

# Evidence

## Hazards from landspreading wastes

Rapid Evidence Assessment: paper sludge ash

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Miranda Kavanagh  
**Director of Evidence**

# Executive summary

The Environment Agency regulates the spreading of waste to agricultural land in England under the Environmental Permitting Regulations (EPR) 2010. Under EPR 2010 the operator is required to obtain a standard rules or bespoke permit, and to make a separate deployment application for the waste to be spread on a specific area of land. The purpose of this Rapid Evidence Assessment (REA) is to identify the primary hazards associated with paper sludge ash (part of waste code 10 01 01) to support staff at the Environment Agency's National Permitting Service in their deployment review.

The REA addresses the overarching primary question: What key hazards are associated with paper sludge ash which could present a risk to critical receptors during or after landspreading on agricultural land? A series of secondary questions were used to obtain more detailed evidence to identify the relevant pathways and receptors for paper sludge ash (PSA), and important hazards which may impact on them. The responses are given in the evidence extraction spreadsheet accompanying this report.

Numerous sources of evidence were identified and used to provide answers to the primary and secondary questions. These sources ranged from peer reviewed journal articles and reports to unpublished documents. The main findings of the evidence extraction process are summarised below.

## **Waste production and form**

PSA is the residue from the incineration of paper sludge. The chemical composition of the sludge can vary, being influenced by the operations and processes at the particular paper mill. In most cases, paper sludge is co-combusted with other material such as wood, rejects and other sludges. To minimise dust release, PSA is often transferred to silos for closed discharge to tankers and/or water is added to the ash to condition it and improve its handling characteristics.

PSA is normally spread to land as a liming or soil treatment agent using conventional manure spreading or lime application equipment, and can be top dressed or incorporated into the receiving soil. It is typically spread at an application rate of 10 t/ha for arable land and 7.5 t/ha for grassland. An unpublished risk assessment by WRc for the Environment Agency estimated that no more than one application of PSA per year or 10 applications in 10 years should be made.

## **Chemical and other hazards**

There is a consensus in the literature that concentrations of metals and trace elements can vary, sometimes substantially, between different batches and producers of PSA. PSA is generally alkaline with a pH of between pH 9.4 and 12.9.

Concentrations of cadmium, copper, chromium, titanium and zinc in PSA can be higher than background concentrations in soil in urban and rural areas. Concentrations of metals tend to be higher in PSA than in virgin wood ash, with concentrations of copper in PSA also tending to be higher compared with other waste ashes. The presence of organic contaminants in PSA is generally regarded as negligible, but there is little quantitative evidence to support this assumption.

The leaching potential of PSA is influenced by a number of factors, including its pH, the solubility of the contaminant and total contaminant concentrations. There is evidence to suggest that phosphorus and cadmium are present in a relatively insoluble form, minimising their potential bioavailability to plant uptake and risks to water receptors. The introduction of PSA with a very alkaline pH to a site can result in dissolution of organic matter, which in turn can facilitate metal transport from the receiving soils,

presenting an indirect risk to water receptors. Chloride is a potential risk to water receptors and crops. Sodium and the high electrical conductivity in PSA leachate are a potential risk to water receptors and soil quality (structure).

In terms of physical contaminants, residual plastic and metal may be present in PSA if paper sludge is co-burnt with other material. There are unlikely to be problems with odour and/or the attraction of pests or scavenging animals. However, given the physical nature of PSA, dust is a potential issue during land applications. It is unlikely that PSA is a risk to receptors through plant and animal pathogens and/or invasive weeds. No other potential environmental hazards were identified.

These findings were used to produce the following Master List of hazards.

#### **Master List of hazards of PSA when applied to agricultural land**

<b>Hazards</b>	<b>Relevant receptor</b>
<b>Chemical hazards</b>	
Metals and metalloids in PSA	Soil quality, human, livestock/ecology and crops
Metals and metalloids – can be influenced by pH of the PSA and organic matter present in receiving soil	Surface water and groundwater
Dioxins and furans	Soil quality, humans and livestock/ecology
Polycyclic aromatic hydrocarbons (PAHs)	Soil quality, humans and livestock/ecology
Phthalates	Soil quality, humans and livestock/ecology
Chloroform	Soil quality, humans and livestock/ecology
Phosphorus	Surface waters
Sodium	Crops and groundwater
Electrical conductivity	Crops and groundwater
Chloride	Crops and surface water and groundwater
<b>Physical contamination</b>	
Residual plastic	Soil quality and humans
Residual metal	Soil quality and humans
<b>Nuisance</b>	
Dust	Air quality and humans

This Master List was screened to determine which hazards represent a significant risk to identified receptors under generic conditions. The resulting Principal List of hazards for PSA is as follows:

- Chemical hazards – metals, metalloids, sodium, electrical conductivity, phosphorus and chloride and their potential to present a significant risk to surface waters and groundwater
- Chemical hazards – chloride and its potential to present a significant risk to crops
- Nuisance – dust and its potential to present a significant issue to air quality and amenity for adjacent human receptors

The REA has a number of limitations; primarily the lack of time to obtain information from UK producers of PSA, the reliance on the unpublished draft WRc report and the lack of further UK based quantitative data.

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# 1 Introduction

## 1.1 Background

The Environment Agency regulates the spreading of waste to agricultural land in England under the Environmental Permitting Regulations (EPR) 2010. Under EPR 2010 the operator is required to obtain a standard rules or bespoke permit, and to make a separate deployment application for waste to be spread on a specific area of land.

On receipt of the deployment application, staff at the Environment Agency's National Permitting Service (NPS) must consider the potential adverse impacts on human health and the environment. This requires a clear understanding of the physical, biological and chemical hazards presented by a specific waste type, particularly in an agricultural context.

The purpose of this Rapid Evidence Assessment (REA) is to identify the primary hazards associated with paper sludge ash (part of waste code 10 01 01) to support NPS officers in their deployment review.

The operator must also demonstrate – and permitting staff must evaluate – the agricultural benefit from applying the wastes under a specific deployment. However, this is not the focus of this REA.

## 1.2 Structure of this report

Section 2 presents a summary of important information on PSA gathered for the REA and an REA roadmap. The latter provides an overview of the REA process and the location of specific information for the waste type. The summary and roadmap are intended to assist Environment Agency staff when reviewing the deployment application.

Section 3 describes the scope of the REA (with primary and secondary research questions), approach and methodology. This is supported by information presented in the evidence extraction spreadsheet in the Appendix.

Section 4 discusses the evidence collected for the REA under the defined headings of the secondary questions. This information was used to compile the Master List and Principal List of hazards presented in Section 4.3, and the refined conceptual model described in Section 4.4. The answers to individual secondary questions and all quantitative data obtained as part of the REA are given in the evidence extraction spreadsheet in the Appendix.

Section 5 presents the conclusions and recommendations based on the information obtained.

## 2 REA summary and roadmap

This section provides:

- a summary of important information on the characteristics of PSA
- ranges of typical contaminant concentrations
- an REA roadmap

### 2.1 Summary table

<b>Waste type:</b> Paper sludge ash	<b>Waste code:</b> 10 01 01 (part)
<b>Is waste a SR2010 No. 4 permitted waste type?:</b> Yes – Table 2.2B List B Waste (Environment Agency 2010)	
<b>Waste description:</b> Paper sludge ash (PSA) is the residue from the incineration of paper sludge	
<b>Date:</b> February 2014	<b>Version:</b> 1.1
<b>Assessment team:</b> Amec Foster Wheeler (compiled by Becky Whiteley, reviewed by Tony Marsland)	
<b>Methodology:</b> ‘Hazards from Landspreading (SR2010 No. 4 wastes): Methodology for Rapid Evidence Assessment’ (draft report for Environment Agency, March 2014)	
<b>Primary question:</b> What key hazards are associated with paper sludge ash which could present a risk to critical receptor during or after landspreading on agricultural land?	

Master List of hazards	Relevant receptor
<b>Chemical hazards:</b>	
Metals and metalloids	Soil quality, humans, livestock/ecology, crops, surface water and groundwater
Dioxins and furans	Soil quality, humans and livestock/ecology
Polycyclic aromatic hydrocarbons (PAHs)	Soil quality, humans and livestock/ecology
Phthalates	Soil quality, humans and livestock/ecology
Chloroform	Soil quality, humans and livestock/ecology
Phosphorus	Surface water
Sodium	Crops and groundwater
Electrical conductivity	Crops and groundwater
Chloride	Surface water and groundwater
Physical Contamination	
Residual plastic	Soil quality and humans



Master List of hazards	Relevant receptor
Residual metal	Soil quality and humans
<b>Nuisance:</b>	
Dust	Air quality and humans
<b>Principal List of hazards</b> <ul style="list-style-type: none"> <li>Chemical hazards – metals and metalloids, including sodium, electrical conductivity, phosphorus and chloride and their potential to present a significant risk to surface waters and groundwater</li> <li>Chemical hazards – chloride and its potential to present a significant risk to crops</li> <li>Nuisance – dust and its potential to present a significant issue to air quality and amenity for adjacent human receptors</li> </ul>	

<b>Items to consider on deployment application</b> <ul style="list-style-type: none"> <li>Application rate and frequency</li> <li>Site sensitivity with respect to groundwater and surface water</li> <li>Analytical testing of waste for Principal List of chemical hazards, as a minimum, to prove their absence or concentrations to inform subsequent risk assessment by operator. Based on the receptors present on site and knowledge of the waste source(s), additional determinands from the Master List should be added to the analytical suite as necessary.</li> <li>Solid and leachate testing to be provided by operator</li> <li>Compliance with standard rules permit conditions</li> <li>Dust management plan</li> </ul>
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## 2.2 Range of typical contaminant concentrations

Table 2.1 lists the range of typical contaminant concentrations identified during the REA for PSA.

The range of concentrations is based on both UK and non UK data. There is likely to be some variation in concentrations of contaminants analysed by different laboratories, using different methodologies and so on. However, for the purpose of this REA, the data are considered to be comparable and representative of contaminant concentrations present in PSA.

**Table 2.1 Range of contaminant concentrations for PSA<sup>1,2</sup>**

Contaminant	No. of samples	Minimum	Maximum
<b>Solid data (mg/kg)<sup>3</sup></b>			
Arsenic (As)	11	1.93	9.58
Cadmium (Cd)	23	0.34	12
Chromium (Cr)	23	21	1036
Cobalt (Co)	5	6.42	15.6

Contaminant	No. of samples	Minimum	Maximum
Copper (Cu)	175	18	562
Lead (Pb)	21	<3	125
Mercury (Hg)	19	0.02	0.86
Manganese (Mn)	162	0.01	3300
Molybdenum (Mo)	9	1.1	61
Nickel (Ni)	21	9.4	91.3
Selenium (Se)	8	0.11	19
Vanadium (V)	4	12.2	41.2
Zinc (Zn)	21	68	3864
Antimony (Sb)	4	2.7	16.5
Aluminium (Al)	159	5,350	86,952
Barium (Ba)	163	71	1549
Fluorine (F)	4	97	885
Iron (Fe)	157	1,748	30,100
Magnesium (Mg)	172	121	31,119
pH	22	9.4	12.9
Sodium (Na)	159	1,187	46,500
Potassium (K)	174	1,826	39,000
Phosphorus (P)	159	652	15,000
Sulphur trioxide (SO <sub>3</sub> )	140	2,800	15,100
Lithium (Li)	155	7.57	1,626
Sulphur (S)	12	90	4,850
Strontium (Sr)	155	280	7,001
Titanium (Ti)	155	0.2	1918
Thallium (Tl)	3	48.7	50
Dioxin (ITEQ) (ng/kg)	8	0.29	0.7
<b>Leachate (mg/l)</b>			
Silver (Ag)	7	<0.001	<0.001
Aluminium (Al)	8	0.891	3.6
Arsenic (As)	10	0.002	<0.025
Barium (Ba)	15	1.01	7.72
Beryllium (Be)	7	—	<0.0005
Cadmium (Cd)	15	<0.0005	<0.001
Cobalt (Co)	10	<0.001	<0.01
Chromium (Cr)	15	0.0004	<0.01

Contaminant	No. of samples	Minimum	Maximum
Copper (Cu)	16	<0.001	0.04
Mercury (Hg)	15	0.00002	0.0005
Molybdenum (Mo)	15	0.001	0.057
Manganese (Mn)	5	<0.005	<0.01
Nickel (Ni)	16	<0.001	0.11
Lead (Pb)	16	0.004	0.18
Antimony (Sb)	8	<0.002	0.005
Selenium (Se)	15	<0.001	<0.002
Tin (Sn)	7	–	<0.001
Thallium (Tl)	10	0.0014	<0.05
Vanadium (V)	10	<0.001	<0.01
Zinc (Zn)	14	<0.001	<0.03
Fluorine (F)	8	0.08	0.834
Chloride (Cl)	15	0.26	1,150
Sulphate (SO <sub>4</sub> )	15	0.06	54.7
Phenols	7	–	<0.003
Ammonia	7	0.001	0.005
Phosphorus (P)	7	0.01	0.025
pH (pH units)	1	–	10.1

Notes: <sup>1</sup> PSA is assumed to be unconditioned.

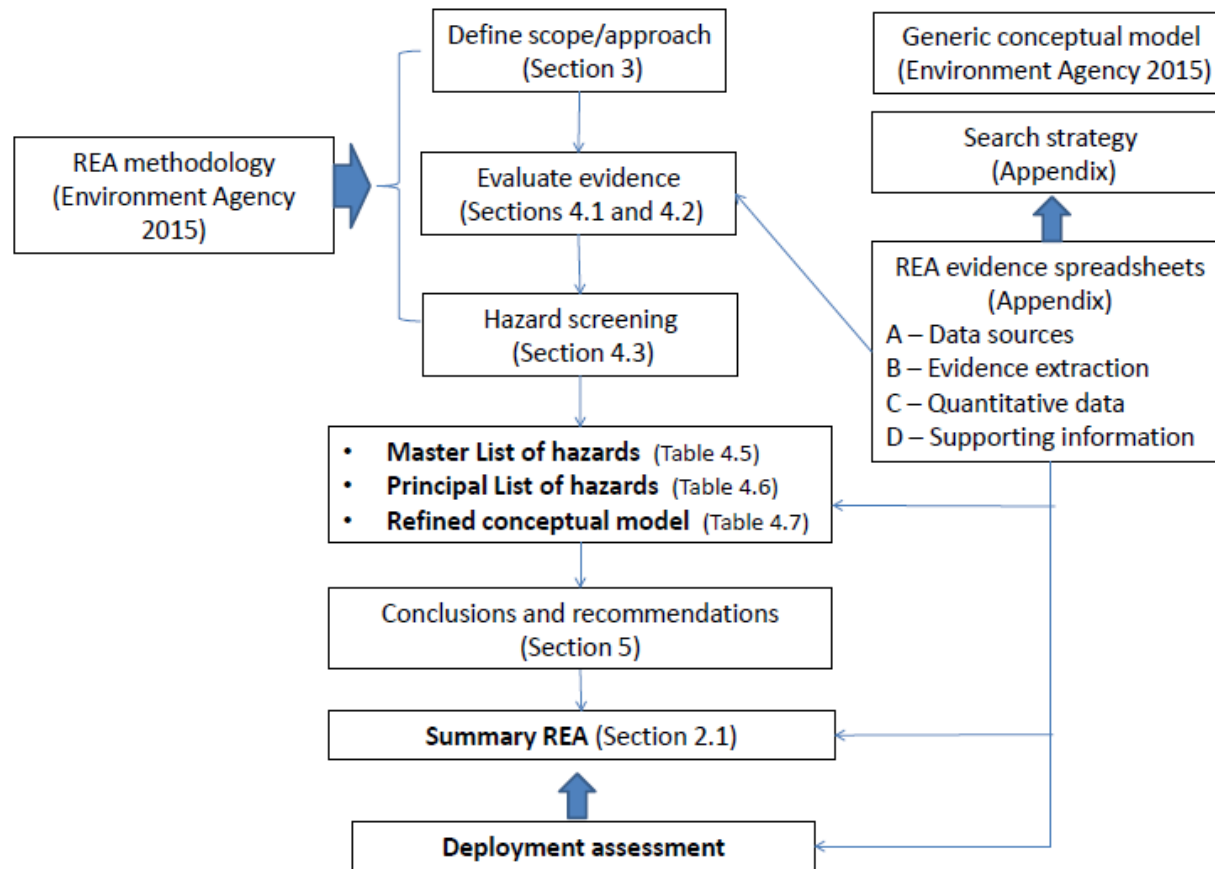
<sup>2</sup> These ranges are provided to identify waste material which may lie outside the norm and are not intended to be used as threshold concentrations for risk assessment purposes.

<sup>3</sup> Assumed to be dry weight, though some of the evidence sources do not specify.

ITEQ = International Toxic Equivalents

## 2.3 PSA roadmap

Figure 2.1 shows a roadmap demonstrating the REA process and location of specific information for PSA in this report.



**Figure 2.1 REA roadmap for paper sludge ash**

# 3 REA scope, approach and methodology

The REA was produced between January and March 2014 following the version of the methodology set out in a draft, unpublished report provided to the Environment Agency in March 2014. The methodology described below may therefore differ slightly from the final published version (Environment Agency, 2015).

## 3.1 Research questions and scope

### 3.1.1 Primary question

The REA addressed the overarching primary question:

What key hazards are associated with paper sludge ash which could present a risk to critical receptors during or after landspreading on agricultural land?

‘Critical receptors’ is the collective term for humans, controlled waters and dependant ecosystems, wildlife, soil (quality), air quality and property in the form of livestock and crops. The critical receptors will depend on the type of waste and the site-specific information for each deployment application.

### 3.1.2 Secondary questions

A series of secondary questions<sup>1</sup> (Table 3.1), common to all individual waste streams, was used to obtain more detailed evidence to identify:

- relevant pathways and receptors for the waste stream
- key hazards which may impact on these pathways and receptors

The secondary questions are based on the generic conceptual understanding of the landspreading process to agricultural land (Environment Agency 2015, Table 3.1).

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<sup>1</sup> See Table A.1 in Appendix A of the methodology report (Environment Agency 2015) for details of the rationale for each secondary question.

**Table 3.1 Secondary questions**

No.	Question
<b>WASTE PRODUCTION AND FORM</b>	
1	How many producers of this waste are there in the UK?
2	Is the waste from a single producer or as a result of a collection of waste from a number of producers?
3	Are there different production processes for this waste and how long have these been followed?
4	Is the waste produced as part of a treatment process (for example, effluent treatment)?
5	If yes, please provide details of the primary treatment process, particularly whether this has the potential to introduce contaminants such as disinfectants and so on.
6	Is there any information on the primary product for this waste (for example, from material safety data sheets or similar)?
7	How variable is the waste between batches and what factors influence this variability?
8	How variable is the waste between producers and what factors influence this variability?
9	Is the waste to be applied as a solid, sludge or liquid?
10	What is the method of application of this waste to land?
11	Why is this material to be spread to land?
<b>CHEMICAL HAZARDS</b>	
12	Are there any analytical data available for this waste?
<b>Groundwater assessment</b>	
13	Does the waste contain any hazardous substances (as defined by JAGDAG)?
14	Does the waste contain any non-hazardous pollutants in concentrations substantially above (greater than twice) typical natural background for shallow groundwater or drinking water standards?
<b>Surface water assessment</b>	
15	Does the waste contain any Priority or Priority Hazardous Substances <sup>1</sup> ?
16	Does the waste contain any Specific Pollutants <sup>2</sup> ?
<b>Soil etc. assessment</b>	
17	Does the waste contain potentially toxic elements (PTEs) or other contaminants?
18	What substances does the waste contain that could benefit the soil?
<b>General assessment</b>	
19	Does the waste contain any contaminants which are considered to be toxic to human health (that is, have proven or suspected carcinogenic, mutagenic, reproductive toxic effects and so on)?
20	Does the waste contain any contaminants with a high bioaccumulation potential?
21	Are there any contaminants present in the waste that are proven or suspected to be persistent in the environment?
22	Does the waste contain any contaminants which are proven or suspected of being endocrine disrupting?
23	Describe any speciation or the form of contaminants identified in the waste which could influence the hazards associated with these.
24	Are pesticides, herbicides or fungicides likely to be present in the waste?
25	Are there any breakdown products or metabolites associated with these contaminants, which could present a significant hazard?

No.	Question
26	Does the waste contain any contaminants which could potentially have cumulative/additive effects?
27	Does the waste contain any contaminants which could present a significant hazard due to their volatility?
28	Does the waste have a biological oxygen demand (BOD) of >6 mg/l?
29	Does the waste have a pH <5.0?
30	Does the waste have the potential to contain any emerging contaminants of concern?
<b>PLANT AND ANIMAL PATHOGENS AND TOXIC COMPOUNDS</b>	
31	Are <i>Salmonella</i> , <i>Listeria monocytogenes</i> , <i>Escherichia coli</i> , <i>Clostridium botulinum</i> or <i>Bacillus cereus</i> , or other bacteria or pathogens, or diseases such as bovine spongiform encephalopathy (BSE) and scrapie likely to be present in the waste, post spreading?
32	Are plant pathogens, fungus and/or soil-borne diseases likely to be present in the waste, post spreading?
33	Are toxic or injurious plants likely to be present in the waste, post spreading?
<b>INVASIVE WEEDS</b>	
34	Is there potential for invasive weeds to be present in the waste, post spreading?
35	Is there potential for exotic species to be present in the waste, post spreading?
<b>PHYSICAL CONTAMINANTS</b>	
36	Is non-biodegradable material such as plastics, metal, brick, concrete or glass likely to be present in the waste, post spreading?
<b>NUISANCE</b>	
37	Are unpleasant odours likely to be associated with the waste?
38	Is dust likely to arise from this waste?
39	Is the waste likely to attract pests such as flies or scavenging animals?
<b>OTHER ENVIRONMENTAL HAZARDS</b>	
40	Does the waste have a high fat or oil content (that is, >4% by weight)?
41	Is the waste likely to cause anoxic soil conditions?
42	Is there the potential for the stability of the waste to come into question?
43	Provide any further details on hazards identified in this waste which are not covered in the questions above.

Notes: <sup>1</sup> Substance of concern to surface water identified in Directive 2008/105/EC on Environmental Quality Standards (EQSs) (as amended).  
<sup>2</sup> Those contaminants identified in the UK to support the aim of achieving 'good status' by 2015 under the Water Framework Directive.  
JAGDAG = Joint Agencies Groundwater Directive Advisory Group  
([www.wfduk.org/stakeholders/jagdags-work-area-0](http://www.wfduk.org/stakeholders/jagdags-work-area-0))

## 3.2 Data search

A comprehensive search was made using multiple information sources so as to provide a variety of evidence sources and to minimise potential bias.

### 3.2.1 Sources used

The data search took into account the hierarchy of information sources listed in Table 4.1 of the REA Methodology (Environment Agency 2015). This is summarised below, starting from the most preferred sources:

1. Producer – specific waste stream data
2. Representative case-specific/compliance data
3. Environment Agency or Defra database
4. European Commission database
5. Generic producer data (UK based)
6. UK published literature, grey literature, expert knowledge and UK academic research
7. European and overseas data

The time constraints for this project meant it was not possible to approach any waste producers for information about PSA or similar wastes. This was discussed and agreed with the Environment Agency before beginning work on the REA.

The databases and websites listed in Table 3.2 were reviewed as part of the data search, in addition to a keyword search on Google and Google Scholar.

**Table 3.2 Databases and organisation websites reviewed during the data search**

Databases	Institution/organisation	Waste producers
World Wide Science	Public Health England	Aylesford Newsprint
Scopus	Institute of Occupational Medicine	Kimberley Clark (tissues)
Science Direct	National Farmers' Union	Smurfit Kappa
BioOne	Food Standards Authority	FGS Agri Ltd
OpenSIGLE	Natural Resources Wales	UPM
	Scottish Environment Protection Agency	
	Northern Ireland Environment Agency	
	European Food Safety Authority	
	US Department of Agriculture	
	University of Wisconsin – Centre for By Product Utilization	
	Irish Agriculture and Food Development Authority	
	Foundation for Water Research	
	Sustainable Organic Resource Partnership	
	Association for Organics Recycling	

### 3.2.2 Keywords

The keywords used for this REA are listed in Table 3.3.



**Table 3.3 Keywords used in the data search**

Waste type	Activity	Hazard identification
• Paper sludge ash	• UK	• Material data sheet
• Waste paper sludge ash	• Producers	• Environmental risks
• Paper byproducts	• Agriculture	• Hazards
• Ash	• Landspreading	• Human health
• Paper mill ash	• Incineration	• Groundwater
• Paper mill sludge ash	• Fertiliser	
• Paper mill fly ash	• Conditioning with water	
• Waste code 10 01 01		

Notes: These keywords were combined to form strings using 'AND' when searching on the internet and individual databases and websites.

The majority of evidence was identified using the keywords 'paper sludge ash' and 'paper mill ash'. During the general internet search, it was noted that the addition of the activity and hazard identification keywords to 'paper sludge ash' made very little difference to the quality of the hits identified. However, the use of the activity and hazard identification keywords for 'paper mill ash' identified new important evidence sources. As expected less and less new relevant information was found as the search proceeded, with any viable hits being identified repeatedly.

Generally, the first 50 hits from the search were screened. However, where it was obvious that unrelated or inappropriate hits were being brought up the number of hits reviewed was reduced.

It became apparent during the search that there was a large amount of research and information available for the primary waste material, paper sludge, its direct application to land and its use in the construction industry. For paper sludge ash, the majority of the information identified related to its potential geotechnical properties and appropriateness for use in bricks and concrete products. With this in mind, the keyword searches on the journal databases, such as Scopus, were restricted using the 'NOT' phrase, where appropriate, or filtered using the filtering system provided by the database itself.

Further details of the keyword searches, number of hits per search and so on are given in the Appendix.

### 3.2.3 Evidence screening

The evidence collected consisted of a mixture of peer reviewed, grey literature and unpublished information. This evidence was screened against the inclusion and exclusion criteria given below to identify the most important evidence for review. This was done by reviewing the title and/or the abstract or executive summary (as appropriate) for each piece of potential evidence.

#### *Inclusion criteria*

- Paper sludge ash forms at least part of the subject of the evidence.

In addition, at least one of the following also had to apply.

- The evidence provides information on the upstream production processes and any pre-treatment that the waste goes through prior to landspreading.
- The evidence provides qualitative or quantitative information about the waste's chemical composition.
- The evidence provides information on the potential microbiological or physical hazards associated with the waste.
- The evidence considers the spreading of the waste to agricultural land.
- The evidence provides a comparison between waste types and/or application to different land types.

### *Exclusion criteria*

- The evidence is not published in English.
- A full text version of evidence is not available.
- The evidence does not identify or focus on paper sludge ash.

### *Number of sources of evidence identified*

Following this initial screening, 20 sources of evidence were identified for review in the REA. Following a more thorough evaluation, however, three of these sources were deemed to hold little value and were therefore not taken forward.

The references for the sources used and a brief description of their content are provided in the Appendix.

# 4 Evaluation of evidence

## 4.1 Introduction

Numerous sources of evidence were identified and used to provide answers to the primary and associated secondary questions. These sources ranged from peer reviewed journal articles and reports to unpublished documents.

Where possible, priority was given to evidence obtained from two reports produced as part of the consideration of PSA as a candidate for a Quality Protocol under the joint Environment Agency and WRAP Waste Protocols Project (WRAP and Environment Agency 2008, WRc 2008). The risk assessment report from WRc forms the basis for the discussion in the technical report published by WRAP and the Environment Agency. However, the draft report is unpublished. As a result, information from peer reviewed journal articles was used to support the observations made by in the WRc risk assessment and, where relevant, to identify any gaps or contradictory evidence.

These two reports and many of the journal articles collected provide quantitative data for PSA or comparators. However, the restricted information provided in these sources on the analytical testing conducted made it difficult to assess the strength and quality of the data. This presented an issue for synthesising data for the REA. Consequently, data are presented and assessed on the basis of a range of concentrations or highest concentrations recorded, rather than deriving averages and so on between datasets. All quantitative data identified are provided in the Appendix. Potential issues with regard to quality and bias are discussed further in Section 4.2.2. Where possible, concentrations have been converted to mg/kg to aid comparison.

The responses to the secondary questions are given in Section 4.2. These findings were subsequently used to answer the primary question and to produce a Master List of hazards which could potentially be associated with PSA. These hazards were further screened to identify a Principal List of hazards which could potentially present a significant risk to identified receptors. The Master and Principal Lists of hazards are discussed and presented in Section 4.3. A refinement of the generic conceptual model for landspreading of waste, based on the Master List of hazards, is presented in Section 4.4.

## 4.2 Responses to secondary questions

The responses to the 43 secondary questions (Table 3.1) are given in the evidence extraction spreadsheet in the Appendix. Where appropriate, evidence was synthesised using the guidance from the REA methodology, both in the secondary question responses and in the detailed discussion below.

For each response, an evidence confidence rating was determined using the quality indicators matrix in Table 4.1. This is based on the strength of the information provided, the number of evidence sources which gave similar findings and the type of evidence source(s) identified. The rating for each secondary question answer is given in the evidence extraction spreadsheet in the Appendix.

The findings with regard to waste processing, form and the hazards associated with PSA are summarised and discussed in Sections 4.2.1 to 4.2.7.

**Table 4.1 Quality indicators for the REA**

Quality	Robustness of evidence	Primary evidence	Objectivity
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ranking	category		
<b>High</b>	Strong evidence with multiple references Most authors and experts come to the same opinion or conclusion Supporting quantitative data	Peer reviewed	No discernible bias
<b>Medium</b>	Evidence provided in a small number of references Authors and experts vary in their opinion or conclusion Limited supporting quantitative data	Grey literature	Weak to moderate bias
<b>Low</b>	Scarce or no evidence Authors/experts opinions/conclusions very considerably No supporting quantitative evidence	Unpublished	Strong bias

## 4.2.1 Waste production and form

### *Paper mill sludge*

Paper mill sludge has two main forms: primary and secondary.

Primary sludge is produced in the primary waste water clarifier, which removes fibre and suspended solids. This can contain rejected wood fibres, sand and small amounts of fly ash. Primary sludge is described as:

‘a combination of short cellulose fibres, water, ink, soap and other minerals (for example, kaolins, carbonates and talcs) separated from the recovered paper feedstock’ (WRAP and the Environment Agency 2008).

Primary sludge typically has a moisture content of 40%, and is generally viscous, sticky and difficult to dry (Dunster 2007).

Secondary sludge from the paper mill is produced during secondary biological treatment, which removes soluble organic pollutants. This sludge generally consists of dead bacteria and other microorganisms (Xioa et al. 1999).

Some producers may combine both types of sludge to act as fuel for the incinerator.

The sludge composition can vary throughout the paper industry, being influenced by operations and processes at the mill. Some authors have indicated that paper sludge is typically low in trace metals (Xioa et al. 1999, Gavrilescu 2008). Others indicate that sludge from paper mills usually contains similar or less contamination to that identified in municipal wastewater treatment sludge (Gavrilescu 2008, Monte et al. 2009).

However, there is the potential for paper sludge to contain dioxins and furans, particularly polychlorinated dibenzodioxins (PCDDs) and dibenzofurans (PCDFs), which can occur at kraft mills<sup>2</sup> that produce bleached pulp (Someshwar et al. 1990). Naphthalene, some phthalates, chloroform and wood extractives or derivatives (abietic acid, dehydroabietic acid, norobietetriene, tetrahydroretene and retene) have also been

<sup>2</sup> The kraft process converts wood into wood pulp consisting of almost pure cellulose fibres.

found in paper sludge in concentrations >10 mg/kg (dry weight) (Scott and Smith 1995).

### *Paper sludge ash*

PSA is the residue from the incineration of paper sludge.

Four main types of ash can be produced by an incineration process (Environment Agency 2013, p. 84):

1. Fly ash – ash that arises with the flue gases and is collected via abatement measures to minimise particulate matter released to the environment
2. Bag ash – this ash is generated through the use of abatement measures (addition of ammonia or urea) to reduce chemical contaminants such as nitrogen oxide being released into the atmosphere from flue gas
3. Bottom ash and bed ash – this is the ash that sinks to the bottom of the incinerator and is discharged into the burning gate
4. Boiler dust – dust collected in the incinerator

The mixture of fly ash and bottom ash is often termed 'boiler ash'.

Bottom ash and bed ash typically only account for 5% of the ash produced from the combustion of paper sludge (WRAP and Environment Agency 2008).

It is important to understand the source and type of ash as this can influence the European Waste Category code for the waste and potential hazards associated with it (Environment Agency 2013).

Some of the evidence sources examined for this REA define which type of ash is being considered, but this is not clear in all sources. Furthermore, fly ash and bottom ash can often be combined prior to disposal, complicating the characterisation of potential hazards (Elliot and Mahmood 2006).

### *Incineration process*

In most cases, paper sludge is co-incinerated with other material. This can be for economic reasons, providing an alternative method for disposal for other waste materials, or operational reasons, with additional material being added to sustain or provide optimal combustion (WRAP and Environment Agency 2008, Gavrilescu 2008, Yang Yin et al. 2007). The material burnt alongside paper sludge can be (Gavrilescu 2008, Monte et al. 2009, Nurmesniemi et al. 2012):

- virgin wood, bark or sawdust
- black liquor (chemical pulp manufacture – kraft process)
- coarse rejects such as metals, stones, wires, paper and fibre bundles, plastics, pieces of foil, and polystyrene
- fine rejects such as sand, glass, staples and other metallic waste
- other sludges generated by the paper mill including pre-treated sludges (for example, de-inking sludges) or those subject to chemical flocculation

The thermal processing of paper sludge generates hot gases which are used to heat boilers, producing steam. This steam is often used in the papermaking process for heating or drying purposes, but can also be fed into a turbine for power generation.

Conventional grate-fired boilers can be used for the incineration of paper sludge. However, the high moisture content, high ash and low oxygen content of the sludge material can reduce the efficiency of the boiler. Alternatively, fluidised bed or circulating fluidised bed incinerators can be used. These tend to be more successful at dealing with high ash, high moisture wastes, with circulating fluidised bed incinerators also being more efficient when burning sludge in association with high amounts of bark (Scott and Smith 1995).

The incineration of paper wastes is regulated by the Waste Incineration Directive (2000/76/EC) which imposes strict emission limits on, for example, sulphur dioxide and nitrogen oxide. The directive was implemented in England and Wales through EPR 2010. It requires that incinerators are operated such that the gas generated is kept at a temperature of 850°C for at least two seconds (for hazardous wastes the temperature is 1100°C). Operating at this temperature provides optimum conditions for sulphur capture and maximises the removal of any organics, including dioxins and furans in the paper sludge (Scott and Smith 1995, WRAP and Environment Agency 2008, Monte et al. 2009). The reduction in concentrations of dioxins and furans in paper sludge during the incineration process has been demonstrated, with less than 1% of the total 2,3,7,8-tetrachlorodibenzo-*p*-dioxin and 2,3,7,8-tetrachlorodibenzofuran originally present in the sludge being identified in the combustion ashes (Someshwar et al. 1990).

### *Pre-treatment of PSA*

The processing of PSA following incineration is described by WRAP and Environment Agency (2008). General information on good practice for the management and distribution of wood ash in general for agricultural use is provided by the University of Georgia College of Agricultural and Environmental Sciences (Risse and Gaskin 2002).

To minimise dust release during transfer to transport vehicles, PSA is often transferred to silos for closed discharge to tankers and/or water is added to the ash to condition it, improving the handling characteristics of the fine ash. However, the addition of too much water to the ash can result in the ash forming a cake, which can make any subsequent landspreading more difficult. As a result, the addition of water is usually carried out at the producers under controlled conditions using a dust or ash conditioner system.

On collection, a delivery note is raised for each batch, with the PSA being taken either directly to the final customer, or to an intermediary who sells the ash on behalf of the producer, or to a third party storage or bagging facility. Subject to deployment approval, the PSA is then spread to land.

### *Land application*

PSA is generally spread to land as a liming or soil treatment agent in solid form. The ash material is applied directly to the receiving land. It can be spread using conventional manure spreading or lime application equipment, and can be either top dressed or incorporated into the receiving soil. Maximum benefits tend to be achieved when the ash is incorporated into the root zone, at a depth of 5 cm for grassland applications and 25 cm for arable applications. The incorporation of the ash into the soil can also minimise the potential for dust release, post spreading (Risse and Gaskin 2002, WRc and Environment Agency 2008).

PSA is typically spread at an application rate of 10 t/ha for arable land and 7.5 t/ha for grassland (WRc 2008). Based on this application rate, the WRc risk assessment estimated that no more than one application of PSA per year or 10 applications in 10 years should be made. This estimate was based on the worst-case contaminant

loading, using the maximum concentrations of metals identified in the study – with the risk driver being copper. However, the risk assessment also notes that, as PSA has a lower neutralising value than natural lime, higher application rates may be required for acid soils. For very acid soils an application rate of up to 22.7 t/ha in any one year could be undertaken, but no more than five of these applications could be applied over a 10-year period.

Based on this information, the application rate and frequency is likely to be dependent on the receiving soil type and use of the land. Hence, application of PSA should be made on a site-by-site basis with supporting calculations provided to ensure compliance with standard rules permit conditions (see Environment Agency 2013).

### *UK producers*

Based on the evidence collected as part of this REA, it appears that the use of PSA for landspreading and other applications is becoming more common, particularly in Europe and Canada. Amec Foster Wheeler was unable to identify how many producers of PSA exist and are operational in the UK at the time of undertaking the REA. However, several producer websites were identified during the evidence search, with three producers (UPM, E-ON and Aylesford Newsprint) also being identified in the literature (Dunster 2007, WRc 2008).

## **4.2.2 Chemical hazards**

Chemical data for PSA were found in several sources of evidence. The WRc risk assessment presents analytical data provided by three PSA producers in the UK (WRc 2008). These data should therefore be representative of material that could be spread to land in the UK. However, as these data were provided by the producers themselves, there could be an element of bias which should be taken into account. Furthermore, the WRc report appears to be in draft form and hence is unpublished. In accordance with the quality indicators presented in Table 4.1, such a document is considered to have a low confidence rating. However, the chemical data provided in the WRc risk assessment report are referred to in the technical report published by WRAP and the Environment Agency, which has a higher confidence rating.

The remaining chemical data obtained during the REA were identified in journal articles, with some PSA data coming from other European countries such as Finland. This information is classed as having a medium confidence rating on the basis that the data may contain some minor bias, despite being presented in journal articles, which are assumed to have been peer reviewed.

Details such as the type of analytical testing, accreditation and limit of detection are mainly absent from the literature. Where the type of analytical testing is discussed, this tends to be limited, with no analytical accreditation details, or information on whether concentrations relate to dry or fresh weight and so on. There is likely to be some variation in concentrations of contaminants analysed by different laboratories (for example, use of different methodologies). However, for the purpose of this REA, the data are considered to be comparable and representative of contaminant concentrations present in unconditioned PSA. The qualitative data obtained during the REA are presented in the Appendix.

## Chemical composition and variability

There is a consensus in the literature that the chemical composition of PSA can vary between batches of PSA and producers. However, Tyrer et al. (2010) noted that ash from a single source can be highly consistent in composition.

The chemical composition of PSA can depend on:

- the incineration processes carried out
- the input materials used, including which material is co-burnt with paper sludge

PSA is primarily composed of inorganics and typically contains very low concentrations of potentially toxic components (Wajima and Munakata 2011). The bulk chemistry is dominated by calcium oxide, silica, alumina and magnesium oxide (WRc 2008). The presence of aluminium, in particular, is likely to be due to aluminosilicate clays and aluminium sulphate, which are added during paper manufacturing (Xioa et al. 1999).

These characteristics of PSA are evident in the quantitative data, with PSA containing higher concentrations of elements such as aluminium, manganese, iron, magnesium, sodium, potassium and phosphorus than more toxic metals such as arsenic, cadmium, mercury and lead.

PSA tends to be highly alkaline, with pH values given in the literature examined ranging from 9.4 to 12.9.

The range of contaminant concentrations present in PSA given in the literature examined are summarised in Table 4.2.

**Table 4.2 Composition of PSA: concentration range (mg/kg)**

Contaminant	WRc (2008) <sup>a</sup>			Other sources of evidence <sup>b,c</sup>		
	No. of samples	Minimum	Maximum	No. of samples	Minimum	Maximum
Arsenic (As)	6	1.93	5.02	5	<3	9.58
Cadmium (Cd)	16	0.34	3.21	7	<1	12
Chromium (Cr)	16	21	58.7	7	31.4	1036
Cobalt (Co)	3	6.42	15.6	2	9.13	14
Copper (Cu)	168	98	562	7	18	233
Lead (Pb)	16	21.4	125	5	<3	99.2
Mercury (Hg)	16	0.02	0.86	3	<0.1	0.09
Manganese (Mn)	157	0.01	1781	5	711	3,300
Molybdenum (Mo)	6	1.1	14.8	3	9.8	61
Nickel (Ni)	16	9.4	38.4	5	9.98	91.3
Selenium (Se)	5	0.11	1	3	1.08	19
Vanadium (V)	3	12.2	19.1	1	41.2	41.2
Zinc (Zn)	16	68	449	5	183	3,864
Antimony (Sb)	3	8.4	16.5	1	2.7	2.7



Contaminant	WRc (2008) <sup>a</sup>			Other sources of evidence <sup>b,c</sup>		
	No. of samples	Minimum	Maximum	No. of samples	Minimum	Maximum
Aluminium (Al)	155	57,368	86,952	4	5,350	82,100
Barium (Ba)	158	71	1,549	5	160	588
Fluorine (F)	3	705	885	1	97	97
Iron (Fe)	155	1748	5,106	2	6,260	30,100
Magnesium (Mg)	167	121	31,119	6	6,000	26,000
pH (pH units)	18	12.4	12.7	4	9.4	12.9
Sodium (Na)	155	1,187	28,487	4	1410	46,500
Potassium (K)	168	1,826	15,800	6	2110	39,000
Phosphorus (P)	155	652	3,650	4	1510	15,000
Sulphur trioxide (SO <sub>3</sub> )	140	2,800	15,100	–	–	–
Lithium (Li)	155	7.57	1,626	–	–	–
Sulphur (S)	12	90	4,850	–	–	–
Strontium (Sr)	155	280	7,001	–	–	–
Titanium (Ti)	155	0.2	1,918	–	–	–
Thallium (Tl)	3	48.7	50	–	–	–
Dioxin (ITEQ) (ng/kg)	8	0.29	0.7	–	–	–

Notes: <sup>a</sup> UK evidence source  
<sup>b</sup> Non-UK evidence sources  
<sup>c</sup> Xiao et al. (1999), Saraber and Haasnoot (2012), Nurmesniemi et al. (2012) and Elliot and Mahmood (2006)  
– No supporting data identified

The WRc report noted that there appeared to be little between-producer variation in composition; a comment based on the results provided by three UK producers. However, it also noted that PSA from a producer who co-burnt the paper sludge with plastic rejects was found to have higher concentrations of molybdenum (six times higher), selenium (four times higher) and barium (two times higher) than those from the other two PSA producers. It also pointed out that leachable concentrations for molybdenum, zinc, chlorides and sulphates were higher for this producer. However, it was recognised that it was possible that this could be partially attributed to the differing leachate test methodologies used (WRc 2008).

The WRc report, however, acknowledged that the data obtained during the risk assessment might not encompass the full range of values that might be attributed to PSA (WRc 2008). This is apparent when comparing its results with others in the literature. The results presented in Table 4.2 show that the upper end concentrations presented by WRc (2008) for cobalt, copper, lead, mercury, antimony, aluminium, barium, fluoride and magnesium are similar to those given by other sources. For some of the other contaminants, however, substantially higher concentrations were identified in the literature. This is likely to be partially due to the inherent variability in composition of PSA, although it may also be influenced by differences in analytical approach and

other factors such as differing input materials and proportions, method of incineration and the type of ash.

The variability in contaminant concentrations is further evident in the evidence sources that formed part of this REA. Concentrations of metals for two samples of ash from 1993 and 1995 were provided by Elliot and Mahmood (2006), with both ash samples resulting from the combustion of pulp and paper residues a Canadian paper mill. The results showed varying concentrations of metals, with substantial differences (that is, relative difference in excess of 50%) in the concentrations identified for aluminium, iron, zinc, copper, molybdenum, lead, nickel and chromium. The concentrations of metals for two samples of paper mill ash (ash 1 and ash 2) were presented by Xiao et al. (1999). The results again show a substantial variation in the concentrations of aluminium, nickel and zinc, in addition to selenium, boron, potassium, sodium and phosphorus. These samples also show different pH levels for the two ash types, with ash 1 being more alkaline (pH 12.9) than ash 2 (pH 9.4).

Table 4.3 compares the contaminant concentrations given in Table 4.2 with the concentrations typically found in virgin/untreated wood ash presented in two evidence sources (Xiao et al. 1999, Sarabèr and Haasnoot 2012). Higher concentrations were identified in PSA for chromium, copper, molybdenum, nickel, selenium, barium, vanadium and zinc; concentrations of arsenic, cadmium, lead and manganese are comparable with those found in virgin/untreated wood ash.

**Table 4.3 Typical contaminant concentrations in virgin/untreated wood ash (mg/kg)**

Contaminant	Xiao et al. (1999)	Sarabèr and Haasnoot (2012)	Range from Table 4.2 <sup>a</sup>
Arsenic (As)	–	20.8	1.93–9.58
Cadmium (Cd)	3–21	14.4	0.34–12
Chromium (Cr)	0.2–200	176	21–1,036
Copper (Cu)	50–110	162	18–562
Lead (Pb)	100	270	<3–125
Manganese (Mn)	–	3948	0.01–3,300
Molybdenum (Mo)	–	39.3	1.1–61
Nickel (Ni)	–	72.1	9.4–91.3
Selenium (Se)	–	<3	0.11–19
Vanadium (V)	–	25	12.2–41.2
Zinc (Zn)	250	1326	68–3,864
Barium (Ba)	–	740	71–1,549

Notes: <sup>a</sup> From UK and non-UK sources

The WRc risk assessment report compared the contaminant concentrations identified in PSA with those typically identified in urban and rural soils.<sup>3</sup> It found that the reported concentrations of arsenic, lead, manganese, mercury, nickel, vanadium and dioxins in PSA were at similar or lower concentrations to those in urban soils. However, the arithmetic mean concentrations for cadmium, copper, chromium, titanium and zinc in PSA exceeded the corresponding mean concentrations in rural and urban soils (WRc 2008).

<sup>3</sup> Using the environmental benchmark average and maximum values from the UK Soil and Herbage Pollutant Survey ([www.gov.uk/government/publications/uk-soil-and-herbage-pollutant-survey](http://www.gov.uk/government/publications/uk-soil-and-herbage-pollutant-survey))

The risk assessment also utilised the maximum contaminant concentrations to calculate the maximum application rates of PSA to soil in accordance with the Code of Practice for the Agricultural Use of Sewage Sludge (DoE 1996). The results identified that copper and molybdenum (maximum of 1.3 and 1.4 applications per year, respectively) were the limiting contaminants with respect to the application of PSA to land. As discussed previously, the highest concentration of molybdenum was identified in PSA that originated from the co-burning of paper sludge and plastic rejects. In contrast, the concentrations of copper were found to be fairly similar regardless of whether other materials had been burnt with the paper sludge (WRc 2008).

Organic contaminants tend to be removed during the incineration process. However, some organic residues can remain following combustion, particularly if the incinerator has not been efficient, leading to the incomplete combustion of some materials (Xiao et al. 1999, Gavrilescu 2008). The presence of dioxins and furans can also be influenced by the type of input materials co-burnt with paper sludge. For example, a linear increase in the generation of dioxins and furans was observed over the range of 0 to 2.5% salt (NaCl) in wood fuel from coastal areas in Canada (Elliot and Mahmood 2006).

Based on the evidence collected as part of this REA, concentrations of dioxins and furans in PSA as a whole appear to be negligible. Although quantitative data are sparse, concentrations of dioxins and furans reported by WRc (2008) are very low, ranging between 0.29 and 0.7 ng/kg (in eight samples analysed). Concentrations of PAHs, polychlorinated biphenyls (PCBs), dioxides and furans were below the detection limit or recorded at negligible concentrations in a PSA sample analysed, originating from 92% wood and 8% paper sludge, by Sarabèr and Haasnoot (2012).

There is some evidence in the literature that paper sludge can contain other organics, such as naphthalene, phthalates and chloroform, which could ultimately end up in PSA. Although the qualitative evidence from Sarabèr and Haasnoot (2012) indicated that PAH concentrations in one sample of PSA were low or negligible, there is no quantitative evidence to support this. Furthermore, it is likely that any phthalates or chloroform present in the primary paper sludge waste would be removed during incineration, though again there is no evidence in the literature to support this assumption.

#### **Main findings (chemical composition and variability)**

- There is a consensus in the literature that concentrations of metals and trace elements can vary (sometimes substantially) between different batches and producers of PSA (Table 4.2).
- PSA is generally alkaline, with a pH value ranging between 9.4 and 12.9.
- Concentrations of cadmium, copper, chromium, titanium and zinc in PSA can be higher than background concentrations in soil in urban and rural areas.
- Concentrations of metals, with the exception of lead, cadmium and manganese, tend to be higher in PSA than in virgin wood ash (Table 4.3).
- The presence of organic contaminants in PSA is generally regarded in the literature as negligible, but there is limited quantitative evidence to support this assumption.

#### **Leachability**

The WRc risk assessment report presents leachability data for up to 15 samples of PSA (WRc 2008) provided by two UK producers. The leachate testing method used for

the two producers was different, which could explain some of the differing results (see the Appendix and Table 4.4).

**Table 4.4 Leachate results for PSA (mg/l) from WRc (2008)**

Contaminant	No. of samples	Minimum	Maximum
Silver (Ag)	7	<0.001	<0.001
Aluminium (Al)	8	0.891	3.6
Arsenic (As)	10	0.002	<0.025
Barium (Ba)	15	1.01	7.72
Beryllium (Be)	7	–	<0.0005
Cadmium (Cd)	15	<0.0005	<0.001
Cobalt (Co)	10	<0.001	<0.01
Chromium (Cr)	15	0.0004	<0.01
Copper (Cu)	15	<0.001	<0.01
Mercury (Hg)	15	0.00002	0.0005
Molybdenum (Mo)	15	0.001	0.057
Manganese (Mn)	5	<0.005	<0.01
Nickel (Ni)	15	<0.001	<0.01
Lead (Pb)	15	0.004	0.096
Antimony (Sb)	8	<0.002	0.005
Selenium (Se)	15	<0.001	<0.002
Tin (Sn)	7	–	<0.001
Thallium (Tl)	10	0.0014	<0.05
Vanadium (V)	10	<0.001	<0.01
Zinc (Zn)	14	<0.001	<0.03
Fluorine (F)	8	0.08	0.834
Chloride (Cl)	15	0.26	1,150
Sulphate (SO <sub>4</sub> )	15	0.06	54.7
Phenols	7	–	<0.003
Ammonia	7	0.001	0.005
Phosphorus (P)	7	0.01	0.025
pH (pH units)	1	–	10.1

The results show fairly low contaminant concentrations in the leachate, with concentrations of several metals (beryllium, cadmium, cobalt, copper, manganese, nickel, antimony, selenium, vanadium and zinc) below the laboratory limit of detection.

With the exception of aluminium and barium, the concentrations of metals are relatively low (that is, <0.1mg/l).

Despite the high total concentrations of phosphorus identified in PSA (Table 4.2), the phosphorus concentrations in the leachate are low, ranging between 0.01 and 0.025 mg/l. This suggests that a large proportion of the phosphorus present in the ash is insoluble. Although this minimises the amount which is available for plant uptake, it will also reduce any potential risk of phosphorus leaching and impacts on water. Given that the eutrophication potential of phosphorus is very high, even at very low concentrations, the possibility of particulate run-off into surface waters is still a potential hazard if PSA is applied directly to the surface with no mechanical incorporation into the soil profile.

The leachability results presented in the WRc risk assessment report show a large concentration range for chloride (0.26–1,150 mg/l) (WRc 2008). The high concentrations of chloride in the PSA can be attributed to the co-combustion of plastics in the incinerator (Tyrer et al. 2010). Paper sludge is characterised by high chloride content (Gavrilescu 2008), which the author noted can be retained in paper sludge fly ash as condensed alkali chlorides. The amount of chloride enrichment is determined by the ash forming constituents present in the primary paper sludge. Such high concentrations may present a risk to groundwater and nearby surface watercourses. Excessive chloride concentrations in the soil can also result in leaf and root scorch, and hence could present a potential risk to crops at the receiving site.

The limited leachate testing undertaken by Yang Yin et al. (2007) on a sample of PSA from Malaysia recorded slightly higher concentrations of copper, lead and nickel compared with those presented by WRc (2008). This may again highlight the varying concentrations which can be recorded for this material, although it could be due to differences in analytical approach. Cadmium was again reported as being below the laboratory detection limit.

Further investigation into the leachability of PSA was made by Xiao et al. (1999), who performed a column leaching study on two samples of PSA (ash 1 and ash 2) from the USA. As discussed above, the two samples contained varying concentrations of heavy metals and other elements. The leachate results identified relatively high electrical conductivities in the first leachate stage for both samples of PSA (24.2 dS m<sup>-1</sup> for ash 1 and 2.32 dS m<sup>-1</sup> for ash 2). The observations for ash 1 in particular revealed that this ash was very saline in nature. The electrical conductivity for both samples dropped substantially (six-fold) between the first and second leaching, suggesting that most of the ions were quite soluble. Sodium concentrations followed this pattern, with most soluble sodium being removed during the first leaching. The authors also noted that the presence of high concentrations of soluble salts in the ash could cause severe adverse effects at high application rates. Similarly, Staples and Rees (2000) identified that the over-application of PSA can result in salt phytotoxic effects to white spruce seedling growth in Canada. This could also potentially present a risk to groundwater through leaching and vertical migration. Excessive concentrations of sodium can have a negative impact on soil structure via the swelling of clay particles and soil dispersion. The sodium induced dispersion can eventually result in reduced infiltration, reduced hydraulic conductivity and surface crusting, with all these factors impacting upon both the soil quality (that is, the soil's structure, form and its ability to act as a habitat) and crops grown at the site. However, increased amounts of calcium and magnesium, both of which are also associated with PSA, can reduce the amount of sodium-induced dispersion.

Xiao et al. (1999) also looked at the leaching potential of heavy metals and observed variations in the concentrations of chromium, selenium, lead and copper during the leaching between the two ash samples, despite similar total concentrations of chromium and copper in these samples. The leaching of chromium, selenium and lead

was generally greatest in ash 1, particularly during the initial leaching tests. Little leaching of chromium, selenium or lead was observed for ash 2. In contrast, both samples showed a similar, high rate of leaching for copper and zinc during the first leaching, but variable rates of leaching of copper and zinc during subsequent tests. No cadmium was detected in leachates from either ash sample, which suggested that the measurable cadmium identified in ash 1 was immobile.

Xiao et al. (1999) concluded that the total concentration of metals in the ash was only one of the factors controlling metal leachability. They observed that the alkaline pH of ash 1 played an important role in controlling metal leachability. In addition, the amount of zinc, copper, nickel and cadmium leached from the forest floor (A Horizon) in the study was positively correlated with organic matter content. The considerable losses of trace metals from the A Horizon were noted to occur under conditions favouring the leaching of organic matter, such as those presented by ash 1. Although the ash itself had low organic matter content, the presence of organic matter in the receiving ground may facilitate metal transport when it is dissolved under alkaline conditions (in the case of ash 1). In contrast, where less alkaline conditions exist, the presence of organic matter as solid phase can enhance the soil's ability to sorb metals, minimising risks of leaching and impacts to groundwater.

The leachate results discussed by Xiao et al. (1999) are similar to those in the WRC report (2008) in that they show a relatively low leaching potential for PSA for certain metals, particularly cadmium. This leaching potential is influenced by a number of factors such as pH, solubility of the contaminant and total contaminant concentrations. However, the leaching potential can also change in response to conditions at the receiving site, as noted during by Xiao et al. (1999) where leaching testing was conducted with the addition of site soils. However, such interactions will not be apparent from leachate data for PSA in isolation, such as that presented by WRC (2008) and Yang Yin et al. (2007).

#### **Main findings (leachability)**

- The leaching potential is influenced by a number of factors, including the pH of the PSA, solubility of the contaminant and total contaminant concentrations.
- Despite the high total concentrations of phosphorus in PSA itself, the phosphorus concentrations in the leachate are low, minimising any potential impact to water. However, the possibility of particulate run-off into surface waters is still a potential hazard given the very high eutrophication potential from phosphorus.
- Chloride present in the PSA can readily leach, presenting a potential risk to water receptors and crops.
- There is evidence from several sources that cadmium found in PSA appears to be present in an insoluble form.
- Some forms of PSA can result in high electrical conductivity and high concentrations of soluble salts (sodium) in leachate. This presents a risk to water and/or a risk of salt phytotoxicity to crops and soil quality (structure).
- The introduction of PSA with a very alkaline pH to a site can result in dissolution of organic matter, which in turn can facilitate metal transport from the receiving soils, presenting an indirect risk to water receptors.

## Comparators

As discussed above, the type of ash can influence the hazards present during landspreading. Nurmesniemi et al. (2012) compared the chemical and physical properties of bottom ash and fly ash. This ash originated from a fluidised bed boiler, with the fuel made up of 97% clean forest residues (that is, bark, woodchips and sawdust) and 3% sludge from a paper mill (from the primary clarifier of a wastewater treatment plant). The results showed that fly ash was a better plant nutrient and soil improvement agent than the bottom ash, due to higher concentrations of calcium (3.4 times higher), magnesium (4.3 times) and acid neutralising value (three times). Although the total phosphorous content was five times greater in the fly ash, the water soluble content of phosphorus in both ash types was negligible (<0.01% dry weight); this supports the finding described in the WRc report (2008) noted above.

Nurmesniemi et al. (2012) found that the concentrations of metals were generally substantially higher in the fly ash than in the bottom ash (between 1.5 times for potassium and 40 times for cadmium). This suggests a high degree of element volatilisation and element retention through other processes such as condensation. Yang Yin et al. (2007) noted that high concentrations of heavy metals are present in the finer fractions of incinerator bottom ash. This suggests that the potential risk to receptors may increase with the proportion of smaller ash particles in the waste.

Leaching tests undertaken by Yang Yin et al. (2007) identified a higher leaching potential for lead and nickel in PSA compared with municipal solid waste (MSW) ash, despite higher total concentrations for these contaminants in the latter. This was again thought to relate to the particle size distribution, with PSA having a much smaller particle size providing a higher surface area to facilitate subsequent leaching. However, the smaller particle size associated with PSA can be a benefit, presenting a greater likelihood for complete combustion, which in turn can minimise the potential concentrations of dioxins and furans and other organic contaminants in the residual ash (Elliot and Mahmood 2006). However, Elliot and Mahmood (2006) did note that dioxin and furans concentrations in fly ash can be substantially greater than those found in bottom ashes, although no quantitative data were provided to support this.

Sarabèr and Haasnoot (2012) compared the composition of a series of different ash types. The primary waste for all ash had a high proportion of wood, with varying secondary fuels including paper sludge, compost, organic waste and grass from roadsides. The results showed generally concentrations of heavy metals and metalloids in the PSA lower or comparable with the other ash types.

Copper was an exception to this, with concentrations in the PSA of 2–3 times that found in the other ash types. Concentrations of copper tend to be higher for PSA originating from newsprint than those from unprinted paper (Webb 2000). Copper can also be associated with de-inking sludge, due to the blue pigments of printing inks which contain phthalocyno-compounds (Gavrilescu 2008).

### Main findings (comparison between ash types)

- Concentrations of metals – and potentially dioxins and furans – in PSA are generally substantially greater in fly ash than in bottom ash, although fly ash was demonstrated to be the better plant nutrient and soil improvement agent.
- Total concentrations of metals tend to be higher in MSW ash, although there is a greater potential for leaching of metals from PSA compared with MSW ash.
- Concentrations of copper can be higher in PSA compared with other waste ashes.

### 4.2.3 Plant and animal pathogens

No reference to plant or animal pathogens was identified in the literature reviewed as part of this REA. Given the nature of the primary waste, it is considered unlikely that such hazards would exist in PSA.

### 4.2.4 Invasive weeds

It is considered unlikely that invasive weeds or exotic species would be present in either the primary waste or introduced to the ash during the incineration process. As a result, the potential risks from such hazards are not considered relevant for PSA.

### 4.2.5 Physical contaminants

As discussed in Section 4.2.1, paper sludge is typically co-burnt with other material such as bark, wood and paper mill rejects, which can include plastics, metals and glass. It is likely that any plastic rejects present will be degraded and destroyed during the incineration process. However, inadequate mixing of waste can result in the incomplete combustion of materials, leading to the potential for physical contaminants remaining in the residual ash (Gavrilescu 2008). Gavrilescu (2008) makes reference to plastics being removed from the ash once they have cooled down to a more stable condition.

There is no further information in the literature about a formal ash screening process to remove such items. There remains the potential for plastics and metals to be present in PSA.

### 4.2.6 Nuisance

#### *Odour*

The alkaline conditions associated with paper sludge can fix compounds present in the waste to a non-volatile and non-odorous form (Webb 2000). This is also likely to apply to PSA, given the similar alkaline conditions. In addition to its high pH, PSA is also characterised by a low organic content – 1.83% compared with 11.24% for MSW ash, with a non-detectable calorific value (Yang Yin et al. 2007). Given both these factors, odours are unlikely to be a hazard for PSA.

#### *Pests and scavenging animals*

Due to the low organic content of this material and fact that the ash is not applied as a surface layer but is incorporated into the soil, potential hazards associated with the attraction of pest and scavenging animals are not considered an issue for PSA.

#### *Dust*

PSA is described as a very fine dust material, with a moisture content of <0.1% and with 40% of particles <0.0063 mm in diameter (WRAP and Environment Agency 2008).

The physical nature of PSA (fly ash) was compared to MSW ash (bottom ash) by Yang Yin et al. (2007). They showed that PSA is made up of much finer particles than MSW ash, with over 85% of the particles in PSA being <125 µm and 4.24% being >212 µm. In contrast, MSW ash has just 0.01% of its particles <125 µm, with nearly 78% being



>212 µm. This difference is thought to be due to the difference in primary waste material, with MSW ashes being the result of a complex amalgamation of different wastes types with different chemical compositions.

Given the physical nature of PSA, the potential for nuisance from dust is a considered to be a hazard.

#### 4.2.7 Other environmental hazards

No other potential hazards were identified for PSA.

### 4.3 Hazard evaluation and screening

#### 4.3.1 Master List of hazards

The review above was used to produce a Master List of hazards for PSA (Table 4.5).

**Table 4.5 Master List of hazards for PSA applied to agricultural land**

Hazards	Relevant receptor
<b>Chemical hazards</b>	
Metals and metalloids in PSA	Soil quality, human, livestock/ecology and crops
Metals and metalloids – can be influenced by pH of the PSA and organic matter present in receiving soil	Surface water and groundwater
Dioxins and furans	Soil quality, humans and livestock/ecology
PAHs	Soil quality, humans and livestock/ecology
Phthalates	Soil quality, humans and livestock/ecology
Chloroform	Soil quality, humans and livestock/ecology
Phosphorus	Surface waters
Sodium	Crops and groundwater
Electrical conductivity	Crops and groundwater
Chloride	Crops and surface water and groundwater
<b>Physical contamination</b>	
Residual plastic	Soil quality and humans
Residual metal	Soil quality and humans
<b>Nuisance</b>	
Dust	Air quality and humans

Notes: In the context of the application of PSA to agricultural land

#### 4.3.2 Principal List of hazards

The Master List of hazards (Table 4.5) was further evaluated to ascertain which ones have the potential to present a significant risk to receptors under generic conditions

(that is, represent a principal hazard). Where relevant, the following factors were taken into account:

- evidence and opinion in the literature on the risks presented by a particular hazard to a given receptor.
- concentrations of the contaminants of concern compared with existing environmental levels in soils and in comparable non-wastes such as fertilisers, manures and soil substitutes **when applied at similar application rates** (taking account of good agricultural practice)
- potential likelihood of a hazard occurring under generic conditions, with controlled application rates and the risk criteria specified in SR2010No 4.
- any underlying requirements for management practices or mitigation to be implemented to minimise the risk (for example, standard permit conditions and good practice under statutory codes)

## *Chemical hazards*

### *Livestock and ecology*

The risk assessment by WRc (2008) considered the potential risks to livestock from contaminant concentrations identified in PSA, primarily to assess the potential use of PSA in animal bedding. However, the results can still be used to inform the current evaluation. A comparison of mean concentrations of contaminants in PSA and maximum limits in animal feed highlighted a potential issue with lead, manganese and mercury if ingested by livestock. However, in reality this scenario was considered unlikely given that PSA is unpleasant to eat and therefore consumption levels by livestock would be minimal. The one exception is during calving where licking may lead to increased ingestion of PSA. However, this is more likely to be an issue when PSA is used in bedding material rather than spread to land, as cattle are normally indoors during calving.

When applied to agricultural fields, the PSA will be incorporated into the ground, minimising the potential for livestock to come into direct contact with this material.

Given all this, the risks to livestock from PSA are unlikely to be significant based on the findings of the WRc risk assessment (WRc 2008).

Note that the WRc risk assessment was based on the maximum concentrations identified during the study. As part of this REA, higher concentrations of certain contaminants have been identified in the literature; these have not been considered with respect to risks to livestock. They include concentrations of zinc, cadmium, selenium and molybdenum, which when compared directly to the Soil Code thresholds (MAFF 1998), could potentially be an unacceptable risk to livestock.

Cadmium in PSA is considered to be relatively insoluble, minimising the potential bioavailability of this contaminant for plant uptake and subsequent ingestion by livestock. Livestock can potentially be exposed to cadmium through the direct ingestion of soil, but this is unlikely to be significant. Thus cadmium, even at the higher concentrations identified in PSA, is considered unlikely to be a significant risk to livestock. However, landspreading of the higher concentrations of zinc, selenium and molybdenum may prove to be unacceptable during the assessment of the deployment application.

No further assessment of the potential risks to ecology was found in the evidence sources used as part of this REA. For initial screening purposes, the maximum concentrations of contaminant concentrations found in PSA were compared with

Environment Agency Soil Screening Values (SSVs) for ecological risk assessment (see Environment Agency 2008). This identified a potential issue with cadmium, chromium, copper, nickel, mercury and zinc in PSA, although the minimum concentrations for each of these contaminants were below their respective SSVs. Furthermore, the maximum concentrations of nickel and mercury were below background concentrations in rural areas and hence unlikely to be significant with respect to risks to ecology (WRc 2008).

In summary, the potential adverse risks to livestock and ecology from the landspreading of PSA are not considered to have been assessed adequately in the evidence sources reviewed. Given that the minimum concentrations of metals such as cadmium, chromium, copper and zinc are below the thresholds in the Soil Code and SSVs, it is likely that potential unacceptable risks to livestock and ecology will only be realised for some types of PSA.

Taking into account the potential for dilution once incorporated into the soil profile after being spread to land, it is unlikely that PSA will present a widespread significant risk to livestock and ecology. However, this should be considered on a site-by-site basis at the deployment stage.

#### Human health

The WRc risk assessment also examined the potential risks to human health from contaminant concentrations identified in PSA (WRc 2008). For the purpose of the assessment, the maximum concentrations of contaminants – primarily metals and metalloids – were used to ascertain whether these could potentially present a risk to human health. A number of health protective assumptions were made, including the application of PSA to soft landscaped areas in commercial premises and residential gardens.

The results identified a theoretical unacceptable risk from aluminium and manganese for the residential setting and manganese for the commercial scenario. In reality, the very health protective assumptions made during the assessment were considered unlikely to be realised, minimising the potential risk presented by these contaminants to humans. Furthermore, when applied to agricultural land, it was concluded that there was no identified risk to humans from aluminium or manganese.

The WRc report provides an insight into the potential risks from contaminant concentrations found in PSA in the UK in 2008. However, the assessment was based on a scenario which bears little resemblance to an agricultural site. Potential contaminant exposure to bystanders at such as site is only really viable from inhalation and possible ingestion of dust from PSA, rather than the combination of direct contact pathways (dermal contact and ingestion) and inhalation considered in the WRc assessment. Furthermore, the assessment was made using data provided by a small number of producers. Not only did these data contain a potential bias, but it is also apparent from Table 4.2 that the assessment may not have considered the full range of contaminant concentrations that could be present in PSA.

Several contaminants have been identified at concentrations which could impact negatively on livestock (see above). This includes cadmium, which has the potential to build up in animals in the kidneys and liver, and which if consumed by humans can present an adverse health risk. However, there is consensus in the literature that the cadmium present in PSA is relatively insoluble, minimising its potential bioavailability of for plant uptake and ingestion by livestock and ultimately human consumers.

As with livestock, whether there is in reality an unacceptable risk to humans via the food chain for metals, such as zinc, selenium and molybdenum, is likely to depend on:

- the chemical composition of the PSA spread to land

- the potential for dilution when the PSA is incorporated into the soil, crops or livestock present at the site
- application of PSA in accordance with good practice and a dust management plan
- the rate and frequency of ingestion of certain food groups by an individual

On this basis, it is unlikely that the concentrations of metals identified in PSA present a widespread significant risk to humans through the food chain.

As discussed, organic contaminants such as dioxins and furans may be present in PSA. However, the limited quantitative evidence collected suggests that their concentrations tend to be very low. Furthermore, there is an apparent consensus in the literature that, under normal conditions, the incineration process is an effective method for removing such contaminants. As a result, the potential for high concentrations of organic contaminants in PSA to present a significant risk to receptors is considered to be low.

Exposure to contaminants in PSA for workers involved in landspreading is likely to be confined to the period of spreading and on an intermittent basis thereafter for farm workers. Such short-term exposure events can be mitigated through the use of gloves and good hygiene practice, that is:

- not eating, drinking or smoking on site
- washing of hands
- carrying out the works in accordance with good practice and SR2010 conditions

Such measures can avoid any potential risks to workers involved in landspreading.

### Crops

Investigations by Xiao et al. (1999) and Staples and Rees (2000) have shown a potential hazard relating to the electrical conductivity and sodium leachate from PSA, specifically a potential risk to crops through salt phytotoxicity. Xiao et al. (1999) found that this risk was greater in one of the two samples of PSA they investigated. This suggested that this may not be a widespread concern for crops, but one which can be an issue for some batches of ash. Staples and Rees (2000) suggested that this was only of real concern in the forestry environment when there were high applications of PSA. As a result, under normal controlled applications this is unlikely to present a significant risk to plants, but should still be borne in mind at the deployment stage.

In addition, the potential presence of high concentrations of chloride in PSA may present a risk to crops in the form of leaf and root scorch. High chloride concentrations in PSA tend to be associated with the co-burning of plastics, although chloride present in the paper sludge itself can also end up in the resultant ash deposits. The concentrations of chloride in PSA leachate have been shown to vary widely between producers with a range of leachate concentrations from 0.26 to 1,150 mg/l (Table 4.4).

Chloride is not absorbed or held back by soils. Hence it is readily available in the soil water and is subsequently taken up by plants and can accumulate in leaf tissue. If the chloride concentrations exceed the tolerance of the plant, injury symptoms can develop. Plant species differ in their tolerance and sensitivity to chloride, with peas, beans, clover and other legumes being generally more sensitive than other crops. The impact of high chloride in the soil can also be influenced by the moisture holding capacity and moisture content of the receiving soil (A & L Canada Laboratories 2008). On this basis, the magnitude of risk is likely to depend on the chloride levels present in

the PSA, the nature of the receiving soil and the type of crops planted at the site. However, given the likelihood of high chloride concentrations in PSA (as discussed above), there is a potentially significant risk to crops.

Chromium is also potentially toxic to plants. The maximum concentration of 1,036 mg/kg identified in PSA exceeds the threshold concentration of 400 mg/kg in the Soil Code (MAFF 1998) for the protection of plants on agricultural land. However, if present in the less toxic form (trivalent chromium), the chromium present is unlikely to be toxic to plants except in extremely acidic soils. Although, the form of chromium present in PSA is unknown, there is no evidence to suggest that paper sludge, and its resultant ash, has the potential to contain the more toxic hexavalent chromium. If so, the risks to plants (crops at the receiving site) are considered unlikely to be significant.

### Controlled waters

The WRc risk assessment report considered the potential risks to surface water and groundwater using representative leachate data for PSA and comparison against EQSs, Drinking Water Standards and Minimum Reporting Values (WRc 2008). PSA was found to cause breaches of the EQS for a number of determinands, including silver, copper and lead, if accidentally released in large quantities to small volumes of surface water, particularly in soft water areas. Likewise, PSA could breach groundwater benchmarks for a number of contaminants including aluminium, arsenic, barium, chloride, mercury and lead. However, it was concluded that there were no issues to surface water or groundwater as long as operators complied with the following use restrictions:

- Ensure good housekeeping during transport, storage and use.
- Protect from flooding and against release to drains or surface water.
- Do not use within 10 metres of surface water.
- Do not use within 50 metres of a potable borehole.
- Carry out routine testing to ensure compliance with the overall ranges provided in the WRc risk assessment (WRc 2008).
- Operate current good practice with respect to the recordkeeping, storage, use and disposal of PSA products.

The distances to surface water and potable boreholes given above are similar to the standard permit conditions in SR2010No4. The operator should take account of other factors relating to good practice and so on as part of the deployment application.

The observations made by Xiao et al. (1999) partially support those made by WRc (2008). They concluded that some ash types may only have minor adverse attributes with respect to land applications (based on observations from ash 2). However, where the ash is highly alkaline, soil organic matter could be dissolved, enhancing metal leachability. Such enhanced leachability may not have been taken into account in the WRc risk assessment. Furthermore, the leachable soluble salts and high conductivity identified in the PSA leachate by Xiao et al. (1999) (see discussion above for crops) and the potential risks from the phosphorus in PSA were not considered in the WRc assessment. These contaminants are a potentially significant risk to groundwater, particularly for PSA with similar characteristics to ash 1 (for sodium and electrical conductivity) from the Xiao et al. (1999) study. The low solubility of phosphorus in PSA means that the potential risk from phosphorus is likely to be reduced substantially if the PSA is incorporated into the soil, or the site is located well away from watercourses, as this will minimise the potential for particle run-off to enter them.

In addition, the risk assessment by WRc reported in 2008 is now out-of-date with respect to controlled waters. Revised surface water EQSs have been introduced in the UK through the Water Framework Directive for both Priority and Specific Pollutants. A brief Tier 1 screen of the WRc leachate data against the current EQSs<sup>4</sup> identified a potential risk from the higher end leachate concentrations for mercury, lead and chloride. These contaminants may warrant further consideration during the deployment stage, as they are a potentially significant risk to water receptors if sufficient management is not in place to prevent their release to the environment.

### Soil quality

The potential risks to livestock and human health, which come under the broad definition of soil quality,<sup>5</sup> are discussed above. This section therefore focuses on the risks to soil biology and structure.

The Soil Code (MAFF 1998) notes that some soil organisms may be affected by additions of zinc above 200 mg/kg, but gives no specific information relating to which organisms are affected and under which conditions this impact is of most concern. A maximum concentration of zinc in PSA of 3,864 mg/kg was identified in the literature. On this basis, there is the potential for adverse impacts to soil biology, although again this will depend on the chemical composition of the PSA and the potential for dilution at the receiving site. However, insufficient information is available to draw any conclusions on the potential for this risk to be significant and the potential for adverse impacts to be presented by other contaminants in PSA.

The potentially high sodium concentrations in PSA can have a negative effect on the structure of the receiving soil, impacting on soil quality (that is, the soil's structure, form and its ability to act as a habitat) and crops grown at the site. Increased amounts of calcium and magnesium (both of which are also associated with PSA) can reduce the amount of sodium-induced dispersion and hence it is considered unlikely that this will present a significant risk to soil quality.

Overall contaminant loading was considered in the WRc risk assessment report (WRc 2008). This is important for soil quality, as the accumulation of potentially toxic elements can have knock on effects for soil biology, as well as risks to crops and livestock and indirectly humans (via the food chain). This assessment is discussed in Section 4.2, with molybdenum and copper identified as the limiting elements for land application to prevent contaminant build-up in accordance with the limit values given in the Code of Practice for the Use of Sewage Sludge in Agriculture (DoE 1996). The findings of this assessment should be considered when reviewing the proposed application rates and tonnage on the deployment application.

### *Physical contamination*

There is evidence in the literature that residual plastics and metals may be present in PSA. This can be due to poor efficiency in the incinerator. However, given that it is in the producer's interest to maximise the energy produced during the incineration process and to minimise the need for treatment or screening of the ash, the likelihood of significant quantities of physical contaminants being present in the ash for

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<sup>4</sup> Priority Substances are detailed in The River Basin Districts Typology, Standards and Groundwater Threshold Values (Water Framework Directive) (England and Wales) Directions 2010.

<sup>5</sup> The capacity of a specific kind of soil to function and sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation by soil microbiology, invertebrates and vertebrates.

landspreading is considered to be low. On this basis, it is considered unlikely that such hazards will present a significant risk to receptors.

### *Nuisance*

The WRc risk assessment report states that the exposure of the potential workforce to dust during the application of PSA to land is considered to be similar to that from exposure to dust arising from lime from other sources. Furthermore, there was no risk to the health of the nearby general population as a result of PSA applications to land. However, in accordance with good practice, the report recommended dust suppression measures (WRc 2008).

Although the potential for harm from dust associated with PSA spread to land is low, this hazard warrants further consideration in the form of a dust management plan in any deployment application to mitigate any risk to air quality and nuisance to nearby residents.

### *Summary of principal hazards*

Table 4.6 lists the principal hazards associated with PSA spread to land.

**Table 4.6 Principal List of hazards of PSA**

<b>Hazards</b>	<b>Relevant Receptor</b>
<b>Chemical hazards</b>	
Metals (particularly mercury and lead based on existing leachate data)	Surface water
Metals (aluminium, arsenic, barium, mercury and lead based on WRc risk assessment)	Groundwater
Phosphorus	Surface water
Sodium	Groundwater
Electrical conductivity	Groundwater
Chloride	Crops, surface water and groundwater
<b>Nuisance</b>	
Dust	Air quality and humans(by-standers)

Notes: In the context of the application of PSA to agricultural land

## **4.4 Refined generic conceptual model**

The findings of the hazard assessment and evaluation were used to refine the generic conceptual model for the landspreading of PSA to agricultural land. The refined generic conceptual model, which takes account of the hazards identified on the Master and Principal Lists of hazards, is presented as Table 4.7.

**Table 4.7 Summary generic conceptual model for landspreading PSA to agricultural land**

Source	Pathway	Receptor	Potential effect
Chemical contamination	Direct contact, ingestion and inhalation (dust and vapour)	Livestock	Toxic, hazardous to health
• Metals and metalloids	Uptake via plants and ingestion		
• Dioxins and furans	Direct contact, ingestion and inhalation (dust and vapour)	Humans (operator)	Toxic, carcinogenic, hazardous to health
• PAHs	Inhalation (dust and vapours)	Humans (bystanders)	
• Phthalates	Uptake via plants and ingestion of produce	Humans (consumer)	
• Chloroform	Ingestion of livestock and ingestion of produce		
• Sodium	Plant uptake	Crops	Reduction in crop yield and productivity due to phytotoxicity, plant die-back, detrimental conditions to plant growth and so on
• Electrical conductivity			
• Chloride	Leaching from soil to groundwater and vertical migration through the unsaturated zone	Groundwater	Groundwater contamination – deterioration of quality, impact on potable water resource requiring treatment or closure of source of supply (borehole, well or spring)
• Phosphorus			
	Surface run-off and lateral migration in groundwater	Surface water	Surface water contamination – deterioration of water quality, sediment loading
	Direct application to land	Soils	Deterioration of soil quality, damage to soil structure, toxicity and other adverse changes to soil micro-organisms impacting soil functions, or increased contaminant loading in site soils affecting amenity and use



Source	Pathway	Receptor	Potential effect
	Direct application to land, direct contact and uptake via soil vertebrates and invertebrates followed by transmission through the ecological food web	Ecological designation/ wildlife	Harm to protected site through toxic contamination or habitat interference (nutrient enrichment, loss, disturbance and so on)
Physical contamination, including glass, plastic and metal	Direct application to land	Soil	Deterioration of soil quality
		Human (bystanders)	Loss of amenity
Release of dust	Airborne transport	Air quality	Deterioration of air quality
	Airborne transport and inhalation (dust)	Humans (bystanders)	Nuisance, impact on quality of life and loss of amenity

# 5 Conclusions and recommendations

## 5.1 Conclusions

This REA identified the potential hazards associated with PSA and its application to agricultural land. The evidence collected was examined to establish a Master List of hazards which apply to PSA (Table 4.5). The potential for these hazards to occur and have a significant impact on identified receptors was further considered to identify a Principal List of hazards (Table 4.6).

The principal hazards associated with PSA when applied to agricultural land are as follows:

- Chemical hazards – metals and metalloids including sodium, electrical conductivity, phosphorus and chloride and their potential to present a significant risk to surface waters and groundwater
- Chemical hazards – chloride and its potential to present a significant risk to crops
- Nuisance – dust and its potential to present a significant issue to air quality and amenity for adjacent human receptors

The risks from principal hazards are likely to be successfully mitigated through:

- the use of good practice during the transport, storage and application of PSA to land
- the use of appropriate management practices, particularly in the form of a dust management plan and compliance with the restrictions on application rates and set-off distances under a standard rules permit

These factors should be considered by the operator and evident on the deployment application to the Environment Agency.

## 5.2 Limitations and recommendations

Time constraints on the preparation of the REA meant it was not possible to liaise with UK producers of PSA. This is a limitation of the study. The REA would have benefited from obtaining further information on the production processes, pre-treatment, typical application rates and methods of application for PSA specific to the UK.

Further UK quantitative data for comparison with that identified in the literature would also have been advantageous and provided more confidence in the contaminant concentration ranges presented in Section 2.2.

The search strategy identified a number of UK producers of PSA (Table 3.2). It is recommended that these producers are contacted to provide further upstream information to inform this REA. The Master and Principal Lists of hazards should then be reviewed to ensure this additional information does not change the conclusions from the REA.

The REA, and the hazard assessment and evaluation, have relied heavily on the risk assessment and data in one report – the risk assessment carried out by WRc on behalf of the Environment Agency as part of the Waste Protocols Project (WRc 2008). But

wherever possible, this has been supported by further evidence sources collected as part of the REA and the review team's knowledge in the subject area.

The limitations of the WRc risk assessment report (Sections 4.2.2 and 4.3) are summarised below.

- The report is a draft and appears to be unpublished.
- The analytical data may contain some bias as they were provided by PSA producers.
- Insufficient information is provided relating to the analysis conducted, the methodologies, accreditation and so on to allow a robust assessment of the quality of the data.
- Comparison with other concentrations for PSA identified in the literature suggests that the study did not consider the full range of contaminant concentrations.
- The leachate data presented and assessed do not take into account any potential influence of interactions with the receiving soils.
- The assessment for human health and controlled waters is not in accordance with current UK guidance and practice.

In addition to the above, the REA and the data obtained suffer from the following limitations.

- There is consensus in the literature that the incineration process is an effective method for removing organic contaminants from paper sludge, but there is little quantitative data to support this assumption.
- With the exception of the WRc risk assessment report, no further UK-based quantitative data or assessments were found during this REA, including data from deployments.
- There appears to be a variance in concentrations (which can be high for some contaminants), not only between different producers (paper mills), but also between the different types of ash obtained from the incinerator and input materials. This information is not always provided or is clear in the literature examined, making it difficult to distinguish between different sets of data for comparison purposes.

Thus it would be prudent to update the risk assessment for relevant receptors, at least with the wider range of contaminant concentrations noted in this REA, but ideally with more producer data.

There appears to be current and ongoing work on this subject in Europe, particularly in Finland. As a result, it may be worth considering liaising with relevant parties in Europe and exchanging information, where practical, to increase the knowledge base for this waste stream.

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# List of abbreviations

EPR	Environmental Permitting Regulations 2010
EQS	Environmental Quality Standard
NPS	National Permitting Service
MSW	municipal solid waste
PAH	polycyclic aromatic hydrocarbon
PSA	paper sludge ash
REA	Rapid Evidence Assessment
SR	Standard Rules [Permit]
SSV	Soil Screening Value

# Appendix: Search strategy and evidence extracted

See Excel spreadsheet accompanying this report.

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