grafen and Baumann 1999).

Ink jet inks are liquid inks and are usually water-based dye types with little or no resin component (CEPI 2002b). Typical dye contents of ink jet inks are 1–6 per cent (w/w) for black inks and 1–5 per cent (w/w) for colour inks (this information is based on material safety data sheets for common ink jet cartridges from the major suppliers in the EU, which were obtained from the internet). The actual concentrations used were not always specified (the values were usually given as < values or a range), but a reasonable ‘typical’ value would appear to be around 3 per cent for black inks and 2.5 per cent for colour inks.

Xerography is a non-impact printing process used in photocopying machines and laser printers, in which an image is created by using small, electrostatically-charged particles that carry, inter alia, pigment and dyestuffs. The dry, fine particles (about 10µm in diameter) are known as toner and these can have a very complex chemical composition. The core of the particles generally comprises an inert inorganic material, such as alumina or silica, which may have had its surface modified with, for example, organosilicon compounds. Charge additives may be added to the toner at concentrations of 1–19 per cent (w/w) and consist of waxes (polyethylene, polypropylene or paraffin), metal salts or metal salts of fatty acids. Waxes are generally added at concentrations of 1–15 per cent by weight. Colourants consisting of cyan, magenta, yellow, black (carbon black or magnetite), red, green or blue pigments or dyestuffs, or mixtures of these, may be used, with the colorant comprising 2–30 per cent (w/w) of the toner particle. For example, copper phthalocyanine compounds are the preferred cyan pigments and CI Solvent Yellow 16 is a preferred yellow pigment. A binder (thermoplastic polymer) is used to hold the components together and this may be a polyester, thermoplastic resin, polyolefin, styrene acrylate, styrene methacrylate, styrene butadiene or crosslinked styrene polymer, epoxy, polyurethane or vinyl resin or a polymeric esterification product of a dicarboxylic acid and a diol such as a diphenol or a bis-phenol. The resin binder may comprise 50–90 weight per cent of the toner (USPTO 2002).

After the toner particles have been electrostatically deposited on the paper, they are subjected to a high temperature, which causes the polymer in the toner particles to melt and adhere to the paper. The discrete particles also fuse together during this high temperature treatment, forming much larger solidified lumps, depending on the size of the image. The toner is then well bonded to the paper fibres.

The amount of coating applied to a paper can vary dramatically and hence useful information on the quantities applied to paper is difficult to obtain. For example, the printer manufacturer Canon (1999) has carried out research that shows that the average page coverage for laser printing (for Xerox copiers and printers) ranges from 2–3 per cent for e-mails to more than 80 per cent for presentations (this relates to both black and coloured toners). The average page coverage for printed output was reported by Canon as 8 per cent. Similar figures have been reported by another manufacturer (Kyocera 2002), which states that toner coverage is sometimes quoted as 5 per cent, 4 per cent or 2 per cent. However, Kyocera asserts that 5 per cent is the figure most commonly used by research companies, as it is considered to be a fair reflection of the amount of toner used for a standard letter according to the relevant ISO standard 10561 (ISO 1999).

A recent estimate by CEPI (2002b) states that the proportion of printing ink in average recovered paper mixtures amounts to around 2 per cent by weight, which is in line with the values in Table2.1. In addition, a recent estimate by WRC-NSF (2002) showed that over a period of one year the amount of toner used by laser printers and photocopiers was 0.91 per cent w/w, which is also within the range shown in Table2.1. These recent figures suggest that the data in Table2.1 still provides reasonable estimates for the amounts of coatings being used.

2.1.7 Sensitised papers

Two major speciality sensitised papers are temperature-sensitive paper (thermal paper) and pressure-sensitive paper (carbonless copy paper).

2.1.7.1 Thermal paper

Thermal paper is widely used in FAX machines, bar code printers and cash till printers. The temperature-sensitive coating consists of two or more colourless components, which react together when heated to give a high contrast mark. The printing layer can contain, for example, a precursor for a fluoran leuco dye together with an acid developer (for example, bisphenol A) in a binder (such as kaolin and polyvinyl alcohol) (Kirk Othmer 2001). As the reaction only occurs where the paper is printed, the majority of the chemicals remain in the paper in an un-reacted form. During alkaline pulping (as in de-inking), the colour-former hydrolyses and, together with all of the co-reactant, is released to water – hence there is 100 per cent release to water in this situation. There is likely to be less release in cases where a de-inking step is not employed (see Section 4.2.1).

2.1.7.2 Carbonless copy paper

Carbonless copy paper is widely used in business pro-formas and traditional credit-card slips. The bottom surfaces of the top and second sheets of these forms (sheets A and B) are coated with a layer of microcapsules that have a diameter of 3–6µm. The coating includes inert spacer particles (often starch) that are larger than the microcapsules and protect the microcapsules from premature rupturing. The capsules, which are filled with a colourless solution of 2–6 per cent leuco dye dissolved in a high boiling organic solvent, make up 3–5 per cent (w/w) of the paper (the complete coating on the bottom surface of the paper makes up 5-8 per cent of the weight of the paper) and rupture under the pressure encountered in normal handwriting or impact printing. The dye solution released is transferred from the bottom surface of sheets A and B to the top surface of sheets B and C, respectively, where it reacts to form an image. The reactive coating on the top surface of sheets B and C may be a phenolic resin, salicylic acid or active clays, such as acid-treated montmorillonite. These coatings contain acidic sites that take part in the colour reaction and form a light-stable image. This coating makes up 8–12 per cent of the paper by weight. Sheet A is called a coated back (CB) sheet, sheet B is a coated front back (CFB) sheet and sheet C is a coated front (CF) sheet. The capsules and reactive coating can also be coated on the same paper surface. In this case, the product is called self-contained carbonless copy paper (Kirk Othmer 2001).

Carbonless copy paper uses a number of leuco dyes; for example, a mixture of crystal violet lactone (CVL) and N-benzoylleucomethylene blue (N-BLMB), which react with the clay to form a blue colour. More recently, fluoran and phthalide leuco dyes and metal chelate systems have been developed to provide a black colour. High boiling point organic liquids used as solvents include benzylated ethylbenzene, benzyl butyl phthalate, isopropylbiphenyl and di-isopropylnaphthalene (DIPN) (Kirk Othmer 2001).

For reactive coatings, clay technology is still the primary approach in Europe (with around a 70 per cent market share in 2003). However, its limitations (notably a more powdery product) have led to an increase in the use of phenolic resins over recent years. These now account for about 20 per cent of the European market. This is in contrast to the US and Japan, where phenolic resins have a market share of around 80 per cent. Zinc salicylate has increased in use in the Far East, mainly in Indonesia and Japan, but it is significantly more expensive than resins (3–4 times) and has to be used in a very specific way to be cost-competitive. At present, only certain plants in the EU have the capability to use this technology cost-effectively (EPRA 2004).

The colour-former and organic solvent will be released to water by hydrolysis during alkaline pulping and both have low solubility in water. Some of the colour-former will react with the reactive substances (generally clays) released during pulping. It is assumed that around 10 per cent of the colour-former is bound up in this way and that 50–70 per cent of the dye-clay complex is released to waste water (PIRA 1991). As for thermal paper, release of the substances may be lower where de-inking is not employed (see Section 4.2.1).

2.2 Paper recycling: production of recycled fibres

2.2.1 Recycled paper and board grades

Recycled waste paper and board comes in a wide range of grades and these different grades cannot be used universally in the production of recycled fibre and paper. Consequently, waste papers are grouped into different categories, which are traded by recycling companies. Ten waste paper groups are recognised by the Paper Federation of Great Britain (PFGB).

- Group 1 – White wood-free unprinted stock: best white shavings, cream shavings, white and cream envelope cuttings, white coated paper, white printers shavings and white soft tissue paper.

- Group 2 – White wood-free printed stock: best one cuts, black and white periodicals and magazines (PAMS), book paper, sulphate waste, tear white shavings, white carbonless copy paper, white continuous stationary, white heavy letter paper and white listings paper.

- Group 3 – White and lightly-printed wastepaper: lightly-printed mechanical paper, lightly-printed scanboard, white mechanical coated paper, white mechanical listings paper, white duplex board, white unprinted newspapers and woody one cuts.

- Group 4 – Coloured wood-free stock: best coloured PAMS, coloured carbonless copy paper, coloured continuous stationery, coloured heavy letter paper, coloured mill broke, coloured shavings, coloured tissue paper, multigrade paper, sulphite bag waste, white and lightly toned shavings.

- Group 5 – Heavily-printed mechanical paper: crushed newspapers, green mechanical listing paper, heavily printed scanboard, mechanical book paper, old newspapers and PAMS, over-issue newspapers, over-issue PAMS and telephone directory paper.

- Group 6 – Coloured kraft and manilla stock: buff and coloured tab cards, buff envelope cuttings, dark and lightly coloured manilla papers, kraft liner, multi-ply kraft sacks, new brown krafts and old brown and coloured krafts.

- Group 7 – New kraft liner stock: double lined kraft paper and new kraft cuttings.

- Group 8 – Container waste stock: unprinted corrugated boxes and solid fibre board.

- Group 9 – Mixed waste paper: mixed and various types of re-pulpable paper, cartons and board.

- Group 10 – Coloured card stock: off-cuts, sheets and blanks of printed and unprinted card, new or used grey chipboard, white lined boxboard or waste based boards.

The utilisation of waste paper by grade in the UK and Western Europe and the relation of these grades to the PFGB groups are shown in Table 2.2.

Table 2.2 Recovered paper utilisation by sector

Paper and board grade	**Waste paper grade used and percent**	**% use by each sector**	
		UK	**Western Europe**
Newsprint	Newsprint grades (Group 5)–100%	110*	69
Printings and writings	High grades (Groups 1-4)–100%	10	9
Corrugated case materials	Brown grades (Group 6–8)–78% Mixed grades (Group 9–10)–15% Newsprint grades (Group 5)–5% High grades (Groups 1–4)–2%	105*	91
Packaging papers	High grades (Groups 1–4)–20% Newsprint grades (Group 5)–3% Brown grades (Groups 6–8)–75% Mixed grades (Group 9–10)–2%	72	52
Packaging board	High grades (Groups 1–4)–10% Newsprint grades (Group 5)–5% Brown grades (Groups 6–8)–60% Mixed grades (Group 9–10)–25%	65	53
Tissue	High grades (Groups 1–4)–85% Newsprint grades (Group 5)–8% Brown grades (Group 6–8)–3% Mixedgrades (Groups 9–10)–3%	79	64
Speciality	Not known	Not known	Not known

Note: *Utilisation rates above 100 per cent are possible because 1 tonne of recovered paper yields on average 850 kg of fibre.

It is common practice to blend old newspapers (ONP) and old magazines (OMG) in the feed for a paper recycling plant. Typical ONP:OMG ratios range from 70:30 to 50:50, depending on the quality of the de-inked pulp required (Chabot *et al.* 1998).

A slightly different system of grades for waste paper is used in continental Europe. A European standard list of grades of recovered paper and board has been developed by the CEPI, the European Recovered Paper Association and the European Standards Organisation (CEN), and has been recently published by CEN (2002). This list has five main groups.

- Group 1: Low qualities – sub-divided into 11 types.

- Group 2: Medium qualities – sub-divided into 12 types.

- Group 3: High qualities – sub-divided into 19 types.

- Group 4: Kraft qualities – sub-divided into eight types.

- Group 5: Special qualities – sub-divided into seven types.

A full version of the CEN list of standard qualities of recovered paper and board is provided in Appendix 2. The CEN list is intended for use by industry professionals, and organisations and individuals with an interest in the recovered paper sector, to assist in the buying and selling of raw material intended for recycling. It is not intended to specify all the qualities of recovered paper and board that exist, but rather to define those qualities most commonly traded in Europe. A comparison of the CEN list with the PFGB grades is provided in Appendix 3.

Table 2.3 provides a more descriptive categorisation in terms of the types of paper recovered and the recycled products made from them (CPI 2005). It should be recognised that there may be considerable variation in the types of paper in any specific batch of recovered papers.

Table 2.3 Products made from recovered papers

Papers recovered	Recycled products made from them
Unprinted or printed paper (such as 'junk' mail) Photocopy and computer paper	Newspapers, printing paper, writing paper, photocopy paper, computer paper, tissue
Newspapers, magazines, directories (white paper)	Newspapers, cartons, corrugated boxes
Paper, cartons, boxes of defined quality and known sources	Food packaging
Cartons, boxes, bags, sacks, tubes, corrugated boxes	Cartons, tubes, boxes, corrugated boxes
Directories (printed colours)	Packaging
Beverage containers, packaging	Packaging, heavy tubes, plasterboard

Waste paper and board recycling processes

The same basic techniques are used for recycling all grades of waste paper, but the end application effectively defines the number of stages that are needed in the process. In general terms, the cleaner the end product required, the more stages needed. The overall process is also known as stock preparation.

The recovered paper processing system varies according to the paper grade produced (packaging paper, newsprint or tissue) and type of furnish (fibre pool) used. Generally, recycled fibre processes can be divided into two main categories:

- processes with mechanical cleaning but without de-inking, for products like packaging grades and corrugating medium;
- processes with mechanical cleaning and de-inking, for products like newsprint, tissue, printing and copying paper, magazine paper or market de-inked pulp.

While many different recovered paper-processing systems are applied by European paper mills, all are based on similar steps that may be combined differently to fulfil their specific task. The typical stages of recycled fibre processing are shown in Table 2.4. The following diagrams outline typical processes in the production of brown grades (Figure 2.2), newsprint (Figure 2.3), tissue (Figure 2.4) and graphic paper (Figure 2.5) from recycled feedstocks. These figures have been adapted from WRAP (2002).

WRAP (2002) indicates that there are no differences in the technologies used for recycled paper across Europe. However, it is thought that some countries with very high collection rates for paper (such as Germany) tend to use more sophisticated systems with more stages (for example, additional screening and cleaning stages). This is a result of the overall lower quality of the secondary fibre caused by the higher collection rate. In addition, some German mills also may have pre-sorting systems (to remove plastic, metal and glass) and may also have more intensive treatment of the waste streams (due to the high costs of landfill/disposal).

Table 2.4 Typical stages of recycled fibre processing (stock preparation)

Recycling stage	Emissions – type	Destination
Repulping	Large particles, such as plastics, metals, stones and glass	Sent to landfill
Enzymatic de-inking	No emissions (inks removed by later flotation step)	
High density cleaner	Large particles, such as plastics, metals, stones and glass	Sent to landfill
Perforated screens	Particles >1mm to >4mm, such as plastics	Sent to landfill
Slotted screens	Particles >0.1mm to >0.5mm, such as stickies[a] and small plastic particles	Sent to landfill
Low consistency cleaner	Small plastic particles and stickies[a]	Sent to landfill
Flotation (de-inking)	Effective for particles in the 20–50μm range, such as ink particles, filler and short fibres	Sludge to land, landfill or incineration
Thickening	Water soluble and small particles (<20μm)	Water to dissolved air flotation or waste water
Washing	Water soluble and small particles (<20μm)	Water to dissolved air flotation or waste water
Dispurger/dispersion	All contaminants still present in pulp	To finished paper
Dissolved air flotation	Particulate material in sludge	Sludge to land, landfill or incineration
	Soluble material in waste water	To waste water or paper
High density storage	Water soluble and small particles (<20μm)	Water to dissolved air flotation or waste water
Bleaching	Water soluble and small particles (<20μm)	To waste water

Source: WRAP (2002).
Note: a) Stickies are small balls of adhesives.

Figure 2.2 Brown grades

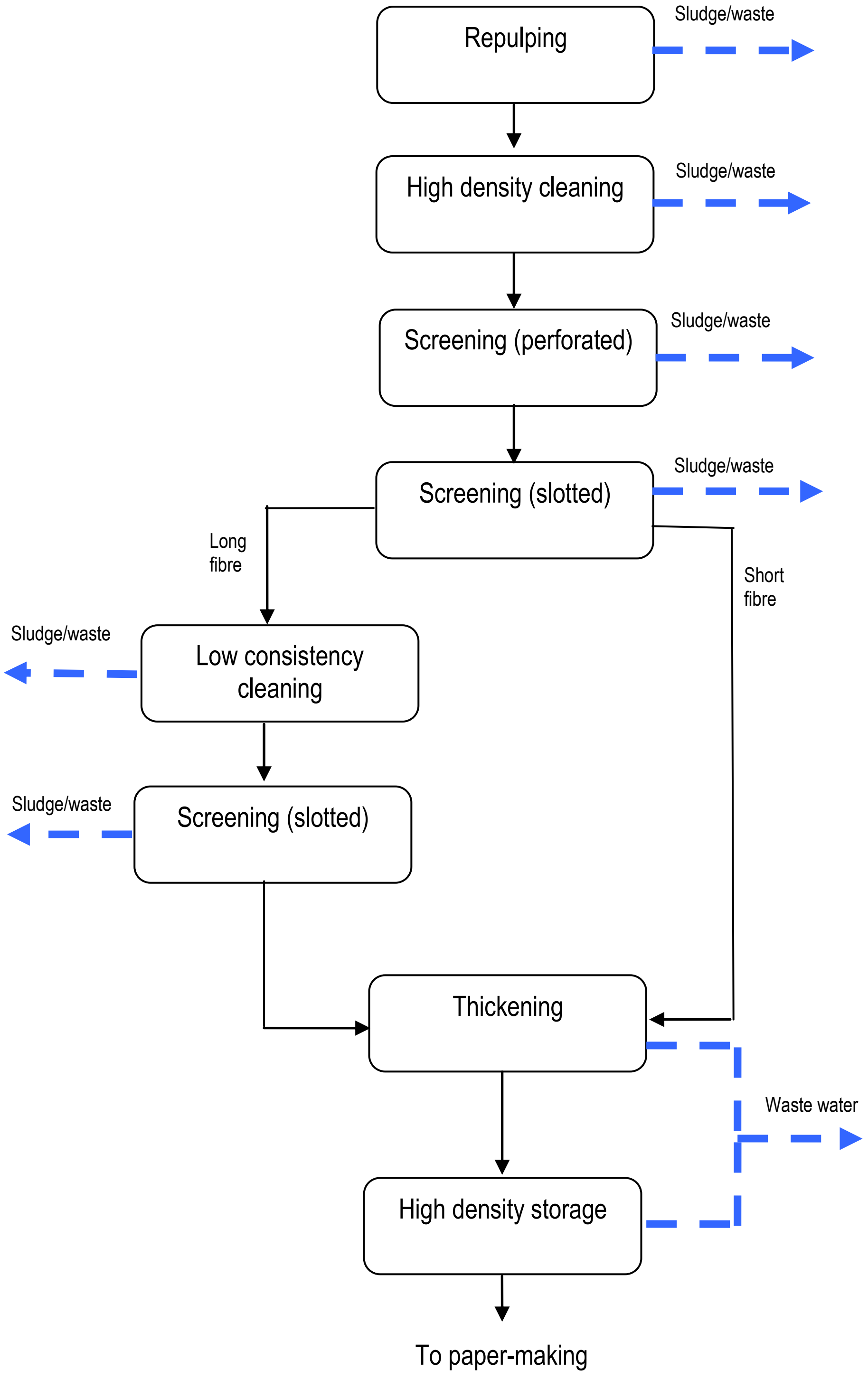


Figure 2.3 Newsprint

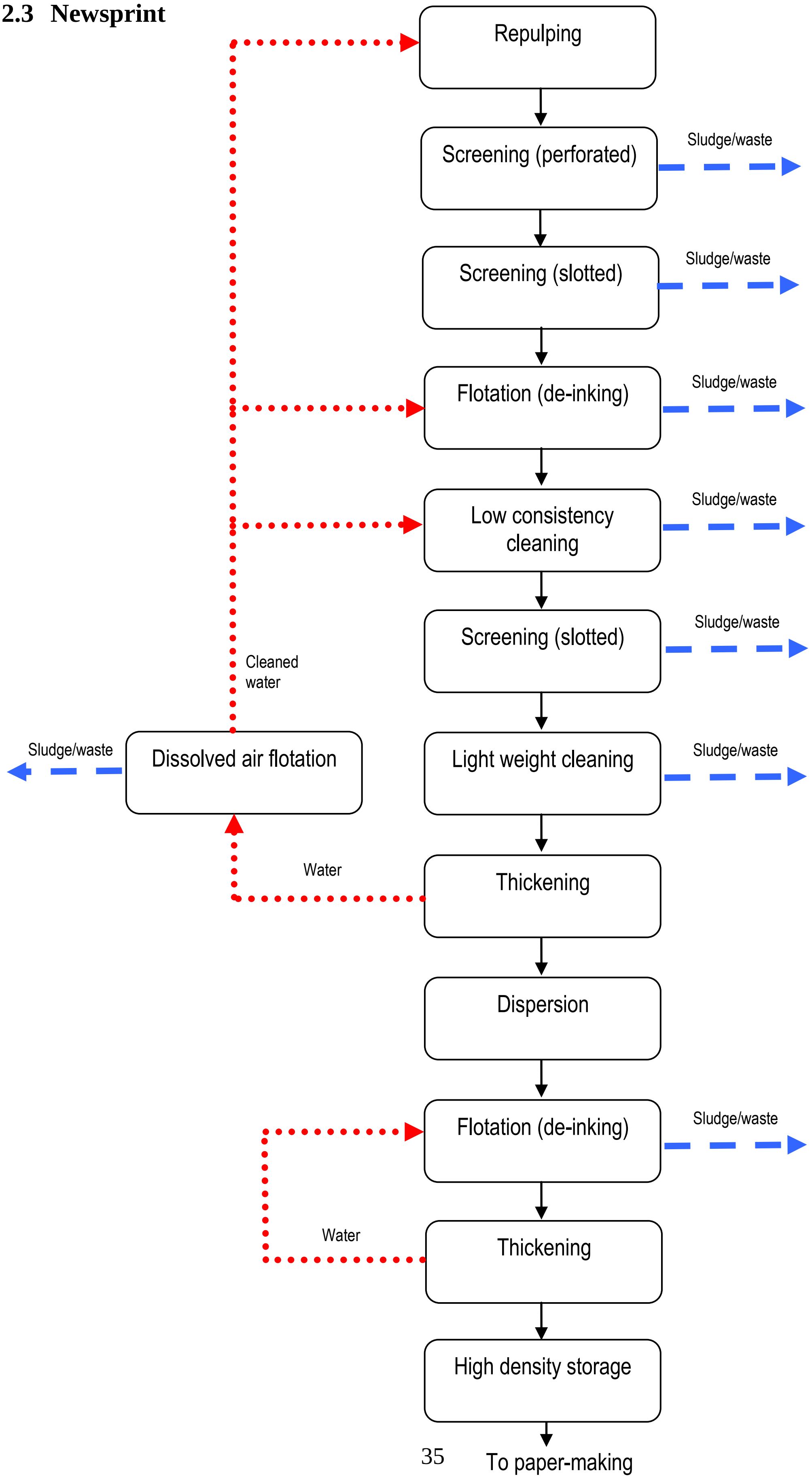


Figure 2.4 Tissue

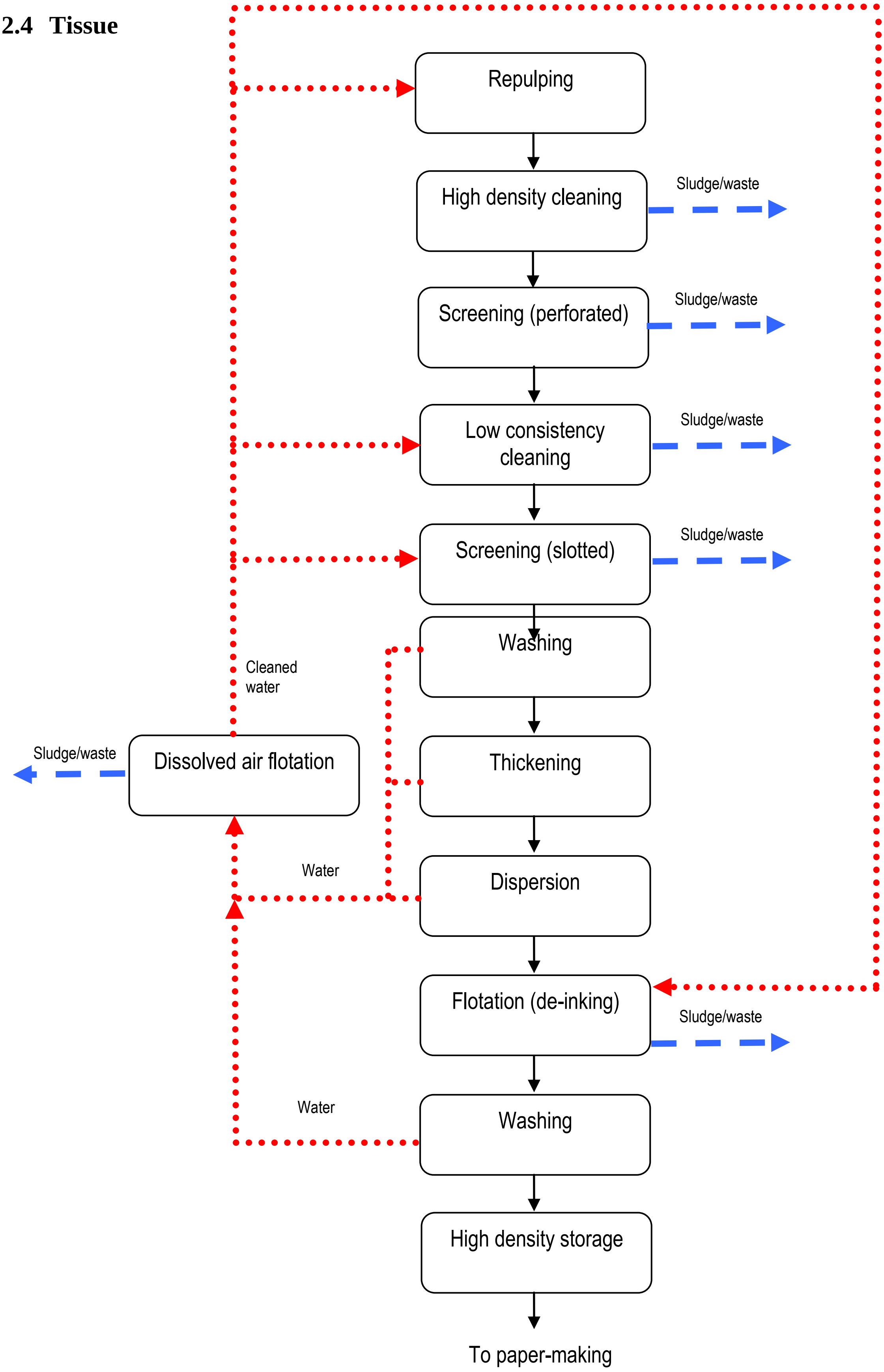
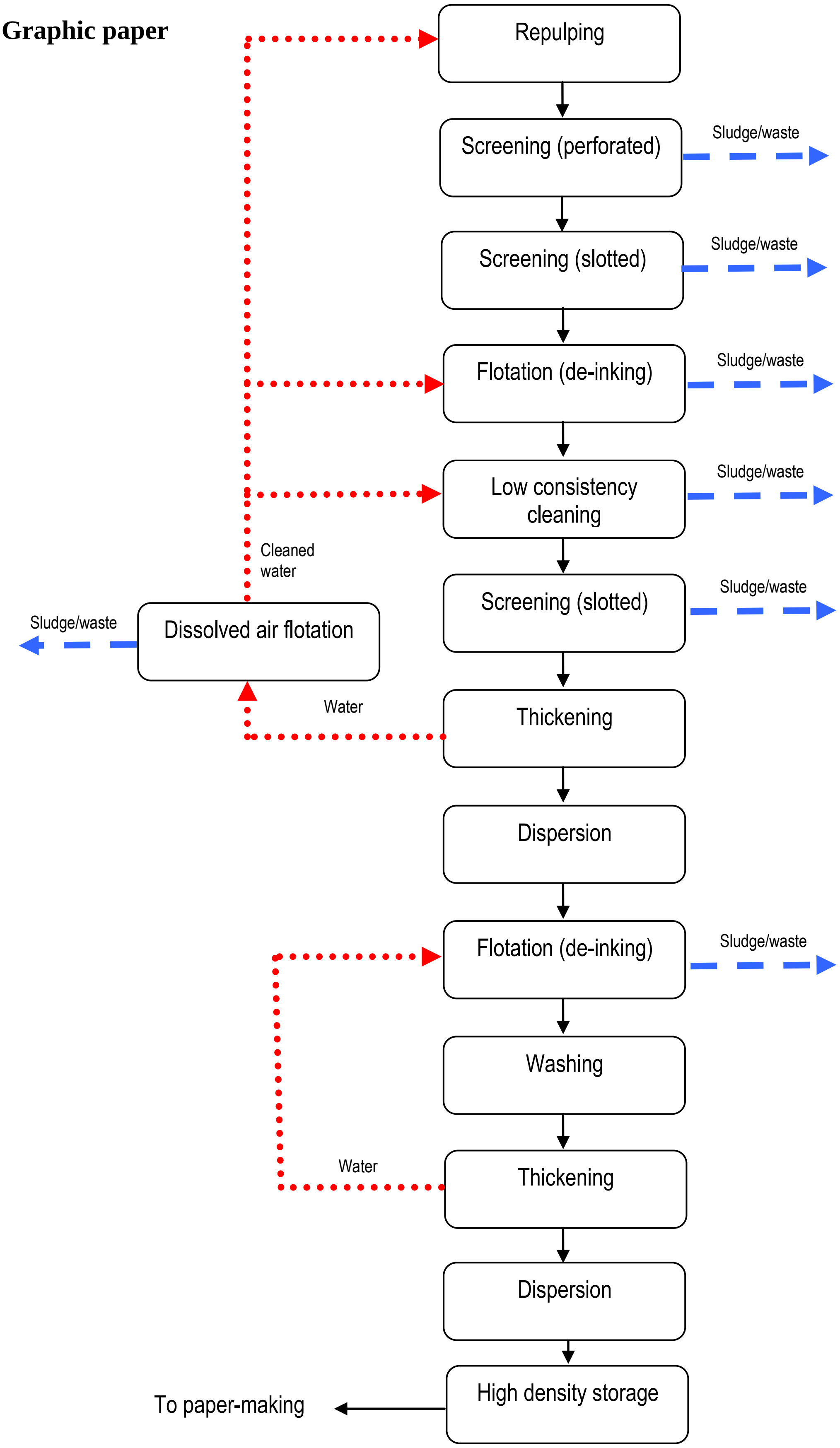


Figure 2.5 Graphic paper



2.3 Comparison of the UK industry with the rest of the EU

Much of the information reported in the preceding sections has been obtained for the UK industry and so it is relevant to consider any differences that may exist between the UK industry and the industry in the rest of the EU.

The production principles and processes used in the UK are, for the most part, comparable with those used in the rest of the EU. Some differences will exist regarding the availability and costs of raw materials, and these are outlined in the following sections.

2.3.1 Use of fibres

2.3.1.1 Virgin fibres

The UK does produce some mechanically-based virgin fibres and, in mills dealing with these fibres, the production processes will be comparable to those of other EU countries. The UK does not, however, produce chemical pulps and so UK mills using chemical pulps will buy it as a raw material in a dry-lap form that is re-slushed for use. The UK does, however, produce semi-chemical pulps.

EU mills producing chemical pulps are, for the most part, integrated with a paper-making operation. This will result in some differences, primarily related to the quality of the recycled water and its ‘knock on’ effect to paper-making additives. The additives used in the EU and the UK will be similar in generic terms, but may vary in terms of molecular weight and charge density. Overall, the paper-making process will be similar throughout the EU (including the UK) depending on the pulp type used. Any differences that may arise across the EU are likely to relate to whether or not individual mills are integrated operations and so they will be site-specific differences rather than national differences.

2.3.2 Recycled fibres

For the most part, the treatment and processing of recycled fibres in the rest of the EU will be similar to that in the UK. For example, de-inking, and the processes used for it, is comparable right across the EU. Some variations may exist, but these are more likely to be company-specific rather than geographically biased.

The fractions of recycled paper used in the UK in 1999 and in Germany and France in 1998 are shown in Table 2.5.

Table 2.5 Use of recycled fibres for paper production in Europe

Type of paper	Use of recycled fibres (%, based on recovered paper used)		
	Germany[1]	France[2]	UK[3]
All types	61	54	72
Printing and writing	37	11	18
Newsprint	117	58	110
Tissue	69	46	78
Board/packaging	96	33	78
Fluted (corrugated)	*	92	105
Manilla Board	*	90	*
Speciality	48	34	78

Notes: 1) VDP (2000); 2) COPACEL (2000); 3) This study.
* Not differentiated, probably included in board/packaging figure.

This shows that there is comparable use of recycled paper across all grades in the UK and Germany and similar use in France, although there is generally less use of recycled paper in France than in the UK and Germany.

2.3.3 Additives

2.3.3.1 Starch

Starch will vary depending on its source of origin, with variations principally revolving around whether it is potato-based or cereal-based (for example, corn).

2.3.3.2 Filler

Talc is used in a number of countries such as Finland, where it is an indigenous material, but it is not used in the UK, where chalk and clay are the predominant mineral fillers.

3. TYPES OF SUBSTANCES USED AND THEIR FUNCTION

The different processes used in paper recycling and paper-making have been described in Section1, and Table 3.1 provides an overview of the types of chemicals used in these processes and their function.

A large number of chemicals are used in the paper industry at various points to improve the operation of the paper machine (process aids) and to impart the required properties to the paper (product aids). Incoming water treatment is practised by many UK mills, with substances such as sodium hypochlorite or bromine-based compounds used as antimicrobial agents to reduce the microbial burden entering the mill. Occasionally, coagulants may be added to aid solids removal.

At the pulping stage, no chemicals are added at mills producing test liner and fluting (and corrugate). However, mills producing tissue and newsprint from recycled fibre will add sodium hydroxide at the pulping stage to assist in ink removal. Sodium hydroxide hydrolyses the ink resins back to their constituent components, allowing them to be separated from the fibre.

Agglomerating chemicals, such as surfactants, are also added at the re-pulping stage. Agglomerants chemically modify the surface of toner flakes to allow agglomeration to occur, and to increase the ink particle size and allow ink removal during flotation. A number of bleaching agents are used for papers requiring high brightness, such as newsprint and tissue. These agents include oxidative bleaching systems, which use hydrogen peroxide, oxygen and ozone, and reductive bleaching systems, which use sodium hydrosulphite or formamidine sulfinic acid (FAS). The premature decomposition of hydrogen peroxide by metal ions can be lessened by stabilising its environment with sodium silicate and chelating or sequestering agents such as pentasodium diethylenetriaminepentaacetate (DTPA) or ethylenediaminetetraacetic acid (EDTA).

Machine biocides are used by all mills to reduce the build-up of microbial deposits within pipes and paper-making equipment in contact with water. Additionally, these substances are used to reduce the planktonic microbial populations that may be retained by the paper sheet. Use of biocides is covered by a separate ESD on water treatment chemicals (Fielden *et al.* 1997) and by the ESD for biocides used as preservatives in paper coating and finishing, which is given in the EU Technical Guidance Document (based on Tisser and Chenais (2001) and Sirkka (2001)).

A wide variety of individual chemicals may be used for each function, either individually or in admixture, to obtain the properties required. Suggested ‘default’ values for the amounts used are given in Table 3.2. Typical ranges for the chemicals (kg) used for each function, based on information from the UK, are listed in the tables in Appendix 1. Where specific information is available, this should be used in preference to the default values.

Table 3.1 Substances used in paper-making and/or paper recycling, and their function

Process stage	Function	Type(s) of chemical	Examples
Incoming water treatment	Softening Disinfection Solids removal	Salts Oxidants Coagulants	Sodium chloride Sodium hypochlorite Polyaluminium hydroxychloride
Stock preparation: 1) De-inking chemicals	Removal of ink particles by flotation	Alkali or soap or detergent	Sodium hydroxide or ethoxylated surfactants
Stock preparation: 2) Bleaching agents	To whiten pulp	Oxidants, reducing agents	Hydrogen peroxide or sodium hydrosulphite
Stock preparation: 3) Colourants and optical brighteners	To change the colour of the product	Dyes, pigments, optical brighteners	Azo dyes and stilbenes
Wet end operation: 4) Drainage and retention	Removal of water from fibre layers	Coagulants	Cationic starch, sodium polyacrylamides
Wet end operation: 5) Dry strength agents	Strengthen paper		Cationic starch
Wet end operation: 6) Wet strength agents	Strengthen paper	Resins	Polyamidamine-epichlorohydrin
Stock preparation: 7) Sizing agents	Control liquid absorbance		Alkyl ketene dimer
Stock preparation: 8) Raw materials	Form the bulk of the product	Pulp or recycled paper, filler	Chalk
Coatings	Surface modification	Resins, pre-polymers	Melamine-formaldehyde, styrene-butadiene
Process aids: 1) Machine biocides	Prevent biological growth in machines	Various	Glutaraldehyde, 2,2-dibromo-2-nitrilopropionamide
Process aids: 2) Deposit and cleaning agents	Removal of deposits from machinery	Acids and surfactants	Phosphoric acid
Process aids: 3) Defoamers	Removal of air bubbles from the pulp	Fatty acid esters, triglycerides	
Process aids: 4) Reagents, lab. chemicals, miscellaneous	Various		
Treatment chemicals	Effluent treatment	Oxidants, coagulants and pH adjusters	Polyaluminium chloride, cyclohexylamine
Maintenance chemicals	Machinery maintenance	Oils, acids, bases and surfactants	Sodium hydroxide, hydrochloric acid

Source: Based on Section 2, updated through consultation (EPCG 2005).

Table 3.2 Amounts based on chemical type and use in paper-making and paper recycling

Process stage	Type(s) of chemical	Examples	Mass of substance used per tonne of paper (M_s) (kg/tonne)			
			Liner, corrugated and fluting	Newsprint	Tissue	Printing and writing
Incoming water treatment	Salts	Sodium chloride	0.1	0.1	0.1	0.1
	Oxidants	Sodium hypochlorite	0.015–0.85	0.015–0.85	0.015–0.85	0.015–0.85
	Coagulants	Polyaluminium hydroxychloride	0.013–009	0.013–0.09	0.013–0.09	0.013–0.09
Pulping	Soluble inorganic	Sodium hydroxide				
Stock preparation: 1) De-inking chemicals	Soluble inorganic	Sodium hydroxide		5–25	5–25	
	Soap or detergent	Ethoxylated surfactants		0.08–5.8	0.08–5.8	
	Bleach	Hydrogen peroxide		2	2	
	Flocculant	Sodium polyacrylamide		0.68	0.68	
Stock preparation: 2) Bleaching agents	Oxidants	Hydrogen peroxide or sodium hydrosulphite		0.1–40	0.1–40	
	Soluble inorganic	Sodium silicate		3	3	
Stock preparation: 3) Colourants and optical brighteners	organic paper dyes and optical brighteners	Basazol blue 15l		0.001–0.05	0.001–8.3	0.001–5
	Inorganic pigments	Titanium dioxide		0.003–40	0.003–40	0.003–40
	Dye fixative	Polyamine		0.08	0.08	0.08
Wet end operation: 4) Drainage and retention	Coagulants	Cationic starch	0.3–10	0.3–5		0.3–8
	Polymeric retention aid	Polyacrylamide	0.1–11	0.1–2		0.1–2
	Clay	Bentonite	1.0–1.8	1.0–1.8		1.0–1.8
	Soluble inorganic	Aluminium sulphate	1–10	1–5		1–5
Wet end operation: 5) Dry strength agents	Organics	Cationic starch	1–10			

Process stage	Type(s) of chemical	Examples	Mass of substance used per tonne of paper (M_s) (kg/tonne)			
			Liner, corrugated and fluting	Newsprint	Tissue	Printing and writing
Wet end operation: 6) Wet strength agents	Resins	Melamine-formaldehyde			0.1–20	
Wet end operation: 7) Sizing agents		Alkyl ketene dimer				0.33–28
Stock preparation: 8) Raw materials	Pulp or recycled paper, filler	Kaolin				
Coatings	Resins, pre-polymers Soluble organic and inorganic	Styrene-butadiene Starch and CMC			1–40 0.02–2.25	0.1–40 0.02–2.25
Process aids: 1) Machine biocides	Various	Glutaraldehyde, 2,2-Dibromo-2-nitrilopropionamide	0.00001–0.2*	0.00001–0.2*	0.00001–0.2*	0.00001–0.2*
Process aids: 2) Deposit and cleaning agents	Acids and surfactants	Phosphoric acid	0.00001–10	0.00001–10	0.00001–10	0.00001–10
Process aids 3) Defoamers	Fatty acid esters, triglycerides		0.003–0.9	0.003–0.9	0.003–0.9	0.003–0.9
Effluent treatment chemicals	Soluble inorganic and organic Insoluble inorganic and organic Nutrient	Hydrochloric acid Polyacrylamide Ammonium salts, urea	0.4–20 0.1–2 0.7–12	0.4–20 0.1–2 0.7–12	0.4–20 0.1–2 0.7–12	0.4–20 0.1–2 0.7–12

Process stage	Type(s) of chemical	Examples	Mass of substance used per tonne of paper (M_s) (kg/tonne)			
			Liner, corrugated and fluting	Newsprint	Tissue	Printing and writing
Maintenance chemicals	Soluble inorganic and organic	Sodium hydroxide, surfactants	0.01–3	0.01–3	0.01–3	0.01–3
	Insoluble inorganic and organic	Insoluble inorganic and organic	0.01–1	0.01–1	0.01–1	0.01–1

Source: Original information collection as in Appendix 1; updates from consultation (EPCG 2005).

Note: *See also the existing ESDs (for example, EU Technical Guidance Document; Tisser and Chenais 2001).

4. IDENTIFICATION OF THE POTENTIAL POINTS OF RELEASE AND ESTIMATES OF THE AMOUNTS OF SUBSTANCE RELEASED AT THESE POINTS

4.1 Sources of emissions to the environment

During the course of pulp- and paper-making and paper recycling, emissions can occur to all parts of the environment and an overall schematic of the possible emission routes is shown in Figure 4.1. These emissions may occur at all stages of the paper-making and recycling process. The typical releases in terms of their route into the environment and percentages are summarised in Table 4.3 and table 4.4.

As the paper recycling stage (or wood pulping stage) of the processes is often integrated with the subsequent paper-making stage, it is not easy to isolate the water usage and waste streams for paper recycling from those of the whole site. But it is important to do so, as some of the substances used or released from paper recycling will only be present in water or waste streams from that process. Subsequently, these waste streams may be mixed with waste streams from other parts of the paper-making process.

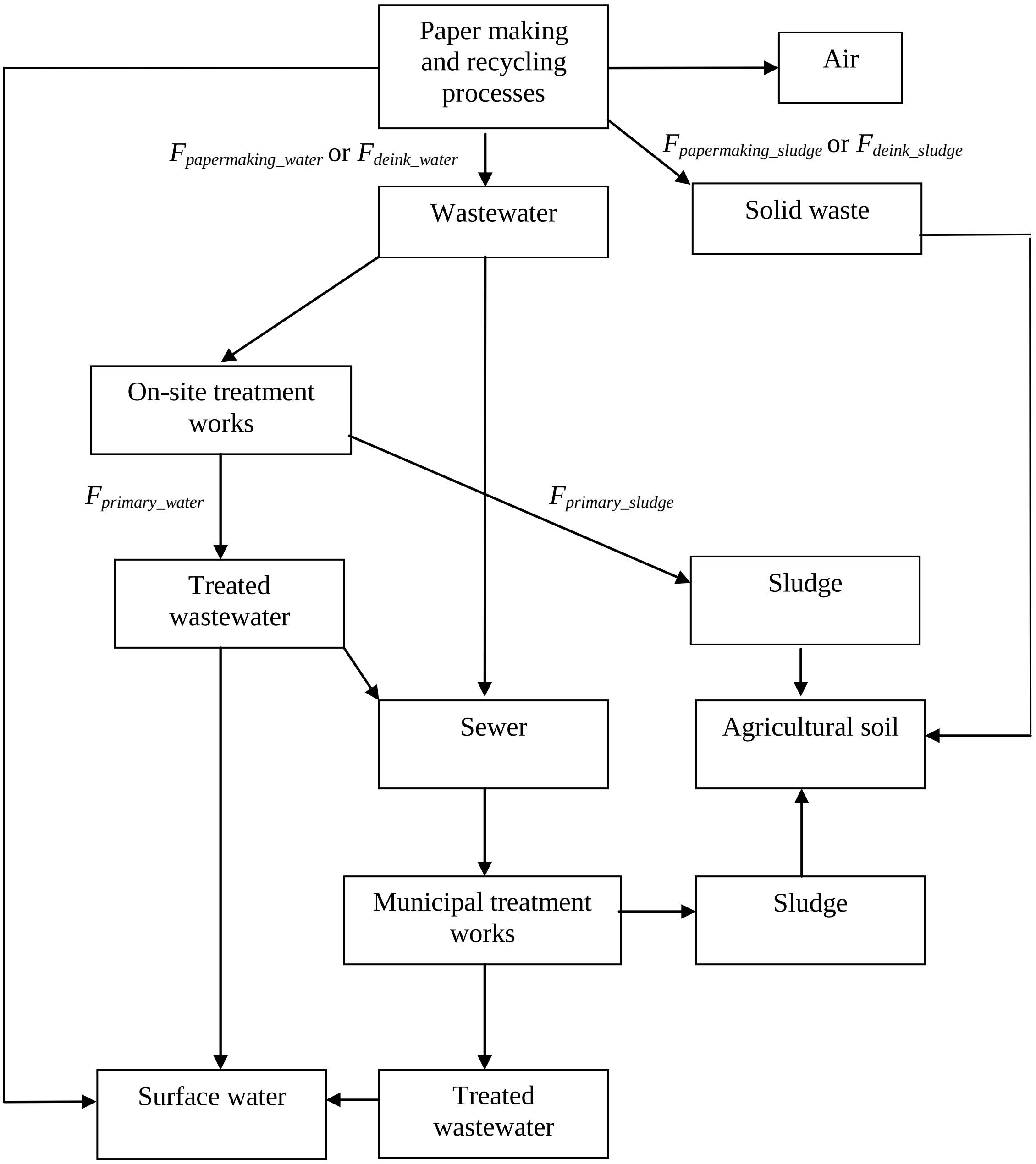
The main points at which releases can occur are identified in Figure 2.2 to Figure 2.5 for paper recycling processes and Figure 2.1 for the overall paper-making process. This section includes some comments on these areas.

4.1.1 Releases to water

Releases to water give rise to the main pollution potential from the pulp and paper industry. For recovered fibre processing and paper-making operations, the main discharges to water are suspended solids and oxygen depleting compounds, as measured by Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). There are also discharges of some of the large number of substances used in the paper-making process and emissions of these substances form the bulk of the assessments and estimates within this ESD.

During paper recycling, some substances present in the waste paper have the potential to be released to water. In addition, a number of chemicals are added to the pulp during the recycling process and these also have the potential to be released to water.

Figure 4.1 Potential emission pathways



A number of prescribed substances may also be detected at low levels in paper mill effluents, including cadmium, mercury and pentachlorophenol. These prescribed substances are not deliberately used by the UK paper industry, but may be present in the raw materials as impurities.

4.1.1.1 Water use

The amount of water used by different mills and for different products can vary dramatically and the information obtained on water usage for UK paper mills is shown in Table 4.1. Where data were available for two mills a range is given, otherwise a single value is presented. These data are taken from measured data collected under the IPPC programme in the UK. Figures for the EU as a whole are given in BREF (2001) and are summarised in Table 4.2.

It should be noted that, as a general rule, the larger the paper plant the more water it will use. Hence, although a larger amount of substance may be released at a larger plant compared with a smaller plant, this will generally be in a larger amount of water and so the overall concentration should be similar.

Wastewater treatment capabilities for paper mills and recycling plants in the UK are described further in Appendix 5.

Table 4.1 Water use in UK paper mills

Product	**Amount used (m^3 per day)**	**Amount used (m^3 per year)**	**Amount used (m^3 per Air Dried Tonne (ADT))**
Newsprint	13,500–16,393	4,927,500–5,318,989	13.4–17
Tissue	8,500	3,102,500	32.5
Liner, fluting and corrugated	2,200	781,000	2.8
Printing and writing	2,473–4,668	902,645–1,704,000	6.6–31
Speciality	14,000	5,110,000	409
Miscellaneous (manilla board, printing and writing and speciality)	3,578	1,306,000	36

4.1.2 Releases to product

Substances that are either present in the waste paper being recycled or are added to the pulp during the recycling process can be carried through to the finished paper product. This means that substances present in the waste paper may be included in different types of paper product from that in which they were first used. The extent to which this occurs depends to a large extent on the processes used during the recycling process. As an example, measurements on the fate of bisphenol A from thermal paper in a paper mill producing packaging materials from recycled paper (and so not using a de-inking process) showed that 90 per cent of the substance remained in the pulp and hence went on to be incorporated into the packaging material (Environment Agency 2004). Substances may also go through a number of life cycles within different products and a number of possible scenarios are considered later in this document. The fibres eventually lose strength and are no longer suitable for recycling. For newsprint, an overall lifetime of 2–2.5 recycles is considered realistic. For packaging grades, the number of recycles is likely to be greater.

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Table 4.2 Information on recovered paper types, water consumption and waste generation from production of paper

Paper type	Fibre source used	Amounts of raw materials used	De-inking	De-ashing	Sludge generation (as % of input raw material)			Waste generation from stock preparation[a]	Total water flow from whole plant[b]
					De-inking	Process water clarification	Waste water		
Newsprint	Recovered fibres: typically a 50:50 mixture of newspaper and magazines	1,120 kg/tonne paper recovered paper, 130 kg/tonne paper wood chips, 50 kg/tonne roundwood, 10 kg/tonne Kraft pulp	Yes					170–190 kg/tonne paper organic content 35–45%	8–16 m^3/tonne paper [8–15 m^3/tonne paper][c]
Printing and writing paper	Recovered fibres: 50:50 mixture of newspapers and magazines (for lower grade writing paper and copy paper)		Yes						
	Virgin fibres								5–40 m^3/tonne paper[d] 5–50 m^3/tonne paper[e] [10–15 m^3/tonne paper][c]
Graphic (supercalen-dered and lightweight	Recovered fibres: mixture of newspapers and magazines		Yes		7–16%	1–5%	~1%	450–550 kg/tonne paper – organic content 45-55%	8–16 m^3/tonne paper

Paper type	**Fibre source used**	**Amounts of raw materials used**	**De-inking**	**De-ashing**	**Sludge generation (as % of input raw material)**			**Waste generation from stock preparation**[a]	**Total water flow from whole plant**[b]
					De-inking	**Process water clarification**	**Waste water**		
coated) papers									
Tissue paper	Recovered fibres: generally a 50:50 mixture of newspaper and magazines (for kitchen roll or toilet paper), but any medium to high quality recovered paper (such as office paper) could be used).	Any mixture between 100% virgin fibre (1,010 kg/tonne paper) and 100% recovered paper (2,000 kg/tonne paper)	Yes	Yes	8–13%	15–25%	~1%	500–600 kg/tonne paper – organic content 40-50%	8–16 m^3/tonne paper
	Recovered fibres							400–1,000 kg/tonne paper (dry weight basis)	10–50 m^3/tonne paper [8–25 m^3/tonne paper][c]
	Virgin fibres: purchased chemical pulp							10–40 kg/tonne paper (dry weight basis)	[10–25 m^3/tonne paper][c]
Light top liner for recovered paper based carton boards	Recovered fibres		Yes						

Paper type	**Fibre source used**	**Amounts of raw materials used**	**De-inking**	**De-ashing**	**Sludge generation (as % of input raw material)**			**Waste generation from stock preparation**[a]	**Total water flow from whole plant**[b]
					De-inking	**Process water clarification**	**Waste water**		
Packaging papers and boards	Recovered fibres: supermarket and mixed recovered paper grades	1,100 kg/tonne paper of recovered paper (for Wellenstoff and testliner)	Not required but can be used depending on the quality of recovered paper used	-	0–1%	~1%		50–100 kg/tonne paper (dry weight basis) – organic content 70–80%	0–4 m^3/tonne paper [<7 m^3/tonne paper][c]
Paper board	Virgin fibres								0–20 m^3/tonne paper
Speciality paper	Unknown							79 kg/tonne paper (wet weight basis)[f]	10–300 m^3/tonne paper
Market deinked pulp	Recovered fibres		Yes		12–15%	15–25%	~1%		

Notes: a) Includes sludge from process water treatment (micro-flotation units). Note also that the figures in this column are related to the amount of paper produced, while those in the sludge generation columns are related to the amount of raw material.

b) The water flow figures include the water used in pulp or recovered paper processing, as well as in the paper-making process.

c) Achievable values using Best Available Techniques (BAT).

d) Value for uncoated paper.

e) Value for coated paper.

f) Based on total sludge (chemi-mechanical, biological and mixed sludge from waste water treatment) produced from 20 mills in the EU. The total specific waste generated (from all sources) was 168kg/tonne paper on a wet weight basis.

Source: BREF (2001).

4.1.3 Releases to land in sludge from effluent treatment works

There may be releases to land in sludge from effluent treatment works. These releases may contain heavy metals and organic compounds, which could be present at low concentrations in the raw materials used for paper-making or, in the case of the metals, may arise from corrosion and wear in the machinery used.

In addition to the sludge from effluent treatment works, sludges/solid waste can be generated by other processes that occur during paper recycling. Examples include cleaning (high density and low consistency), screening (perforated and slotted), de-inking (flotation de-inking) and dissolved air flotation of water streams. Depending on the process, sludge wastes will contain large particulates (plastics, metals), smaller particulates (grit, sand) and paper fibres, as well as the inks, toners and fillers initially present in the paper being recycled.

The larger metal and plastic particulate wastes appear mainly to be disposed to landfill. However, other sludges/waste streams are disposed of by other methods. For example, they may be combined with the other solid waste streams from the mill (such as the sludge from the effluent treatment works) and then either incinerated, disposed of to landfill or spread onto agricultural land as a soil improver. The latter option is currently common practice in the UK. Further information on sludges from paper production in the UK is included in Appendix 5, but overall 80 per cent of paper sludges are applied to agricultural land and 20 per cent are used for energy recovery or disposed to landfill. For estimating emissions on a regional basis, it is suggested that 80 per cent of the substance in the sludge is assumed to be applied to agricultural land and that the remaining 20 per cent is assumed not to give rise to releases to the environment.

4.2 Estimation of percentage emission of chemicals (based on process)

4.2.1 Paper-making

Estimated emissions of the chemicals used in paper and board production processes are presented in Table 4.3. These emission routes and percentages were developed from: data supplied by UK mills for this study; previously published information (Fielden *et al*. 1997, PIRA 1991); and expert knowledge of the types of chemicals and processes used. Table 4.3 is divided into sections based on the use of the chemicals and the information provided is then grouped into the chemical type, since each type of chemical will have similar physicochemical properties and should behave in a similar manner.

It should be noted that substances are used at different stages of the paper-making process and this could potentially affect the overall emissions from the process. For example, a substance that is added before or during the wet end operations potentially goes through more processing steps (and hence has more opportunities for removal or emission) than substances added after wet end operations (see Figure 2.1). There is currently little information available on the effect of the number of processing stages on the emissions of specific substances during paper-making.

Table 4.3 Emission routes and fractions in paper-making

Process stage	Type(s) of chemical	Examples	Primary emission routes[a]	Emission fractions[b]		
				$F_{papermaking\_sludge}$	$F_{papermaking\_water}$	$F_{papermaking\_paper}$
Incoming water treatment	Salts	Sodium chloride	100% to ETP	0	1	0
	Oxidants	Sodium hypochlorite	Residual consumed during pulping	0	0	0
	Coagulants	Polyaluminium hydroxychloride	100% to PS	1	0	0
Pulping	Soluble inorganic	Sodium hydroxide	100% to ETP	0	1	0
Stock preparation: 1) De-inking chemicals	Soluble inorganic	Sodium hydroxide	100% to ETP	0	1	0
	Soap or detergent	Ethoxylated surfactants	50% to PS/50% to ETP	0.5	0.5	0
	Bleach	Hydrogen peroxide	Consumed in process	0	0	0
	Flocculant	Sodium polyacrylamide	100% to PS	1	0	0
Stock preparation: 2) Bleaching agents	Oxidants, reducing agents	Hydrogen peroxide or sodium hydrosulphite	Most consumed in process; 1% to ETP	0	0.01	0
	Soluble inorganic	Sodium silicate	100% to ETP	0	1	0
Stock preparation: 3) Colourants and optical brighteners	Organic paper dyes and optical brighteners	Azo dyes and stilbenes	80–95% to P; 2–10% to ETP; 2–10% to PS	0.02–0.1	0.02–0.1	0.80.95
	Inorganic pigments	Titanium dioxide	75% to P; 25% to PS	0.25	0	0.75
	Dye fixative	Polyamine	100% to P	0	0	1
Wet end operation: 4) Drainage and retention	Coagulants	Cationic starch	80% to P; 10% to ETP; 10% to PS	0.1	0.1	0.8
	Polymeric retention aid	Polyacrylamide	98% to P; 2% to PS	0.02	0	0.98
	Clay	Bentonite	75% to P; 25% to PS	0.25	0	0.75
	Soluble inorganic	Aluminium sulphate	60% to P; 40% to ETP	0	0.4	0.6

Process stage	**Type(s) of chemical**	**Examples**	**Primary emission routes**[a]	**Emission fractions**[b]		
				$F_{papermaking\_sludge}$	$F_{papermaking\_water}$	$F_{papermaking\_paper}$
Wet end operation: 5) Dry strength agents	Organics	Cationic starch	90% to P; 5% to PS; 5% to ETP	0.05	0.05	0.9
Wet end operation: 6) Wet strength agents	Resins	Melamine-formaldehyde	80% to P; 10% to PS; 10% to ETP	0.1	0.1	0.8
Wet end operation: 7) Sizing agents		Alkyl ketene dimer	80% to P; 10% to PS; 10% to ETP	0.1	0.1	0.8
Stock preparation: 8) Raw materials	Pulp or recycled paper, filler	Kaolin	PS			
Coatings	Resins, pre-polymers Soluble organic and inorganic	Styrene-butadiene Starch and CMC	99% to P; 1% to ETP 50% to P; 50% to ETP	0 0	0.01 0.5	0.99 0.5
Process aids: 1) Machine biocides	Various	Glutaraldehyde, 2,2-Dibromo-2-nitrilopropionamide	See existing emission scenario*			
Process aids: 2) Deposit and cleaning agents	Acids and surfactants	Phosphoric acid,	95–100% to ETP	0	0.95–1	0
Process aids: 3) Defoamers	Fatty acid esters, triglycerides		100% to ETP	0	1	0

Process stage	**Type(s) of chemical**	**Examples**	**Primary emission routes**[a]	**Emission fractions**[b]		
				$F_{papermaking\_sludge}$	$F_{papermaking\_water}$	$F_{papermaking\_paper}$
Effluent treatment chemicals	Soluble inorganic and organic	Hydrochloric acid	100% to ETP	0	1	0
	Insoluble inorganic and organic	Polyacrylamide	100% to ETP	0	1	0
	Nutrient	Ammonium salts, urea	100% to ETP	0	1	0
Maintenance chemicals	Soluble inorganic and organic	Sodium hydroxide, surfactants	100% to ETP	0	1	0
	Insoluble inorganic and organic	Insoluble inorganic and organic	20% to P; 80% to ETP	0	0.8	0.2

Notes: a) Emissions are included as percentages and need to be converted to fractions for use in the calculations. The emission fractions are $F_{papermaking\_sludge}$ and $F_{papermaking\_water}$ as appropriate (and finished paper values are $F_{papermaking\_paper}$).

PS = paper sludge; ETP = effluent treatment plant; P = product. The percentage figure given here is F, the degree of fixation.

b) Amounts of substance retained in containers are not considered here, the fractions apply to the amount of substance as used. For information on container residues see OECD (2006a,b,c) and Environment Agency (2007b).

* See also existing ESDs (such as EU Technical Guidance Document, Tisser and Chenais 2001).

Source: See text.

In addition, it is possible that a chemical may be used in more than one process during paper-making. In this case, the data presented in Table 4.3 would allow an assessment to be made of the emissions from each process.

4.2.2 Recycling

The amount and types of substances released into the environment as a result of recycling will depend on the mix of recycled paper used, the overall amount of recycled paper being processed and the type of paper being produced. The main recycling processes leading to the release and dissolution of the substances contained in the printing inks, dyestuffs, pigments, toners and microcapsules are alkaline hydrolysis (effected by sodium hydroxide) and washing (effected using surfactants). Typical amounts of the substances that may be present in waste paper are summarised in Table 2.1. These figures should be used only in the absence of more specific information about the substance.

Estimated emissions of substances present in paper during paper recycling, and the medium to which the emission occurs, are shown in Table 4.4. The values in this table were estimated by expert judgement in 1991 (PIRA 1991); more specific or up-to-date information should be used if available.

The values in Table 4.4 are removal rates for those instances where de-inking processes are used, which will be the case for the production of newsprint, tissue paper and graphic grades. Where such processes are not used, as may be the case in the production of packaging materials, then the removal rate from the waste paper is expected to be less. There is little information on this aspect at present and further information is needed. For substances used in the paper-making process (those marked with superscript b in Table 4.4), the degree of retention when they are applied ($F_{papermaking\_paper}$) could be used to indicate the fraction retained on the pulp when de-inking is not applied (see Table 4.3).

One factor that may need to be considered is that the simple re-pulping process may not break down some of the materials included on some types of paper. In Table 4.4, the assumption of 100 per cent release from thermal paper is based on the hydrolysis of the colour-former under the conditions used in de-inking. If this process is not used, then the substance may not be as available for removal. As an example, measurements of bisphenol-A (used in thermal paper) at paper recycling sites show a high degree of removal (95 per cent) from the waste paper when de-inking is used. In contrast, measurements at a site where de-inking is not used showed a removal from the waste paper of only 10 per cent (Environment Agency 2004). Information from the industry (AEMCP 2005) indicates that the majority of the capsules in carbonless copy paper would not be ruptured by high consistency pulping without a de-inking step. Also, information on a specific substance used in carbonless copy paper (European Chemicals Bureau, personal communication) gave a capsule rupture rate of 2 per cent, in contrast to the 100 per cent removal detailed in Table 4.4. Further information is needed on such issues.

Table 4.4 Percentage emissions of substances present in paper during recycling

Substance type	Processes included	Medium to which emission occurs	Worst case percentage emission (defaults) [a]	Worst case emission fractions (defaults)
Highly soluble substances (and overall default)	Pulping, de-inking, washing, thickening, primary treatment of effluent	Sludge	0	$F_{deink\_sludge} = 0$
		Water	100%	$F_{deink\_water} = 1$
		Finished paper	0	$F_{deink\_paper} = 0$
Mineral oil-based inks	De-inking and washing	Sludge	60–80%	$F_{deink\_sludge} = 0.6–0.8$
		Water	14–28% (70% of ink remaining after flotation)	$F_{deink\_water} = 0.14–0.28$
		Finished paper	6–12% (30% of ink remaining after flotation)	$F_{deink\_paper} = 0.06–0.12$
Flexographic inks	Pulping, de-inking, washing and thickening	Sludge	Very little (default 1%)	$F_{deink\_sludge} = 0.01$
		Water	30–90%	$F_{deink\_water} = 0.3–0.9$
		Finished paper	10–70%	$F_{deink\_paper} = 0.1–0.7$
Non-impact toners	De-inking and washing	Sludge	60–80% (can be as high as 90-95% for some, as low as 30-50% for others)	$F_{deink\_sludge} = 0.6–0.8$
		Water	6–28% (30–70% of toner remaining after flotation)	$F_{deink\_water} = 0.06–0.28$
		Finished paper	12–14%	$F_{deink\_paper} = 0.12–0.14$
Pigments[b]	De-inking and washing	Water	50%	$F_{deink\_water} = 0.5$
		Fibres[c]	50%	$F_{deink\_sludge} = 0.02$ $F_{deink\_paper} = 0.48$
Dyes[b]	De-inking and washing	Water	50%	$F_{deink\_water} = 0.5$
		Fibres[c]	50%	$F_{deink\_sludge} = 0.02$ $F_{deink\_paper} = 0.48$
Optical brighteners[b]	De-inking and washing	Water	50%	$F_{deink\_water} = 0.5$
		Fibres[c]	50%	$F_{deink\_sludge} = 0.02$ $F_{deink\_paper} = 0.48$
Fillers (clay)[b]	De-inking	Water	55%	$F_{deink\_water} = 0.55$
		Fibres[c]	45%	$F_{deink\_sludge} = 0.02$ $F_{deink\_paper} = 0.43$

Substance type	Processes included	Medium to which emission occurs	Worst case percentage emission (defaults)[a]	Worst case emission fractions (defaults)
Colour-formers and co-reactants (thermal paper)[d]	Pulping, de-inking, washing and thickening	Water	100%	$F_{deink\_water} = 1$
Colour former (carbonless copy paper)[e]	Pulping, de-inking, washing and thickening	Water	90 (+5–7% as dye-clay complex)	$F_{deink\_water} = 0.9$ (+0.05-0.07 as dye-clay complex)
		Sludge	3–5% as dye-clay complex	F_{deink_sludge} = 0.03-0.05 as dye-clay complex

Notes: a) Emissions are included as percentages and need to be converted to fractions for use in the calculations. The emissions are F_{deink_sludge} and F_{deink_water} as appropriate (and finished paper values and fibres are F_{deink_paper}). Values are from PIRA (1991).

b) Where possible, the distribution between water and fibres should be based on the degree to which the specific substance binds to the fibre when first used (Table 4.3, or see TGD Appendix 1 (EC 2003) for IC 12). The values are defaults if this information is not available.

c) In these cases, there is no specific information on the split between sludge and finished paper. As a default, it could be assumed that 2 per cent of the fibres go to sludge at this stage (and so 2 per cent of the substance on the fibres also goes to sludge) (PIRA 1991). Hence F_{deink_sludge} is 0.02 in these cases.

d) See text for situation with no de-inking.

e) Figures relate to the dye component with de-inking taking place. For the solvent component, use values for mineral oil-based inks. For recycling without de-inking, assume capsules are removed from fibres without rupturing and then go to sludge.

The worst case assumption for local emissions would be to assume that de-inking takes place. The types of paper produced without de-inking recycled material are packaging materials, which tend to use a range of waste types. Hence, this route may be relevant for larger-scale estimates of emission, as most types of paper are likely to end up in packaging to some extent.

One other consequence of the lower degree of removal is that some of the substance may be present at low levels in different paper types (such as packaging) to those in which it was first used. There might therefore be more substance input to the recycling plant than would be expected from the intended use. An approach to estimating the significance of this is outlined in Section 5.2.3 and Appendix 6

4.2.3 Waste water treatment

The emission figures given in Table 4.3 for paper-making and in Table 4.4 for paper recycling are before any on-site or off-site effluent treatment. The waste water from the paper-making and paper recycling processes will undergo at least primary treatment (sedimentation) on site. If specific information relating to the substance is available then this should be used to estimate any removal from the water stream. In the absence of such information, the following default values are suggested ($F_{primary\text{-}water}$ = fraction going to water and $F_{primary\text{-}sludge}$ = fraction going to sludge during primary treatment).

	$F_{primary\text{-}water}$	$F_{primary\text{-}sludge}$
Soluble substances (solubility >100mg/l)	1	0
Low solubility substances (solubility 1–100mg/l)	0.5	0.5
Poorly soluble substances (solubility <1mg/l)	0.1	0.9

It would also be possible to calculate the distribution of a substance in primary treatment using a primary sedimentation model, such as that which forms part of the SimpleTreat model (see below). This model would need to include suitable conditions found in the paper industry, such as the typical concentration of solids and the sedimentation rate.

The water may then be treated in a biological plant on site or may be passed to an off-site treatment plant. Removal by biological treatment is not included in this ESD, but can be estimated using an effluent treatment plant model such as SimpleTreat (which is incorporated into the EUSES 2.0 software (EUSES 2004)). It should be noted that paper plants use large quantities of water, which means that the size of the biological treatment plant will probably need to be adjusted in accordance with the size of the paper plant. Wastewater treatment capabilities for paper mills and recycling plants in the UK are discussed further in Appendix 5.

Sludges from an individual process are assumed to be combined with those from all other processes carried out at the site (and possibly with the sludges from biological processes).

There may be the production and emission of secondary chemicals (for example halomethanes and chlorophenols), but these are not considered in this emission scenario. Some paper mills treat their incoming water supply with disinfectants, and a residual of the disinfectant chemical will remain in the water after disinfection has occurred. This residual will be consumed at the stage when the water is mixed with the fibre (pulping) and hence there will be no emission to effluent.

5. EMISSION SCENARIOS

In this section, emission scenarios for the production of paper products from recovered (recycled) paper and from virgin pulp are developed. In principle, the scenarios developed for the paper-making stage are similar regardless of the starting raw material (recovered paper or virgin pulp).

The basic steps in the process are similar for both paper-making and paper recycling. These steps are outlined in Figure 5.1 for paper-making and in Figure 5.2 for paper recycling. To calculate the local emissions, the scenarios are built around a default mill size using a default amount of water per tonne of paper[4]. This approach is in contrast to the more usual methods used in ESDs for calculating the local emissions, which consider the fraction of total annual supply tonnage of the substance that would be used on representative local sites of different sizes (for example, large and small sites).

The scenarios take account of: the mass of substance used per tonne of paper; the distribution behaviour of the substance during the paper-making or paper recycling process (fractions to water, sludge and the paper itself); and the behaviour of the substance during primary treatment of the effluent from the mill (fractions to water and sludge). For paper-making, it is assumed that a given chemical will be used in the production of all the paper produced at the local site on one day. For paper recycling, the fraction of the paper recycled is taken into account in order to estimate the fraction of the recycled paper that will contain the substance.

5.1 Paper making (applicable to both recycled pulp and virgin pulp)

5.1.1 Size of operation

5.1.1.1 Amounts of paper produced

Paper mills tend to be large manufacturing sites that lend themselves to economies of scale. This is particularly evident for newsprint production. Lower production tonnage, on the other hand, is often associated with niche speciality paper mills that manufacture higher value products, such as banknotes. Table 5.1 summarises the site production data for different types of mills in the UK.

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[4] The method used does not require the use of a large site. If a larger site is used, the amounts of both the water used and sludge produced also increase and so the concentrations in the waste water and sludge remain the same. Specific size information could be used if required; in such cases, the waste water volume would need to be taken into account when considering the size of any off-site waste water treatment plant.

Figure 5.1 Summary of emission scenario for paper-making

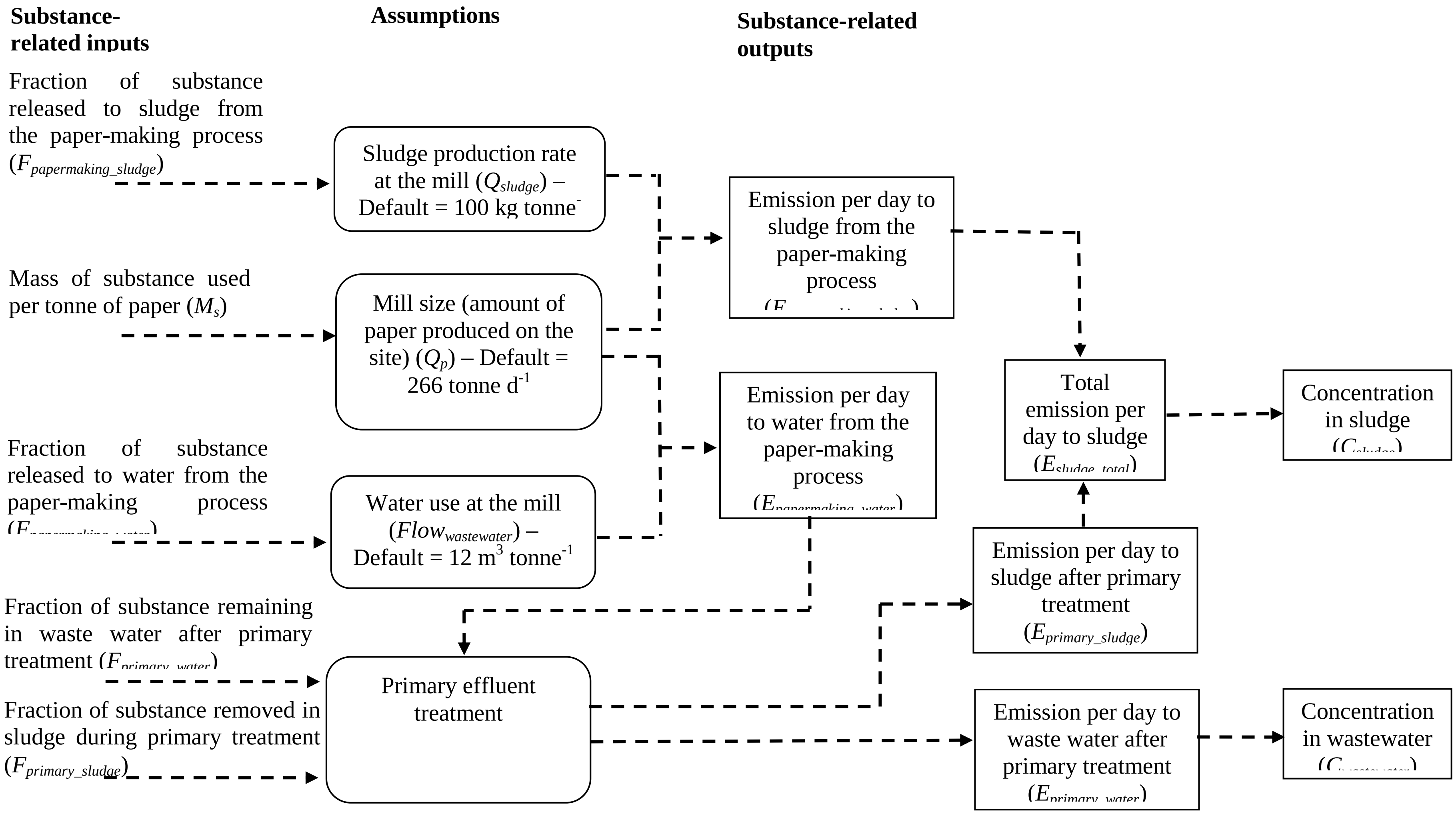

Figure 5.2 Summary of emission scenario for paper recycling

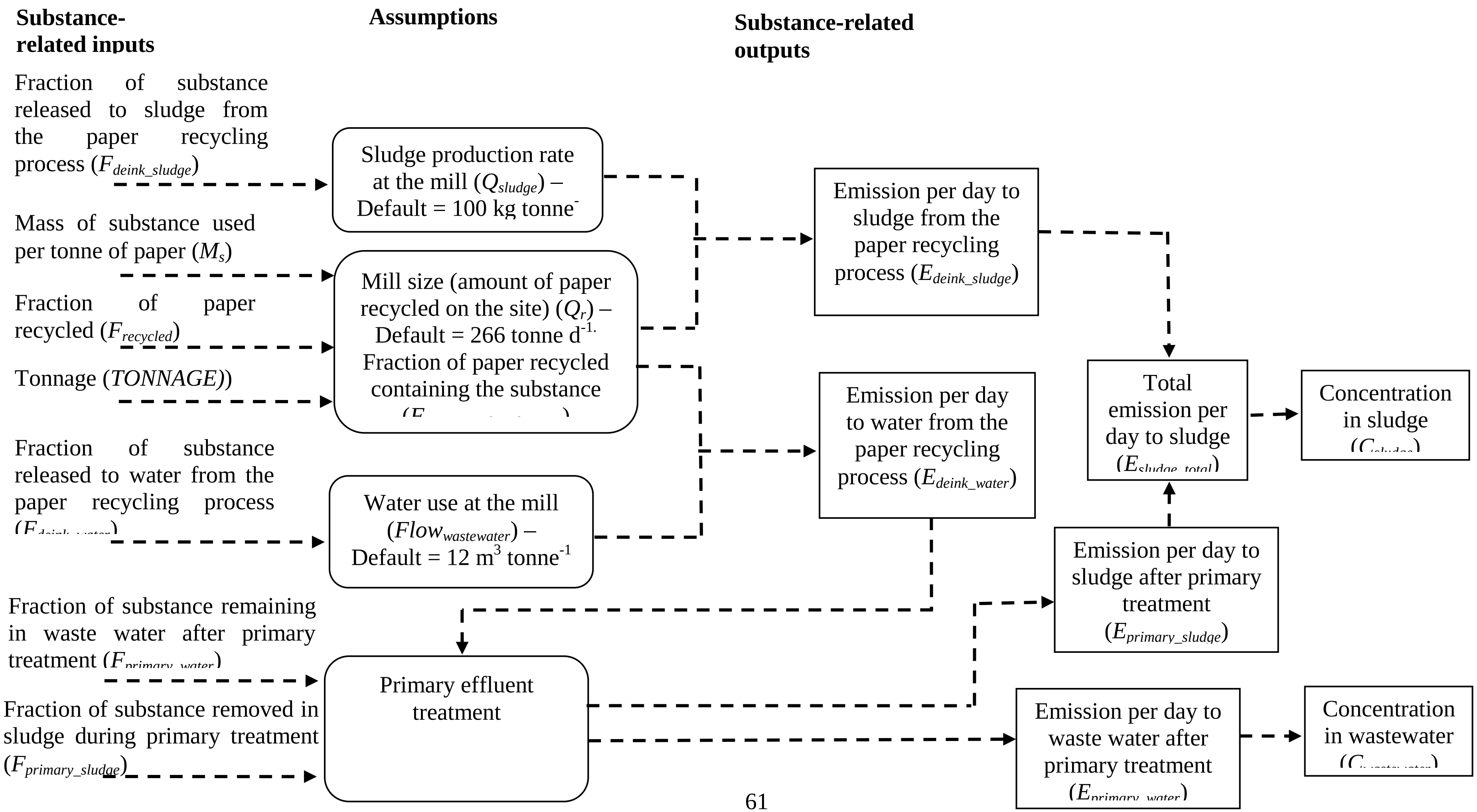

Table 5.1 Tonnage of products made by sector for surveyed paper mills

Sector	Number of mills sampled	Production range across sites (annual dry tonnes/year)
Newsprint	2	290,000–400,000*
Test liner and fluting	4	94,000–280,000
Printings and writings	3	50,000–380,000
Speciality	1	12,500
Tissue	4	40,000–130,000
Various paper products such as manilla board	3	33,000–136,000
Market de-inked pulp	1	100,000

Note: *Data from Phillips International 2002 Paper Directory.

These figures could be used as the basis for emission scenarios in cases where the specific sector for which the paper is produced or recycled is known. It is more likely, however, that the waste paper containing the substance will be used in a number of different sectors. The size of site chosen for estimating local emissions does not have a major effect on the resulting concentrations, as the amount of water used (and sludge produced) is proportional to the amount of paper produced – so a larger plant has larger emissions in terms of quantity, but also a larger water use. As such, an average size plant can be proposed for use in local calculations. The total amount of waste paper used in the EU is 46,475,000 tonnes (from Table 1.2). As the recycling rate in the EU is currently just above 50 per cent, a similar amount of paper will also be produced from virgin fibres. The estimated number of paper production sites in the EU is around 1,000, of which 50 per cent are considered to use recovered materials and 50 per cent use virgin fibres, meaning around 500 sites for each. The average amount of material, either new or recovered, used at a single site is therefore around 93,000 tonnes per year. Some sites will use a combination of recovered and new material, but as a worst case it can be assumed that only new material or recovered material is used at the default site.

As there are around 500 sites in the EU using recovered paper materials and around 500 sites using virgin materials, it is reasonable to assume that 10 per cent of this activity takes place in the region, in the absence of more specific information.

Production occurs virtually continuously during the year, with breaks only for routine annual maintenance and unscheduled repair and maintenance activities. It has been estimated that for UK mills production typically takes place on 350–365 days a year and so an assumption of 350 production days per year should be used in the absence of specific information. This gives a daily use of 266 tonnes of recovered paper materials or new paper materials at the site. This value is suggested as a default value for Q_p in the subsequent emission scenarios.

5.1.1.2 Fraction of paper produced using the substance at a site

In the absence of other information to the contrary, it should be assumed that a given chemical will be used in the production of all the paper produced at the local site on one day (all the paper produced at the site on one day contains the substance). This assumption may not be appropriate for chemicals produced in only small quantities and an alternative approach for low tonnage chemicals is given in Section 5.1.3.

5.1.1.3 Water use

In a similar approach to that detailed in Section 5.2.1.4, the water usage at the default paper plant (93,000 tonnes/year) can be assumed to be around 1,116,000m^3/year or 3,058m^3/day based on a water usage rate of 12m^3/tonne. It is suggested that this figure could be used as a default value for $Flow_{wastewater}$ in the subsequent emission scenarios. Further information on water usage at various plant types is contained in Table 4.2 in Section 4.1.1.1.

5.1.1.4 Sludge production

In a similar approach to that detailed in Section 5.2.1.5, a sludge production rate of around 10 per cent (and a value of Q_{sludge} of 100kg/tonne) can be assumed as a default value in the subsequent emission scenarios (as may be typical for an integrated site manufacturing paper from recycled pulp). Further information on sludge production at various plant types is contained in Table 4.2 in Section 4.1.1.1.

5.1.2 Emission scenarios for paper-making

Emissions from paper-making can occur to waste water and to sludge from various stages of the process. In addition, biological waste water treatment of the final effluent from the mill is relatively common and the sludge from this process can be spread on land. This process also needs to be taken into account in any emission scenario (see Section 5.1.4). The following assumptions are used in the development of the emission scenario.

- Additives used in the paper-making process distribute between waste water, sludge and paper according to the information in Section 4.2.

- The waste water generated in the paper-making process will be diluted within the total waste water generated at the mill (the water use figures in Section 4.1.1.1 are total use figures and so include this dilution).

The relevant equations are shown below and apply equally to chemicals added during the paper recycling process and those added during the paper-making process. The emissions relate to the daily release of the substance to sludge or waste water after the primary treatment plant but before any subsequent biological treatment plant, whether on-site or off-site.

$$E_{papermaking\_water} = M_s \times Q_p \times F_{papermaking\_water} \quad \text{Equation 1}$$

$$E_{papermaking\_sludge} = M_s \times Q_p \times F_{papermaking\_sludge} \quad \text{Equation 2}$$

$$E_{primary\_water} = E_{papermaking\_water} \times F_{primary\_water} \quad \text{Equation 3}$$

$$E_{primary\_sludge} = E_{papermaking\_water} \times F_{primary\_sludge} \quad \text{Equation 4}$$

$$E_{sludge\_total} = E_{papermaking\_sludge} + E_{primary\_sludge} \quad \text{Equation 5}$$

Explanation of symbols:

$E_{papermaking\_water}$	Emission per day to water from the paper-making process	[kg d^{-1}]

$E_{papermaking\_sludge}$	Emission per day to sludge from the paper-making process	[kg d^{-1}]	
$E_{primary\_water}$	Emission to waste water after primary treatment of effluent	[kg d^{-1}]	
$E_{primary\_sludge}$	Emission to sludge after primary treatment of effluent	[kg d^{-1}]	
E_{sludge_total}	Total emission to sludge from paper recycling (excluding any biological sludge)	[kg d^{-1}]	
M_s	Mass of substance used per tonne of paper	[kg t^{-1} paper]	Substance specific data, or Table2.1 and Table 3.2
Q_p	Quantity of paper produced at one site per day	[t d^{-1}]	Default 266 t d^{-1}; other information in Table 5.1
$F_{papermaking\_water}$	Fraction of substance released in water from the paper-making process	[-]	Substance specific data or Table 4.3
$F_{papermaking\_sludge}$	Fraction of substance released in sludge from the paper-making process	[-]	Substance specific data or Table 4.3
$F_{primary\_water}$	Fraction of substance remaining in waste water after primary treatment	[-]	Substance specific data or Section 4.2.3
$F_{primary\_sludge}$	Fraction of substance removed in sludge during primary treatment	[-]	Substance specific data or Section 4.2.3

The concentration of the substance in water and sludge can then be calculated using the water flow and sludge generation rates for the mill and Equation 6 and Equation 7.

$$C_{wastewater} = \frac{E_{primary\_water}}{Flow_{wastewater} \times Q_p} \times 1000$$

Equation 6

Explanation of symbols:

$C_{wastewater}$	Concentration in waste water from the mill	[mg/l]	
$E_{primary\_water}$	Emission per day in waste water after primary treatment	[kg d^{-1}]	Equation 3
1000	Conversion factor (kg m^{-3} to mg l^{-1})		
$Flow_{wastewater}$	Waste water generated from whole plant	[m^3 t^{-1} paper]	Default 12 m^3 t^{-1}; other information in Table 4.2
Q_p	Quantity of paper produced at one site per day	[t d^{-1}]	Default 266 t; other information in Table 5.1

Note that the concentration in water is without any biological treatment. Calculations of removal in biological treatment, for example with SimpleTreat, will need to take account of the higher water flow from paper plants.

$$C_{sludge} = \frac{E_{sludge\_total}}{Q_{sludge} \times Q_p} \times 10^6$$

Equation 7

Explanation of symbols:

C_{sludge}	Concentration in sludge from the mill	[mg kg^{-1}]	
E_{sludge_total}	Emission per day to sludge	[kg d^{-1}]	Equation 5
10^6	Conversion factor	[mg kg^{-1}]	
Q_{sludge}	Sludge generation rate for whole mill	[kg t^{-1} paper]	Section 5.1.1.4
Q_p	Quantity of paper produced at one site per day	[t d^{-1}]	Default 266 tonnes/day; other information in Table 5.1

Combining Equation 1 and Equation 3 with Equation 6 gives the following overall equation for estimating $C_{wastewater}$.

$$C_{wastewater} = \frac{M_s \times F_{papermaking\_water} \times F_{primary\_water} \times 1000}{Flow_{wastewater}}$$

Equation 8

Similarly, combining Equation 1, Equation 2, Equation 4 and Equation 5 with Equation 7 gives the following overall equation for estimating C_{sludge}.

$$C_{sludge} = \frac{M_s \times 10^6 \times (F_{papermaking\_sludge} + F_{papermaking\_water} \times F_{primary\_sludge})}{Q_{sludge}}$$

Equation 9

5.1.3. Considerations for very low tonnage substances

It should be noted that the default quantity of paper produced at one site (Q_p) of 266 tonnes per day is equivalent to a total of 93,100 tonnes of paper produced at the site per year (assuming 350 days per year production). For substances with a low-tonnage, a possible problem occurs with these emission scenarios if the combination of the supply volume and the application rate mean that the amount of paper containing the substance is less than 93,100 tonnes per year. This may occur when

$$\frac{M_s \times Q_P}{1{,}000} \geq TONNAGE$$

Equation 10

Explanation of symbols:

M_s	Mass of substance used per tonne of paper	[kg t^{-1}]	Substance specific data, or Table2.1 and Table 3.2
TONNAGE	Tonnage of substance used in paper in the EU	[t year^{1}]	Substance specific data
1,000	Conversion factor	[kg t^{-1}]	
Q_p	Quantity of paper produced at one site per day	[t d^{-1}]	Default 266 tonnes/day; other information in Table 5.1

In these cases, three different approaches could be considered.

The first approach would be to estimate the appropriate maximum size of the site assuming that the substance is used in all of the paper produced at the site over the year. This can be estimated using Equation 11.

$$Q_p = \frac{TONNAGE \times 1{,}000}{M_s \times 350}$$

Equation 11

Explanation of symbols:

M_s	Mass of substance used per tonne of paper	[kg t^{-1}]	Substance specific data, or Table2.1 and Table 3.2
TONNAGE	Tonnage of substance used in paper in the EU	[t $year^{1}$]	Substance specific data
1,000	Conversion factor	[kg t^{-1}]	
Q_p	Quantity of paper produced at one site per day	[t d^{-1}]	
350	Number of days of operation of site per year	[d $year^{-1}$]	Default

This value of Q_p can then be used in the equations above. This would result in a lower daily emission from the site than assuming the default size. However, the overall water consumption at the smaller size site would be correspondingly reduced, resulting in similar concentration estimates in waste water and sludge.

The second approach would be to accept the default plant size but assume that the paper containing the substance is not manufactured for 350 days each year. In this case, the appropriate number of manufacturing days for the specific paper containing the substance can be estimated using Equation 12.

$$N_{days\_subst} = \frac{TONNAGE \times 1{,}000}{Q_p \times M_s}$$

Equation 12

Explanation of symbols:

M_s	Mass of substance used per tonne of paper	[kg t^{-1}]	Substance specific data, or Table2.1 and Table 3.2
TONNAGE	Tonnage of substance used in paper in the EU	[t $year^{1}$]	Substance specific data
1,000	Conversion factor	[kg t^{-1}]	
Q_p	Quantity of paper produced at one site per day	[t d^{-1}]	Default 266 tonnes/day; other information in Table 5.1
N_{days_subst}	Number of days of manufacture of paper containing the substance at the site	[d $year^{-1}$]	

N_{days_subst} should be rounded up to the nearest whole number. In this approach, the value N_{days_subst} would affect only the total yearly emission from the site and not the daily emission or daily water flow from the site. Thus the concentrations in waste water and sludge will be the same as for the default size site.

The third approach would be to consider the default plant size but assume that only a fraction of the paper made each day contains the substance. The total number of days of operation would be 350. The fraction of paper manufactured each day containing the substance (F_{paper_subst}) can be estimated from Equation 13.

$$F_{paper\_subst} = \frac{Tonnage \times 1{,}000}{M_s \times 350 \times Q_p}$$

Equation 13

Explanation of symbols:

M_s	Mass of substance used per tonne of paper	[kg t^{-1}]	Substance specific data, or Table2.1 and Table 3.2
TONNAGE	Tonnage of substance used in paper in the EU	[t $year^{1}$]	Substance specific data
1,000	Conversion factor	[kg t^{-1}]	
Q_p	Quantity of paper produced at one site per day	[t d^{-1}]	Default 266 tonnes/day; other information in Table 5.1
350	Number of days of manufacture of paper containing the substance at the site	[d $year^{-1}$]	Default value
F_{paper_subst}	Fraction of the paper manufactured each day containing the substance	[-]	

In this case, Equation 1and Equation 2 above need to be modified as follows.

$$E_{papermaking\_water} = M_s \times Q_p \times F_{paper\_subst} \times F_{papermaking\_water}$$

Equation 1a

$$E_{papermaking\_sludge} = M_s \times Q_p \times F_{paper\_subst} \times F_{papermaking\_sludge}$$

Equation 2a

Further, Equation 8 and Equation 9 are modified as follows.

$$C_{wastewater} = \frac{M_s \times F_{paper\_susbt} \times F_{papermaking\_water} \times F_{primary\_water} \times 1000}{Flow_{wastewater}}$$

Equation 8a

$$C_{sludge} = \frac{M_s \times F_{paper\_subst} \times 10^6 \times (F_{papermaking\_sludge} + F_{papermaking\_water} \times F_{primary\_sludge})}{Q_{sludge}}$$

Equation 9a

In this case, the estimated emissions per day, the total emissions per year and the resulting concentrations in waste water and sludge will all be reduced compared with the calculations based purely on the default size of site.

In terms of a realistic worst case approach, the first (Equation 11) and second (Equation 12) approaches should be preferred, as it is unlikely that the use of a low-tonnage substance will be spread evenly over a fraction of the total paper produced each day (it is more likely that, on any particular day, the

substance will either be used or not used). It should be noted that the first and second approaches lead to similar estimates for the total emissions from the site on an annual basis and will also lead to similar estimates of concentrations in water and sludge.
Biological treatment plant sludge

The above scenario estimates emissions to sludge from the paper-making process. However, at many mills, the effluent from the plant may be further treated in a biological treatment plant. The sludge from this process may contain chemicals used in the paper-making process and could eventually be spread onto land. In order to estimate the concentrations of chemicals in such biological sludge, an appropriate waste water treatment plant model would need to be used (for example, the SimpleTreat model in the EUSES[5] program). This should be of the appropriate size for the water use at the mill (the default amount of waste water generated is taken to be $12 m^3 t^{-1}$ and, using the default size of the plant ($266 t\ day^{-1}$), the equivalent size of the waste water treatment plant would be $3{,}192 m^3 d^{-1}$). The value for $C_{wastewater}$ should be used as the influent concentration to the biological waste water treatment plant when estimating the appropriate concentration in biological sewage sludge.

5.2 Plants using recovered (recycled) paper

5.2.1 Size of operation

5.2.1.1 Amounts of paper produced and recovered paper used

Using a similar approach to that detailed in Section 5.1.1.1, the average amount of paper produced at a site can be estimated as around 93,000 tonnes per year for paper produced from recycled pulp. Assuming production occurs on 350 days a year, this gives a paper production rate at a site of this size of 266 tonnes/day. It is suggested that this value is used as a default for the value of Q_r in the subsequent emission scenario. Again, it is reasonable to assume that 10 per cent of this activity takes place in the UK, in the absence of more specific information.

5.2.1.2 Fraction of paper types recycled

Table 1.2 shows the percentage of paper materials that enter the recycling stream in each country in the EU. The average value is 54 per cent at present, but the rate varies between countries. To take some account of this variation, a default value of 60 per cent is proposed. The rates may also change in the future.

For some speciality papers, this value is an over-estimate. The current uses of thermal paper are in point of sale receipts (50 per cent), self-adhesive labels (30 per cent), fax papers (10 per cent) and lottery tickets (10 per cent). The papers from these various uses have different rates at which they enter the recycling stream, estimated to be 10 per cent, 30 per cent, 20 per cent and 100 per cent respectively. The overall result is that around 30 per cent of thermal paper enters recycling streams (Environment Agency 2004).

For carbonless copy paper, one-third is assumed to be archived, due to the nature of its use. From a survey of office waste in London, only 22 per cent of the waste papers were recovered (Davis 2002). Hence, the overall recovery rate for carbonless copy papers was 15 per cent. For tissue paper, it is unlikely that a significant proportion is recycled after use. The suggested default values are therefore:

Paper type	**Fraction recycled (F_{recyc})**
General (default)	0.6

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[5] European Union System for the Evaluation of Substances

Thermal paper	0.3
Carbonless copy paper	0.15
Tissue	0

These figures apply to paper that has been used. For all types of paper, including tissue, material rejected at the production step (known as broke) may be recycled without having gone into use.

5.2.1.3 Fraction of paper at local site containing the substance

5.2.1.3.1 Generic worst case assumption

The worst case assumption would be that all of the recovered paper used at the local site on a single day contained the substance of interest. However, unless the substance is used in the majority of a paper type and that paper type makes up the whole of the input to the site, this is likely to be a large over-estimation. In most cases, it will be necessary to consider the proportion of recovered paper that contains the substance. In the absence of more specific information, it is assumed that the paper containing the substance is distributed evenly through recovered paper material in the EU. The fraction of recycled paper containing the substance is given by Equation 14.

$$F_{paper\_with\_subst} = \frac{TONNAGE \times F_{recyc} \times 10^3}{M_s} \times \frac{1}{Q_{tot\_EU\_recyc}} \qquad \text{Equation 14}$$

Explanation of symbols:

$F_{paper\_with\_subst}$	Fraction of recycled paper (at site and over EU) containing the substance	[-]	
$TONNAGE$	Tonnage of substance used in paper in EU	[t year^{-1}]	Substance specific data
F_{recyc}	Fraction of paper containing substance that is recycled	[-]	Section 5.2.1.2
10^3	Correction factor for units	[kg t^{-1}]	
M_s	Mass of substance used per tonne of paper	[kg t^{-1}]	Substance specific data or Table2.1 and Table 3.2
$Q_{tot\_EU\_recyc}$	Total amount of paper material recycled in EU	[t year^{-1}]	46,475,000

5.2.1.3.2 Approach for newsprint

Equation 14 effectively assumes that the paper containing the substance is not collected and used separately, but is mixed in with other paper types. In the case of newsprint, there are recycling mills that only use recovered newsprint to produce newsprint. In this case, the appropriate total amount of paper material should be that for newsprint (and other graphic papers), which from Table 1.3 is 12,300,000 tonnes. In such cases, this figure should be used as the value for $Q_{tot\_EU\_recyc}$.

5.2.1.3.3 Approach for recycling plants taking broke

Another exception to the generic approach is where the recycling plant takes waste paper direct from the paper producers. This waste paper is known as broke and never enters the normal paper use cycle. From information gathered for the risk assessment of a specific substance in thermal paper, the amount of thermal paper production disposed of as broke is 10 per cent. No specific information is available for other types of paper, so it is suggested that 10 per cent be used as a general figure in the absence of other information. (It should be noted that as this material never enters use, the amount of broke should strictly be deducted from the tonnage used in the EU before calculating the fraction of paper.) Where paper is coated, it is possible that the coating may not be applied right up to the edge of the paper and so edge cuts of paper may not contain the coating (or not to the full extent). Adjustments could be made to calculations in such cases.

The recycling of broke means that sites receiving it will have a higher level of this type of paper and the substances that it contains. It is difficult to propose default values for the fraction of paper in this situation, as relevant information is limited. From the work on thermal paper, it would be unrealistic to assume that such waste made up all of the paper on any one day. At the two sites surveyed in the thermal paper work, the thermal paper content on days when thermal paper broke was being used was around 10 per cent (Environment Agency 2004) and this value is suggested in the absence of other more specific information.

For some types of paper, the broke may undergo specific treatment. For example, at least one producer recovers and incinerates the microcapsules in broke from the production of carbonless copy paper (Arjo Wiggins 2002b). Such information needs to be considered on a case-by-case basis.

5.2.1.4 Water use

Section 4.1.1.1 presented information on the amount of water used at sites producing paper from recycled material (in Table 4.2). The waste water from the specific paper recycling steps will be combined with that from other parts of the plant, and the figures in the table relate to the overall water usage. For the majority of paper types, the typical water usage rate is 8–16m^3 per tonne of paper produced. Taking the average (12m^3/tonne paper) gives a water use at the default plant (93,000 tonnes) of 1,116,000m^3/year, or 3,058m^3/day. Note that this is larger than the default waste water treatment plant used in the EU Technical Guidance Document (EC 2003), and so the size of the waste water treatment plant will need to be adjusted in this case. The European Thermal Paper Association (ETPA; quoted in TNO 2000) considered that a waste water plant of 4,000m^3/day was appropriate for this industry and may be an under-estimate for some areas. The value of 12m^3/tonne paper is suggested as a default value for $FLOW_{wastewater}$ in the subsequent emission scenarios for paper recycling.

5.2.1.5 Sludge production

The values for sludge production in Table 4.2 are variable and are presented for two different bases: the amount of raw material used and the amount of paper produced. The calculations in this section concentrate on recycled material, which means that the first set of values should be preferred. If the addition of other materials is ignored, then the percentages can be applied to the recovered paper used. For cases where de-inking is not used, the packaging figure of 2 per cent is appropriate (the site without de-inking mentioned earlier in the context of bisphenol A has a sludge production rate of 2.3 per cent). Where de-inking is used, the lowest production rate will give the worst case concentrations in sludge. This is the case for graphic paper, where sludge production of 7–16 per cent, 1–5 per cent and ~1 per cent at different stages give a combined value of around 10 per cent, which is similar to the value suggested for newsprint in PIRA (1991). The sludge production rate Q_{sludge} is therefore 100kg per tonne of recovered paper used.

Assuming that the amount of paper recycled on a site each day is 266 tonnes (see Section 5.2.1.1), a 10 per cent sludge production rate leads to estimated sludge production of 26.6 tonnes/day for such a site. This value is similar to the average of 28 tonnes/day derived from UK data (see Appendix 5).

5.2.2 Emission scenarios for recycling

Emissions from paper recycling can occur to waste water and to sludge at various stages of the process. In addition, biological waste water treatment of the final effluent from the mill is relatively common and the sludge from this process can be spread on land. This process also needs to be taken into account in any emission scenario. The following assumptions are used in the development of the emission scenario.

- Additives present in the paper materials being recycled (substances added in the course of the recycling process are considered in Section5.1.2) distribute between waste water, sludge and paper according to the information in Section 4.2.

- The waste water generated in the recycling process will be diluted within the total waste water generated at the mill (the water use figures in Section 4.1.1.1 are total use figures and so include this dilution).

- Large particles of plastic, metal and stones will be sent to landfill and not released to the environment.

- The paper recycled at a mill will usually be a mixture of different paper types, with different additives present.

The equations below can be used to calculate a value for the daily release of the substance to sludge or waste water (before any biological treatment plant, whether on-site or off-site).

$$E_{deink\_water} = M_s \times Q_r \times F_{deink\_water} \times F_{paper\_with\_subst}$$ Equation 15

$$E_{deink\_sludge} = M_s \times Q_r \times F_{deink\_sludge} \times F_{paper\_with\_subst}$$ Equation 16

$$E_{primary\_water} = E_{deink\_water} \times F_{primary\_water}$$ Equation 17

$$E_{primary\_sludge} = E_{deink\_water} \times F_{primary\_sludge}$$ Equation 18

$$E_{sludge\_total} = E_{deink\_sludge} + E_{primary\_sludge}$$ Equation 19

Explanation of symbols:

E_{deink_water}	Emission per day to water from de-inking or washing process	[kg d^{-1}]
E_{deink_sludge}	Emission per day to sludge from de-inking or washing process	[kg d^{-1}]
$E_{primary\_water}$	Emission to waste water after primary treatment of effluent	[kg d^{-1}]
$E_{primary\_sludge}$	Emission to sludge after primary treatment of effluent	[kg d^{-1}]
E_{sludge_total}	Total emission to sludge from paper recycling (excluding any biological sludge)	[kg d^{-1}]

M_s	Mass of substance used per tonne of paper	[kg t^{-1} recycled paper]	Substance specific data or Table 2.1 and Table 3.2.
Q_r	Quantity of paper recycled at one site per day	[t d^{-1}]	Default 266 tonnes/day; other information in Table 5.1.
F_{deink_water}	Fraction of substance released to water from de-inking or washing process	[-]	Substance specific data or Table 4.4.
F_{deink_sludge}	Fraction of substance released to sludge from de-inking or washing process	[-]	Substance specific data or Table 4.4
$F_{paper\_with\ subst}$	Fraction of recycled paper containing the substance	[-]	Equation 14
$F_{primary\_water}$	Fraction of substance remaining in waste water after primary treatment	[-]	Substance specific data or Section 4.2.3
$F_{primary\_sludge}$	Fraction of substance removed via sludge during primary treatment	[-]	Substance specific data or Section 4.2.3

The concentration of the substance in water and sludge can then be calculated using the water flow and sludge generation rates for the mill. The following equations can be used.

$$C_{wastewater} = \frac{E_{primary\_water}}{Flow_{wastewater} \times Q_r} \times 1000 \qquad \text{Equation 20}$$

Explanation of symbols:

$C_{wastewater}$	Concentration in waste water from the mill	[mg/l]	
$E_{primary\_water}$	Emission per day in waste water after primary treatment	[kg d^{-1}]	Equation 17
1000	Conversion factor (kg m^{-3} to mg l^{-1})		
$Flow_{wastewater}$	Waste water generated from whole plant	[m^3 t^{-1} recycled paper]	Default 12m^3 t^{-1}; other information in Table 4.2
Q_r	Quantity of paper recycled at one site per day	[t d^{-1}]	Default 266t; other information in Table 5.1

Note that the concentration in water is without any biological treatment. Calculations of removal in biological treatment, for example with SimpleTreat, will need to take account of the higher water flow from paper plants.

$$C_{sludge} = \frac{E_{sludge\_total}}{Q_{sludge} \times Q_r} \times 10^6 \qquad \text{Equation 21}$$

Explanation of symbols:

C_{sludge}	Concentration in sludge from the mill	[mg kg^{-1}]	
E_{sludge_total}	Emission per day to sludge	[kg d^{-1}]	Equation 19
10^6	Conversion factor	[mg kg^{-1}]	
Q_{sludge}	Sludge generation rate for whole mill	[kg t^{-1} recycled paper]	Section5.2.1.5; default 100kg/tonne
Q_r	Quantity of paper recycled at one site per day	[t d^{-1}]	Default 266 tonnes/day; other information in Table 5.1

Combining Equation 14, Equation 15 and Equation 17 with Equation 20 gives the following overall equation for estimating $C_{wastewater}$.

$$C_{wastewater} = \frac{TONNAGE \times F_{recyc} \times F_{deink\_water} \times F_{primary\_water} \times 10^6}{Q_{tot\_EU\_recyc} \times Flow_{wastewater}} \qquad \text{Equation 22}$$

Similarly, combining Equation 14, Equation 15, Equation 16, Equation 18 and Equation 19 with Equation 21 gives the following overall equation for estimating C_{sludge}.

$$C_{sludge} = \frac{TONNAGE \times F_{recyc} \times 10^9 \times (F_{deink\_sludge} + F_{deink\_water} \times F_{primary\_sludge})}{Q_{tot\_EU\_recyc} \times Q_{sludge}} \qquad \text{Equation 23}$$

5.2.3 Estimating the amounts of chemicals remaining in the finished paper and subsequent releases from repeated recycling

A number of chemicals used in the paper recycling and paper-making process end up in the finished paper, along with any substances added after the paper-making process (such as printing inks and dyes). These chemicals can subsequently be released during the paper recycling step, but some of the substance may be retained in the regenerated pulp and so will be included in the new paper. Hence, there may be a background concentration of substances in a range of paper types other than the one in which they were originally used. In Section 4.1.2, it is estimated that the number of times a given paper is recycled is around 2–2.5 cycles for newsprint, but could be greater for packaging grades.

Appendix 6 contains the derivation of equations for calculating the background concentration in paper products of substances retained on the pulp during recycling. This background concentration can be used to estimate further releases for recycling, which should be added to those from Section 5.2.2. The equations in Section 5.2.2 can be applied by replacing the M_s value with the $M_{s\_background}$ value calculated according to Appendix 6. The fraction of the recycled paper containing the substance also needs to be considered. As a worst case, it is suggested that a fraction of 1 be used (assuming that all of the waste paper being used contains the substance at the background level).

5.2.4 Biological treatment plant sludge

The above scenario estimates the emissions to sludge from the paper recycling process. However, at many mills, the effluent from the plant may be further treated in a biological treatment plant. The sludge from this process may contain chemicals used in the paper recycling and paper-making process and can be spread onto land. Similarly to the case with paper-making (see Section 5.1.4), the resulting concentrations in sludge can be estimated from $C_{wastewater}$ using an appropriate waste water treatment plant model (for example the SimpleTreat model in the EUSES program).

5.3 Example calculations

Below are example calculations to show how the scenarios can be used.

The term M_s has been used in the equations for all substances. There are some situations where the value from the tables needs to be adjusted. For substances used in paper-making (Section5.1.2) and for substances used in the processing of recycled paper, the values of M_s in Table 3.2 can be used. Where the substance is present in the recovered paper used for recycling, the correct value of M_s is not the amount of substance applied to the paper but the amount retained on the paper. For substances applied during paper-making, the fraction $F_{papermaking\_paper}$ converts the application rate to the level found in the finished paper. Table 2.4 has values for both the amount applied and the amount retained, where appropriate. For substances applied after the paper is made (for example, printing inks), the application rate is the same as the M_s value in Table 2.4. In the examples, the value of M_s is adjusted to account for the fraction retained where appropriate, but the term M_s has been used throughout for simplicity.

Guidance on how the estimated emissions can be incorporated into the EUSES program for subsequent calculation of environmental concentrations is available as a separate annex to this report (Environment Agency 2007c).

5.3.1 Paper-making – Example 1

A cationic starch drainage and retention aid used at a rate of 10kg/tonne paper: EU usage is 5,000 tonnes; solubility = 5mg l^{-1}.

Data

Substance			Site		
$TONNAGE$	5,000t	S	Q_p	266t d^{-1}	D (Section 5.1.1.1)
M_s	10kg t^{-1}	S	$FLOW_{wastewater}$	$12m^3$ t^{-1}	D (Section 5.1.1.3)
$F_{papermaking\_water}$	0.1	D (Table 4.3)	Q_{sludge}	100kg t^{-1}	D (Section 5.1.1.4)
$F_{papermaking\_sludge}$	0.1	D (Table 4.3)			
$F_{papermaking\_paper}$	0.8	D (Table 4.3)			
$F_{primary\_water}$	0.5	D (Section 4.2.3)			
$F_{primary\_sludge}$	0.5	D (Section 4.2.3)			

Calculation

$E_{papermaking\_water} = 10 \times 266 \times 0.1 = 266\text{kg d}^{-1}$ Equation 1

$E_{papermaking\_sludge} = 10 \times 266 \times 0.1 = 266\text{kg d}^{-1}$ Equation 2

(In addition, a fraction of $F_{papermaking\_paper}$, or 0.8, would remain in the finished paper.)

$E_{primary\_water} = 266 \times 0.5 = 133\text{kg d}^{-1}$ Equation 3

$E_{primary\_sludge} = 266 \times 0.5 = 133\text{kg d}^{-1}$ Equation 4

$E_{sludge\_total} = 266 + 133 = 399\text{kg d}^{-1}$ Equation 5

Note that it is most likely that the effluent will be treated in a biological treatment plant as well, but this is not included in the above calculations.

5.3.2 Paper-making – Example 2

An organic fatty acid ester compound used as a defoamer in manufacture of tissue paper: EU usage is 500 tonnes; solubility = 200mg l^{-1}.

Data

Substance			Site		
TONNAGE	2,000t	S	Q_p	266t d^{-1}	D (Section 5.1.1.1)
M_s	0.9 kgt^{-1}	D (Table 3.2)	$FLOW_{wastewater}$	$12m^3\ t^{-1}$	D (Section 5.1.1.3 and 5.1.1.4)
$F_{papermaking\_water}$	1	D (Table 4.3)	Q_{sludge}	100kg t^{-1}	D (Section 5.1.1.4 and 5.2.1.5)
$F_{papermaking\_sludge}$	0	D (Table 4.3)			
$F_{papermaking\_paper}$	0	D (Table 4.3)			
$F_{primary\_water}$	1	D (Section 4.2.3)			
$F_{primary\_sludge}$	0	D (Section 4.2.3)			

Calculation

$E_{papermaking\_water} = 0.9 \times 266 \times 1 = 239kg\ d^{-1}$ Equation 1

$E_{papermaking\_sludge} = 0.9 \times 266 \times 0 = 0kg\ d^{-1}$ Equation 2

(In this case the fraction remaining in the finished paper ($F_{papermaking\_paper}$) is 0.)

$E_{primary\_water} = 239 \times 1 = 239kg\ d^{-1}$ Equation 3

$E_{primary\_sludge} = 216 \times 0 = 0kg\ d^{-1}$ Equation 4

$E_{sludge\_total} = 0 + 0 = 0kg\ d^{-1}$ Equation 5

Note that it is most likely that the effluent will be treated in a biological treatment plant as well, but this is not included in the above calculations.

5.3.3 Paper recycling – Example 3

A pigment in a mineral oil-based ink (not a pigment for colouring paper), used at an average rate of 2 per cent (20kg t^{-1}) on newsprint: EU usage is 1,000 tonnes; substance is of very low solubility (<1mg l^{-1}). The paper undergoes three recycling cycles.

Data

Substance			Site		
TONNAGE	1,000t	S	Q_r	266t d^{-1}	D (Section 5.2.1.1)
M_s	20kg t^{-1}	S	$FLOW_{wastewater}$	$12m^3\ t^{-1}$	D (Section 5.2.1.4)
F_{deink_water}	0.21*	D (Table 4.4)	Q_{sludge}	100kg/t	D (Section 5.2.1.5)
F_{deink_sludge}	0.7*	D (Table 4.4)	$Q_{total\_EU\_recyc}$	12,300,000t	$D^{\#}$ (Section 5.2.1.3)
F_{deink_paper}	0.09*	D (Table 4.3)			
$F_{primary\_water}$	0.1	D (Section 4.2.3)			

$F_{primary\_sludge}$	0.9	D (Section 4.2.3)			
F_{recyc}	0.6	D (Section 5.2.1.2)			

Values marked S are specific information for the scenario or substance. D values are defaults taken from this document. The two values marked * are the middle values of the ranges given in Table 4.4. The value marked # is the newsprint default for the total amount of paper.

Calculation

The first step is to consider the emissions from the recycling of 'first use' paper. As newsprint can be made completely from recycled newsprint, it is assumed that the recovered paper goes into further newsprint production and so undergoes a de-inking step.

$$F_{paper\_with\_subst} = \frac{1{,}000 \times 0.6 \times 1{,}000}{20} \times \frac{1}{12{,}300{,}000} = 2.4 \times 10^{-3} \qquad \text{Equation 14}$$

$E_{deink\_water} = 20 \times 266 \times 0.21 \times 0.0024 = 2.7\text{kg d}^{-1}$ Equation 15

$E_{deink\_sludge} = 20 \times 266 \times 0.7 \times 0.0024 = 8.9\text{kg d}^{-1}$ Equation 16

A fraction of F_{deink_paper}, or 0.09, remains on the fibres and this is considered below.

$E_{primary\_water} = 2.7 \times 0.1 = 0.27\text{kg d}^{-1}$ Equation 17

$E_{primary\_sludge} = 2.7 \times 0.9 = 2.4\text{kg d}^{-1}$ Equation 18

$E_{sludge\_total} = 8.9 + 2.4 = 11.3\text{kg d}^{-1}$ Equation 19

Note that it is most likely that the effluent will be treated in a biological treatment plant as well, but this is not included in the above calculations.

Emissions may also occur from newsprint containing the substance as a result of it being left on the fibres during earlier recycling steps. Appendix 6 has equations to calculate the background level of substances in paper through this route. For each recycling step, it is assumed that the paper undergoes a de-inking step, as would be expected for use in newsprint. The resulting concentrations are:

$M_{s\_R1} = 4.32\text{x}10^{-3}\text{kg t}^{-1}$

$M_{s\_R2} = 4.71\text{x}10^{-3}\text{kg t}^{-1}$

$M_{s\_R3} = 4.74\text{x}10^{-3}\text{kg t}^{-1}$.

Average concentration is $M_{s\_background} = 4.6\text{x}10^{-3}\text{kg t}^{-1}$.

This value is used in place of M_s in Equation 15 and Equation 16, with a value of 1 used for the fraction of paper containing the substance (assuming that all of the recovered paper has this level of substance).

$E_{deink\_water\_back} = 4.6 \times 10^{-3} \times 266 \times 0.21 \times 1 = 0.26\text{kg d}^{-1}$ Equation 15

$E_{deink\_sludge\_back} = 4.6\times10^{-3} \times 266 \times 0.7 \times 1 = 0.86\text{kg d}^{-1}$ Equation 16

$E_{primary\_water\_back} = 0.26 \times 0.1 = 0.026\text{kg d}^{-1}$ Equation 17

$E_{primary\_sludge\_back} = 0.26 \times 0.9 = 0.23\text{kg d}^{-1}$ Equation 18

$E_{sludge\_total\_back} = 0.86 + 0.23 = 1.09\text{kg d}^{-1}$ Equation 19

The combined emissions are therefore:

$E_{primary\_water} = 0.27 + 0.026 = 0.3\text{kg d}^{-1}$

$E_{sludge\_total} = 11.3 + 1.09 = 12.2\text{kg d}^{-1}$.

Concentrations can be calculated at this stage if required:

$C_{wastewater} = (0.3 \times 1000) / (12 \times 266) = 0.094\text{mg l}^{-1}$ Equation 20

$C_{sludge} = (12.2 \times 10^6) / (100 \times 266) = 459\text{mg kg}^{-1}$ Equation 21.

The local site in this case uses 93,000 tonnes per year, which is 1/132 of the total for newsprint. Hence, the total EU emissions are 132 times those calculated above and the regional emissions are 10 per cent of this total. The daily rates should be converted to annual emissions using a figure of 350 days. Only 80 per cent of the amount of the substance in sludge should be considered as released to agricultural land, as explained in Section 4.1.3.

5.3.4 Paper recycling – Example 4

A dye used to produce coloured paper at a level of 4kg t^{-1} in paper (this is specific information, but is in the range of the values in table 2.1 – note that, in this example, this is the actual level in paper, rather than the applied amount). EU tonnage is 2,000 tonnes per year (the tonnage could be adjusted to account for any losses at paper production, but this has not been done in this example); solubility = 5mg l^{-1}.

Data

Substance			Site		
TONNAGE	2000t	S	Q_r	266t d^{-1}	D (Section 5.2.1.1)
M_s	4kgt^{-1}	S	$FLOW_{wastewater}$	12m^3 t^{-1}	D (Section 5.2.1.4)
F_{deink_water}	0.5	D (Table 4.4)	Q_{sludge}	100kg t^{-1}	D (Section 5.2.1.5)
F_{deink_sludge}	0.02	D (Table 4.4)	$Q_{total\_EU\_recyc}$	46,475,000t	D (Section 5.2.1.3)
F_{deink_paper}	0.48	D (Table 4.4)			
$F_{primary\_water}$	0.5	D (Section 4.2.3)			
$F_{primary\_sludge}$	0.5	D (Section 4.2.3)			
F_{recyc}	0.6	D (Section 5.2.1.2)			

Values marked S are specific information for the scenario or substance. D values are defaults taken from this document.

Calculation

For the first calculation it is assumed that the paper is recovered with higher quality waste materials and is used to make higher quality products. A de-inking step is therefore relevant.

$$F_{paper\_with\_subst} = \frac{2{,}000 \times 0.6 \times 1{,}000}{4} \times \frac{1}{46{,}475{,}000} = 0.0065 \qquad \text{Equation 14}$$

$E_{deink\_water} = 4 \times 266 \times 0.5 \times 0.0065 = 3.43\text{kg d}^{-1}$ Equation 15

$E_{deink\_sludge} = 4 \times 266 \times 0.02 \times 0.0065 = 0.14\text{kg d}^{-1}$ Equation 16

A fraction of F_{deink_paper}, or 0.48, remains on the fibres. As the products being made are of a higher quality, it is assumed that the re-pulped fibres will be bleached to remove existing colours and so the dye will be degraded. Hence, it will not be retained in the new products.

$E_{primary\_water} = 3.43 \times 0.5 = 1.77\text{kg d}^{-1}$ Equation 17

$E_{primary\_sludge} = 3.43 \times 0.5 = 1.77\text{kg d}^{-1}$ Equation 18

$E_{sludge\_total} = 0.14 + 1.77 = 1.91\text{kg d}^{-1}$ Equation 19

Note that it is most likely that the effluent will be treated in a biological treatment plant as well, but this is not included in the above calculations.

An alternative route would be to assume that the paper entered the packaging recycling stream. In this case, the re-pulping process would probably not involve de-inking. For this substance there is no specific information on its fate in such a process. It could be assumed that the degree of retention will be the same as for the initial production of the paper. Values for $F_{papermaking\_paper}$ are included in Table 4.3. For dyes, a range of values from 0.8 to 0.95 are proposed, and the value of 0.9 is used in this instance. This value is used as $F_{deinking\_paper}$ in Appendix 6. The resulting concentrations are:

$M_{s\_R1} = 0.023\text{kg t}^{-1}$

$M_{s\_R2} = 0.044\text{kg t}^{-1}$

$M_{s\_R3} = 0.062\text{kg t}^{-1}$.

Average concentration is $M_{s\_background} = 0.043\text{kg t}^{-1}$.

This value is used in place of M_s in Equation 15 and Equation 16, with a value of 1 used for the fraction of paper containing the substance (assuming that all of the recovered paper has this level of substance). There is no specific information about the fractions released from paper to water and sludge, so an equal distribution of the released fraction (0.1) is assumed – hence $F_{deink\_water} = F_{deink\_sludge} = 0.05$. Note that the F_{deink} values used in this part of the calculation are different from those in the table above.

$E_{deink\_water\_back} = 0.043 \times 266 \times 0.05 \times 1 = 0.57\text{kg d}^{-1}$ Equation 15

$E_{deink\_sludge\_back} = 0.043 \times 266 \times 0.05 \times 1 = 0.57\text{kg d}^{-1}$ Equation 16

$E_{primary\_water\_back} = 0.57 \times 0.5 = 0.29\text{kg d}^{-1}$ Equation 17

$E_{primary\_sludge\_back} = 0.57 \times 0.5 = 0.29\text{kg d}^{-1}$ Equation 18

$E_{sludge\_total\_bcak} = 0.57 + 0.29 = 0.86\text{kg d}^{-1}$ Equation 19

It is also necessary to calculate the emissions from ‘first use’ paper at a site with no de-inking.

$E_{deink\_water} = 4 \times 266 \times 0.05 \times 0.0065 = 0.35\text{kg d}^{-1}$ Equation 15

$E_{deink\_sludge} = 4 \times 266 \times 0.05 \times 0.0065 = 0.35\text{kg d}^{-1}$ Equation 16

$E_{primary\_water} = 0.35 \times 0.5 = 0.18\text{kg d}^{-1}$ Equation 17

$E_{primary\_sludge} = 0.35 \times 0.5 = 0.18\text{kg d}^{-1}$ Equation 18

$E_{sludge\_total} = 0.35 + 0.18 = 0.53\text{kg d}^{-1}$ Equation 19

The combined emissions are therefore:

$E_{primary\_water} = 0.18 + 0.29 = 0.47\text{kg d}^{-1}$

$E_{sludge\_total} = 0.53 + 0.86 = 1.39\text{kg d}^{-1}$.

The local site is the average size site in the EU, based on 500 sites using recycled paper. If information is available on the relative amounts of dyed paper recycled by each of the two routes detailed above then this can be used to estimate the total emissions. In the absence of such information, it can be assumed that all recycling involves a de-inking step. This assumption gives higher emissions, which may be an over-estimate. The total emissions are 500 times those detailed above and the regional emissions are 50 times. The daily rates should be converted to annual emissions using a figure of 350 days.

5.3.5 Paper recycling – Example 5

A non-impact toner, with 200 tonnes used in the EU per year. In this case, the waste paper goes into general waste for board production; solubility = 0.1mg l^{-1}.

Data

Substance			Site		
TONNAGE	200t	S	Q_r	266t d^{-1}	D (Section 5.2.1.1)
M_s	20kg t^{-1*}	D (Table 2.1)	$FLOW_{wastewater}$	12m^3 t^{-1}	D (Section 5.2.1.4)
F_{deink_water}	0.28$^{\$}$	D (Table 4.4)	Q_{sludge}	100kg t^{-1}	D (Section 5.2.1.5)
F_{deink_sludge}	0.6	D (Table 4.4)	$Q_{total\_EU\_recyc}$	46,475,000t	D (Section 5.2.1.3)
F_{deink_paper}	0.12	D (Table 4.4)			
$F_{primary\_water}$	0.1	D (Section 4.2.3)			
$F_{primary\_sludge}$	0.9	D (Section 4.2.3)			
F_{recyc}	0.6	D (Section 5.2.1.2)			

Values marked S are specific information for the scenario or substance. D values are defaults taken from this document. The value marked * is the maximum value from Table 2.1. The label $ indicates that there may not be a de-inking step for board production. There are no retention factors for application as in

Example 2, as the substance is added after paper production. It is assumed that the fraction for removal after de-inking, from Table 4.4, can be applied to removal through washing.

Calculation

$$F_{paper\_with\_subst} = \frac{200 \times 0.6 \times 1{,}000}{20} \times \frac{1}{46{,}475{,}000} = 1.3 \times 10^{-4}$$ Equation 14

$E_{deink\_water} = 20 \times 266 \times 0.28 \times 1.3\text{x}10^{-4} = 0.19\text{kg d}^{-1}$ Equation 15

$E_{deink\_sludge} = 20 \times 266 \times 0.6 \times 1.3\text{x}10^{-4} = 0.41\text{kg d}^{-1}$ Equation 16

(A fraction of $F_{deink\_paper,}$ or 0.12, remains on the fibres.)

$E_{primary\_water} = 0.19 \times 0.1 = 0.019\text{kg d}^{-1}$ Equation 17

$E_{primary\_sludge} = 0.19 \times 0.9 = 0.17\text{kg d}^{-1}$ Equation 18

$E_{sludge\_total} = 0.41 + 0.17 = 0.58\text{kg d}^{-1}$ Equation 19

The equations in Appendix 6 can be used to estimate the concentration of the substance in the board after a number of recycling steps. The resulting concentrations are:

$M_{s\_R1} = 3.1\text{x}10^{-4}\text{kg t}^{-1}$
$M_{s\_R2} = 3.47\text{x}10^{-4}\text{kg t}^{-1}$
$M_{s\_R3} = 3.51\text{x}10^{-4}\text{kg t}^{-1}$.

Average concentration is $M_{s\_background} = 3.37\text{x}10^{-4}\text{kg t}^{-1}$.

The estimated emissions are:

$E_{deink\_water\_back} = 3.37 \times 10^{-4} \times 266 \times 0.28 \times 1 = 0.025\text{kg d}^{-1}$ Equation 15

$E_{deink\_sludge\_back} = 3.37 \times 10^{-4} \times 266 \times 0.6 \times 1 = 0.054\text{kg d}^{-1}$ Equation 16

$E_{primary\_water\_back} = 0.025 \times 0.1 = 0.003\text{kg d}^{-1}$ Equation 17

$E_{primary\_sludge\_back} = 0.025 \times 0.9 = 0.023\text{kg d}^{-1}$ Equation 18

$E_{sludge\_total\_back} = 0.054 + 0.023 = 0.077\text{kg d}^{-1}$ Equation 19.

The combined emissions are therefore:

$E_{primary\_water} = 0.019 + 0.003 = 0.022\text{kg d}^{-1}$

$E_{sludge\_total} = 0.58 + 0.077 = 0.66\text{kg d}^{-1}$.

Note that it is most likely that the effluent will be treated in a biological treatment plant as well, but this is not included in the above calculations.

The local site is the average size site in the EU, based on 500 sites using recycled paper. Hence, the total emissions are 500 times those detailed above and the regional emissions are 50 times. The daily rates should be converted to annual emissions using a figure of 350 days.

5.3.6 Paper recycling – Example 6

A substance used in thermal paper at 7 per cent of paper by weight: EU usage is 1,000 tonnes; solubility = 200mg l^{-1}. This calculation is for a site receiving thermal paper broke, which is waste from the paper production process that goes directly to the recycling plant. Based on measurements at the site, which is a similar size to the default site, the rate of removal of the substance from water on primary treatment is 95 per cent. One recycling cycle is considered.

Data

Substance			Site		
$TONNAGE$	1,000t	S	Q_r	266t d^{-1}	D (Section 5.2.1.1)
M_s	70kg t^{-1}	S	$FLOW_{wastewater}$	12m^3 t^{-1}	D (Section 5.2.1.4)
F_{deink_water}	1	D (Table 4.4)	Q_{sludge}	100kg t^{-1}	D (Section 5.2.1.5)
F_{deink_sludge}	0	D (Table 4.4)	$Q_{total\_EU\_recyc}$	46,475,000t	D (Section 5.2.1.3)
F_{deink_paper}	0	D (Table 4.4)			
$F_{primary\_water}$	0.05	S			
$F_{primary\_sludge}$	0.95	S			
F_{recyc}	0.3	D (Section 5.2.1.2)			

Values marked S are specific information for the scenario or substance. D values are default values taken from this document.

Calculation

For this situation, $F_{paper\_with\_subst}$ is 0.1 (10 per cent) from Section 5.2.1.3.

$E_{deink\_water} = 70 \times 266 \times 1 \times 0.1 = 1{,}862 \text{kg } d^{-1}$ Equation 15

$E_{deink\_sludge} = 70 \times 266 \times 0 \times 0.1 = 0 \text{kg } d^{-1}$ Equation 16

$E_{primary\_water} = 1862 \times 0.05 = 93 \text{kg } d^{-1}$ Equation 17

$E_{primary\_sludge} = 1862 \times 0.95 = 1{,}676 \text{kg } d^{-1}$ Equation 18

$E_{sludge\_total} = 0 + 1676 = 1{,}676 \text{kg } d^{-1}$ Equation 19

Note that it is most likely that the effluent will be treated in a biological treatment plant as well, but this is not included in the above calculations.

The input level of 10 per cent will not be maintained throughout the year. The input of the substance to paper is 1,680kg per day (from Equation 15 above, as all the substance is removed from the paper). If 10 per cent of the thermal paper is broke, then this translates to a total of 100 tonnes of the substance. Hence, there would be 59 days of input at this level and the total EU emissions are 59 times the values calculated above. As this is a process that only occurs at a few places, assuming that all of the releases occur in the region would be a reasonable worst case.

5.3.7 Paper recycling – Example 7

A substance used as a cyan dye in inkjet printer inks: EU usage is 3 tonnes; solubility = 1,350mg l^{-1}. The example considers both a recycling site where de-inking is used (for producing recycled writing paper) and also a scenario for where no de-inking occurs (for producing recycled packaging paper).

The mass of ink applied to the paper is assumed to be, on average, 5 per cent by weight, based on the information reported in Section 2.1.6. In this case, in order to determine the amount of dye applied to the paper, it is necessary to know the dye content of the ink. Using the information outlined in Section 2.1.6, it is assumed that the dye makes up 2.5 per cent by weight of the ink, which means that the amount of dye applied to the paper would be 0.13 per cent by weight or 1.3kg t^{-1} (M_s)

The fractions to sludge, water and paper during recycling are based on flexographic inks and are taken from Table 4.4**.**

Data

Substance			Site		
$TONNAGE$	3t	S	Q_r	266t d^{-1}	D (Section 5.2.1.1)
M_s	1.3kg t^{-1}	S	$FLOW_{wastewater}$	12m^3 t^{-1}	D (Section 5.2.1.4)
F_{deink_water}	0.9	D (Table 4.4)	Q_{sludge}	100kg t^{-1}	D (Section 5.2.1.5)
F_{deink_sludge}	0.01	D (Table 4.4)	$Q_{total\_EU\_recyc}$	46,475,000t	D (Section 5.2.1.3)
F_{deink_paper}	0.1	D (Table 4.4)			
$F_{primary\_water}$	1	D (Section 4.2.3)			
$F_{primary\_sludge}$	0	D (Section 4.2.3)			
F_{recyc}	0.6	D (Section 5.2.1.2)			

Values marked S are specific information for the scenario or substance. D values are default values taken from this document.

Calculation

$$F_{paper\_with\_subst} = \frac{3 \times 0.6 \times 1000}{1.3} \times \frac{1}{46{,}475{,}000} = 2.9 \times 10^{-5}$$ Equation 14

$E_{deink\_water} = 1.3 \times 266 \times 0.9 \times 2.9{\times}10^{-5} = 9.0{\times}10^{-3}\text{kg d}^{-1}$ Equation 15

$E_{deink\_sludge} = 1.3 \times 266 \times 0.01 \times 2.9{\times}10^{-5} = 1.0{\times}10^{-4}\text{kg d}^{-1}$ Equation 16

$E_{primary\_water} = 9.0{\times}10^{-3} \times 1 = 9.0{\times}10^{-3}\text{kg d}^{-1}$ Equation 17

$E_{primary\_sludge} = 9.0{\times}10^{-3} \times 0 = 0\text{kg d}^{-1}$ Equation 18

$E_{sludge\_total} = 0 + 1.0{\times}10^{-4} = 1.0{\times}10^{-4}\text{kg d}^{-1}$ Equation 19

A fraction of F_{deink_paper} of 0.1 remains on the fibres. In this example, as the products being made are of a higher quality, it is expected that the re-pulped fibres will be bleached to remove existing colours and so the dye will be degraded. Hence, it will not be retained in the new products.

Note that it is most likely that the effluent will be treated in a biological treatment plant as well, but this is not included in the above calculations.

An alternative route would be to assume that the paper entered the packaging and recycling stream. In this case, the re-pulping process would probably not involve de-inking. There is no specific information on the fate of this substance in such a process. It could be assumed that the degree of retention will be the same as for a dye used during paper-making. Values for $F_{papermaking\_paper}$ are included in Table 4.3. For dyes, a range of values from 0.8 to 0.95 are proposed, and a value of 0.8 is used in this example, as the substance has a reasonably high water solubility. This value is used as $F_{deinking\_paper}$ in Appendix 6. The resulting concentrations are:

$M_{s\_R1} = 3.0{\times}10^{-5}$ kg t^{-1}
$M_{s\_R2} = 5.4{\times}10^{-5}$ kg t^{-1}

$M_{s\_R3} = 7.4\times10^{-5}$ kg t^{-1}.

Average concentration is $M_{s\_background} = 5.3\times10^{-5}$ kg t^{-1}.

This value is used in place of M_s in Equation 15 and Equation 16, with a value of 1 used for the fraction of paper containing the substance (assuming that all of the recovered paper has this level of substance). In this case, there is no specific information about the fractions released from paper and sludge. It is assumed here that, as the substance has a relatively high water solubility, the values of F_{deink_water} and F_{deink_sludge} will also be applicable in this situation, even though no de-inking is carried out.

$E_{deink_water_back} = 5.3\times10^{-5} \times 266 \times 0.9 \times 1 = 0.013$kg d^{-1} Equation 15

$E_{deink_sludge_back} = 5.3\times10^{-5} \times 266 \times 0.01 \times 1 = 1.4\times10^{-4}$kg d^{-1} Equation 16

$E_{primary_water_back} = 0.013 \times 1 = 0.013$kg d^{-1} Equation 17

$E_{primary_sludge_back} = 0.013\times 0 = 0$kg d^{-1} Equation 18

$E_{sludge\_total\_back} = 1.4\times10^{-4}$ kg $d^{-1} + 0 = 1.4\times10^{-4}$ Equation 19

It is also necessary to calculate the emissions from ‘first use’ paper at a site with no de-inking.

$E_{deink_water} = 1.3 \times 266 \times 0.9 \times 2.9\times10^{-5} = 9.0\times10^{-3}$kg d^{-1} Equation 15

$E_{deink_sludge} = 1.3 \times 266 \times 0.01 \times 2.9\times10^{-5} = 1.0\times10^{-4}$kg d^{-1} Equation 16

$E_{primary_water} = 9.0\times10^{-3} \times 1 = 9.0\times10^{-3}$kg d^{-1} Equation 17

$E_{primary_sludge} = 9.0\times10^{-3} \times 0 = 0$kg d^{-1} Equation 18

$E_{sludge_total} = 0 + 1.0\times10^{-4} = 1.0\times10^{-4}$kg d^{-1} Equation 19

The combined emissions are therefore:

$E_{primary\_water} = 9\times10^{-3} + 0.013 = 0.022$

$E_{sludge\_total} = 1.0\times10^{-4} + 1.4\times10^{-4} = 2.4\times10^{-4}$.

The local site is the average size site in the EU, based on 500 sites using recycled paper. Hence, the total emissions are 500 times those detailed above and the regional emissions are 50 times. The daily rates should be converted into annual emissions using a figure of 350 days.

5.3.8 Paper-making followed by recycling – Example 8

An azo dye with an EU usage of 600 tonnes; solubility = 0.05 mg l^{-1}. No specific information on paper types.

Data

Substance	Site

$TONNAGE$	600t	S	Q_p	266	D (Section 5.1.1.1)
M_s	8.3kg t^{-1}	D (Table 3.2)	Q_r	266	D (Section 5.2.1.1)
$F_{papermaking\_water}$	0.02	D (Table 4.3)	$FLOW_{wastewater}$	12m^3 t^{-1}	D (Section 5.1.1.3)
$F_{papermaking\_sludge}$	0.02	D (Table 4.3)	Q_{sludge}	100kg t^{-1}	D (Section 5.1.1.4 and 5.2.1.5)
$F_{papermaking\_paper}$	0.95	D (Table 4.3)	$Q_{total\_EU\_recyc}$	46,475,000t	D (Section 5.2.1.3)
F_{deink_water}	0.5	D (Table 4.4)			
F_{deink_sludge}	0.02	D (Table 4.4)			
F_{deink_paper}	0.48	D (Table 4.4)			
$F_{primary\_water}$	0.1	D (Section 4.2.3)			
$F_{primary\_sludge}$	0.9	D (Section 4.2.3)			
F_{recyc}	0.6	D (Section 5.2.1.2)			

Calculation

For the initial paper-making stage

$E_{papermaking\_water} = 8.3 \times 266 \times 0.02 = 44\text{kg d}^{-1}$ Equation 1

$E_{papermaking\_sludge} = 8.3 \times 266 \times 0.02 = 44\text{kg d}^{-1}$ Equation 2

(In addition a fraction of $F_{papermaking\_paper}$, or 0.95, would remain in the finished paper.)

$E_{primary\_water} = 44 \times 0.1 = 4.4\text{kg d}^{-1}$ Equation 3

$E_{primary\_sludge} = 44 \times 0.9 = 40\text{kg d}^{-1}$ Equation 4

$E_{sludge\_total} = 44 + 40 = 84\text{kg d}^{-1}$ Equation 5

Recycling

For recycling, two sets of calculations are performed: for the situations where de-inking is carried out and for reuse without de-inking.

Recycling with de-inking

For the recycling of ‘first use’ paper.

$$F_{paper\_with\_subst} = \frac{600 \times 0.6 \times 1000}{8.3} \times \frac{1}{46{,}475{,}000} = 0.0009$$ Equation 14

The value of M_s needs to be adjusted to represent both the amounts used in the paper and recycled. The fraction remaining on the paper ($F_{papermaking\_paper}$) is 0.95, hence the value for M_s for recycling is 8.3 x 0.95 = 7.9kg t^{-1}.

$E_{deink\_water} = 7.9 \times 266 \times 0.5 \times 0.0009 = 0.95\text{kg d}^{-1}$ Equation 15

$E_{deink\_sludge} = 7.9 \times 266 \times 0.02 \times 0.0009 = 0.038\text{kg d}^{-1}$ Equation 16

$E_{primary\_water} = 0.95 \times 0.1 = 0.095\text{kg d}^{-1}$ Equation 17

$E_{primary\_sludge} = 0.95 \times 0.9 = 0.855\text{kg d}^{-1}$ Equation 18

$E_{sludge\_total} = 0.038 + 0.855 = 0.893\text{kg d}^{-1}$ Equation 19

For the background contribution from paper passing through several recycling steps, the equations in Appendix 6 are used. The resulting concentrations are:

$M_{s\ \_R1} = 3.4\text{x}10^{-3}\text{ kg t}^{-1}$

$M_{s\ \_R2} = 5.1\text{x}10^{-3}\text{ kg t}^{-1}$

$M_{s\ \_R3} = 5.8\text{x}10^{-3}\text{ kg t}^{-1}$.

Average concentration is $M_{s\_background} = 4.8\text{x}10^{-3}\text{ kg t}^{-1}$.

This value is used in place of M_s in Equation 15 and Equation 16, with a value of 1 used for the fraction of paper containing the substance (assuming that all of the recovered paper has this level of substance).

$E_{deink\_water\_back} = 4.8\times10^{-3} \times 266 \times 0.5 \times 1 = 0.64\text{kg d}^{-1}$ Equation 15

$E_{deink\_sludge\_back} = 4.8\times10^{-3} \times 266 \times 0.02 \times 1 = 0.026\text{kg d}^{-1}$ Equation 16

$E_{primary\_water\_back} = 0.64 \times 0.1 = 0.064\text{kg d}^{-1}$ Equation 17

$E_{primary\_sludge\_back} = 0.64 \times 0.9 = 0.58\text{kg d}^{-1}$ Equation 18

$E_{sludge\_total\_back} = 0.026 + 0.58 = 0.61\text{kg d}^{-1}$ Equation 19

The combined emissions are therefore:

$E_{primary\_water} = 0.095 + 0.064 = 0.16\text{kg d}^{-1}$

$E_{primary\_sludge} = 0.893 + 0.61 = 1.5\text{kg d}^{-1}$.

Recycling without de-inking

For the recycling of ‘first use’ paper.

The values of $F_{paper\_with\_subst}$ (0.0009) and M_s (7.9kg/tonne) are the same as derived for the de-inking scenario. The fraction remaining on the pulp (F_{deink_paper}) is taken as the same as $F_{papermaking\_paper}$ – 0.95; the fractions released to water (F_{deink_water}) and to sludge (F_{deink_sludge}) are assumed to be the same as the equivalent $F_{papermaking}$ values – 0.02 each.

$E_{deink\_water} = 7.9 \times 266 \times 0.02 \times 0.0009 = 0.038\text{kg d}^{-1}$ Equation 15

$E_{deink\_sludge} = 7.9 \times 266 \times 0.02 \times 0.0009 = 0.038\text{kg d}^{-1}$ Equation 16

$E_{primary\_water} = 0.038 \times 0.1 = 0.004\text{kg d}^{-1}$ Equation 17

$E_{primary\_sludge} = 0.038 \times 0.9 = 0.034\text{kg d}^{-1}$ Equation 18

$E_{sludge\_total} = 0.004 + 0.034 = 0.072\text{kg d}^{-1}$ Equation 19

For the background contribution from paper passing through several recycling steps, the equations in Appendix 6 are used. The resulting concentrations are:

$M_{s\_R1} = 6.8 \text{ x}10^{-3}\text{kg t}^{-1}$

$M_{s\_R2} = 13.2 \text{ x}10^{-3}\text{kg t}^{-1}$

$M_{s\_R3} = 19.4 \text{ x}10^{-3}\text{kg t}^{-1}$.

Average concentration is $M_{s\_background} = 0.013\text{kg t}^{-1}$.

This value is used in place of M_s in Equation 15 and Equation 16, with a value of 1 used for the fraction of paper containing the substance (assuming that all of the recovered paper has this level of substance).

$E_{deink\_water\_back} = 0.013 \times 266 \times 0.02 \times 1 = 0.07\text{kg d}^{-1}$ Equation 15

$E_{deink\_sludge\_back} = 0.013 \times 266 \times 0.02 \times 1 = 0.07\text{kg d}^{-1}$ Equation 16

$E_{primary\_water\_back} = 0.07 \times 0.1 = 0.007\text{kg d}^{-1}$ Equation 17

$E_{primary\_sludge\_back} = 0.07 \times 0.9 = 0.063\text{kg d}^{-1}$ Equation 18

$E_{sludge\_total\_back} = 0.07 + 0.063 = 0.13\text{kg d}^{-1}$ Equation 19

The combined emissions are therefore:

$E_{primary\_water} = 0.004 + 0.007 = 0.011\text{kg d}^{-1}$

$E_{primary\_sludge} = 0.072 + 0.13 = 0.2\text{kg d}^{-1}$.

If the recycling is carried out at the same site as the paper-making, then the total emission from the site would be the sum of the two sources (the emissions from the initial paper-making and the emissions from recycling).

Note that it is most likely that the effluent will be treated in a biological treatment plant as well, but this is not included in the above calculations.

In the absence of specific information on the relative amounts likely to be recycled with and without a de-inking step, the emissions from de-inking could be scaled up to give a worst case for EU emissions. The site considered is the average size for the EU, based on 500 sites using recycled paper. Hence, the total emissions would be 500 times those detailed above and the regional emissions would be 50 times. Daily rates can be converted to annual rates assuming 350 days of operation.

6. UNCERTAINTIES

This ESD has been developed using available information on emissions from the paper-making and paper recycling processes. In order to make the ESD usable for the chemicals used in paper-making and paper recycling in general, a number of assumptions and simplifications have had to be made, which inevitably introduces uncertainties into the approach. The key data needed to use the ESD are summarised below.

- Mass of substance used per tonne of paper.
- Fraction of the substance that goes to waste water, paper-making sludge, de-inking (and other sludge) and the paper during the process.
- Sludge production rate per tonne of paper produced or recycled.
- Water consumption rate per tonne of paper produced or recycled.

Suggested (default) values are given in the ESD for these data where appropriate, but it should be recognised that further information would be useful to define more accurately these values for different chemicals and sites. In particular, if specific information is available for the chemical or site of interest, it should be used in preference to the suggested default values.

A number of sludges are generated during the paper-making process and methods for disposing of these sludges are an important consideration in the ESD. In many cases, these sludges are spread onto agricultural land, thereby providing a potential route of exposure for any substance contained in the sludges. However, this may not always be the case. Further information on the disposal aspects of sludges would be useful to reduce the uncertainties in this area.

Another area of uncertainty is the amount of paper containing a specific substance that is recycled at a site. The ESD assumes that the paper containing any given substance is distributed evenly throughout the total recovered paper material. This may not always be the case. However, there is very little information currently available to address this issue further.

It should also be noted that the amount of paper recycled is growing year-on-year. The methods presented are based on recycling figures for the EU in 2004.

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8. ABBREVIATIONS

ADT	Air-dried tonne
AKD	alkyl ketene dimmer
BAT	Best available techniques
BOD	Biochemical Oxygen Demand
CEN	European Standards Organisation
CEPI	Confederation of European Paper Industries
COD	Chemical Oxygen Demand
DIP	De-inked pulp
DIPN	di-isopropylnaphthalene
DTPA	diethylenetriaminepentaacetate
EDTA	ethylenediaminetetraacetic acid
ESD	Emission scenario document
EUSES	European Union System for the Evaluation of Substances
FAS	formamidine sulfinic acid
IPPC	Integrated Pollution Prevention and Control
OMG	Old magazines
ONP	Old newspapers
PAMS	Periodicals and magazines
PE	polyethylene

9. GLOSSARY

Biocides	Chemicals with biocidal properties that are generally added to treat incoming water and process water circuits to control microbiological growth. They can also be used to prevent growth on some speciality papers.
Board	Papers of 220gsm (gram per square meter) and over are generally called boards. They often have more than one ply.
Bleach	Oxidising agents added to the stock to increase the whiteness of the fibres; examples include hydrogen peroxide and sodium hypochlorite.
Bleaching	The process of brightening fibre by removing the coloured substances or decolourisation.
Broke	Any formed paper that has been discarded at any point in the manufacturing process. There are two kinds: wet broke, which is accumulated at any stage on the wet end of the machine; and dry broke from the dry end of the machine, which includes trimmings from the reeling, slitting and cutting operations, as well as paper or board rejected during sorting.
Calendar	A machine that smoothes or otherwise finishes the paper using a series of rollers.
Coatings	These can be applied on one or both sides, using polymeric materials or a mix of clay or carbonates and latex to create a high quality printing surface. May also include dyestuffs to give a desired colour to the finished product.
Corrugated (paper or paperboard)	Composed of liner and fluting, where fluting is paper that has undergone a treatment in order to give it a regular and permanently undulated aspect. The corrugated product is mostly used for packaging.
De-inking	The process of removing ink and other undesirable materials from printed waste papers. Uses a variety of chemicals including soaps, detergents and sodium hydroxide.
Defoamer	Used at the wet end of the paper machine to prevent foaming and before the coating colour is applied to destroy existing foam.
Disperger	A machine that reduces the size of contaminants, such as flakes of ink and varnish, to allow their removal by flotation or make them too small for the eye to resolve.
Dispersion agents	Surfactants used to clean felts, wires and water circuits and also to disperse resins and slimes.
Dry end	The part of the paper-making process after formation of the paper web.
Dry strength agents	Chemicals added at the wet end or to the paper surface to improve the dry-strength of the product; typical examples include natural starch and cationic starch.
Dyes	Substances that are added to give colour or tint to paper. They are mainly added to the furnish at the wet end, but can also be added at the size press.
Fillers	Paper-making additives in the form of powder or slurry, usually mineral clays or calcium carbonates, which are used to improve the smoothness, opacity, brightness and dimensional stability of paper and board.
Furnish	Fibre (pool).
Grammage	Mass of the paper/board, usually expressed as g/m².
Ligneous	Woody; consisting of lignin or xylem.

Optical brighteners or fluorescent whiteners	Substances added to enhance the white impression of paper by producing blue fluorescent light when excited with ultra-violet radiation. Optical brighteners are added to the furnish at the wet end or at the size press, or can be a component of the coating colours.
Paper	The finished product, consisting of a sheet of fibres with various added chemicals. Different grades are assigned according to the weight per square cm, namely paper <150g/m² <paperboard (or board) <250g/m² <cardboard.
Paper grade	Paper is classified into different grades according to the end use, the pulp used and the treatment of the paper.
Recovery rate	The proportion of the total used paper and board that is recycled.
Recycled fibre (or pulp)	Fibres (or pulp) produced from material that has been previously used for paper and/or board production.
Size	Non-fibrous materials used in paper-making to control the absorbency of paper. They are applied at the wet end (internal sized paper) or at the size press (surface sized paper). Typical examples are alkyl ketene dimer, rosin, alum, starch and gelatine.
Stickies	Primary stickies arise from the presence of adhesives and glues on the paper product entering the recycling system. Secondary stickies result from the dissolution or suspension of hydrophobic organic materials during de-inking and when destabilised by acid conditions, resulting in sticky particles.
Stock	The term used to describe paper-making material at all stages of the process, but especially applied to wet pulp before it is fed onto the paper machine.
Supercalendar	A machine that produces a very smooth surface on paper by passing it at high pressure through a series of rollers revolving at high speed.
Tinctorial strength	Colour strength – the amount of ink per unit area required to give a given strength of colour.
Tissue paper	Absorbent paper used for a variety of hygienic purposes.
Utilisation rate	The amount of recovered paper used (by paper mills) as a proportion of their total output.
Virgin fibre (or pulp)	Fibres (or pulp) produced from material (mostly wood) that has not been previously used for paper and/or board production.
Wet end	The part of the paper-making process that takes place prior to the formation of the paper web.
Wet strength agents	Chemicals added at the wet end of the process to improve the wet strength of the product, generally by incorporating a polymeric material into the fibres. Examples include melamine-formaldehyde resins and polyamide-epichlorohydrin resins.
White water	A general term for all of the waters within a paper mill that have been separated from the stock or pulp suspension and are derived either from the paper machine or accessory equipment or from pulp grinders. White water contains some fibre and may also contain varying amounts of fillers and dyestuffs.

APPENDIX 1: CHEMICALS USED IN PAPER-MAKING

The chemical use data collected from IPPC submissions for England and Wales, questionnaires and direct contact with paper mill employees has been collated into a series of spreadsheets, with the chemicals sorted according to the process/function for which they are used. The following sections list the chemicals and, where appropriate information was available, provide comments on their use and function and on the amounts used per tonne of product. This information is summarised in Table 3.2 of the main report.

It should be noted that the information collected in this appendix is reported as it was obtained and so presents a 'snapshot' of the chemicals used. It is not intended to be comprehensive, and will inevitably become out of date as new chemicals are developed and practices change (the original surveys were carried out in 2001, so there are already likely to have been changes). It is hoped that these tables may be useful in indicating the types of substances that are used in the different areas. The inclusion of a substance is no guarantee that it is either in current use or representative, merely that it was indicated as being used for that purpose in the survey. Where available, specific information on the substance of interest should be used in preference to any information included here.

Water treatment chemicals

The influent water may be treated with softeners if it contains high amounts of calcium salts and treated with biocides and coagulants if it is surface water taken from a river or estuary. This means that not all paper mills will use influent water treatment, and in the present study only five out of 17 mills used these chemicals. Table A1.1 shows the function and amount used per tonne of product where this information was available.

Table A1.1 Chemicals used for influent water treatment

Chemical	Function	Amount used (M_s) (kg per tonne of product)
Chemisolve CB1826	Coagulant	0.013
Chlorine dioxide (CAS no. 10049-04-4).	Disinfectant	Not known
Ferric sulphate	Coagulant	Not known
Poly(aluminiumhydroxychloride)	Coagulant	0.09
Sodium bromide (CAS no. 7647-15-6)	Disinfectant	0.015
Sodium chloride	Water softener	0.1
Sodium hypochlorite (CAS no. 10022-70-5).	Disinfectant	0.2 –0.85

Stock preparation chemicals

De-inking

De-inking chemicals are used to remove inks and associated materials during paper recycling. A variety of chemicals can be used to remove and/or solubilise inks and concentrate them into solid material (floc), which can then be removed. Such chemicals are used by all mills where newsprint and other forms of paper are recycled. Table A1.2 shows the chemicals used by the mills surveyed in the present study. It also identifies with a **B** those compounds that were specified by the paper mills as being readily biodegradable or which have structures that suggest they will be readily biodegradable.

Table A1.2 Chemicals used for de-inking

Chemical	**Usage (M_s) (kg per tonne of product)**	**Function**
Alkoxylated non-ionic de-inking surfactant (containing ethylene oxide, propylene oxide or glycol ethers) (**B**)	0.5 to 0.08	Surfactant in de-inking process
Calcium chloride (CAS no. 10043-52-4)	Not known	Adjusts water hardness to improve soap efficiency.
Fatty acids (**B**)	1.25–5.8	Flotation of particles
Hydrogen peroxide (CAS no. 7722-84-1)	2	Bleaching
Magnesium silicate (Talc)	15	De-inking pulper additive
Sodium hydroxide (CAS no. 1310-73-2)	5	Addition to high consistency pulpers/regeneration of anion exchange resins in plants
Sodium polyacrylamide + sodium carbonate (CAS no. 497-19-8)	0.68	Flocculant
Sodium salts of long chain fatty acids (soaps) (**B**)	2.2–5	Flotation of particles
Sodium silicate (CAS no. 1344-09-8)	20	De-inking pulper additive
Sulphuric acid	25	pH adjustment

Notes: **B** = readily biodegradable.

Bleaching

Bleaching is used to ‘whiten’ the stock by decolourising residual inks and dyes in recycled pulps and natural colorants in virgin pulp. Typical chemicals used in the bleaching process are shown in Table A1.3.

Table A1.3 Chemicals used during bleaching

Chemical	Usage (M_s) (kg per tonne product)	Function
Aluminium sulphate (CAS no. 10043-01-3)	Not known	Not known
Formadine sulfinic acid	1.2	
Sodium hydrosulphite (CAS no. 7775-14-6)	2–10	Reducing agent
Sodium hydroxide (CAS no. 1310-73-2)	3	pH adjustment
Sodium hypochlorite (CAS no. 10022-70-5)	40	Oxidising agent
Sodium silicate (CAS no.1344-09-8)	Not known	pH buffer

Colourants and optical brighteners

A wide range of colourants and optical brighteners are used to impart desired colour characteristics to the finished product. Some of the chemicals used are shown in Table A1.4.

Table A1.4 Dyestuffs and optical brighteners

Chemical	Usage (M_s) (kg per tonne of product)	Function
Anionic stilbene (CAS no. for stilbene is 588-59-0)	0.1–2	Optical brightener
Aqueous acrylamide pigment preparation	1.2	Pigment
Aqueous Beta-Oxy -Napthol acrylamide pigment preparation	1.2	Pigment
Aqueous dioxazine pigment preparation	1.2	Pigment
Astrazon yellow	Not known	Methine dye preparation containing acetic acid
Azo dyes (basic and acid)	0.0006–3.3	Dye
Basazol blue 15l	0.025	Minimum amount; colour control of product via existing dosing system
Basazol C black PR8124	Not known	Dye
Basazol green 20l	0.005	dye
Basazol red 72l	0.0075	Dye for paper machine shade control
Basazol yellow	Not known	Methine dye
Basic and phthalocyanine (blue-violet)	0.05	All retained; poor biodegradability.
Basic C1 dyes	0.4–2.0	Solution in acetic acid and diethylene glycol

Chemical	Usage (M_s) (kg per tonne of product)	Function
Benzenecarboxylic acid amide derivative (cationic)	7.5×10^{-4}	Optical brightening agent quencher, added with dyes
Calcinated china clay	0.05	Pigment additive
Copper phthalocyanine (CAS no. 147-14-8)	0.4–2	Used to adjust colour of product
Dioxanne dyestuff	2	Dye
Halogenated copper phthalocyanine preparation	1.2	Dye
Iron oxide	0.003	Not known
Methine and triarylmethine dyes	0.03–0.41	Dye
Monoazo	0.003	Dye
Optical brightening agent	8.3	Water soluble stilbene derivatives; no contaminants; distilbene alternatives
Polyamine	0.08	Dye fixative
Titanium dioxide (CAS no. 13463-67-7)	40	Pigment
Triarylcarbenium	0.4–1	Dye

Drainage and retention additives

These chemicals are added to modify the disposition of the fibre in order to enhance its retention on the wire and water drainage. Typical chemicals used are shown in Table A1.5.

Table A1.5 Drainage and retention aids

Chemical	Usage (M_s) (kg per tonne product)	Function
Aliphatic polyamine	1.1	Retention aid
Aliphatic polyamine derivative – cationic	0.30	Coagulant
Aluminium sulphate (CAS no. 10043-01-3)	5.6	Retention aid
Bentonite clay (CAS no. 1302-78-9)	1.0–1.8	Coagulant
Carboxymethylcellulose (CAS no. 9000-11-7) (**B**)	2.00	Flow modifier
Cationic starch (CAS no. 56780-58-6) (**B**)	5.00–18	Not known
Colloidal dispersion of silica	5.00–11	Retention aid
Natural starch (CAS no. 9005-25-8) from maize, corn, wheat (**B**)	20.00	Not known

Chemical	**Usage (M_s) (kg per tonne product)**	**Function**
Poly aluminium chloride	16.00	Flocculant
Polyacrylamide (CAS no. 9003-05-8)	0.1–1.0	Retention aid
Poly-dimethyl dialkyl ammonium chloride	Not known	Not known
Polyethyleneimine, modified in aqueous solution	0.50	Retention aid
Sodium carboxymethylcellulose (CAS no. 9004-32-4) (**B)**	6.00	Biodegradable; any residual expected to be removed within effluent treatment works
Sodium polyacrylate (CAS no. 9003-04-7).	Not known	Viscosity modifier

Note: **B** = readily biodegradable.

Dry strength

These chemicals are added to improve the strength of the product when the fibres are dry. Common chemicals used are shown in Table A1.6.

Table A1.6 Dry strength chemicals

Chemical	**Usage (M_s) (kg per tonne of product)**	**Comments**
Alkyl ketene dimer (AKD)	7.3	Mixture with cationic starch
Aluminium sulphate (CAS no. 10043-01-3).	0.6	Not known
Cationic starch (CAS no. 56780-58-6) (**B)**	0.03–2.7	Added to pulpers
Gelatin (CAS no. 9000-70-8) (**B)**	14–34	Provides additional paper strength
Polyvinylalcohol (PVOH; CAS no. 9002-89-5)	26.4	Not known
Natural starch (CAS no.9005-25-8), potato, maize **(B)**	0.1–47	Raw starch
Sodium carboxymethyl cellulose (CAS no. 9004-32-4) **(B)**	3.5	Not known
Sodium hydroxide (CAS no. 1310-73-2)	0.33	Starch pH neutraliser
Sorbitol (CAS no. 50-70-4) (**B)**	10.0–24	Not known

Note: **B** = readily biodegradable.

Wet strength chemicals

These chemicals are added to improve the strength of the product when the fibres are wet. Common chemicals used are shown in Table A1.7.

Table A1.7 Wet strength additives

Chemical	**Usage (M_s) (kg per tonne of product)**	**Comment**
Cationic polyamide/epichlorohydrin (CAS no. 106-89-8) resin	1.4–50	Not readily biodegradable
Cationic polyamide-amine epichlorohydrin (CAS no. 106-89-8) resin	1.4–12	Low environmental impact; very pure product with high retention
Melamine (CAS no. 108-78-1)	8–22	Not known
Melamine formaldehyde resin	48	Wet strength agent
Polyamide-amine resin	0.1	Resin; potential environmental impact; poor biodegradability
Sodium carboxymethyl cellulose (CAS no. 9004-32-4)	Not known	Added to machine chest and after refiners
Sodium persulphate	Not known	Wet strength aid

Sizing

These are non-fibrous materials used to control the absorbency of the paper produced. Typical examples are shown in Table A1.8.

Table A1.8 Sizing chemicals

Chemical	**Usage (M_s) (kg per tonne of product)**	**Comments**
Akyl ketene dimer (AKD)	0.33–28	No known contaminants; ASA and rosin/alum are less efficient alternatives for current system
Alum (CAS no. 7784-24-9)	7.3	Used in conjunction with rosin size
Aluminium sulphate (CAS no. 10043-01-3)	27.00	Not known
Alkenyl succinic anhydride (ASA)	0.40	Not known
Styrene/acrylate co-polymer	0.70	Jet size
Rosin emulsion	15.00	Not known
Rosin (CAS no. 8050-09-7)	14.50	Aqueous solution of fortified rosin

Raw materials

The main raw materials used are recycled paper, virgin pulp and water, and these have been discussed in the earlier sections. The dry weight of fibre used can be greater than the dry weight of the paper product, particularly when recycled pulp is used, due to losses of fibre during the paper-making process.

Water use is considerable, varying from 3,000–40,000 kg per tonne of dry product (it may be considerably more for some specialist products).

Coatings

Coatings are applied on one or both sides of the paper, using polymeric materials or a mix of clay or carbonates and latex to create a high quality printing surface. Some of the typical chemicals used are shown in Table A1.9.

Table A1.9 Coating chemicals

Chemicals	**Usage (M_s) (kg per tonne of product)**	**Comments**
Alpha amylase (CAS no. 9000-90-2) (**B)**	0.01	Not known
Ammonia (CAS no. 7664-41-7)	0.021	pH control
Ammonium persulphate (CAS no. 7727-54-0).	0.036	Not known
Anionic and non-ionic surfactants	0.2	Emulsifying agent
Polyvinylacetate (PVA; CAS no. 9002-89-5)	0.083	Adhesive; aqueous emulsion polymer
Polyamide/epichlorohydrin resin	0.75	Not known
Carboxymethyl cellulose (CAS no. 9000-11-7) (**B)**	0.3	Not known
China clay	16.0	Coating pigment
Copper phthalocyanine (CAS no. 147-14-8)	0.006	Dye
Cross-linked polyurethane/polyacrylate	40	Not known
Fatty acid amide	0.2	Not known
Melamine-formaldehyde resin	0.45	Not known
Phosphate	0.13	Not known
Polyalkanol/polyalkylene glycol	0.78	Not known
Polyvinyl alcohol (CAS no. 9002-89-5)	1–35	Laminating adhesive
Sodium hydroxide (CAS no. 1310-73-2)	2	pH modifier in coat mix
Sodium perborate (CAS no. 7632-04-4)	0.1	Not known

Chemicals	Usage (M_s) (kg per tonne of product)	Comments
Cross-linked polyurethane containing *N*-methylpyrollidone and a polyfunctional aziridine	40	Not known
Sorbitol (CAS no. 50-70-4) (**B**)	2.25	Not known
Styrene polymer	9.1	Latex used in coating kitchen
Styrene-butadiene polymer	38	Not known
Sugar (**B)**	1	Adhesive
Tioxide	76	Not known

Note: **B** = readily biodegradable.

Process aids

Machine biocides

Biocides are added to control microorganism growth in the paper-making process. Some typical examples are shown in Table A1.10.

Table A1.10 Machine biocides

Chemical	Usage (M_s) (kg per tonne)	Comments
1-bromo-3-chloro,-5,5-dimethyl hydantoin (CAS no. 16079-88-2)	0.00015–0.045	Slimicide
2(methoxy-carbamoyl)benzimidazole	0.004	Not known
2,2-dibromo-2-nitrilopropionamide	0.03	Not known
2-bromo-2-nitropropane-1,3-diol (BNPD; CAS no. 52-51-7)	0.073	Not known
2-bromo-2-nitropropane-1,3-diol (CAS no. 52-51-7) and dipropylene glycol methyl ether (CAS no. 34590-94-8)	0.073	Not known
2-bromo-4-hydroxy-acetophenone	0.005	Not known
2-methyl-4-isothiazolin-3-one (CAS no. 2682-20-4)	Not known	Not known
3,5-dimethyl-tetrahydro-1,3,5-2H-thiodiazine-2-thione	Not known	Not known
5,5-dichloro-2,2-dihydroxy-diphenylmethane	Not known	Not known
5-chloro-2-methyl-4-isothiazolin-3-one (CAS no. 26172-55-4)	Not known	Not known
5-oxo-3,4-dichloro-1,2-dithiol	Not known	Not known
Benzalkonium chloride (CAS no.8001-54-5),	0.28	Not known

Chemical	**Usage (M_s) (kg per tonne)**	**Comments**
benzoisothiazole, glutaraldehyde (CAS no. 111-30-8)		
Bis (trichloromethyl) sulphone (CAS no. 3064-70-8)	Not known	Not known
Bromochlorodimethylhydantoin (BCDMH; CAS no. 16079-88-2)	0.04	Not known
Bromochlorodimethylhydantoin (BCDMH; CAS no. 16079-88-2)	Not known	Not known
Bromonitrostyrene (CAS no. for beta-bromo-beta-nitrostyrene – 7166-19-0)	Not known	Not known
Combination of dimethylamides of long chain fatty acids with surfactants	0.2	Biodispersant
Dicyandiamide formaldehyde	0.045	Slimicide
Diethylene glycol (CAS no. 111-46-6)	Not known	Not known
Dodecylguanidine hydrochloride (CAS no. 13590-97-1)	Not known	Not known
Glutaraldehyde (CAS no. 111-30-8), 5-chloro-2-methyl-4-isothiazolin-3-one (CAS no. 26172-55-4), 2-methyl-4-isothiazolin-3-one (CAS no. 2682-20-4), magnesium nitrate (CAS no. 10377-60-3)	0.13	Biocide
Glutaraldehyde (CAS no. 111-30-8)	0.03–0.13	Not known
Isothiazolone derivative	0.015–0.1	Retention aid biocide
Magnesium nitrate/5-chloro-2-methyl-isothiazoline	0.00005	Not known
Methyl bis thiocyanate (CAS no. 6317-18-6)	0.03	Not known
N-methyl pyrrolidone/5-oxo-3, 4-dichloro-1, 2-dithiol / propylene glycol (CAS no. 57-55-6)	8.3E-05	Not known
N-methylpyrrolidone (CAS no. 872-50-4)	Not known	Not known
Quarternary ammonium salts	Not known	Bacteriocide
Quarternary phosphonium salt blended with surfactant	Not known	Bacteriocide
Magnesium nitrate/5-chloro-2-methyl-2H-isothiazol-3-one (CAS no. 26172-55-4)	0.013	Not known
Sodium bromide (CAS no. 7647-15-6)	Not known	Not known
Sodium dimethyl dithiocarbamate (CAS no. 128-04-1); disodium ethylene bis dithiocarbamate	Not known	Not known
Sodium hydroxide (CAS no. 1310-73-2)	Not known	Starch biocide
Tetrahydro-3,4-dimethyl-2H-1,3,5-thiadiazine-2-thione	Not known	Starch biocide
Tetrakis hydroxy methyl phosphonium sulphate	0.1	Not known

Chemical	**Usage (M_s) (kg per tonne)**	**Comments**
(THPS)		

Further and more detailed information on the use of biocides is given in ESDs for biocides used in paper coating and finishing (Tisser and Chesnais 2001) and for slimicides (Van der Poel 2000).

Deposit and cleaning agents

Most of these chemicals are supplied as mixed products and are used to clean paper-making machines and to reduce the build-up of deposits. Typical examples are shown in Table A1.11.

Table A1.11 Deposit control and cleaning agents

Chemical	Usage (M_s) (kg per tonne of product)	Comment
10% naphtha	0.044	Fabric cleaner
Alkyldimethylbenzyl ammonium chloride (CAS no. 63449-41-2)	8	Fabric cleaner
Alkylphenol ether sulphate	Not known	
Aromatic hydrocarbons	Not known	Fabric cleaner
Blend of detergents	1. 7E-05	Not readily biodegradable
Cationic filming amine/surfactants blend	0.00073	
Cationic polymer and surfactant, mildly alkaline soap	0.46	Felt cleaner
Caustic	0.046	Caustic cleaners, added to paper machine
Caustic surfactant/NaOH (CAS no. 1310-73-2)	0.2–0.67	
Citric acid (CAS no. 77-92-9)	0.075	Felt conditioning
Alkylethoxylate (neutral)	0.1–0.2	
Blend of molybdate, specific copper inhibitor and phosphinocarboxylate copolymers	Not known	Corrosion and deposit inhibitor
Dimethyl formamide	Not known	
EDTA (CAS no. 60-00-4) salt/butyl diglycol ether	0.00012	Chelating agent
EDTA (CAS no. 60-00-4) salt/surfactants	0.00028	Not readily biodegradable
Formic and hydrochloric acid	2.78	No known contaminants; hydrochloric acid and phosphoric acid are under consideration
Hydrochloric acid	0.5–1	Softener and resin regenerant
Low molecular weight formaldehyde polymer	0.1	Wire passivator
Nalco 74409	0.0075	Control of scale build-up
Non-ionic surfactants (**B**)	1.17	Readily biodegradable; alternatives consist of similar products from different companies
Nonyl phenol ethoxylates	0.5	
Orthophosphoric polyamine formaldehyde	8	Fabric cleaner
Phosphoric acid, (1-hydroxyethylidene) bis	0.32	

Chemical	**Usage (M_s) (kg per tonne of product)**	**Comment**
Poly (oxy-1, 2-ethanediol, alpha-phenyl-omega-hydroxy)	0.083	
Polyamine formaldehyde condensate solution + phosphoric acid (CAS no. 7664-38-2)	0.5	Wire cleaner
Polyamine-formaldehyde condensate solution, phosphoric acid (CAS no. 7664-38-2)	0.075	Wire passivation.
Polycarboxylic acid salt and EO/PO copolymer	0.5	Not readily biodegradable; not expected to bioaccumulate; materials used in tandem with biocides – complete system evaluation required
Amino-tris-methylene phosphonic acid (**B)**	0.58	Scale inhibitor
Shock wash (sodium hydroxide; CAS no. 1310-73-2) + amino-tris (methylene phosphoric acid)	0.14	Wire and felt cleaner added at backwater system
Silicate/sulphate, polyamine blend	0.67	
Sodium chloride	0.1–0.5	Salt-softener, resin-regenerant
Sodium hydroxide (CAS no. 1310-73-2) + sodium glucoheptonate	0.39	System cleaner; used during shutdown for entire system cleanout
Sodium metasilicate/EDTA propylene glycol ether	10	Fabric cleaner
Solvent refined hydrocarbon mineral oil	0.0025	
Sulphuric acid (CAS no. 7664-93-9)	0.0075	Flowbox foam cleaning

Note: **B** = readily biodegradable.

Defoamers

Defoamers are used to control foam production in the effluent from paper production and may be proprietary products consisting of mixtures of components. Some typical examples are given in Table A1.12.

Table A1.12 Defoamers

Chemical	**Usage (M_s) (kg per tonne of product)**	**Comments**
Afranil AP liquid	Not known	
Afranil MG	0.25	Removal of air from paper-making stock
Afranil PR 8132	0.09	Control of air in stock

Chemical	**Usage (M_s) (kg per tonne of product)**	**Comments**
Afranil PR 8133	0.9	Control of air in stock
Aliphatic hydroxy emulsion (**B)**	0.4	Defoamer
Blend of natural triglycerides/synthetic fatty acid esters/hydrocarbon oil	0.0025	Foam controlling agent
Dispelair BT 578	0.10	Effective defoamer for use in sugar beet transport water
Dispelair DP 255	0.017	Used as a foam control agent in the Vac Pump Seal Water system
Dispelair DP 592	0.75	
Dispelair DP 594	Not known	
Emulsion of organic hydroxy compounds, fatty acid esters and surfactants (**B)**	0.02–0.8	PM14 deaerator
Fats, waxes, hydrocarbons, non-ionic emulsifiers, polyalcoxyether esters	0.28	.
Fatty acid amides	Not known	
Kemazur 4799	Not known	
Mineral oil	0.024–0.6	Coating defoamer.
Aqueous fatty acids (**B)**	1	Paper machine defoamer
PEG fatty acid triglyceride esters	0.2	
Polyalkylene glycol	0.33	
Polyglycolether	0.021	Starch defoamer
Siloxanes	Not known	

Note: **B** = readily biodegradable.

Reagents, laboratory chemicals etc.

A wide variety of chemicals, including solvents, are used as reagents and general laboratory chemicals in paper mills. The amounts used per annum are very small and consequently they have not been considered further in this study.

Treatment chemicals

These are chemicals used to treat the effluents from paper-making operations prior to discharge of the final effluent to sewers or surface waters. Some typical chemicals are shown in Table A1.13.

Table A1.13 Treatment chemicals

Chemical	**Usage (M_s) (kg per tonne of product)**	**Function**

Chemical	**Usage (M_s) (kg per tonne of product)**	**Function**
1,3,5-tris(2-hydroxyethyl)hexahydro-1,3,5-triazine (CAS no. 4719-04-4)	Not known	Effluent odour control
Aluminium sulphate (CAS no. 10043-01-3)	13.3	Flocculating agent
Ammonium carbonate (CAS no. 506-87-6) (**B**)	0.73	Source of ammonia and inorganic carbon required to ‘breed’ nitrifying bacteria
Ammonium nitrate (CAS no. 6484-52-2) (**B**)	Not known	Source of ammonia and inorganic nitrogen required to ‘breed’ nitrifying bacteria
Ammonium persulphate	Not known	Oxidising reagent for starch
Ammonium sulphate (CAS no. 7783-20-2) (**B**)	Not known	Source of ammonia required to ‘breed’ nitrifying bacteria
Anionic polyacrylamide	0.5–1	Coagulant
Calcium hydroxide (CAS no. 1305-62-0)	2. 7	Alkalinity control
Cationic amine	1	Flocculant
Cationic polyacrylamide	1–1.8	Flocculant
Aqueous solution of polydimethyl diallylammoniumchloride	0.38	Coagulant
Cyclohexylamine (CAS no. 108-91-8), morpholine (CAS no. 110-91-8)	Not known	Acidity neutraliser for steam condensate
Ferric sulphate (CAS no. 10028-22-5)	3. 7	Oxidiser used for odour control
Hydrochloric acid	Not known	pH adjustment
Inorganic pigment	1	Coagulant
Krofta coagulant	4	Short chain polymer for agglomeration of suspended solids within internal water recovery unit
Krofta flocculant	2.5	Long chain polymer for agglomeration of suspended solids and fibre within internal water recovery unit
Millfloc EQ 2100	Not known	Settlement aid in biological treatment process
Cationic polyamine	Not known	Coagulant for de-ink kroftas
Cationic water soluble polymer	0.94	Not known
Anionic water soluble polymer	Not known	Flocculant
Monosodium phosphate (CAS no. 7558-80-7)	3.9	Effluent treatment
Urea and ammonium phosphate salts (**B**)	11. 7	Nutrient

Chemical	**Usage (M_s) (kg per tonne of product)**	**Function**
Oxygen	3	Respired by micro-organisms in ETP
Polyacrylamide (CAS no. 9003-05-8)	0.1–0.58	Flocculant – expected to all be absorbed onto solids and removed with sludge
Polyaluminium chloride	1	All retained
Scisol Vitamax (**B)**	1.9	Nutrient for biological effluent treatment
Sodium bicarbonate (CAS no. 144-55-8)	1.46	Provides additional inorganic carbon whilst controlling pH in the reactor
Sodium bromide (CAS no. 7647-15-6), sodium hypochlorite (CAS no. 10022-70-5)	0.8	Water treatment chemicals, after disc filters prior to process
Sodium nitrate (CAS no. 7631-99-4)	Not known	Odour and septicity control
Sulphuric acid	20	pH adjustment
Suspension of calcium hydroxide (CAS no. 1305-62-0) in water/calcium carbonate (CAS no. 471-34-1)/magnesia/trace elements	Not known	Addition to aeration tank to aid settleability

Note: **B** = readily biodegradable.

Maintenance chemicals

A variety of chemicals are used for machinery maintenance in paper mills, such as lubrication and cleaning. Some typical examples are shown in Table A1.14.

Table A1.14 Maintenance chemicals

Chemical	**Usage (M_s) (kg per tonne of product)**	**Function**
2,2-dibromo-3-nitrilopropionamide/sodium bromide	Not known	Controls the growth of legionella in open evaporative cooling water systems
3-butoxypropan-2-ol (CAS no.5131-66-8)	Not known	Hood cleaner
Sodium hydroxide/polymer blend	0.07	Alkalinity builder
Amine	0.10	Condensate corrosion inhibitor
Aromatic hydrocarbon	0.04	Felt cleaner
Aromatic hydrocarbons/triethanolamine/ethanol biodegradable surfactants (**B**)	0.01	Gas turbine compressor blade washing
Chelating agent	0.10	Boiler scale inhibitor

Chemical	**Usage (M_s) (kg per tonne of product)**	**Function**
Cobalt sulphate/potassium hydroxide/sodium metabisulphite	Not known	Corrosion inhibitor for cooling systems
Amine	0.10	Condensate corrosion inhibitor
Amine based on morpholine (CAS no. 110-91-8)	Not known	Condensate line protection
Cyclohexylamine (CAS no. 108-91-8)/morpholine (CAS no. 110-91-8)/2-diethylaminoethanol (CAS no. 100-37-8)	0.07	Ensures efficient boiler operation
Didecyl dimethyl ammonium chloride in isopropanol	Not known	Cooling tower biocide
Di-octyl sodium sulphosuccinate (**B**)	Not known	Pre- and post-treatment for cooling towers
Ethylene glycol (CAS no. 107-21-1) (**B**)	Not known	Anti-freeze in coolant systems
Fatty alcohol ethoxylate (**B**)	0.10	Cleaning agent
Greases	Not known	Long chain hydrocarbons
Hydrocarbon distillate		Washing solvent
Hydrochloric acid (CAS no. 7647-01-0)	0.10–0.2	Cleaning agent, softener resin regenerant and anti-scalant.
Hydroquinone	0.10	Boiler oxygen inhibitor
Hydrotreated light naphthenic alkanolamine esters	0.20	Lubricant
Methoxypropanol/terpene hydrocarbon	0.01	Floor cleaner
Mineral oil	0.10	Hydraulic and lubrication oil
Phosphonate in aqueous solution	Not known	Anti-scalant
Non ionic surfactants	0.01	Direct application (diluted) to plant floors as a cleaner
Nonylphenoxypoly (ethyleneoxy) ethanol, alkylene glycol ether (**B**)	0.05–0.06	Conditioning of pick-up felt
Organic solvents	0.03	Fabric cleaner
Oxygen scavenger – sodium bisulphite (CAS no. 7631-90-5)	0.1–0.17	Not biodegradable
Paraffin	Not known	Cleaning washer fabrics
Paraffinic mineral oil	Not known	Lubricating oil
Petroleum hydrocarbons and additives	Not known	Automotive gear and hydraulic oil
Phosphoric acid	0.01–0.1	Cleaning of machine framework and rollers

Chemical	**Usage (M_s) (kg per tonne of product)**	**Function**
Polyaminoamine	0.04	Scale control
Potassium hydroxide (CAS no. 1310-58-3)	0.10	Anti-scalant
Potassium hydroxide, alkyldimethyl aminoxide, potassium alkylphosphate ester, sodium hypochlorite	0.03	Approximately 10 tonnes annually; cleaning of filters at effluent plant
Quaternary ammonium polymer	0.04	Wire cleaner
Phosphate	0.05	Scale inhibitor
Sodium alkyl ether sulphate (**B**)	Not known	Hood cleaner
Sodium chloride (CAS no. 7647-14-5)	0.20–1.17	Water softener resin regeneration
Sodium hydroxide (CAS no. 1310-73-2).	0.01–2.7	Descaler, cylinder cleaner, boiler degreasing, system cleaner, felt cleaner
Sodium hydroxide, alkaline liquid bromine antimicrobial	Not known	Cooling tower water treatment
Sodium hypochlorite (CAS no. 10022-70-5)	0.1–1.9	Washer fabric cleaner, foam cleaning of cooling towers, steriliser in coating kitchen
Sodium metabisulphite/sodium hydroxide (CAS no. 1310-73-2)	Not known	Oxygen scavenger for various cooling systems
Sodium tetraborate	Not known	Closed air conditioning system water treatment
Synthetic hydrocarbons and additives	0.01	Industrial gear oil and anti-rust inhibitor
Triglyceride oil	0.35	MG lubricant

Note: **B** = readily biodegradable.

APPENDIX 2: THE EUROPEAN LIST OF STANDARD GRADES OF RECOVERED PAPER AND BOARD (EN 643, CEN 2002)

Group 1: Low qualities

1.01 Mixed paper and board, unsorted, but unusable materials removed

A mixture of various grades of paper and board, without restriction on short fibre content.

1.02 Mixed papers and board (sorted)

A mixture of various qualities of paper and board, containing a maximum of 40 per cent of newspapers and magazines.

1.03 Grey board

Printed and unprinted white, lined and unlined grey board or mixed board, free from corrugated material.

1.04 Supermarket corrugated paper and board

Used paper and board packaging, containing a minimum of 70 per cent of corrugated board, the rest being solid board and wrapping papers.

1.05 Old corrugated containers

Used boxes and sheets of corrugated board of various qualities.

1.06 Unsold magazines

Unsold magazines, with or without glue.

1.06.01 Unsold magazines without glue

Unsold magazines without glue.

1.07 Telephone books

New and used telephone books, with unlimited content of pages coloured in the mass, with and without glue. Shavings allowed.

1.08 Mixed newspapers and magazines I

A mixture of newspapers and magazines, containing a minimum of 50 per cent of newspapers, with or without glue.

1.09 Mixed newspapers and magazines II

A mixture of newspapers and magazines, containing a minimum of 60 per cent of newspapers, with or without glue.

1.10 Mixed magazines and newspapers

A mixture of newspapers and magazines, containing a minimum of 60 per cent of magazines, with or without glue.

1. 11 Sorted graphic paper for de-inking

Sorted graphic paper from households; newspapers and magazines, each at a minimum of 40 per cent. The percentage of non-deinkable paper and board should be reduced over time to a maximum level of 1.5 per cent. The actual percentage is to be negotiated between buyer and seller.

Group 2: Medium qualities

2.01 Newspapers

Newspapers, containing a maximum of 5 per cent of newspapers or advertisements coloured in the mass.

2.02 Unsold newspapers

Unsold daily newspapers, free from additional inserts or illustrated material coloured in the mass.

2.02.01 Unsold newspapers, no flexo-graphic printing allowed

Unsold daily newspapers, free from additional inserts or illustrated material coloured in the mass, strings allowed. No flexo-graphic printed material allowed.

2.03 Lightly printed white shavings

Lightly printed white shavings, mainly mechanical pulp-based paper.

2.03.01 Lightly printed white shavings without glue

Lightly printed white shavings, mainly mechanical pulp-based paper, without glue.

2.04 Heavily printed white shavings

Heavily printed white shavings, mainly mechanical pulp-based paper.

2.04.01 Heavily printed white shavings without glue

Heavily printed white shavings, mainly mechanical pulp-based paper, without glue.

2.05 Sorted office paper

2.06 Coloured letters

Correspondence, in mixed papers coloured in the mass, with or without print, of printing or writing paper. Free from carbon paper and hard covers.

2.07 White wood-free books

Books, including misprints of books, without hard covers, mainly of wood-free white paper, black printed only. Containing a maximum of 10 per cent of coated paper.

2.08 Coloured wood-free magazines

Coated or uncoated magazines, white or coloured in the mass, free from non-flexible covers, bindings, non-dispersible inks and adhesives, poster papers, labels or label trim. May include heavily printed circulars and coloured in the mass shavings. Containing a maximum of 10 per cent mechanical pulp-based papers.

2.09 Carbonless copy paper

2.10 Bleached wood-free PE-coated board

Bleached wood-free PE-coated board from board manufacturers and converters.

2.11 Other PE-coated board

Other PE-coated board. May contain unbleached board and paper from board manufacturers and converters.

2.12 Mechanical pulp-based computer print-out

Continuous computer print-out, mechanical pulp-based, sorted by colours, may include recycled fibres.

Group 3: High qualities

3.01 Mixed lightly coloured printers shavings

Mixed shavings of printing and writing papers lightly coloured in the mass, containing a minimum of 50 per cent of wood-free paper.

3.02 Mixed lightly coloured wood-free printers shavings

Mixed shavings of printing and writing papers lightly coloured in the mass, containing a minimum of 90 per cent of wood-free paper.

3.03 Wood-free binders

White wood-free lightly printed shavings with glue, free from paper coloured in the mass. May contain a maximum of 10 per cent of mechanical pulp-based paper.

3.04 Tear white shavings

White wood-free lightly printed shavings without glue, free from wet-strength paper and paper coloured in the mass.

3.05 White wood-free letters

Sorted white wood-free writing papers, originating from office records, free from cash books, carbon paper and non-water soluble adhesives.

3.06 White business forms

White wood-free printed business forms.

3.07 White wood-free computer print-out

White wood-free computer print-out, free from carbonless paper and glue.

3.08 Printed bleached sulphate board

Heavily printed sheets of bleached sulphate board, without glue, polycoated or waxed materials.

3.09 Lightly printed bleached sulphate board

Lightly printed sheets of bleached sulphate board, without glue, polycoated or waxed materials.

3.10 Multi-printing

Wood-free, coated, lightly printed, free from wet-strength paper or paper coloured in the mass.

3.11 White heavily printed multiply board

New cuttings of heavily printed white multiply board, containing wood-free, mechanical or thermo-mechanical pulp plies, but without grey plies.

3.12 White lightly printed multiply board

New cuttings of lightly printed white multiply board, containing wood-free, mechanical or thermo-mechanical pulp plies, but without grey plies.

3.13 White unprinted multiply board

New cuttings of unprinted white multiply board, containing wood-free, mechanical or thermo-mechanical pulp plies, but without grey plies.

3.14 White newsprint

Shavings and sheets of white unprinted newsprint, free from magazine paper.

3.15 White mechanical pulp-based coated and uncoated paper

Shavings and sheets of white unprinted coated and uncoated mechanical pulp based paper.

3.15.01 White mechanical pulp-based containing coated paper

Shavings and sheets of white unprinted mechanical pulp-based coated paper.

3.16 White wood-free coated paper, without glue

Shavings and sheets of white unprinted wood-free coated paper, without glue.

3.17 White shavings

Shavings and sheets of white unprinted paper, free from newsprint and magazine paper, containing a minimum of 60 per cent of wood-free paper; may contain a maximum of 10 per cent of coated paper. Without glue.

3.18 White wood-free shavings

Shavings and sheets of white unprinted wood-free paper; may contain a maximum of 5 per cent of coated paper. Without glue.

3.18.01 White wood-free uncoated shavings

Shavings and sheets of white unprinted wood-free paper, free from coated paper. Without glue.

3.19 Unprinted bleached sulphate board

Unprinted sheets of bleached sulphate board, without glue, polycoated or waxed materials.

Group 4: Kraft qualities

4.01 New shavings of corrugated board

Shavings of corrugated board, with liners of kraft or testliner.

4.01.01 Unused corrugated kraft

Unused boxes, sheets and shavings of corrugated board, with kraft liners only, the fluting made from chemical or thermo-chemical pulp.

4.01.02 Unused corrugating material

Unused boxes, sheets and shavings of corrugated board, with liners of kraft or testliner.

4.02 Used corrugated kraft I

Used boxes of corrugated board, with kraft liners only, the fluting made from chemical or thermo-chemical pulp.

4.03 Used corrugated kraft II

Used boxes of corrugated board, with liners of kraft or testliners but having at least one liner made of kraft.

4.04 Used kraft sacks
Clean used kraft sacks. Wet-strength and non wet-strength.

4.04.01 Used kraft sacks with polycoated papers
Clean used kraft sacks. Wet-strength and non wet-strength, may include polycoated papers.

4.05 Unused kraft sacks
Unused kraft sacks. Wet-strength and non wet-strength.

4.05.01 Unused kraft sacks with polycoated papers
Unused kraft sacks. Wet-strength and non wet-strength, may include polycoated papers.

4.06 Used kraft
Used kraft paper and board of a natural or white shade.

4.07 New kraft
Shavings and other new kraft paper and board of a natural shade.

4.08 New carrier kraft
New carrier kraft, may include wet-strength paper.

Group 5: Special qualities

5.01 Mixed recovered paper and board
Unsorted paper and board, separated at source.

5.02 Mixed packaging
A mixture of various qualities of used paper and board packaging free from newspapers and magazines.

5.03 Liquid board packaging
Used liquid packaging board including used PE-coated liquid packaging board (with or without aluminium content), containing a minimum of 50 per cent by weight of fibres, and the balance being aluminium or coatings.

5.04 Wrapper kraft
Poly-lined, sprayed, or laminated used kraft. Must not contain bitumen or wax coatings.

5.05 Wet labels
Used wet labels from wet-strength papers, containing a maximum of 1 per cent glass content and a maximum of 50 per cent moisture, without other unusable materials.

5.06 Unprinted white wet-strength wood-free papers
Unprinted white wet-strength wood-free papers.

5.07 Printed white wet-strength wood-free papers
Printed white wet-strength wood-free papers.

APPENDIX 3: CEN RECOVERED PAPER AND BOARD TYPES LISTED UNDER TRADITIONAL UK (PFGB) GRADES

Group 1: Unprinted wood-free

- 3.16 White wood-free coated paper without adhesives
- 3.17 White shavings
- 3.18 White wood-free shavings
  - 3.18.01 White wood-free uncoated shavings
- 3.19 Unprinted bleached sulphate board
- 5.06 Unprinted white wet-strength wood-free papers

Group 2: Unprinted wood-free

- 2.07 White wood-free books
- 2.10 Bleached wood-free pre-coated board
- 3.03 Wood-free binders
- 3.04 Tear white shavings
- 3.05 White wood-free letters
- 3.06 White business forms
- 3.07 White wood-free computer paper
- 3.08 Printed bleached sulphate board
- 3.09 Lightly printed bleached sulphate board
- 5.07 Printed white wet strength wood-free paper

Group 3: Mechanical

- 2.03 Lightly printed white shavings
  - 2.03.01 Lightly printed white shavings without glue
- 2.04 Heavily printed white shavings
  - 2.04.01 Heavily printed white shavings without glue
- 2.12 Wood containing cpo
- 3.11 White heavily printed multiply board
- 3.12 White lightly printed multiply board
- 3.13 White unprinted multiply board
- 3.14 White newsprint
- 3.15 White wood containing coated and uncoated paper
  - 3.15.01 White wood containing coated paper only

Group 4: Coloured wood-free

- 2.05 Sorted office papers
- 2.06 Coloured letters
- 2.08 Coloured wood-free magazines
- 2.09 Carbonless copy paper
- 3.01 Mixed lightly-coloured printers shavings
- 3.02 Mixed lightly-coloured wood-free printers shavings
- 3.10 Multi-printing

Group 5: Newspapers and magazines (ordinary grade de-inking)

- 1.06 Unsold magazines
  - 1.06.01 Unsold magazines without glue
- 1.07 Telephone books
- 1.08 Mixed newspapers and magazines I (minimum 50 per cent news)

- 1.09 Mixed newspapers and magazines II (minimum 60 per cent news)
- 1.10 Mixed magazines and newspapers (minimum 60 per cent mags)
- 1.11 Sorted graphic paper for de-inking
- 2.01 Newspapers
- 2.02 Unsold newspapers
  - 2.02.01 Unsold newspapers containing no flexo printing

Group 6: Coloured kraft and manilla

Group 7: New kraft liner sacks and unused krafts

- 4.01 New shavings of corrugated board
  - 4.01.01 Unused corrugated kraft
  - 4.01.02 Unused corrugating materials
- 4.05 Unused kraft sacks
  - 4.05.01 Unused kraft sacks with poly-coated papers
- 4.07 New kraft
- 4.08 New carrier kraft

Group 8: Container waste stock (post-consumer)

- 1.04 Supermarket corrugated paper and board
- 1.05 Old corrugated containers
- 4.02 Used corrugated kraft I
- 4.03 Used corrugated kraft II
- 4.04 Used kraft sacks
  - 4.04.01 Used kraft sacks with poly-coated papers
- 4.06 Used kraft
- 5.04 Wrapper kraft

Groups 9 and 10: Mixed and coloured card

1.01 Mixed paper and board unsorted but unusables removed

1.02 Mixed paper and boards (sorted)

1.03 Greyboard

2.11 Other pre-coated board

5.01 Mixed recovered paper and board

5.02 Mixed packaging

5.03 Liquid board packaging

5.04 Wt labels

APPENDIX 4: FURTHER INFORMATION ON THE SIZE OF OPERATIONS IN THE UK PAPER INDUSTRY

The information presented in this section has been sourced directly from industry representatives, and also from industry associations and publications. These include: Pulp and Paper International July 2001; the Paper Federation of Great Britain website; and a competitiveness study for paper-related industries in the UK, which was published by the Confederation of Paper Industries in December 2000.

General statistics for the scale of the operation in the UK

Per capita consumption of paper and board: 216kg.

Number of paper and boardmills: 88.

Number of pulp mills: 5 (semi-chemical = 1; mechanical = 3; non-wood = 1).

Paper and board capacity: 7,020,000 tons.

Pulp capacity: 595,000 tons.

(Source: Pulp and Paper International, July 2001).

Overall UK production, consumption, imports, exports and utilisation

Recent general data (for 1998, 1999 and 2000) for production, imports and exports for the UK industry are shown in Tables A4.1 and A4.2.

Table A4.1 General UK data (paper, board and pulp)

	Production (1,000 tons)			Imports (1,000 tons)			Exports (1,000 tons)		
	1998	**1999**	**2000**	**1998**	**1999**	**2000**	**1998**	**1999**	**2000**
PAPER & BOARD									
Newsprint	1,046	1,071	1,100	1,646	1,720	1,692	192	206	175
Printing and writing, of which	1,742	1,737	1,747	3,209	3,443	3,551	500	479	474
W/f uncoat	841	790	756	833	879	941	228	198	178
W/f coat	451	489	495	1,066	1,193	1,235	157	151	150
Mechanical uncoated	17	17	13	500	517	564	2	3	1
Mechanical coated	210	219	260	704	709	698	80	95	112
Corrugating materials, of which	1,760	1,813	1,871	970	918	897	188	169	234
Virgin liner	0	0	0	616	589	588	0	0	0
Waste liner	857	882	911	125	125	94	92	80	94
Virgin flute	114	117	886	79 132	73	192	32	33	138
Waste flute	712	744			109		63	59	
Other wrapping	160	141	130	327	304	265	42	45	49
Tissue	635	718	722	295	256	283	3	1	21
Other paper/board	1,134	1,087	1,031	949	1,003	1,005	487	475	457
TOTAL	6,477	6,567	6,601	7,396	7,635	7,693	1,412	1,374	141
PULP									
Bleached sulphate	0	0	-	1,416	1,470	1,463	15	22	5

	Production (1,000 tons)			**Imports (1,000 tons)**			**Exports (1,000 tons)**		
	1998	**1999**	**2000**	**1998**	**1999**	**2000**	**1998**	**1999**	**2000**
Unbleached sulphate	0	0	-	30	30	29	0	0	-
Bleached sulphite	0	0	-	55	35	33	0	0	-
Unbleached sulphite	0	0	-	0	1	1	0	0	-
Semichem	75	63	75	48	53	52	0	0	-
Mechanical	509	411	442	42	40	58	3	1	3
Nonwood	N/A	N/A	NA	3	4	5	0	0	-
Other pulp	-	-	-	-	25	20	-	-	-
TOTAL	584	474		1,594	1,658	1,661	18	23	8

Source: Pulp and Paper International, July 2000.

Table A4.2 General UK data on recovered (waste) paper

	Recovery (1,000 tons)			**Consumption (1,000 tons)**			**Imports (1,000 tons)**			**Exports (1000 tons)**		
	1998	**1999**	**2000**	**1998**	**1999**	**2000**	**1998**	**1999**	**2000**	**1998**	**1999**	**2000**
Wastepaper	5,028	4,815	5,305	4,655	4,434	4,882	29	62	124	424	443	547

Source: Pulp and Paper International, July 2000.

UK production

Information on UK production has also been detailed in a competitiveness study for paper-related industries in the UK, which was published by the Confederation of Paper Industries (December 2000). This indicates that, since 1983, the carton manufacturing sector has seen more than 30 per cent growth, while the corrugated board sector has seen a 60 per cent increase. Coming from a lower base, paper manufacturing has almost doubled its output from 3.3 million tonnes (in 1983) to over 6.5 million tonnes in 1999.

There are large variations in production between sectors. Only in newsprint and case materials (fluting and liner production that go into corrugated paper and board) has domestic production grown at a higher rate than consumption, whilst printings and writings (which achieved significant growth in 1994) have since been static. The tissue sector, however, has made the majority of its advances in the past five years, with investment still coming on-stream. Although individual carton makers have achieved growth, domestic carton board manufacture has declined from a peak in 1995, as mills have closed and imports have increased. Packaging papers have also seen a reduction, though this is mainly due to competition from other packaging materials (notably plastics) since consumption has also decreased.

UK consumption

Over 12.9 million tonnes of paper and board are currently consumed per annum in the UK. Growth in paper consumption is strongly correlated with general economic development, and overall usage has increased by nearly 80 per cent since 1983. There are, however, considerable variations in growth pattern between different types of paper and board, as shown in Table A4.3.

Table A4.3 Size and evolution of consumption by paper sectors 1983–1999 (1,000 tonnes)

Sector	1983	1993	1999	2000	% change 1983 to 2000
Newsprint	1,316	1,937	2,585	2,600	+98
Printing and writings	1,900	3,693	4,666	4,800	+153
Corrugated material	1,595	2,169	2,557	2,500	+57
Carton board	825	1,330	1,183	1,100	+33
Wrappings	464	489	399	300	-35
Tissue	488	730	973	1,000	+105
Other	571	302	359	500	-12
Total	7,159	10,650	12,722	12,800	+79

Source: CPI report, December 2000; Paper Federation of Great Britain Industry Facts, May 2001.

Nations that consume a lot of paper are generally large producers. However, the UK ranks fifth in the world in terms of consumption, but only ranks twelfth as a producer. This compares starkly with data from the 1960s, when the UK was third in terms of production. The UK now imports 59 per cent of its paper and board requirements.

APPENDIX 5: INFORMATION ON EMISSION CONTROL METHODS FOR THE UK PAPER INDUSTRY

Control of discharges to water

Releases to water give rise to the main pollution potential for the industry and minimising water use is a principal technique for reducing releases. Effluents from most UK mills are treated on-site prior to discharge or are discharged to municipal waste water treatment plants for treatment. Wastewaters are typically subjected to primary treatment (solids removal and recovery) followed by secondary biological treatment, which reduces soluble BOD (Biochemical Oxygen Demand) load. These two processes are considered to be Best Available Technique (BAT) for the industry. An overview of effluent treatment plant operation and the discharge sink is shown in Table A5.1. From this, it can be seen that for those sites where information on treatment processes is available, all utilise primary treatment, 80 per cent utilise secondary treatment processes and 80 per cent utilise clarification processes. Where no treatment exists on-site, the effluent will be discharged via the sewer to a municipal waste water treatment plant.

Most of the chemicals used in the paper industry are non-biodegradable and will pass unchanged through effluent treatment. They will then be released either in sludge to land or in effluent to surface water. Those chemicals that should be readily biodegradable in an effluent treatment plant are listed in Appendix 1.

Table A5.1 Overview of effluent treatment plant operation and discharge sinks at UK mills (data correct at December 2001)

Mill site	Wastewater treatment and sink				Paper sludge disposal option				
	primary treatment stage	secondary treatment stage	clarification	sink	energy recovery	beneficial land application	composting	landfill	other
Site A	yes	activated sludge	yes	river	on-site energy recovery			landfill cover (ash only)	
Site B	yes	activated sludge	yes	canal		land application			
Site C	yes	biological fixed film	yes	sewer		land application			
Site D	yes	activated sludge	yes	river		land application			
Site E	yes	no	no	sewer	not known	not known	not known	not known	
Site F	yes	activated sludge	yes	estuary		land application			
Site G	yes	activated sludge	yes	river		land application			
Site H	yes	activated sludge	yes	river		land application			
Site I	yes	activated sludge	yes	river				off-site landfill owned by mill	
Site J	yes	no	no	sewer	energy recovery		composting		
Site K	yes	two-stage activated sludge process	yes	river					spoil heap reclamation
Site L	yes	activated sludge and anaerobic bioreactor	yes	river				off-site landfill	

Mill site	Wastewater treatment and sink				Paper sludge disposal option				
	primary treatment stage	secondary treatment stage	clarification	sink	energy recovery	beneficial land application	composting	landfill	other
Site M	yes	no	no	sewer					
Site N	yes	sequencing batch reactor	yes	sewer		land application			
Site O	yes	activated sludge	yes	sewer	Off-site energy recovery	land application			
Site P	not known	not known	not known	sewer		land application			
Site Q	not known	not known	not known	sea	not known	not known	not known	not known	

Control of discharges to land

The solid wastes that cause the greatest disposal concern are paper sludges. These can be generated from de-inking (fibre, filler, ink and other contaminants), pulping and paper-making (filler and fibre recovered from primary treatment) and wasted biomass (sludge) recovered from the secondary treatment process of an effluent treatment plant (ETP).

The following notes are based on a scoping study produced for the Environment Agency[6] and mainly relate to the production of waste from paper mills. Some values of relevance to the ESD have been derived from the data and are indicated in [ ].

The study conducted a survey of the 56 paper mills in England and Wales to obtain information on their waste disposal practices. The majority of the waste was applied to agricultural land, with 699,000 tonnes of fresh waste from 28 mills applied in 2003. Smaller quantities were disposed of in other ways:

• Composted	3,000 tonnes
• Landfill	50,000 tonnes
• Energy recovery	147,000 tonnes
• Land restoration	85,000 tonnes.

[The average waste production from the 28 sites is 25,000 tonnes per year, or 71 tonnes per day assuming 350 days of operation. These are fresh weight figures. The percentage of waste applied to land is around 80 per cent, if agricultural, composting and land restoration are included. It is suggested that, for estimating regional emissions, 80 per cent of the substance in the waste sludges from paper production/recycling can be assumed to go to agricultural land. The remaining 20 per cent (energy recovery and landfill) should not lead to significant emissions.]

The majority of the waste applied to land had undergone some form of secondary treatment (in whole or in part), in addition to the initial primary settlement. Around 380,000 tonnes (fresh weight) were treated with either biological or chemical/physical secondary treatment, or a mixture of the two, and 165,000 tonnes (fresh weight) contained a fraction consisting of 5–25 per cent biologically-treated waste.

The primary treated waste had an average of 43 per cent solids; waste receiving secondary biological treatment had an average of 27.5 per cent solids; waste receiving secondary chemical/physical treatment had an average of 40 per cent solids. The overall solids content was 39 per cent.

[Assuming a 39 per cent solids content, the average daily production of 71 tonnes of fresh weight waste is equivalent to 28 tonnes dry weight per day.]

In most cases, the paper waste materials were stored for a relatively short time, with 78 per cent stored for less than two months. There is no information currently available on what happens to the materials during storage.

Paper waste was applied to 10,500ha of agricultural land in 2003. The majority (89 per cent) was applied to tillage land (arable or re-seeded grassland). The application rates depended on the type of land to

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[6] Gibbs, P., Muir, I., Richardson, S., Hickman, G. and Chambers, B., 2004. *Scoping study on the production and landspreading of paper wastes*. Report for Environment Agency (P5-088). ADAS Gleadthorpe Research Centre.

which the waste was applied. The mean application rates were (t/ha; FW value from report, DW value calculated using 39 per cent average solids content):

• Tillage land (not biologically-treated)	76 fw	30 dw
• Tillage land (biologically-treated)	41 fw	16 dw
• Surface of grassland	6 fw	10 dw
• Grass re-seed	145 fw	56 dw

[For comparison, the EU Technical Guidance Document specifies sludge application rates from biological treatment plants of 50t/ha for arable land and 10t/ha for grassland, both on a dry weight basis.]

The Confederation of Paper Industries has produced a code of practice for the land spreading of paper sludge, which is available from www.paper.org.uk.

The revision of EC Directive 86/278/EEC ‘on the protection of the environment and in particular, when sewage sludge is used in agriculture’ is likely to extend to paper sludge and will require increased monitoring for heavy metals and organic compounds. These may be present at low concentrations in raw materials used for paper-making or, in the case of the metals, may arise from corrosion and wear in the paper-making machinery. Limit values for these substances are shown in Tables A5.2 and A5.3.

Table A5.2 Limit values for concentrations of metals in sludge for use on land

Element	**Limit value (mg/kg dry matter)**	
	Directive 86/278/EEC	**Proposed**
Cd (cadmium)	20–40	10
Cr (chromium)	-	1,000
Cu (copper)	1,000–1,750	1,000
Hg (mercury)	16–25	10
Ni (nickel)	300–400	300
Pb (lead)	750–1,200	750
Zn (zinc)	2,500–4,000	2,500

Table A5.3 Limit values for concentrations of organic compounds and dioxins in sludge for use on land

Organic compound	Limit value (mg/kg dry matter)
AOX[1]	500
LAS[2]	2,600
DEHP[3]	100
NPE[4]	50
PAH[5]	6
PCB[6]	0.8
Dioxins (PCDD/F)[7]	100ng toxic equivalents/kg dry matter

Notes: 1) Sum of halogenated compounds.
2) Linear alkylbenzene sulphonates.
3) Di-(2-ethylhexyl)-phthalate.
4) Comprises nonylphenol and nonylphenol ethoxylate with 1 or 2 ethoxy groups.
5) Sum of polycyclic aromatic hydrocarbons.
6) Sum of polychlorinated biphenyl components.
7) Polychlorinated dibenzodioxins/dibenzofurans.

APPENDIX 6: ESTIMATION OF BACKGROUND CONCENTRATIONS IN PAPER THROUGH REPEATED RECYCLING

This section derives a method for estimating the background concentration arising in paper products from the retention of a substance in the regenerated pulp, when recovered paper is used as the raw material for the products.

Symbols

E_{paper_Rn} = ‘emission’ of substance in paper products produced after nth recycling (kg d^{-1})

M_{s_Rn} = mass of substance per tonne of paper product produced by nth recycling

$M_{s\_Rn} = E_{paper\_Rn}/Q_r$

A lifetime of 2–2.5 recycles is considered realistic for newsprint; the method detailed here considers up to three recycling steps. The recovered paper input to a recycling plant will be made up of a mixture of papers that have been through different numbers of recycling steps. This method estimates the worst case input for each recycling step and the resulting concentration in paper products. It then calculates the average concentration, assuming an even input from each ‘age’ of paper.

First recycling step

At this step only new material containing the substance is considered. The input amount per day is given by

$$Input_{R1} = M_s \times Q_r \times F_{paper\_with\_subst}$$

The amount remaining on the paper is

$$E_{paper\_R1} = M_s \times Q_r \times F_{paper\_with\_subst} \times F_{deink\_paper}$$

The concentration in the paper is M_{s_R1},

$$M_{s\_R1} = M_s \times F_{paper\_with\_subst} \times F_{deink\_paper}$$

Second recycling step

The worst case for this step would be if all of the paper used at the site contained the substance at the background concentration from recycling step 1 (M_{s_R1}). There would also be an input of 'new' paper containing the substance being recycled for the first time. The input per day would be given by

$$Input_{R2} = M_{s\_R1} \times Q_r + M_s \times Q_r \times F_{paper\_with\_subst}$$

and the output (the amount remaining on the paper) by

$$E_{paper\_R2} = M_{s\_R1} \times Q_r \times F_{deink\_paper} + M_s \times Q_r \times F_{paper\_with\_subst} \times F_{deink\_paper}$$

$$E_{paper\_R2} = M_{s\_R1} \times Q_r \times F_{deink\_paper} + E_{paper\_R1}$$

The concentration in the paper is M_{s_R2} and E_{paper_R2}/Q_r. So

$$M_{s\_R2} = M_{s\_R1} \times F_{deink\_paper} + {E_{paper\_R1}}\big/{Q_r}$$

$$M_{s\_R2} = M_{s\_R1} \times F_{deink\_paper} + M_{s\_R1}$$

$$M_{s\_R2} = M_{s\_R1} \times \left(1 + F_{deink\_paper}\right)$$

Third recycling step

As above, the worst case is taken as being where all of the paper has the background concentration from the second recycling step, together with a fresh input of new paper containing the substance.

The input to this step is

$$Input_{R3} = M_{s\_R2} \times Q_r + M_s \times Q_r \times F_{paper\_with\_subst}$$

and the output (the amount remaining on the paper) is given by

$$E_{paper\_R3} = M_{s\_R2} \times Q_r \times F_{deink\_paper} + M_s \times Q_r \times F_{paper\_with\_subst} \times F_{deink\_paper}$$

$$E_{paper\_R3} = M_{s\_R2} \times Q_r \times F_{deink\_paper} + E_{paper\_R1}$$

The concentration in the paper is M_{s_R3} and E_{paper_R3}/Q_r. So, dividing by Q_r

$$M_{s\_R3} = M_{s\_R2} \times F_{deink\_paper} + M_{s\_R1}$$

$$M_{s\_R3} = M_{s\_R1} \times \left(1 + F_{deink\_paper}\right) \times F_{deink\_paper} + M_{s\_R1}$$

$$M_{s\_R3} = M_{s\_R1} \times \left(1 + F_{deink\_paper} + F_{deink\_paper}^2\right)$$

The input for the actual calculation is taken as an equal contribution from each of the three recycles – the average of M_{s_R1}, M_{s_R2} and M_{s_R3}. This is used as the background concentration in the general paper feed and so the $F_{paper\_with\_substance}$ for this is 1. For two recycling steps, the average of M_{s_R1} and M_{s_R2} should be used. The background concentration is denoted by $M_{s\_background}$.

APPENDIX 7: ORGANISATIONS CONSULTED

Consultations with a number of stakeholders have been carried out during the development of this ESD. The Environment Agency would like to formally acknowledge the useful comments and information that have been provided voluntarily by the following organisations during these consultations.

- Arjo Wiggins Fine Papers Ltd
- AECPM – Association of European Carbonless Paper Manufacturers
- CEPI – Confederation of European Paper Industries
- Ciba Speciality Chemicals, Water and Paper Treatment
- CPI – Condederation of Paper Industries
- EPCG – European Paper Chemicals Group
- EPRA – European Phenolic Resins Association
- Environment Canada
- ETPA – European Thermal Paper Association
- RIVM – National Institute for Public Health and the Environment
- SEPA – Scottish Environmental Protection Agency