Leaching from recycled and secondary aggregates – a review

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Executive Summary

Summary of key issues

There is no doubt that the use of recycled and secondary aggregates is a cornerstone of sustainable construction. However, the need for "conserving resources" and "minimizing waste" must be rationalized against any negative environmental impact resulting from trace materials present in these aggregates. This report demonstrates that the perceived risk of leaching from recycled and secondary aggregates is often overstated, particularly when used in unbound engineering applications. The risk of deleterious leaching is significantly reduced by binding aggregates in bitumen bound materials, hydraulically bound materials or concrete. The literature review demonstrates that the majority of recycled and secondary aggregates pose no significant risk to controlled waters when used in properly designed and constructed engineering applications that account for the sensitivity of the local environment. Where any doubt exists over the potential contaminants that could be leached from the recycled and secondary aggregates, or bound materials containing them, risk assessment on a project by project, or a source by source, basis may allay any concerns.

The review of the issues surrounding leaching from recycled and secondary aggregates highlights the complexity of assessing deleterious leaching, as no specific guidance on the topic is provided. The tests to be used and the limiting values applied are not clear. The increased use of recycled and secondary aggregates would be facilitated by simple, clear, decision-making procedures that would benefit users of such materials.

Simple risk assessments concerning the use of recycled and secondary aggregates are possible; for example, comparing the results of appropriate leaching tests against water quality standards applicable to the place of use. This approach is reliant on the regulator accepting that leaching tests on monolithic materials (for bound recycled and secondary aggregates), and unbound aggregates in their inherent or processed grading (rather than aggregates ground to test requirements) are appropriate test regimes for these materials. Currently this would only be possible on a project by project basis.

There is a scientific-knowledge gap related to the comparative leaching performance of primary aggregates and recycled and secondary aggregates. If available, this information would assist in the development of appropriate guidance for users and a research project to fill this information gap could be used to confirm appropriateness of leaching tests which reflect the nature of the aggregates in service, that is, monolithic and aggregate leaching tests, as opposed to waste characterization tests.

Summary of key concepts included in this report

This report adopts the Source – Pathway – Receptor approach to assessing the potential for pollution of controlled waters:

**Source**: An unbound recycled or secondary aggregate or the asphalt, hydraulically bound material or concrete containing the recycled or secondary aggregate.

**Pathway**: The route by which contaminants move from the source to the receptor.

**Receptor**: The point at which pollution will impact. This could be a nearby aquifer, lake, river or other surface water body.

Two examples are given in the schematic diagram below.
If possible, leach testing should be conducted on the aggregate as it will be used in the construction project, so on the graded aggregate for unbound use or on the asphalt, hydraulically bound material or concrete. The results of leach testing will be the ‘worst case scenario’ as there is far more water present in these tests than there would be in the elements of the building or structure.

If these leaching results compare favourably with water quality standards then the recycled or secondary aggregates, or the asphalt, hydraulically bound materials or concrete containing them, should be suitable for use. If the results exceed the water quality standards then more attention may need to be paid to the reduction in contamination that occurs as the water moves along its pathway. This type of assessment should be conducted by an experienced risk assessor.

However, if the results exceed the water quality standards but the surface run-off water and sub-surface run-off water is combined through road drainage, then it is unlikely that any contaminants leached from the recycled or secondary aggregates will have a deleterious environmental impact. There are much higher quantities of contaminants in the surface run-off water and these should only be discharged in an environmentally sensitive manner.

Most recycled or secondary aggregates can be used without the need for excessive concern, particularly if they have been produced in accordance with a Factory Production Control regime specified by the new European Standards for aggregates. This report considers to following approaches are applicable:

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<thead>
<tr>
<th>Use as if primary aggregates</th>
<th>Use in accordance with industry standards</th>
<th>Consider on a project by project, or source by source, basis</th>
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<td>China clay sand</td>
<td>Blastfurnace slag</td>
<td>Burnt collier spoil</td>
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<td>Slate aggregates</td>
<td>Steel slag</td>
<td>Unburnt colliery spoil</td>
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<td>Pulverized-fuel ash</td>
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<td>Furnace bottom ash</td>
<td>Foundry sand</td>
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<td>Incinerator bottom ash</td>
<td>Recycled tyres</td>
</tr>
<tr>
<td></td>
<td>Recycled glass</td>
<td></td>
</tr>
</tbody>
</table>
# Contents

1 **Introduction** ................................................................................................................................. 1
  1.1 Background to the report ............................................................................................................ 1
  1.2 Project methodology .................................................................................................................. 2
  1.3 Transportation and handling on site .......................................................................................... 2
  1.4 Total environmental impact assessment ..................................................................................... 2
  1.5 End-of-life issues ........................................................................................................................ 3
  1.6 Describing contamination movement in the environment ........................................................ 3

2 **Context** ........................................................................................................................................ 5
  2.1 Barriers to the use of recycled and secondary aggregates ........................................................... 5
  2.2 Regulatory context ..................................................................................................................... 5
  2.3 Contaminated land risk assessment ............................................................................................ 8
  2.4 European Standards for aggregates ........................................................................................... 9
  2.5 Summary .................................................................................................................................... 10

3 **Leaching behaviour** ..................................................................................................................... 11
  3.1 Introduction ............................................................................................................................... 11
  3.2 Water movement in roads ......................................................................................................... 12
  3.3 Highway drainage ..................................................................................................................... 12
  3.4 Movement of contaminants ....................................................................................................... 14
  3.5 Unbound aggregates used at or below ground level .................................................................. 16
  3.6 Bitumen bound aggregates used at or below ground level ......................................................... 17
  3.7 Hydraulically bound aggregates and concrete used at or below ground level ......................... 18
  3.8 Hydraulically bound aggregates and concrete used above ground level ................................. 19
  3.9 Summary ................................................................................................................................... 19

4 **Assessing the risk of deleterious leaching** .................................................................................... 20
  4.1 Leach testing ............................................................................................................................. 20
  4.2 Assessment of leaching ............................................................................................................. 22

5 **Material specific information** ..................................................................................................... 27
  5.1 Recycled aggregate, Recycled concrete aggregate and Recycled asphalt ................................ 27
  5.2 Blastfurnace slag and Steel slag ............................................................................................... 28
  5.3 Pulverised-fuel ash and Furnace bottom ash .......................................................................... 28
  5.4 Incinerator bottom ash aggregate ............................................................................................ 29
  5.5 Unburnt colliery spoil, Burnt colliery spoil and Spent oil shale ................................................. 30
  5.6 Foundry sand ............................................................................................................................ 30
  5.7 Recycled tyres .......................................................................................................................... 31
  5.8 Recycled glass ........................................................................................................................... 32
  5.9 China clay sand, Slate aggregate and Primary aggregates ......................................................... 32

6 **Stakeholder interviews** ................................................................................................................. 34
  6.1 Lack of guidance ....................................................................................................................... 34
  6.2 Waste Management Licensing .................................................................................................. 34
  6.3 Landfill Directive ....................................................................................................................... 35

7 **Conclusions** ............................................................................................................................... 36

8 **References** .................................................................................................................................. 37

Appendix 1 ........................................................................................................................................... 42
Appendix 2 ........................................................................................................................................... 43
Appendix 3 ........................................................................................................................................... 44
1 Introduction

1.1 Background to the report

There is no doubt that the use of recycled and secondary aggregates is a cornerstone of sustainable construction. However, the need for “conserving resources” and “minimizing waste” [1] must be rationalized against any negative environmental impact resulting from trace materials present in these aggregates.

Reid and Chandler [2] note that “barriers [to the use of recycled and secondary aggregates] are non-technical and relate to the perception of new materials and techniques.” These barriers include:

- Reliability and quality control: Alternative materials perceived as highly variable and of low quality.
- Environmental concerns: Potential long term leaching of contaminants into controlled waters; dust and noise during construction.
- Waste regulation including Waste Management Licensing and PPC [Pollution Prevention and Control] Regime: [Concerns as users are] unclear whether materials are waste or covered by exemptions, potential long time scale required by waste permitting processes.

This view was shared by the attendees of the conference “Beneficial use of recycled materials in transportation applications” [3]; whose most prevalent response to a delegate questionnaire demonstrated concerns over the risk and environmental impact of using recycled and secondary materials.

When reading this report it is important to remember that primary aggregates are routinely used without difficulty in construction projects, that is, there is a ‘presumption of innocence’ related to their use. In contrast, recycled and secondary aggregates are subject to more environmental qualification, a ‘presumption of guilt’. This disparity does, without doubt, affect the use of recycled and secondary aggregates, despite the general view of suppliers, upheld by this report, that recycled and secondary aggregates have limited environmental impact when used appropriately. However, in order to fully examine the issues related to leaching from recycled and secondary aggregates, this report works from the ‘presumption of guilt’ standpoint, and, from this viewpoint, seeks to provide the information required by users of recycled and secondary aggregates to allay any environmental concerns. This report, however, does highlight the potential for leaching from primary aggregates, the lack of information on this subject and the detrimental impact this knowledge gap plays in the use of recycled and secondary aggregates in construction.

A recent review [4] of the environmental information provided on AggRegain concluded that:

"The present AggRegain website gives extremely limited information (2.5 lines) on the limits of chemical contamination which can be tolerated in a recycled or secondary aggregate. ...A large amount of generic, some specific, information is available of which the current documents mentioned on the website provide limited assistance. ...

In particular the following information is not readily available:

- Regulatory references and summary content of relevance (it is available for mechanical requirements drawing on the SHW [Specification for Highway Works] but not for environmental issues);
- Industry acceptance documents for specific recycled and secondary/reused materials which have been developed between material suppliers and the environmental regulator;
- General summary guidance of the issues of importance and the pointers to more substantial guidance documents;
- Leachate test procedures;
- Amelioration and specific use techniques available to reduce or remove impacts."

Given the perceived importance, to users, of the environmental risks from recycled and secondary aggregates, there is a need to provide some level of information on the AggRegain web site to allay concerns. This project was initiated by WRAP to provide four information sheets for AggRegain, related to the environmental and leaching impacts of using recycled and secondary aggregates for:

- Unbound applications used at or below ground level.
- Bitumen bound applications used at or below ground level.
- Cement and concrete bound applications used at or below ground level. (Note: this description has been changed to "Hydraulically bound materials and concrete used at or below ground level" as this includes the use of other binders such as lime, ground granulated blast furnace slag and pulverized-fuel ash.)
- Cement and concrete bound applications used above ground level. (Note: this description has been changed to "Concrete used above ground level", as hydraulically bound materials are not used above ground in buildings and structures.)

These information sheets will be specifically aimed at potential users of recycled and secondary aggregates who have reservations about the materials, based on their perceptions of the attendant risks. The sheets will not be directed
towards regulators, suppliers, scientists or others who require more specific or more detailed information. It is, however, hoped that this report will be published by WRAP and act as a further information resource for these stakeholders. The information sheets for AggRegain also intend to direct users to readily available sources of information if further detail is required.

1.2 Project methodology

This project has undertaken an extensive literature review to examine the environmental and leaching issues related to the use of recycled and secondary aggregates. In total, over 125 papers and books have been reviewed, many of which are cited in this report; due to the time constraints upon the project, the literature review has relied upon web-based literature, electronic documents available through subscription databases and hard-copy information to hand. The authors recognize that more reference material may be published that has been inaccessible during the project period.

In addition to the literature review, discussions have take place with relevant stakeholders in the use of recycled and secondary aggregates in construction. These stakeholders include regulators, suppliers and scientists, and the discussions were conducted to ensure that the information presented on the information sheets reflects the key issues related to the topic.

The authors would particularly like to thank the following stakeholders for their time in supporting this project:
- Annette Hill and David Cragg of Scott Wilson.
- Howard Robinson and Nizar Ghazireh of Tarmac.
- David York of Ballast Phoenix.
- Lindon Sear of the UK Quality Ash Association.

The primary objective of this report is to review the knowledge base related to the environmental impacts of leaching resulting from the use of recycled and secondary aggregates in construction. The report also examines the regulatory context for the concerns over leaching from these materials and discusses the assessment of leaching and its mitigation. The project also made a limited review of other environmental aspects, which are included in the following introductory sections.

1.3 Transportation and handling on site

The recent report reviewing the use of Incinerator bottom ash (IBA) as a construction aggregate [5] includes an assessment of environmental impacts associated with the production, transportation and handling of IBA aggregates, at aggregate processing facilities, at asphalt or ready-mix concrete plants or on construction sites. A review of aggregate, asphalt and ready-mix concrete production issues is beyond the scope of this project, which seeks to address the concerns of users of recycled and secondary aggregates, not to provide information for suppliers or regulators.

However, the IBA report [5] identifies that the potential impact of fugitive dust emissions should be considered as part of any environmental impact assessment, but that the impact is most likely to be of concern to local workers and can be mitigated by standard dust suppression measures, such as water sprays. Such methods are also recommended for handling Pulverized-fuel ash (pfa) [6]. Since fugitive dust is a hazard irrespective of its source, such dust suppression is relevant to all construction aggregates, primary, recycled and secondary, and is not discussed further in this report, or the information sheets. Dust suppression should be considered alongside other hazards, for example handling issues for recycled glass, when complying with the Construction, Design and Management (CDM) Regulations and Health and Safety Legislation.

1.4 Total environmental impact assessment

Roth and Eklund [7] suggest that, in order to effectively evaluate the environmental benefits and impacts of using recycled and secondary materials in construction, the full context of the construction project should be considered. This includes the material-specific impacts such as leaching of contaminants, but also could include the material impacts within the environmental impact of the road construction, such as evaluating the impact of the contaminants against the impacts of say, surface run-off water. Further to this, a narrow life-cycle level is considered, which is limited to factors related to the use of the aggregate material and thus, may well ignore the life-cycle impact of the road itself (which will be the dominant impact). The final assessment stage is the "Industrial system level", which includes assessment of the industry producing the by-products, the impact of the reuse of materials upon policies and programmes and the reduction in quality of use associated with recycling materials.

This brief summary of the Roth and Eklund paper [7] clearly demonstrates the complexity of full environmental impact assessment, life cycle analysis (LCA) and other broader mechanisms of environmental impact assessment. Hjelmar [8]
encapsulates this issue: “In its current stage of development, LCA may be useful in choosing between different construction designs and materials, but not in setting actual risk-related environmental criteria in terms of material properties that can be tested.” Environmental assessment tools for use in construction projects are well known in the UK, including BREEAM and Eco-homes (www.bre.co.uk), and CEEQUAL (www.ceequal.com). Given the lack of information relating to the use of recycled and secondary aggregates to total environmental impact assessment, this topic is not considered further in this report or in the information sheets.

1.5 End-of-life issues

In the context of this report, end-of-life refers to the demolition and recycling of buildings and structures containing recycled and secondary aggregates. Several papers by van der Sloot [9, 10, 11] suggest that consideration of end-of-life changes in leaching behaviour should be integrated into the risk assessment for the use of recycled and secondary aggregates in construction. The review of IBA [5] identifies three possible end-of-life scenarios for an IBA-containing asphalt road:

- Disposal at landfill.
- Reuse of the road as an aggregate in asphalt or concrete.
- Reuse as a fill material.

All these scenarios, disposal to landfill or reuse in construction, will be governed by rules in place at the end-of-life. These rules cannot be known at the time of first construction, as they will probably be refined over the lifetime of the building or structure. The only reasonable assessment of end-of-life issues, at the time of construction, would be to compare materials proposed for use against available end-of-life materials, for example, comparing Recycled aggregate from a conventional source (demolition and recycling of a road pavement) with Recycled aggregate from a source already containing Recycled aggregate (demolition and recycling of a road pavement constructed with concrete containing Recycled aggregate). Thus, only in exceptional circumstances is end-of-life a concern for the use of recycled and secondary aggregates in the first instance. For this reason, the end-of-life issue is not considered further in this report or in the information sheets.

1.6 Describing contamination movement in the environment

The approach to pollution risk assessment from contaminated land is clearly summarized in the Scottish Environment Protection Agency (SEPA) document “Water Pollution Arising from Land Containing Chemical Contaminants” [12]. In order to explain the approach to pollution management, key statements from this document that have relevance to the use of recycled and secondary aggregates are reproduced below, with additional explanatory text inserted. However, it must be remembered that this document is related to pollution from contaminated land and as such is not directly applicable to recycled and secondary aggregates.

“There are two key stages to any assessment to establish whether water is being, or could be, polluted...”

Stage 1: establishing likely pollutant linkages i.e. considering if there are pathways by which substances can enter water,
Stage 2: establishing if the linkage is resulting in, or could result in, water pollution.”

“A pollutant linkage comprises three components: a contaminant (source) which has a mechanism (pathway) by which it can cause an adverse impact on a target (receptor). In identifying possible pollutant linkages, it is important that all sources, pathways and receptors are considered.”

This is exemplified for an unbound recycled or secondary aggregate in the sub-base layer of a road:

**Source:** The recycled or secondary aggregate.
**Pathway:** There are numerous potential pathways dependant on the construction site, for example:
- Water movement through the sub-base into an adjacent drainage ditch that flows into a public surface water drainage system.
- Water movement through the sub-base, into the ground below, through the ground into an aquifer which is used to supply drinking water.
- Water movement through the sub-base into highway drainage where it is combined with surface run-off water from the road and then treated before discharge into a local stream at a location agreed with the regulator.
- Water movement through the sub-base to the soil pore water under the sub-base.
**Receptor:** The receptor is dependant on the construction site and for the examples above would be:
- The public surface water drainage system.
- The aquifer.
- The local river.
- The soil pore water.

Anecdotal evidence, collected during the industrial consultations for this project, suggests that the regulator prefers to establish the risk of pollution to a receptor local to the recycled and secondary aggregates, such as the public surface...
water drainage system or soil pore water under the sub-base. However, users may be able to ‘argue their case’ for a more remote, less local, receptor, by presenting evidence to the regulator of the correctness of their approach.

“For contaminants dispersed in soil, the concentration of contaminant released to the soil pore water should be considered rather than the total concentration of the contaminant in the soil. The pore water concentration can be determined by sampling and analysing pore water, conducting soil leaching tests or calculation based on soil-water partitioning equations. Any leach test, for example NRA note 301, should be appropriate to the site under consideration.”

For recycled and secondary aggregates this implies that it is the concentrations of contaminants that are leached from the aggregate or bound material that are important, not the levels at which these contaminants are present, because not all the contaminants will be available for leaching. In the case of recycled and secondary aggregates, or bound materials containing recycled or secondary aggregates, the potential levels of contamination can be assessed by leach testing, although if stockpiled or landfilled materials (such as Pulverized-fuel ash) are recovered for use, it may be possible to assess contamination by analysis of the in situ water. Leach testing is discussed further in Section 4 of this report.

“A review of models for such Tiered assessments is given in a report by Whittaker et al [13], which included the modelling package recommended by the Environment Agency (EA), ConSim. Further details of the EA approach are given in Section 2.3.

A schematic diagram of the Source-Pathway-Receptor approach is given below.
2 Context

2.1 Barriers to the use of recycled and secondary aggregates

Of the concerns over the use of recycled and secondary aggregates identified by Reid and Chandler [2], the "Potential long term leaching of contaminants into controlled waters" is of particular concern for this report. Issues related to quality control are of importance when establishing a consistent supply of material to ensure that leaching limits will not be surpassed. Such assurances may be provided by the implementation of a Factory Production Control (FPC) scheme in accordance with the new European Standards for aggregates [14, 15, 16, 17, 18, 19]. The issue of "Waste regulation" is pertinent when users are concerned over the ongoing responsibilities related to a site covered by a Waste Management Licence. The need to comply with Waste Management Licensing regulations often makes the use of recycled and secondary aggregates uneconomical. The application of "Waste regulation" is beyond the scope of this report and the information sheets, since the definition of a material as a waste will not inherently change its environmental properties, only the regulations for use.

Unfortunately, unlike a mechanical performance specification, a set of pass/fail environmental criteria cannot be fixed for the use of recycled or secondary materials in all locations. The environmental sensitivity of the local area needs to be accounted for when assessing the impacts of construction projects and, thus, the usage of any particular recycled or secondary aggregate. This creates a barrier to use, adding a level of complexity to the decision that is not otherwise present when designing/approving construction projects.

2.2 Regulatory context

As with many environmental issues, the legalisation and regulations concerning environmental protection are complex and may require specialist knowledge to implement. There are independent regulations for England and Wales, for Scotland and for Northern Ireland. This report does not presume to address all the complex issues related to contaminated land or pollution and specialist expertise should be sought when necessary.

However, this report attempts to provide a 'layman's' interpretation of the legislation and regulations, supported by the information gleaned through industrial consultations conducted as a part of this project. This approach is preferred as this report does not wish to reproduce information available elsewhere or, in the context of the AggRegain information sheets, overburden the reader with information. A good starting point for construction organizations with an interest in environmental issues is the "NETREGS" web site (www.environment-agency.gov.uk/netregs). Although aimed specifically at small to medium sized enterprises, the web site does provide a useful introduction to many environmental topics.

2.2.1 Contaminated Land

On 1st April 2000, Part IIA of the Environmental Protection Act 1990 came into force in England. The legislation defines contaminated land as "any land which appears to the Local Authority in whose area it is situated to be in such a condition, by reason of substances in, on or under the land, that –
(a) Significant harm is being caused or there is a significant possibility of such harm being caused; or
(b) Pollution of controlled waters is being, or is likely to be, caused" [20].

This clearly places the responsibility for identifying contaminated land in the hands of Local Authorities. The Environment Agency (EA) policy statement on Part IIA [21] states "Local Authorities are the lead regulator on Part IIA, but the Agency has specific roles in provision of information, consultation on Local Authority inspection strategies, acting as the enforcing authority in the case of Special Sites, providing site-specific advice to Local Authorities on matters of water pollution and other matters where it has specific expertise and compiling the State of Contaminated Land Report from time to time."

The planning authorities play a significant role in the assessment and redevelopment of contaminated land. A circular from the Department of the Environment, Transport and the Regions (DETR) [22], now the Department for the Environment, Food and Rural Affairs (DEFRA), from March 2000, states that the legislation adopts a "suitable for use approach" consisting of three elements, one of the three elements being:

"(b) ensuring that land is made suitable for any new use, as planning permission is given for that new use - in other words, assessing the potential risks from contamination, on the basis of the proposed future use and circumstances, before official permission is given for the development and, where necessary to avoid unacceptable risks to human health and the environment, remediating the land before the new use commences; this is the role of the town and country planning and building control regimes."
In practice, these responsibilities often mean that site specific environmental risk assessments are required as conditions of planning permissions for large projects and redevelopments, irrespective of the condition of the site (greenfield or brownfield). These will include the assessment of potential contamination from the use of recycled and secondary aggregates. Similar planning conditions may be attached to smaller projects.

In principle, the contaminated land regulations are not directly applicable to the use of recycled and secondary aggregates as replacements for primary aggregates. The regulations are designed to assist Local Authorities in prioritizing their actions to remediate contaminated land and in setting target levels of residual contamination following such remediation. The regulations are not intended to set permitted levels of contamination following the use of recycled and secondary aggregates.

**What does this tell us?**

Often, environmental risk assessments are required for large construction projects as a condition of planning permission. In such cases, the risks presented by recycled and secondary aggregates will be addressed using risk assessment methods (see Section 2.3). However, the regulations used to set remedial targets for contaminated land are not directly applicable to the use of recycled and secondary aggregates and are not designed to establish limits for new contamination. In practice, for the use of recycled and secondary aggregates, it is the potential pollution of controlled waters that is of most concern to users [2].

### 2.2.2 Pollution of controlled waters in England and Wales

There are differences in the policies concerning the pollution of controlled waters in England and Wales and in Scotland [23]. In England and Wales, the document "Environment Agency technical advice to third parties on Pollution of Controlled Waters for Part IIA of the Environmental Protection Act 1990" [23] includes the definition of controlled water, taken from the Water Resources Act 1991, as:

"terrestrial waters...which extend seawards for three miles..., coastal waters..., inland freshwaters, that is to say, the waters in any relevant lake or pond or of so much of any relevant river or watercourse as is above the freshwater limit, and ground waters, that is to say, any waters contained in underground strata."

The controlled waters of routine interest to users of recycled and secondary aggregates will be surface waters (i.e. lakes and ponds) and ground waters, unless construction is taking place on or near the coast.

The EA document [23] states "With specific regard to ground waters, it is important to note the distinction between the definition of ground waters under the Water Resources Act 1991, which includes all waters contained in underground strata, and the definition of groundwater under the Groundwater Directive (80/68/EEC) which is restricted to water in the saturation zone, i.e. below the water table). Ground waters therefore includes groundwater (as defined in Directive 80/68/EEC) as well as any soil water and pore water present in the unsaturated zone."

Therefore, the regulations relating to controlled waters are applicable to a wider number of water bodies than those for groundwater, see Section 2.2.4. However, the document [23] also states that: "For the purposes of Part IIA the Agency currently considers ground waters to be only those waters in the saturated zone. As such, the Agency recommends that groundwater (at the water table) is considered as the receptor rather than soil / pore water and water in the unsaturated zone." Nevertheless, anecdotal evidence suggests that the regulator may consider receptors more local to the final building or structure when considering the risks of pollution arising from recycled or secondary aggregates.

The EA policy [24] states that, for surface waters, “the Agency will seek to protect existing water quality” and its advice to third parties [23] indicates that “Ordnance Survey maps showing surface water bodies” can be “helpful to identify the proximity and significance of water features”. This indicates that the proximity and current status of surface water bodies will be important when assessing the risks of pollution from recycled and secondary aggregates. Assessing the risk to groundwater is discussed in Section 2.2.4.

The EA document [23] states that “Part IIA defines the pollution of controlled waters as: The entry into controlled waters of any poisonous, noxious or polluting matter or any solid waste matter”.

Other important points within the document [23] are:

- “Poisonous, noxious and polluting substances are considered to be substances that have the potential to cause detriment to human health or the environment. This implies that they must be present in concentrations or quantities that could give rise to such detrimental effects.”
- “Ground waters in made-ground, fill, the unsaturated zone, or in hydraulically isolated perched bodies are likely to be considered receptors of low resource value.”
- “It should be noted that Annex 2 of DETR Circular 02/2000 [22] makes reference to “very slight levels of water pollution” and states that the Government are minded to amend primary legislation to exclude very low levels of pollution from the Part IIA regime. It is understood that this may be achieved by amending the definition of contaminated land to refer to ‘significant pollution of controlled waters’, which is in line with the existing requirement for ‘significant harm’. Whilst this is not explicitly stated in Wales, it is the Agency’s intention to adopt..."
the same approach as in Wales. Therefore, in the meantime, sites where controlled waters are not sensitive, or where levels of pollution are known to be very low (i.e. of no environmental significance), should be given a low prioritisation within the inspection strategy. In the first instance the significance of water pollution may be established by comparing water chemical analyses with the water quality standards. Where higher levels of pollutants are [already] present, discussion with the local Environment Agency office is recommended.

- "With regard to the potential for pollution of controlled waters, the assessor will be principally concerned with contaminants that are in a mobile form. Total contaminant concentrations in soils may indicate elevated concentrations, however pollution of controlled waters is only likely if those contaminants are in a form that are mobile. The Agency normally recommends an appropriate leach test to assess the soluble (leachable) fraction of soil contamination".

What does this tell us?

These regulations stem from the need to protect controlled waters from pre-existing contaminated land and as such, are not directly related to the potential for 'new' contamination. Pollution of controlled waters occurs when contaminant levels are sufficient to impact on health and the environment, not when non-deleterious contaminant concentrations enter controlled waters. Leachable fractions of contaminants are more important when assessing the risk to controlled waters than the total contaminant concentrations in the ground. Leachate concentrations may be compared to water quality standards to establish the significance of any pollution. The proximity of surface water bodies is important when assessing the risk of pollution.

2.2.3 Pollution of controlled waters in Scotland

The Scottish Environment Protection Agency (SEPA) document "Water Pollution Arising from Land Containing Chemical Contaminants" [12] defines controlled waters as:

- "relevant territorial waters, i.e. waters extending seaward for three nautical miles from the baselines from which the breadth of the territorial sea adjacent to Scotland is measured."
- "coastal waters, including waters extending from the baselines above as far as the limit of the highest tide or as far as the freshwater limit of any relevant river or watercourse."
- "inland waters, i.e. the waters of any relevant loch or pond and relevant rivers and other watercourses above the freshwater limit."
- "ground waters, i.e. waters contained in underground strata, including water in wells, boreholes and excavations into underground strata."

Although these definitions are slightly different to those for England and Wales, and there may be differences in the specifics of legislation and regulation, in the context of recycled and secondary aggregates, the approaches adopted towards risk assessment for contaminated land are similar and, thus, the system in place in England and Wales forms the basis of this discussion.

2.2.4 Protection of groundwater

The Groundwater Protection Regulations came into force in 1998, to complete the implementation of the European Groundwater Directive. Importantly, this legislation controls the discharge of List I and List II substances (given in Appendix 1).

The EA's "Policy and Practice for the Protection of Groundwater" [25] states "Groundwater forms the part of the natural water cycle which is present within underground strata (aquifers)". The importance of groundwater is also demonstrated in this policy document: "The volume of water stored in the pores and fractures of the strata vastly exceeds the volumes of fresh surface water. Groundwaters have a substantial strategic significance in public water supply; they provide 35 per cent of present demand and in some areas are the only available future resource."

The policy document also notes "The principal general use for groundwater is water supply. However, the quality of groundwater is generally much better than the requirements for potable waters under the EC Directive on the Quality of Water Intended for Human Consumption (80/778/EEC), as implemented and extended by the Water Supply (Water Quality) Regulations 1989."

The EA have produced maps to demonstrate the vulnerability of groundwater; the vulnerability is dependant on the presence and nature of overlying soil, the presence and nature of Drift deposits, the nature of strata and the depth of unsaturated zone. In addition, the Agency specify "Source Protection Zones" dependant on the proximity to groundwater abstraction points. These Zones are:

- Zone I (Inner Source Protection)
- Zone II (Outer Source Protection)
- Zone III (Source Catchment).

The protection zones are shown on the EA web site (http://216.31.193.171/asp/1_map.asp).
The EA's policy document [25] is clear concerning "Discharges into underground strata", which will "normally reach the underground strata via a soakaway system". One of the areas of concern is identified as "surface water discharges which include contaminated run-off from roofs and impermeable areas such as major roads, amenity areas, car/lorry parks, storage areas, etc." The document also states that "The impact of urban surface water run-off on river quality has led to the encouragement of Best management practices for surface water disposal which primarily involve discharge to ground."

The policies of the EA include:

- **The Environment Agency will control discharges into underground strata within areas where groundwater is judged to be at risk**.....Surface water run-off (with the exception of clean roof drainage) will be controlled whenever possible in areas where groundwater is at risk. It will generally be subject to standard conditions, such as installation of petrol/oil interception where applicable. Where control is necessary, the Agency will require a hydrogeological assessment to be carried out to identify the potential impact of the discharge on water resources.
- **The Environment Agency will refuse to consent the discharge of List I substances into underground strata and will limit the entry of List II substances in accordance with the EC Groundwater Directive (80/68/EEC)..... acceptable disposal arrangements should be found. Exceptions may be made where the quality and concentration of the substances will not pollute groundwater.”

The document also contains a summary of the policy statements for the different Source Protection or Resource Zones, reproduced in Appendix 2, for discharges relevant to recycled and secondary aggregates.

**What does this tell us?**

It is likely that any recycled or secondary aggregate that leaches higher than specified List I substances will not be approved for use. Assessing the vulnerability and level of protection at the place of construction can be used to inform choices concerning recycled and secondary aggregates. It may still be possible to use these materials in protected areas if sufficient precautions are taken.

### 2.2.5 Water Framework Directive

The European Water Framework Directive (WFD) was adopted as UK legislation in December 2003. "The principal objective of the Directive is for water bodies to reach good status by 2015" [26] and full implementation to achieve this objective will take place between now and 2015 [27].

Issues related to the implementation of the WFD are discussed in the EA’s R&D Technical Report P2-143/TR "R&D Strategy to Support Implementation of the Water Framework Directive - Preliminary scoping report" [28]. The Technical Report summarizes the aim of the WFD to: "establish a framework for the protection and management of surface waters, including estuaries, coastal waters and groundwaters in the EU. The main objectives of the proposed Directive are to:

- prevent further deterioration and to protect and enhance the aquatic environment;
- achieve 'good' water quality for all surface waters and groundwaters unless it is impossible or prohibitively expensive;
- promote sustainable water management based on long-term protection of water resources."

During the implementation, much of existing legislation related to water quality will be subsumed into the WFD. A timetable for the Directives to be repealed is given on the EA web site [29]:

- **December 2007**
  - Surface Water Abstraction Directive
  - Exchange of Information on Surface Water Decision
  - Surface Water Abstraction Measurement/Analysis Directive

- **December 2013**
  - Freshwater Fish Directive
  - Shellfish Waters Directive
  - Groundwater Directive
  - Dangerous Substances Directive

Thus, it is the existing Directives that will impact on the control of pollution over the short to medium term (1 to 10 years); the WFD is not considered further in this report.

### 2.3 Contaminated land risk assessment

The generic approach to contaminated land risk assessment is described in Section 1.6. The following section provides more detail to the approach recommended by the EA.

The EA, with the support of SEPA, produced the document "Methodology for the Derivation of Remedial Targets for Soil and Groundwater to Protect Water Resources" [30] which aims to provide a framework for risk assessment of contaminated land. Associated with this risk assessment is an Excel spreadsheet which is available through the Environment Agency's web site at www.environment-agency.gov.uk/science/454158/110943.
The document provides “a methodology to derive the level of remediation required to protect groundwater and surface water and forms part of the overall process to evaluate the health and environmental risk that contaminated soil and groundwater represent. The methodology is based on a risk assessment approach incorporating a source-pathway-receptor analysis, that leads to the derivation of site-specific remediation criteria based on an assessment of the potential impact at the identified receptor.”

The document [30] identifies that users should:
1) “Determine a target concentration at the receptor or compliance point in relation to its [the receptor’s] use.
2) Undertake the tier assessment to determine whether the contaminant source would result in the target concentration being exceeded at the receptor or compliance point. At each tier, a remedial target is determined.
3) If the contaminant concentrations on-site exceed the remedial target, then the decision whether it is appropriate to upgrade the tier analysis is based on:
   - timescale - the decision to proceed to the next tier analysis should only be made if any risk involved in delaying the decision to implement the remedial action is acceptable;
   - what additional information is required and can be obtained;
   - cost-benefit analysis, i.e. the cost of tier upgrade in relation to the potential reduction in the cost of the remedial solution.”

The Excel spreadsheet associated with the methodology would allow calculation of maximum contaminant levels generated from recycled and secondary aggregates acceptable at the receptor. However, the user manual associated with the spreadsheet [31] states that the “worksheet should only be used by suitably experienced risk assessors who have previously read the Methodology for the derivation of remedial targets for soil and groundwater to protect water resources, and who are conversant with the relevant UK legislation, policy and guidance.”

This approach should be differentiated from the CLEA approach, ”The Contaminated Land Exposure Assessment Model” [32], which is designed to assess the human health risks from exposure to contaminants in soil. Since the recycled and secondary aggregates used in construction are most commonly covered over or bound by cement or asphalt, the risks to human health are minimal and this exposure route is not considered further in this report (See Section 1.3 for transportation and handling issues).

What does this tell us?
Although the risk assessment approach is specifically related to the remediation of contaminated land, not setting levels of ‘acceptable contamination’ by recycled and secondary aggregates, it does demonstrate an accepted approach to pollution risk assessment. The first Tier assessment could be used to assess the risks posed by contaminants leaching from recycled and secondary aggregates.

If further analysis is required, specialist expertise would need to be used to complete the more detailed Tiers. For recycled and secondary aggregates, the more complex Tiers will seldom be appropriate. If the risks of causing pollution are still of concern when a first Tier assessment is completed, the costs of further risk assessment are likely to make the use of the recycled and secondary aggregates uneconomical. However, such assessment may still be cost-effective where a site-specific environmental risk assessment is required as a planning condition (see Section 2.2.1) and the use of recycled or secondary aggregates is integrated into this risk assessment. Environmental risk assessment on small projects, purely to enable the use of recycled and secondary aggregates, is unlikely to be cost-effective.

2.4 European Standards for aggregates

The introduction of European Standards for aggregates [14 - 19] broadens the scope of materials that are acceptable to include recycled and secondary aggregates. The Standards introduce the concept of CE or conformity marking, to demonstrate that the aggregates have been produced in accordance with a Factory Production Control (FPC) system. For the majority of aggregate uses in the UK, CE marking will not require third party attestation of conformity. This FPC/CE marking approach provides a mechanism to address user concerns over aggregate quality and consistency [2].

Although the Standards, as yet, do not include any specific clauses for environmental requirements, there are requirements for suppliers to have knowledge of their raw materials. For example, the following selected sections are reproduced from the new Standard “Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction” [16].

“C.3.4 Knowledge of the raw material
It is the producer’s responsibility to ensure that if any dangerous substances are identified their content does not exceed the limits in force according to the provisions valid in the place of use of the aggregate.”

“NOTE: Most of the dangerous substances defined in Council Directive 76/769/EEC are not usually present in most sources of aggregates of mineral origin. However [the] Note in [Section] ZA.1 of annex ZA is drawn to the attention of the aggregates producer.” This Note is reproduced below.
“C.4 Management of production
The factory production control system shall fulfil the following requirements:”
"b) there shall be procedures to identify and control any hazardous materials identified in C.3.4 to ensure that they do not exceed the limits in force according to the provisions valid in the place of use of the aggregate.”

“ZA.1 Scope and relevant characteristics”
"NOTE: In addition to any specific clauses relating to dangerous substances contained in this standard there may be other requirements applicable to the products falling within its scope (e.g. transposed European legislation and national laws, regulations and administrative provisions). In order to meet the provisions of the EU Construction Products Directive these requirements need also to be complied with when and where they apply.”

What does this tell us?
This clearly indicates that producers of recycled and secondary aggregates (and primary aggregates) need to be aware of any potentially deleterious substances in the materials they produce, even though the criteria to assess the environmental impact of such substances in their place of use are not yet standardized.

2.5 Summary
The regulations and guidance associated with risks of pollution from contaminated land are not directly applicable to the use of recycled and secondary aggregates. Remedial targets for contaminated land set target concentrations for residual contamination, not tolerances for new contamination. However, approaches to environmental risk assessment for contaminated land could be used to establish the levels of risk posed by recycled and secondary aggregates. A simple first Tier assessment could assess the risks posed by the recycled or secondary aggregates. Assessment at more detailed Tiers could be included in a project environmental risk assessment required by conditions attached to planning permission. Such complex assessment, purely to enable the use of recycled and secondary aggregates, is not likely to be cost-effective for small projects.

The risks of deleterious environmental impact would be considered minimal if the quantities of contaminants leached from recycled and secondary aggregates, or materials containing them, are insufficient to cause harm to human health or the environment. The vulnerability of local groundwater, the level, or presence of, Source Protection Zones and the proximity to surface water bodies, can be used to indicate the environmental sensitivity of a construction site. Use of recycled and secondary aggregates in sensitive areas is still possible if appropriate precautions are taken. Suppliers of aggregates, conformity marked according to the new European Standards for aggregates, should be aware of the content of potentially deleterious substances in the materials they produce, whether they are recycled, secondary or primary aggregates.
3 Leaching behaviour

3.1 Introduction

Four information sheets are required for AggRegain:
- Unbound materials used at or below ground level (e.g. sub-base, capping, railway ballast, fill).
- Hydraulically bound materials and concrete used at or below ground level (e.g. foundations, concrete paving, stabilized fill).
- Bitumen bound materials used at or below ground level (e.g. asphalts, tanking).
- Concrete used above ground level (e.g. bridges, buildings, concrete blockwork).

In some cases, the water movement issues related to each application will be similar, in other cases there will be differences, which this section seeks to explain. The information differentiates between surface run-off water and subsurface water movement, and probable mechanisms of contaminant transport are reviewed. Finally, this section describes the implications of binding recycled and secondary aggregates in asphalt or cement.

3.2 Water movement in roads

The CIRIA Report “Use of industrial by-products in road construction - water quality effects” [33] provides a review of water movement in roads. A more recent and more technical review, “A Review of Water Movement in the Highway Environment: Implications for Recycled Materials Use”, has been conducted by the Recycled Materials Resource Center, University of New Hampshire [34] and is available on the world wide web. The review includes an excellent schematic diagram, and supporting table, concerning water movement, which are reproduced here (Note: not all of the ‘Routes’ for water movement, given in the University of New Hampshire review [34] and reproduced in the table below, are relevant to UK circumstances, such as “Frost lenses melting during spring thaw”).

The review [34] suggests that “infiltration through cracks and joints is thought to be the major ingress route and engineered drainage is believed to be the major egress route.”. This continues to support the conclusion of Baldwin et al [33] that “the greatest leachate pollution occurs when an unprotected surface is exposed during construction or when fully constructed permanent surfaces are allowed to become badly deteriorated or excessively cracked.”

Table 2.1 Routes of ingress and egress (Reproduced from “A Review of Water Movement in the Highway Environment: Implications for Recycled Materials Use”[34]).

<table>
<thead>
<tr>
<th>Direction</th>
<th>From</th>
<th>Route</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingress</td>
<td>Pavement</td>
<td>Construction joints</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surface</td>
<td>Cracks resulting from shrinkage during/after construction</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cracks resulting from distress due to loading</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Diffusion through intact materials</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Subgrade</td>
<td>Artesian flow</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pumping action under traffic loading</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Capillary action of lower pavement layer(s)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Water vapour rising through subgrade soils</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Road Margins</td>
<td>Reverse gradient of permeable layers above formation level</td>
<td>Not all of the Routes for water movement are relevant to UK circumstances.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lateral or median drain surcharging</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Capillary action of pavement layers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other Sources</td>
<td>Pavement or ground run-off via unsealed shoulder</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct rainfall on pavement during construction</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frost lenses melting during spring thaw</td>
<td></td>
</tr>
<tr>
<td>Egress</td>
<td>Pavement</td>
<td>Pumping through cracks/joints existing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surface</td>
<td>Capillary rise and evaporation through cracks</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Diffusion/evaporation through intact material</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Subgrade</td>
<td>Infiltration to permeable, low water-table subgrade</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Capillary action of subgrade</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Road Margins</td>
<td>Gravitational flow in aggregate to lateral or median drain</td>
<td>Vertical flow in aggregate to open-graded drainage layer below</td>
</tr>
</tbody>
</table>
Figure 2.1 Routes of water ingress and egress (Reproduced from "A Review of Water Movement in the Highway Environment: Implications for Recycled Materials Use"[34]).

What does this tell us?
There is limited water movement through well constructed pavement layers, although increased infiltration can be expected through poorly sealed joints, cracked pavement layers and exposed foundation layers. This indicates that protection of unbound layers during construction and control of excess water during construction (for example, bleed water from concrete) will minimize the potential for deleterious leaching. Rapid construction will minimize the exposure of pavement layers to water. Attention to joint construction, as well as routine maintenance, will all minimize the infiltration of water and reduce risks of leaching. Measures to minimize water ingress during construction, or in-service, are routinely applied as excessive water reduces the durability of the building or structure.

3.3 Highway drainage

In urban areas, the drainage mechanism for run-off water from buildings is often directly connected to the highway drainage systems. This conclusion is made clearly in the CIRIA report "Source control using constructed pervious surfaces-Hydraulic, structural and water quality performance issues" [35], which connects urban hydrology with surface run-off water. Additionally, highways and infrastructure are the largest consumer of aggregate materials in the UK [36]. For these reasons, the highway drainage issues form the basis of this discussion.

Santhalingham [37] states that highway drainage can be "broadly categorized into two elements – surface run-off and sub-surface run-off: these two elements are not completely disparate in that some of the surface water may find its way into the road foundation through surfaces which are not completely impermeable thence requiring removal by sub-drainage. Based on these fundamental principles, drainage methods in the UK are broadly divided into two categories: (a) combined systems, where the surface and sub-surface water are collected and transported in the same pipe, and (b) separate systems, where the two elements are collected and transported separately."

Sub-surface drainage on motorways and trunk roads is provided by fin and narrow filter drains. These drains remove water from the lower pavement layers and prevent water entering these layers. Anecdotal evidence from the stakeholder interviews has indicated that there is little water movement into these low capacity drains. Drainage on other roads may be provided by fin and narrow filter drains, by drainage ditches, by soakaways or by other means.

Surface run-off water, in more recently constructed roads, is collected into drains which usually flow to treatment areas, such as gully pots, to sediment particulates and possibly oil separators [38]. Luker and Montague [39] state that over 50% of the total pollution in highway run-off is associated with sediments and that collected sediments may continue to leach into the soil water. The Highways Agency requires the routine emptying of such traps. The water leaving the traps, which is then discharged may contain other major routine pollutants:

- Hydrocarbons – 70 to 75% of hydrocarbon oils are adsorbed to sediment particulates, polyaromatic hydrocarbons having a greater adsorption affinity [39].
- Metals – Cadmium, copper, iron, lead and zinc are all found in motorway discharges [40]. Lead and cadmium are present in small, and reducing levels, whereas the more common metals, copper, zinc and iron are present in greater quantities [39].

It is informative to compare the data for pollutant concentrations in surface run-off water, presented by Luker and Montague [39], with the contaminant concentrations leached from Incinerator bottom ash (IBA) produced in the UK[5]
and tested using the ‘NRA test’ [41]. The concentrations of pollutants present in Motorway surface run-off water are only exceeded in 3 out of the 49 test results for IBA (where the levels of copper leached are greater than those present in the run-off) but in all instances the contaminant concentrations leached from the IBA are less than that present in Urban surface run-off water. This provides evidence, in accordance with the common assumption, that the levels of contaminants leached from recycled and secondary aggregates are almost always less than those present in surface run-off water.

The summary of the EA’s approach to discharge to underground strata [25], presented in Appendix 2, indicates that the Highways Agency and other responsible authorities, would probably require consent from the EA for the discharge of surface run-off water in Source Protection Zones, but not in Resource Zones if adequate precautions are taken.

The engineering and environmental requirements of constructed pervious surfaces are fully discussed in the CIRIA Report “Source control using constructed pervious surfaces-Hydraulic, structural and water quality performance issues” [35]. Constructed pervious surfaces reduce, or remove, the need for conventional surface run-off water drainage systems and may play a role in sustainable urban drainage schemes [35]. “Pervious surfaces...provide the uppermost layer of pavement systems that are pervious throughout their entire construction depth. They allow water to infiltrate through the surfacing into the underlying sub-base and capping layers and, if required, into the foundation soils” [35]. The CIRIA Report [35] considers the environmental sensitivity of the receptor when completing a risk assessment to determine if any potential contaminants in the water infiltrating through the constructed pervious surfaces are likely to cause pollution. Under these circumstances, the potential for contamination from recycled and secondary aggregates could be integrated into the risk assessment. Due to the open nature of the pavement layers in such a scheme, they are only suitable for lightly trafficked and low axle weight roads. As yet, constructed pervious surfaces are not specified by the Highways Agency and are not considered further in this report. The use of porous asphalt as a road surfacing is considered in Section 3.6.

What does this tell us?
The contaminants in surface run-off water, generated by traffic over the road, will exceed those produced by sub-surface drainage through recycled and secondary aggregates. The nature of the local drainage system will impact on the level of environmental risk presented by the use of recycled and secondary aggregates. Where surface and sub-surface run-off water are combined and discharged together, the mechanisms to mitigate the impact of contaminants in surface run-off water may substantially reduce the environmental risks presented by the recycled and secondary aggregates. Surface run-off water discharged in sensitive areas is only acceptable if adequate pre-treatment is part of the drainage scheme. If the surface and sub-surface run-off water are kept separate and fin and narrow filter drains, soakaways, or other sub-surface drainage mechanisms are provided, consideration should be given to the discharge of potential contaminants. Run-off from above ground structures is routinely collected and discharged with surface run-off water from highways, indicating that run-off water from above ground concrete containing recycled and secondary aggregates poses minimal environmental risks.

A schematic diagram of the Source-Pathway-Receptor approach to water movement in roads is given below.
3.4 Movement of contaminants

An introduction to the factors that affect leaching is given in the report by Abbott et al [5]. The report confirms that "The physical access of the leachant [the leaching liquid] to the ash [aggregate] as well as the chemical solubility of the substance concerned determines the leaching characteristics". A simplified introduction is provided here. In this instance the phrase 'contaminants' is used, but it should be remembered that any chemical compound, whether it is deleterious or not, can dissolve from the aggregate into the surrounding water (leachant).

Aggregate surface area and porosity
Fine aggregates with high porosity will have a higher surface area accessible to the surrounding water than coarse, non-porous aggregates. The higher the surface area exposed to the water the greater the opportunity for contaminants to dissolve or diffuse out of the aggregate into the water.

Concentrations of materials at the aggregate surface
Only materials at the interface of the aggregate and the water can dissolve. Once a contaminant has been removed from the surface, its place will be taken by another contaminant within the aggregate particle. This occurs by diffusion, which in this case, is moving molecules in the aggregate particle until they are uniformly spread throughout. Clearly, this 'molecular reorganization' will continue if molecules continue to dissolve into the water at the surface of the aggregate. In most instances, the diffusion of molecules within solids is significantly slower than diffusion of molecules through water.

Water movement
In a static water environment, contaminants will dissolve from the aggregate surface into the water until an equilibrium is achieved with the aggregate or until the solubility limit of the contaminant molecules in the water is reached. The solubility limit defines the number of molecules that can be dissolved in the water at any one time. Once the solubility limit is reached a molecule must precipitate out of the solution for another one to dissolve. This is analogous to a full car park, cars queue to get in while a 'one in/one out' system operates. The solubility limit can be affected by a number of chemical factors, such as pH, discussed later.

When water is flowing over aggregate particle surfaces, the dissolved contaminants are removed from the local environment and water without dissolved contaminants reaches the aggregate surface. If there are still contaminants at the surface of the aggregate particles, these will dissolve into the flowing water. If the water is flowing slowly, then the contaminants may achieve equilibrium with the surrounding water or their dissolution might be stopped by the solubility limit. If the water is flowing quickly, only a few contaminants may be able to dissolve into the water as it passes, meaning that the contaminant concentration in the water is very low, but all of the surface contaminants will be able to dissolve since neither equilibrium, or the solubility limit, will ever be reached. Once all the easily accessible contaminants have dissolved, only the diffusion process within the solid aggregate particle will bring more contaminants to the aggregate surface.

Diffusion through the static water is much quicker than through the solid aggregate particle, and so, once all the contaminants at the aggregate surface have dissolved and diffused, further leaching will be much slower.

In both cases, where water is flowing and dissolved contaminants are quickly removed or where contaminants diffuse through static water, it will be the same number of contaminants molecules, those that are readily available at, or close to, the aggregate surface that readily leach away.

Sorption
Once a contaminant has dissolved into water, it may come out of solution by getting stuck to another particle, perhaps another aggregate particle, or a particle of a different aggregate, or a soil particle. This sticking is called sorption. All surfaces have a number of ‘sorption sites’ on their surfaces where contaminants can stick. Whether sorption occurs is dependant on how many sites there are, how many are already filled, and how ‘sticky’ they are.
pH
pH is a measure of how acidic or alkaline a solution is. Pure water is pH 7, which means that it is neutral, neither acidic nor alkaline. In reality, most water is slightly acidic because it contains dissolved carbon dioxide from the atmosphere; natural chemicals in the ground, or other contaminants, can increase this acidity significantly. Equally, some environments, like concrete, are very alkaline. The solubility of contaminants, and the solubility limit, will vary depending on the pH of the water they are dissolving into. This means that fewer, or more, contaminants may be leached, or that the available contaminants will take a longer, or a shorter, period to be leached. It may also mean that more contaminants could be released if the pH of the water surrounding the aggregate particle changes. Many metallic elements have a minimum solubility at a pH of approximately 10, i.e. moderately alkaline conditions.

Complex molecules
Some molecules (complex molecules), which can be present in the aggregate or in the water, can bind up the contaminants such that the contaminant molecule is not added towards the solubility limit (this is called complexing). In this way more contaminants can dissolve from the aggregate particle into the water than would have been possible without these complex molecules being present. However, the contaminant can be released from the complex molecule later, effectively causing more molecules to be leached than would be the case with pure water.

Redox potential
Some metals can exist in two or three different states called oxidation states. The most well known example is iron which is often seen as iron II oxide, which is green, or iron III oxide, which is brown (rust colour). The redox potential describes the requirements of the surrounding conditions to change from one state to another. In ‘oxidizing conditions’, iron II oxide will convert to iron III oxide, which is much less soluble. In ‘reducing conditions’, iron III oxide will convert to iron II oxide, which is more soluble. So, the state of the contaminant in the aggregate, and their surrounding conditions will determine how likely they are to leach.

What does this tell us?
The contaminants at the aggregate surface are important when assessing the risks of deleterious leaching from recycled and secondary aggregates. This supports the contaminated land assessment approach, that it is the leachable contaminants in the aggregate, not their total concentration, which are important when determining the risks of pollution.

Reducing the surface area reduces the risks of leaching; for example by using coarse aggregates or binding in bitumen or cement. If water flow is minimal then contaminant movement will rely on diffusion processes and, thus, be slower than when there is rapid water flow, although total contaminant leaching will, ultimately, be the same. Contaminants may be sorbed from the water onto other particles as they move along the ‘pathway’, this is one of the attenuation processes mentioned in Section 1.6. The anticipated pH of the water around the aggregate influences the degree of contaminant leaching.

These concepts are demonstrated in the schematic diagram below.
3.5 Unbound aggregates used at or below ground level

Often the Specification for Highway Works (SHW) [42] is used as the basis for ground engineering works, irrespective of the nature of the above ground construction (roads, housing, low-rise buildings). Within the SHW, many different types of recycled and secondary aggregates are permitted for use in unbound applications. Examples of the materials that can be used are given in the table below [42, 43]:

<table>
<thead>
<tr>
<th>General granular fill Class 1A</th>
<th>Capping Class 6F2</th>
<th>Unbound sub-base Type 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recycled aggregate</td>
<td>Recycled aggregate</td>
<td>Recycled aggregate</td>
</tr>
<tr>
<td>Recycled concrete aggregate</td>
<td>Recycled concrete aggregate</td>
<td>Recycled concrete aggregate</td>
</tr>
<tr>
<td>Recycled asphalt</td>
<td>Recycled asphalt</td>
<td>Recycled asphalt</td>
</tr>
<tr>
<td>Blastfurnace slag</td>
<td>Blastfurnace slag</td>
<td>Blastfurnace slag</td>
</tr>
<tr>
<td>Steel slag</td>
<td>Steel slag</td>
<td>Steel slag</td>
</tr>
<tr>
<td>Pulverized-fuel ash</td>
<td>Pulverized-fuel ash</td>
<td>Burnt colliery spoil</td>
</tr>
<tr>
<td>Furnace bottom ash</td>
<td>Furnace bottom ash</td>
<td>China clay sand</td>
</tr>
<tr>
<td>Burnt colliery spoil</td>
<td>Burnt colliery spoil</td>
<td>Slate aggregate</td>
</tr>
<tr>
<td>Unburnt colliery spoil</td>
<td>Unburnt colliery spoil</td>
<td></td>
</tr>
<tr>
<td>Spent oil shale</td>
<td>Spent oil shale</td>
<td></td>
</tr>
<tr>
<td>China clay sand</td>
<td>China clay sand</td>
<td></td>
</tr>
<tr>
<td>Slate aggregate</td>
<td>Slate aggregate</td>
<td></td>
</tr>
</tbody>
</table>

The schematic diagrams in Section 3 demonstrate that unbound materials below pavement layers will be protected from water flow by the impervious upper layers. Adequate compaction is required to ensure the appropriate load bearing capacity is achieved and that settlement doesn't occur after the road has been built. This compaction also minimizes water movement though the unbound layers. Such layers are designed to be largely unaffected by movement in the water table as such movement would affect their performance. Construction of roads very close to, or below, the water table would require specialist consultancy input and is not considered further in this report.
Leaching from recycled and secondary aggregates – a review

Sub-base and capping layers, although well-compacted, may consist of large aggregate particles, meaning that bigger pores occur in between the particles than for fine aggregates. When fine materials are compacted, the small holes between the aggregate particles can create ‘capillary suction’, where water is sucked up from the ground into the spaces between the particles. This is unlikely to occur with the coarse sub-base, fill and capping aggregates, and if fine materials are being used, such as Pulverized-fuel ash (pfa), then ‘capillary breaks’ (a layer of coarse aggregate) is normally placed below the material.

Fill materials are also used to build embankments rising from ground level. In these instances it is important that good compaction is achieved to prevent later settlement and to ensure they provide the required engineering performance [44]. Capillary suction may be a concern for embankments constructed with fine materials. (This is considered in more detail in the material specific section.) Modern highway embankments are constructed with positive drainage measures to prevent moisture infiltration (a known cause of embankment failure) [44].

Blending of recycled or secondary aggregates with primary aggregates will usually proportionally reduce the contaminants available. For example, if a 50%/50% mixture of secondary aggregates and primary aggregates is used, it is reasonable to assume that only half of the contaminants, available from 100% of the secondary aggregate, would be available for leaching. This quantitative assumption could be applied to the construction design as a method to mitigate the leaching from recycled and secondary aggregates and, thus, achieve any limiting values for leachable-contaminant concentrations.

This quantitative assumption does not account for any naturally-occurring ‘contaminants’ leached from the primary aggregates, as primary aggregates are a ‘natural’ material and, de facto, generally accepted for use without consideration of leaching. If the example primary and secondary aggregate blend were leach tested, it is possible that such naturally-occurring contaminants would be leached and would lessen the anticipated decrease in contaminant loading following blending. Equally, it should be noted that the presence of primary aggregates may alter the pH of the water around the secondary aggregates and enhance, or reduce, the leaching of contaminants. However, the presence of the primary aggregates may reduce leaching more than anticipated, when the blend is tested, by providing an increased number of sorption sites for any contaminants leached from the secondary aggregate.

What does this tell us?
Leaching from recycled and secondary aggregates is reduced in well-compacted layers that allow limited water flow through them; this is reduced further if the unbound aggregates are covered with impervious layers, such as asphalt. Blending of recycled or secondary aggregates with primary aggregates can usually be expected to proportionately reduce the quantities contaminants available from the recycled and secondary aggregates.

3.6 Bitumen bound aggregates used at or below ground level

Production of hot or cold asphalt involves coating aggregate particles with bitumen. The asphalt is bound together by both the bitumen and interlock between the aggregate particles. The bitumen coating reduces the surface area of the aggregate exposed to water and, thus, that which is able to leach. It is particularly important that aggregate particles in foamed asphalt are well-coated in bitumen, as it is the bitumen that provides the engineering properties of foamed asphalt. Thus the bitumen coating will, to degree, off-set any increased propensity to leach from these foamed asphalts which may have a more open pore structure.

Once compacted in the surface and binder courses or bases of roads, water movement through the asphalt layers is minimal and asphalt layers are considered to be impermeable. Water causes degradation of asphalt layers and thus minimizing its presence in the road is desirable from an engineering perspective. Again, aggregate blending has the potential to reduce the quantities of contaminants available.

Contaminants leached from surface courses of roads containing recycled or secondary aggregates will be contained in the surface-run-off water from the road, see Section 3.3. Porous asphalt layers are specified as surface courses by the Highways Agency [42], although this is no longer a preferred option for road surfacing. These surfaces are designed to reduce tyre noise and to remove water from the road surface more rapidly, thus improving driver safety. The water flows through the porous asphalt and then flows, at the interface with impermeable binder course, or an impermeable barrier specifically added, to the road drainage system. This water is treated in the same manner as any surface run-off water, see Section 3.3.

The following recycled and secondary aggregates are allowed for use in asphalt pavement layers:

- Recycled aggregate
- Recycled concrete aggregate
- Recycled asphalt
- Blastfurnace slag
- Steel slag

Contaminants leached from surface courses of roads containing recycled or secondary aggregates will be contained in the surface-run-off water from the road, see Section 3.3.
Limited leaching is anticipated from the bitumen binder itself [45] but particular consideration should be given to the leaching of water which results from the ‘break’ of cold emulsion mixtures. This water may contain chemicals from the emulsion formulations, which could be potentially polluting. The water may also contain contaminants leached from any recycled or secondary aggregates in the emulsion mix.

What does this tell us?
Binding recycled and secondary aggregates in bitumen will minimize the availability of contaminants. Adequate compaction of road layers will minimize the water available for leaching, as will upper impermeable surfacing layers. Blending with primary aggregates may reduce the proportion of contaminants available for leaching.

3.7 Hydraulically bound aggregates and concrete used at or below ground level

Hydraulically bound materials are aggregates bound by small quantities of cement or other cementitious binders such as lime, slag or pfa. Although generally less effective than a thorough bitumen coating, coating by a small quantity of cementitious binder reduces the aggregate surface available for leaching. Compaction further reduces leaching by minimizing the movement of water through the hydraulically bound material. Concrete contains far more cementitious binder than hydraulically bound materials and the aggregate particles are thoroughly coated. The final compacted concrete is highly impermeable.

Hydraulically bound materials and concretes contain residual water from the mixing process, called pore water. This water is highly alkaline, at which pH many contaminants are relatively insoluble. Exceptions are lead and zinc compounds which are soluble in both acidic and alkaline conditions. Over time, the pH of the pore water will reduce, possibly through reaction with atmospheric carbon dioxide (carbonation) or the ingress of chlorides from de-icing salts. For many metallic elements, if present and leachable from the recycled and secondary aggregates, this will, initially, make them less soluble than for the unbound aggregate.

As discussed previously, blending of recycled or secondary aggregates with primary aggregates will usually be expected to reduce the proportion of contaminants available for leaching.

A wider variety of recycled and secondary aggregates are used in hydraulically bound materials than in concrete, as shown in the table below.

<table>
<thead>
<tr>
<th>Hydraulically bound material</th>
<th>Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recycled aggregate</td>
<td>Recycled concrete aggregate</td>
</tr>
<tr>
<td>Recycled concrete aggregate</td>
<td>Blastfurnace slag</td>
</tr>
<tr>
<td>Recycled asphalt</td>
<td>Pulverized-fuel ash</td>
</tr>
<tr>
<td>Blastfurnace slag</td>
<td>Furnace bottom ash</td>
</tr>
<tr>
<td>Steel slag</td>
<td>China clay sand</td>
</tr>
<tr>
<td>Pulverized-fuel ash</td>
<td>Slate aggregate</td>
</tr>
<tr>
<td>Furnace bottom ash</td>
<td></td>
</tr>
<tr>
<td>Burnt colliery spoil</td>
<td></td>
</tr>
<tr>
<td>Unburnt colliery spoil</td>
<td></td>
</tr>
<tr>
<td>Spent oil shale</td>
<td></td>
</tr>
<tr>
<td>China clay sand</td>
<td></td>
</tr>
<tr>
<td>Slate aggregate</td>
<td></td>
</tr>
</tbody>
</table>

Cementitious binders will themselves leach metallic elements, in particular sodium, potassium, calcium and magnesium [46] can be expected to leach in greater quantities from hydraulically bound materials and concrete than from the corresponding unbound recycled or secondary aggregates. It should be noted that hydraulically bound materials and concrete are highly alkaline materials when first mixed and still wet, irrespective of the aggregates used. Appropriate health and safety and environmental precautions should always be taken when handling these materials.

What does this tell us?
Cement paste forms a physical and a chemical barrier to leaching, although the chemical barrier may be degraded over time. Adequate compaction reduces water permeation and thus the risk of deleterious leaching. Blending may also reduce the proportions of contaminants available for leaching. The cementitious binders will probably contribute to leaching, irrespective of the aggregates used.
3.8 Hydraulically bound aggregates and concrete used above ground level

Hydraulically bound aggregates are not commonly used in structures above ground level. Concrete is used in many structural elements of buildings and structures and in concrete blocks. Internal concrete (such as concrete blocks on the internal walls of a house) will not be exposed to water and the risks of deleterious leaching are negligible.

As with concrete used at or below ground level, the cementitious binder forms a physical and chemical barrier to leaching, although the chemical barrier may be degraded over time. Structural concrete is commonly a well-compacted, high strength, impermeable material. Only those aggregate particles very close to the surface will be able to leach. In most concrete above ground, even the aggregates particles close to the surface are enclosed in an exterior layer of cement paste, reducing their leaching potential. An exception is exposed aggregate concrete where the exterior layer of cement paste is removed for decorative reasons. Blending of recycled or secondary aggregates with primary aggregates will usually be expected to proportionately reduce the quantities of contaminants in the concrete and, hence, available to leach from the concrete surface.

If any contaminants are leached from above ground concrete, these will be washed away during rainfall, the surface run-off water being collected and disposed of with other surface run-off water. The contaminants in surface run-off water, generated by traffic over roads, will exceed the very limited concentrations of contaminants produced by leaching from aggregates at the surface of the above ground concrete. The mechanisms to mitigate the impact of contaminants in surface run-off water will substantially reduce the environmental risks presented by limited concentrations of contaminants leached from recycled and secondary aggregates contained in concrete above ground.

If water running-off from above ground concrete infiltrates through cracked or poorly jointed road layers, any minor concentrations of contaminants in the water, which have leached from the recycled or secondary aggregates in the concrete, may well be retained on aggregate particles in the road layers (attenuation).

What does this tell us?
Above ground concrete structures containing recycled and secondary aggregates present negligible risk of pollution caused by leaching of contaminants.

3.9 Summary

The type of road drainage provided will significantly affect the environmental risk presented by recycled and secondary aggregates. Where surface and sub-surface run-off water are combined, the impact of leaching from recycled and secondary aggregates will be minimal; the contaminants in surface run-off water exceed those leached from recycled and secondary aggregates and any mitigating measures or discharge controls applied to the surface run-off water will be equally applied to the sub-surface run-off.

More consideration of leaching impacts may be required when sub-surface waters are collected separately. However, the leaching from all pavement layers and embankments containing recycled and secondary aggregates are minimized by good compaction and impermeable surfacings, to minimize water ingress and improve engineering durability. Binders form a physical barrier to leaching from recycled and secondary aggregates and cementitious binders provide a chemical barrier due to their inherent high pH, although this chemical barrier may be degraded over time.

Above ground concrete structures containing recycled and secondary aggregates present negligible risk of pollution caused by leaching of contaminants.
4 Assessing the risk of deleterious leaching

4.1 Leach testing

4.1.1 Introduction

There are a vast number of publications discussing leach testing and many of the tests themselves are discussed in the UKQAA report "Environmental Testing and Emerging UK and EU Legislation" [47]. This publication is available on the world wide web. The “ALT-MAT” project was a European project that aimed to "bridge the gap between laboratory tests and field behaviour" [48] and reviewed the tests for mechanical and environmental properties of recycled and secondary aggregates. The project’s reports are also available on the world wide web. Recently, new European leach testing standards for the assessment of leaching from aggregates [49] and for the characterization of waste [50, 51, 52, 53] have been introduced; these are discussed later in this section.

The introduction of the European Standards for the characterization of wastes [50-53] includes a description of the framework for the standardized leach tests. "In the different European countries, tests have been developed to characterise and assess the constituents which can be leached from waste materials. The release of soluble constituents upon contact with water is regarded as a main mechanism of release which results in a potential risk to the environment during the reuse or disposal of waste materials. The intent of these tests is to identify the leaching properties of waste materials. The complexity of the leaching process makes simplifications necessary.

"Not all of the relevant aspects of leaching behaviour can be addressed in one standard. Tests to characterise waste materials and their behaviour can generally be divided into three categories:

(1) "Basic Characterisation" tests are used to obtain information on the short and long term leaching behaviour and characteristics properties of waste materials. Liquid/solid (L/S) ratios, leachant composition, factors controlling leachability such as pH, redox potential, complexing capacity and physical parameters are addressed in these tests;
(2) "Compliance" tests are used to determine whether the waste complies with specific reference values. The tests focus on key variables and leaching behaviour identified by basic characterisation tests;
(3) "On-site verification" tests are used as a rapid check to confirm that the waste is the same as that which has been subjected to the compliance test(s)."

Van der Sloot provides examples of each type of testing procedure [54], reproduced in the table below.

<table>
<thead>
<tr>
<th>Management perspective</th>
<th>Scenario perspective</th>
<th>Test parameters</th>
<th>Test methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characterization tests</td>
<td>Percolation controlled release (granular materials)</td>
<td>pH, redox, complexation</td>
<td>pH controlled test, redox capacity test</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Time, liquid to solid ratio</td>
<td>Column test</td>
</tr>
<tr>
<td></td>
<td>Transport limited (construction products and stabilized wastes)</td>
<td>pH, redox, complexation</td>
<td>pH controlled test</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Time, tortuosity</td>
<td>Tank leach test</td>
</tr>
<tr>
<td>Compliance tests</td>
<td>Percolation controlled release (granular materials)</td>
<td>pH, redox, complexation</td>
<td>pH controlled test</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Time, liquid to solid ratio</td>
<td>Two-step serial batch</td>
</tr>
<tr>
<td></td>
<td>Transport limited (construction products and stabilized wastes)</td>
<td>pH, redox, complexation</td>
<td>pH controlled test (selected pH)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Time, tortuosity</td>
<td>Tank leach test (short version)</td>
</tr>
<tr>
<td>On-site verification tests</td>
<td>Percolation controlled release (granular materials)</td>
<td>pH, redox, conductivity, grain size</td>
<td>pH, redox, conductivity measurement, sieve analysis</td>
</tr>
<tr>
<td></td>
<td>Transport limited (construction products and stabilized wastes)</td>
<td>Stability</td>
<td>Durability test</td>
</tr>
</tbody>
</table>

Van der Sloot provides examples of each type of testing procedure [54], reproduced in the table below.

All four European leach testing standards for characterization of waste are considered to be compliance tests. Basic characterization tests include column tests and pH-static tests [48]. Common test methods are summarized here.
4.1.2 Batch leaching/ extraction tests
BS EN 12457 Parts 1, 2 and 4 [50, 51, 53] are single batch extraction tests at different L/S ratios. They are similar to the UK’s ‘NRA test’ [41] for assessing leaching from contaminated land. These tests work on the principle that equilibrium is achieved with the surrounding leachant (water) during the test. The L/S ratio of the test will impact on the quantity of contaminant leached. If more water is present, more contaminants can enter the solution.

BS EN 12457-3 [52] is a two stage process, where the leachant (water) is changed during the extraction. In this test, equilibrium with the water is achieved twice and this test can provide useful information on changes in leaching behaviour with time or with contaminant concentration in the leachant. It is an intermediate test between the single batch extraction tests and the column test (see Section 4.1.6).

4.1.3 BS EN 1744-3 Aggregate test
The leaching tests BS EN 12457-Parts 1 to 4 (discussed above) have been specifically developed for assessment of wastes and inappropriate application of such tests, conducted upon material ground to the test requirements, may well not be representative of aggregate leaching behaviour. "The relevant committee for construction aggregates, CEN/TC 154 "Aggregates"...has had reservations about a compliance test in which extraction is carried out after grinding, rather than on the aggregate particles as used in construction. They also regard the CEN/TC 292 tests [BS EN 12457-1 to -4 discussed above] as being prepared specifically for waste and thus not appropriate for material which is not designated as waste. Consequently, CEN/TC 154 have produced their own extraction method" [55]. Given the previous inappropriate use of other tests [56, 57], this cautious approach is understandable. Additionally, testing to ‘waste standards’ may result in identification of the recycled and secondary aggregates as wastes; unnecessarily incurring the associated Waste Management Licensing implications (see Section 3.1).

The single extraction test for aggregates is designed for granular materials with a particle size below 32 mm. The aggregate is placed on a screen and surrounded by water which is continuously, but gently, agitated. After 24 hours the water is collected and analyzed.

4.1.4 Monolithic leaching tests
For bitumen bound materials, hydraulically bound materials and concrete, it is more appropriate to test leaching from the recycled and secondary aggregates in the bound form in which they will be when in-service, that is, using a monolithic leaching test. There is a Dutch standard for leaching of inorganic materials from building materials, NEN 7345 [58]. The test specimen is placed in the leachant (water) for 64 days, with the leachant replaced at specified intervals. There is no pH control imposed on the leachant. The concentrations of contaminants leached over time can be used to assess leaching over time. The equipment is similar to BS EN 1744-3 (see above) except that no agitation is required.

4.1.5 pH-static test
A European Standard of a pH-static test is being prepared [59]. "This test provides information on the pH sensitivity of leaching behaviour of the material. The test consists of a number of parallel extractions of a material at a liquid/solid ratio (L/S) of 10 (l/kg) for 48 h at a series of pre-set pH values. Since pH is one of the main leaching controlling parameters, the information can be used to evaluate the repeatability in testing (resulting from measurement at steep concentration - pH slopes) and to provide information on the sensitivity to pH in specific field scenarios. The acid neutralisation capacity derived from the test is a useful property in this respect" [60]. These results are suitable for implementation where the pH is controlled or in analytical models in which the pH itself is a variable computed by the model.

4.1.6 Column test
A Dutch column leaching test is currently available, NEN 7343 [61]. Column tests provide an indication of the time dependant leaching progress from the material [62]. In such tests the L/S ratio can be varied, providing data for modelling processes. The tests take, approximately 21 days to complete [60].

4.1.7 TCLP test
The Toxicity Characteristic Leaching Procedure was developed in the USA for assessing the leaching characteristics of municipal solid waste (MSW) landfills. The test was inappropriately used to assess leaching from different materials for use in other applications [56] and has largely fallen out of favour [57].

What does this tell us?
The most appropriate test for unbound recycled and secondary aggregates is BS EN 1744-3 [49] and for bitumen bound materials, hydraulically bound materials or concrete containing recycled and secondary aggregates, is a monolithic leaching test such as NEN 7345 [58]; since these tests are more representative of the material in service. Where other tests are used, such as BS EN 12457-1 to -4 [50-53], the interpretation of results should account for the difference between the samples used in tests (ground to the test requirements) and the aggregates in service.
4.2 Assessment of leaching

4.2.1 Introduction
When assessing leaching characteristics it must be remembered that limiting criteria are given in concentrations of contaminants, not in total quantities leached. This indicates that slowing the rate of release of contaminants, for example by adequate compaction or protection from water ingress, may enable materials to fall within the limiting concentrations. This clearly demonstrates the importance of minimizing water flow over aggregates so that the leaching of contaminants is controlled by diffusion processes (see Section 3.4).

It is generally accepted that the leaching test used should reflect the environmental conditions of the material in use. Thus, testing of aggregates to be bound in concrete should be conducted using monolithic leaching tests, and testing of unbound aggregates should be conducted on the aggregates at the particle size they will be used in the construction. The selection of appropriate leaching tests is discussed in more detail later in this section.

van der Sloot [9] proposes the use of ENV 12920 [63] as a framework to describe a scenario approach to the assessment of leaching. “As an example, the following question can be addressed: can alternative materials be used in an environmentally acceptable manner in road sub-base or in embankment? Clearly a single-step leaching test will not provide the answer to that question. Issues to be addressed are:

- Type of impact data needed: treatment optimization, comparison between potential materials for the application, soil and/or (ground) water impact.
- Compliance with regulatory criteria, if present.
- Technical requirements (load bearing, strength, etc.).
- Performance at different stages in the life cycle: service life – recycling – ‘end of life’.

The UK highway and building specifications will address the required engineering properties and their durability over time. Testing for these properties is well understood and does not pose an issue. End-of-life issues will be subject to the regulatory environment at the moment of recycling or disposal; for example, appropriate Health and Safety on construction sites for in situ recycling and appropriate planning controls over the establishment of the demolition waste recycling facilities.

The ”type of impact data needed”[9] is clearly important when establishing leaching characteristics and the suitability of materials, and any anticipated changes during the service life of the final construction product, should be considered. The "type of impact data" may be the leaching characteristics for the material, for comparison to water quality standards applicable to the place of use. The selection of a leach test to establish such leaching characteristics is discussed in Section 4.2.2.

Kosson et al [57] propose a tiered approach to assessment of leaching:

1) Screening tests – to provide an estimate of maximum contaminant release under the anticipated environmental conditions, not accounting for release over time. These are referred to as availability tests.
2) Equilibrium testing – provides an estimate of contaminant release over time and includes assessment over a range of pH and liquid to solid (L/S) ratios.
3) Mass transfer tests – account for leaching via mechanisms such as diffusion and are applicable to ‘monolithic materials’ such as asphalt and concrete, for example tank testing of a continuously saturated material.

The web-based “Protocols for alternative materials in construction” produced by Viridis [64] provide a decision making framework for the assessment of acceptability, both mechanical and environmental, of recycled and secondary aggregates in all forms of construction. A similar web-based system has been produced in the USA [65] along with a user handbook containing material-specific information on recycled and secondary aggregates [66].

Most suppliers and users of recycled and secondary aggregates would like to be able to conduct a single leach test and compare the results to a set of pass/fail criteria to establish suitability of use, such as Kosson et al’s screening tests [57]. This approach may be appropriate under certain circumstances. This discussion has a similar goal, to arrive at a conclusion that will support users looking further into the use of recycled and secondary aggregate rather than dismissing their use out of hand.

4.2.2 Selection of leach test
It would generally be considered best practice to evaluate leaching using the new European standardized tests. For unbound aggregates, this would mean using the test BS EN 1744-3 "Tests for chemical properties of aggregates - Part 3: Preparation of eluates by leaching of aggregates" [49]. Some minor concerns have been expressed over this testing method [60]: "No particle size requirements are provided to limit the contribution of fines." However, the test is designed to replicate the aggregates in, or close to, the state they would be used in the construction project and thus it may be appropriate to use material with a grading curve similar to that which will be used in practice.
The discussion in Section 3 demonstrates that bound and unbound aggregates will be used in circumstances where limited water permeation will take place. This would be equivalent to a low L/S ratio in leach testing; a L/S ratio of 1/10, that is, 0.1/1, might apply to largely immobile sub-surface water in saturated pavement layers. The European Standard for aggregate leaching specifies a L/S ratio of 10/1 and thus, any contaminants will be more rapidly leached using the aggregate test procedure than would be the case in service. Thus, using the European Standard aggregate leaching test would seem appropriate for the assessment of aggregate materials in order to provide 'worst case scenario' leaching data. However, there are no pass/fail criteria or accepted risk assessment approaches associated with the European Standard leaching test for aggregates [49] and this may well not be considered an appropriate test regime by the regulator.

For bitumen bound materials, hydraulically bound materials or concrete, leaching tests that represent the material in service are more appropriate, such as monolithic leaching tests. No European Standard monolithic leaching test exists but the Dutch Standard test is available [58]. Again, this testing does not form part of an accepted risk assessment regime in the UK and its suitability for use should be confirmed with the regulator.

As most risk assessment approaches are based around a corresponding test type, other leaching tests, such as BS EN 12457-2, may be specified for use, dependant on the final pass/fail criteria used to establish suitability. This is discussed further below.

4.2.3 Assessment using pollution of controlled waters and contaminated land guidance
The 'NRA leach test' [41] (similar to the European Standard test BS EN 12457-2 [51]) was specifically developed to assess leaching from contaminated land, and it is this test and its results that are integrated into setting remediation targets for contaminated land [30]. However, these targets are established to determine levels of remediation required, not to determine the 'degree of pollution that can occur'. Anecdotal evidence suggests that linking the use of recycled and secondary aggregates to the contamination of land may not be a persuasive approach to acceptability of recycled or secondary aggregates.
Despite such reservations, there are lessons to be learnt from the contaminated land approach to the risks of pollution of controlled waters. As part of this approach, the water quality standard applicable at the receptor is established, such as an environmental quality standard, a surface water abstraction standard or a drinking water standard. These standards are based on the List I and List II substances whose release into the environment needs to be controlled. Further information is available on the EA web-site. A number of water quality standards (and the inert waste acceptance criteria) are reproduced in Appendix 3 for ease of reference when using this report. However, it should be noted that these tables are reproduced out of context and will not be updated and the source documents should be referred to whenever comparisons are necessary.

Assessment against drinking water standards is probably inappropriate for recycled and secondary aggregates; in particular, the EA groundwater policy reminds us that “the quality of groundwater is generally much better than the requirements for potable waters under the EC Directive on the Quality of Water Intended for Human Consumption (80/778/EEC), as implemented and extended by the Water Supply (Water Quality) Regulations 1989.” [25]. However, many suppliers will argue that assessment against drinking water standards increases user confidence; the belief that they can drink the leachate water without harm implying that it must be harmless.

If an assessment approach, comparing leaching test results to water quality standards, is adopted, it will be worth checking with the regulator if BS EN 1744-3 [49] is acceptable for unbound materials or NEN 7345 [58] for bound materials, since these are more representative of the materials in service, or if assessment against the ‘NRA test’ [41, 51] is required. If an aggregate material leaches lower concentrations of contaminants than the limiting values in the applicable water quality standard, it is likely to be suitable for use. This will be particularly the case if the unbound aggregate has been tested but it will be bound in bitumen or cementitious binders when in service.

Direct assessment against water quality standards takes no account of dilution or attenuation (see Section 1.6). Thus a ‘fail’ result against such criteria should not be taken at face value, particularly if an inappropriate test regime is used (see above). The extent to which pass/fail criteria are exceeded, the sensitivity of the location of the construction site (see Section 2), the nature of the drainage systems and the degree of water infiltration around the aggregates (see Section 3) will all impact on the environmental risk posed by any contaminants leached from the recycled or secondary aggregates.

Construction sites in areas outside Source Protection Zones I-III, not close to surface water bodies and not in areas of ground water vulnerability, are likely to be in low sensitivity areas. Local vulnerability can be assessed using the groundwater vulnerability maps. These could be purchased for a particular Local Authority area and they may be useful for other construction projects where contaminated land or sensitive areas are involved, irrespective of the use of recycled and secondary aggregates. Suppliers of recycled and secondary aggregates could purchase a full set of vulnerability maps on CD-ROM from The Stationery Office, but the cost is £3500.

The nature of the drainage system should also be considered. For roads where the surface run-off and sub-surface run-off water are collected together before discharge, the levels of contaminants arising from the use of recycled and secondary aggregates will be minimal in comparison to those occurring from the road operation. Only where sub-surface drainage occurs separately via fin and filter drains, soakaways, or other means, and without control over the discharge, is pollution of the local environment likely to occur.

4.2.3 Assessment against inert landfill criteria

The Environment Agency’s “Landfill Directive Regulatory Guidance Note 2 (version 4.1, November 2002) Interim waste acceptance criteria and procedures” [67] lists the criteria a material must fulfil to be accepted as inert waste onto a landfill site. The draft “The quality protocol for the production of aggregates from inert waste” [68] adopts this approach to determine that recycled aggregates produced from construction, demolition and excavation waste are appropriately processed to be classified as aggregate products. The assessment forms part of an FPC regime for compliance with the new European Standards for aggregates.

The acceptance criteria state that concrete, bricks, tiles and ceramics and mixtures of these materials can be accepted as inert waste without testing “provided that they are a single stream of materials from a known and reliable source”. The criteria do not include excavation wastes (only soil and stones from gardens and parks wastes are acceptable and top soil and peat are excluded). Construction and demolition waste cannot include materials from buildings polluted with inorganic or organic dangerous substances (unless it can be made clear that the demolished building was not significantly polluted), or waste from buildings treated, covered or painted with materials containing dangerous substance in significant amounts.

This approach to classifying recycled aggregates as aggregate products, rather than wastes, is advantageous since, in accordance with the EA’s “Interim waste acceptance criteria and procedures” [67], it allows acceptance of recycled aggregates without the need for leach testing. However, the procedure [67] does not extend this assumption to any secondary aggregates but does state that “Wastes not included… must be subjected to the draft CEN Standard two part batch test for inorganic constituents” (now BS EN 12457-3 [52]) and the test results must not exceed the limit values...
given in the EA’s guidance note [67]. Additional testing may also be applied to assess sulfate and dissolved organic content. It should be noted that WRAP are also working to prepare a number of equivalent ‘quality protocols’ for secondary aggregates.

Again, when assessing bound aggregates, even if evaluation is being made against the inert waste acceptance criteria, it is more appropriate to use a monolithic leaching test [58], and for unbound aggregates, the aggregate leaching test, BS EN 1744-3 [49], is more appropriate. However, the acceptability of these leach testing regimes should be confirmed with the regulator who may prefer leach testing using BS EN 12457-3 [52], or even the ‘NRA test’ [41, 51].

It should be noted that the acceptance criteria for inert waste [67] are significantly different to the acceptable concentrations of contaminants given in water quality standards, and a comparison is given in Appendix 3. For example, although similar concentrations of nickel are allowed in the leachate from inert waste leach testing and in the environmental quality standard for freshwater in the softest water areas (0-50 µg/l of CaCO₃), 2000 times as much copper is allowed in the leachate from inert waste leach testing than in this environmental quality standard.

Given that the current approach to remediation of contaminated land is by establishing targets at the receptor [12], and that for controlled waters this is commonly done using water quality standards, it is unlikely that the use of inert waste acceptance criteria as a water quality standard will be acceptable where there are pathways to controlled waters (see Section 1.6 for the Source-Pathway-Receptor approach). Thus, the use of the inert waste acceptance criteria [67] to evaluate the risks posed by leaching from recycled and secondary aggregates is only likely to be acceptable in areas of low vulnerability and in areas not close to surface water bodies. However, such data may be useful on construction projects where a full environmental risk assessment is being conducted and more detailed Tier analysis is being undertaken.

Assessment of leaching against inert waste criteria [67] may reassure the user of the recycled and secondary aggregates that the material does not pose an end-of-life disposal concern, that is, its leaching is below the inert waste landfill criteria and therefore can be disposed of without significant cost. However, this assumption will clearly be subject to changes in regulation over time. For further consideration of end-of-life issues see Section 1.5.

4.2.4 Assessment against primary aggregates

The concern over the leaching potential of recycled and secondary aggregates is exacerbated by limited availability of information on the leaching behaviour of the primary materials they replace [69]. One approach to the assessment of the acceptability of recycled and secondary aggregates is the comparison to these primary materials. This approach could use the European Standard test for aggregates, BS EN 1744-3 [49], or the monolithic test, NEN 7345 [58], and be adopted on a project by project basis. Limited data available concerning leaching from primary materials is presented in Section 5. There is some evidence that primary aggregates, although used without difficulty, would have similar leaching characteristics as certain recycled or secondary aggregates. This evidence highlights the disparity in the environmental qualification requirements for recycled and secondary aggregates and primary aggregates.

The gap in the scientific knowledge concerning the potential leaching from primary aggregates affects users’ and regulators’ abilities to effectively assess the comparative performance of recycled and secondary aggregates. There is a complete lack of UK data examining the environmental impacts of primary aggregates, which could be used as a baseline reference for the use of recycled and secondary aggregates.

A common sense approach that compares the recycled or secondary aggregate to the local aggregate it is proposed to replace, could simplify the acceptance criteria for alternative aggregates. However, such an approach, if applied without a clear understanding of the background to the issue, could result in both recycled and secondary aggregates and local primary aggregates being considered potentially ‘polluting’ and an alternative ‘non-polluting’ primary aggregate being imported to the construction site, with wider environmental and sustainability consequences, such as transportation, noise and pollution or diminished economic viability of the local aggregate industry.

An independently-funded study that bench marks the leaching potential of aggregates, primary, recycled and secondary, would benefit the whole construction community and the resulting information database could be used for comparative reference, and establishing standard reference materials for ensuring testing compliance. It would provide information to enable the effective and clear regulation of leaching from recycled, secondary and primary aggregates (to ensure the ‘common sense’ situation described above is applied) and facilitate compliance testing to meet requirements concerning “dangerous substances” mentioned in European Standards for aggregates [14-19]. The project could be used to determine the appropriateness of the aggregate leaching test, BS EN 1744-3 [49] and a monolithic leaching test such as NEN 7345 [58] compared to the European Standard tests for the characterization of wastes, BS EN 12457-1 to -4 [50-53].

What does this tell us?

Assessment of the risks of pollution by comparison to the water quality standard applicable at the place of use has an established pattern of use in the UK. The test used to support this approach is also well known and accepted by the
regulator. If assessment using tests that are more representative of the recycled and secondary aggregates in service are proposed, the suitability of this testing regime should be agreed with the regulator.

Assessment of the risks of pollution by comparison to the inert waste criteria is unlikely to be acceptable where there are pathways to controlled water. However, this approach is more likely to be acceptable in area of low sensitivity and such data may be more useful on projects where full environmental risk assessments are being conducted.

Comparison to primary aggregates which are being replaced by the recycled or secondary aggregates may be an acceptable approach to risk assessment on a project by project basis, if agreed by the regulator.
5 Material specific information

The most well known text that addresses environmental (and mechanical and other) issues related to the use of recycled and secondary aggregates is “The reclaimed and recycled construction materials handbook” [70], published in 1999. Another useful report, which can be obtained through the world wide web, is “By-products and recycled materials in earth structures: Materials and applications” [71], which provides compositional information and environmental property requirements, applicable to Finland, for a wide variety of recycled and secondary aggregates. Information on recycled and secondary aggregates is also available on-line, in the “User Guidelines for Waste and Byproduct Materials in Pavement Construction” [66], at www.rmrc.unh.edu/Partners/mainMenu.htm.

5.1 Recycled aggregate, Recycled concrete aggregate and Recycled asphalt

The starting point for production of high quality Recycled aggregate and Recycled concrete aggregate is the controlled demolition of a building or structure [70, 71, 72, 73]. This includes stripping out materials such as plasterboard, wiring, glass and so on, to leave an homogenous demolition product, relatively common practice in the UK. The current BR392 “Quality control – the production of recycled aggregates” [74] and the draft replacement document “The quality protocol for the production of aggregates from inert waste” [68], both specify acceptance criteria for demolition waste to minimize product contamination before production of recycled aggregates.

Between 1992 and 1994, Trankler et al [72] leach tested a number of 0-45 mm Recycled aggregate samples using the German standard test, DIN 38414, using a L/S ratio of 10/1, similar to the ‘NRA test’ [41] and to BS EN 12457-2 [51]. The research results demonstrate that limited leaching of metals occurred from Recycled aggregate, but that in some cases the material could not have been accepted onto a landfill site as inert waste [67].

In the study by Trankler et al [72], sizeable concentrations of sulfate (340 to 1570 mg/kg) were leached, but this would be acceptable for inert landfilling (a limit of 6000 mg/kg is imposed if the batch leaching test with a L/S ratio of 10/1 is used). In all cases, the Dissolved Organic Carbon (DOC) and Phenol Index requirements for inert landfill were met. This supports the conclusions of Wahlstrom et al [75] who noted that PCB (polychlorinated biphenyl) and PAH (polyaromatic hydrocarbon) levels were acceptable and that sulfate leaching did not pose a significant risk. Jang and Townsend note that the risk of deleterious sulfate leaching, from fine debris resulting from reprocessing construction and demolition waste, are increased if “gypsum drywall” (plasterboard) is not effectively removed from mixed waste [76]. Leaching of sulfate from gypsum and cement paste is noted as a constraint on the use of Recycled concrete aggregate in the “Handbook of reclaimed and recycled construction materials” [70].

Nilsson et al [62] demonstrate that calcium and sodium have the largest leaching potential from crushed concrete, using a two stage batch process at a L/S ratio of 100/1 and using pH 7 and then pH 4 during the two steps, with chromium, nickel and lead being the most available elements in column and batch (BS EN 12457-3 [52]) tests. However, the results presented for chromium leaching are below the limits for inert waste acceptance. These conclusions are supported by D’Andrea et al [77].

Recycled asphalt essentially contains bitumen and primary aggregates [66]. Lindgren [45] concluded, from total concentration analysis, that the major source of metal contaminants was the primary aggregate, with a minor contribution from bitumen, but that the primary aggregates in the asphalt have an adsorption capacity for metal ions. This suggests that Recycled asphalt containing primary aggregate offers minimal environmental risk. This conclusion is supported by the report “By-products and recycled materials in earth structures: Materials and applications” [71], which concludes that bitumen is considered chemically inert and is not dissolved by water. It should be noted that old road construction materials containing tar should not be recycled as tar is hazardous to human health [42].

What does this tell us?

A range of studies on Recycled aggregate, Recycled concrete aggregate and Recycled asphalt demonstrate that the materials are likely to fall within the leach testing acceptance criteria for inert waste. This supports the approach in the draft document “The quality protocol for the production of aggregates from inert waste” [68] (based on the acceptance criteria for inert waste at landfill [67]) that Recycled aggregates from concrete, bricks, tiles and ceramics and mixtures of these materials can be accepted as aggregate products without leach testing “provided that they are a single stream of materials from a known and reliable source”.

However, it should be noted the levels of acceptable leachate for disposal of waste in inert landfill are significantly different to the contaminant concentration specified by water quality standards (see Appendix 3) and Recycled
aggregate, Recycled concrete aggregate or Recycled asphalt may only be acceptable for use if they comply with other standards, appropriate to their place of use.

### 5.2 Blastfurnace slag and Steel slag

The BRE information paper IP18/01 on Blastfurnace (BF) and Steel (BOF) slags [78] states "Adverse environmental impacts associated with the use of these materials are rare and can be attributed to bad practice or inappropriate use. The potentially leachable lime and sulfur compounds present in BF slag, and the lime present in BOF slag, can be contained by appropriate material selection and pavement design. Blastfurnace slag typically contains less than 1% total sulfur; only a very small part of this is potentially leachable when in contact with groundwater because most of it is bound up within the aggregate. In the UK, at least 100 million tonnes of unbound blastfurnace slag have been used in construction projects with very few cases of environmental pollution. Most BF and BOF slag has been used within a thirty-mile radius of the steel works, providing ample opportunity for major environmental incidences to occur. ... There is no migration of sulfur compounds from the interior of BF slag particles to replace the dissolved material on the surface. Therefore, after initial dissolution, the process rapidly slows down, only restarting if the slag is crushed to expose fresh surfaces."

Leaching tests performed on Blastfurnace slag by Tossavainen and Forssberg [69], using a two stage batch test process at a L/S ratio of 100/1 and using pH 7 and then pH 4 during the two steps, demonstrated the leaching of trace quantities of vanadium, chromium, copper, nickel, lead and zinc, from Swedish Blastfurnace slags, in addition to the leaching of sulfur compounds, as discussed above. Nilsson et al [62] noted the leaching, from Blastfurnace slag, of vanadium above copper and cobalt, with some testing demonstrating vanadium leaching at approximately 300 µg/l. Although this concentration exceeds the limiting values for some water quality standards (it is within acceptable levels for surface water abstraction - given in Appendix 3), it is impossible to appropriately relate the results of this research to slag produced in the UK or the UK test methods for leaching, and thus to the UK water quality standards.

According to the Finnish report [71], Blastfurnace slag does not “generally consist of any heavy metals or other hazardous secondary constituents amounts, which may exceed permitted limits.” This is supported by the conclusion, for both Blastfurnace slag and Steel (BOF) slags in the CIRIA “Handbook” [70] which states that “CIRIA Report 167: Use of industrial by-products in road construction – water quality effects [33], recommended the unrestricted use ... in road constructions. ... This report found ... no serious leaching despite utilising leaching tests designed to maximise the release of species”. However, concerns have been expressed over the continued validity of the conclusions drawn in CIRIA Report 167 [33], since “the interpretative framework on the relative utility of the candidate materials is now flawed because:

- it adopts a 10x, 100x, 1000x dilution factor approach which is generally unacceptable,
- it uses then current, but now superseded, water quality standards as the basis for acceptance or rejection whereas site-specific values will now, often, be defined” [4].

However, guidance on the use of air-cooled Blastfurnace slag from iron production as an unbound aggregate, has been produced by the British Aggregate Construction Materials Industry (now the Quarry Products Association) and the Environment Agency [79]. The guidance recommends:

- the use of stockpiled Blastfurnace slag in preference to fresh slag
- unbound Blastfurnace slag is not used in water logged or poorly drained areas or below the water table
- best practice construction to achieve good compaction and avoid ponding in large, exposed, trafficked areas
- the potential for water pollution to be considered at the materials selection stage of a construction project to ensure appropriate storage and handling of large quantities of unbound Blastfurnace slag.

The National House Building Council (NHBC) has issued a Technical Circular [80] enabling the use of Blastfurnace slag as a fill material if purchased from specified sources to specified quality standards. The Blastfurnace slag is specified as a fill, up to a depth of 600 mm, beneath ground bearing slabs and subject to the same compaction as primary materials.

**What does this tell us?**

Blastfurnace and Steel (BOF) slags have been used widely throughout the UK and based on this history of acceptable use, for Blastfurnace slag, an environmental guidance note has been produced and the material is accepted for use by the NHBC. It can be assumed that where the use of slag is acceptable in its unbound form, it will also be acceptable bound in bitumen or cement, since there is a commensurate reduction in the risk of deleterious leaching.

### 5.3 Pulverized-fuel ash and Furnace bottom ash

The CIRIA “Handbook” [70] states that Pulverized-fuel ash (pfa) and Furnace bottom ash (fba) are “not toxic and generally considered to be environmentally benign.” A review of the leaching of fpa is freely available from the UK Quality Ash Association web site [81], and since the data presented in that study relates to the use of UK produced material, it is an excellent reference document for potential users. The review helpfully contains water analysis from ash
lagoons, discharge water and water local to the power stations where the ash is produced. In most cases the concentrations of contaminants are within the limitations specified by inert waste acceptance criteria, but often the data are presented as ‘less than result’ (i.e. <0.01) which does not enable comparison with the water quality standards given in Appendix 3. However, the review does demonstrate that ash producers have sufficient knowledge of their materials to support decision making by potential users.

Twardowska and Szczepanska [82] conducted leaching tests on power plant fly ashes from Poland using the German DIN 38414 test (similar to BS EN 12457-2 [51]). These experiments show leaching of contaminants in excess of those reported for UK pfa, and exceeding the limiting values given in the water quality standards, although the elemental composition of the ashes was similar to that produced in the UK [81]. The laboratory testing conducted as a part of this research indicated that an initial phase of leaching ‘wash-out’ increased the pH of the surrounding water, to approximately pH 12, and limited metal leaching occurred. Following subsequent batch or column leaching tests, the pH reduced to pH 7 and the leaching stabilized, with no delayed leaching observed. However, analysis of field samples at a fly ash landfill site indicated that, over a 12 year period, delayed leaching had occurred, resulting from weathering, dissolution of amorphous phases in the fly ash and the formation of secondary minerals, and the water flow conditions upon ionic strength and pore solution composition.

A UK field evaluation of ground water and surface water contamination adjacent to pfa containing embankments built between 1967 and 2000 [83] concluded that “it is very unlikely that pfa is a significant cause of contamination of groundwater at a level of concern to the environment” and “pfa is not the source of a generic contamination”. This difference in field results, compared to the Polish study [82], may well result from the compaction of the pfa in embankments, and thus the minimization of permeability to water. The UKQAA web site contains a code of practice for the use of pfa [6]. For embankment construction, building on a drainage blanket is recommended, “to provide a capillary break, preventing saturation and frost heave”. This drainage blanket will minimize the water available for leaching and, should leaching occur, the drainage blanket will provide a layer of sorption sites to which contaminants can ‘stick’ [45].

The successful use of pfa as an unbound aggregate in embankments in the UK indicates that minimal risks are posed by the material in bound forms. Further information on the use of pfa in hydraulically bound materials [84, 85] are provided on the UK Quality Ash Association web site (www.ukqaa.org.uk).

Pfa and fba are also commonly used in block making. Although there are negligible risks of leaching from concrete blocks used in above ground construction, there has been some discussion over the levels of radio-nuclides, naturally occurring in coal deposits and concentrated in the ash. Sear [86] reviews this aspect, in addition to other environmental issues, and concludes that the risk to human health is minimal in ash produced from coals in the UK, but that the risk may be increased for coals from Eastern Europe which contain increased quantities of naturally-occurring radioactive minerals.

**What does this tell us?**

Pfa has been widely used in embankments across the UK and field data has demonstrated no deleterious environmental impact from its use. The chemical properties of pfa are well understood by the producers who should be consulted for further information. The available data indicates UK-produced pfa does not pose an environmental risk in its unbound form and thus, also in hydraulically bound forms. The use of pfa and fba in concrete blocks in buildings and structures above ground level does not pose an environmental risk.

### 5.4 Incinerator bottom ash aggregate

A comprehensive review of leaching and other environmental impacts from the use of Incinerator Bottom Ash (IBA) in the construction of a hot mix asphalt road is presented in the web-based report "Environmental and health risks associated with the use of processed incinerator bottom ash in road construction" [5], available at www.breweb.org.uk. The report carried out a full risk assessment and used predictive modelling to establish the extent of environmental risks. The report concluded that "the risks to human health and the environment from municipal waste incinerator bottom ash use in road construction are likely to be minimal and certainly undetectable in a typical UK situation".

The report recommended that UK-produced IBA could be used in road construction, in it bound and unbound forms, in areas with water hardness above 100 µg/l of calcium carbonate (CaCO₃) (Note: the report [5] gives this hardness in mg/l, but reference to the EA web site, www.environment-agency.gov.uk/business/444217/590750/590821/295597, indicates water hardness should be presented as µg/l). Concerns were expressed regarding the potential leaching of copper from IBA in soft (<100 µg/l CaCO₃) water areas and the report recommended that these uses be evaluated on a project by project basis. The potential for copper leaching is confirmed by Freyssinet et al [87] and Lapa et al [88].

Unsurprisingly, a comparison of the contaminant concentrations leached from UK-produced IBA [5], using the ‘NRA test’ [41], and the water quality standards demonstrates in some instances the leaching concentrations exceed the limiting values. However, in many instances the data are presented as ‘less than result’ (i.e. <0.01) which does not enable
comparison with the standards given in Appendix 3. Data is also presented for testing of UK-produced IBA using BS EN 12457-3 [52], and in 2 of the 7 data sets presented, the leaching results are above the limiting values for classification as inert waste.

What does this tell us?
On the basis of the risk assessment carried out in the report “Environmental and health risks associated with the use of processed incinerator bottom ash in road construction” [5], it is reasonable to assume that IBA is safe to use in unbound and bound forms in all except soft ground and surface water areas, where some further risk assessments may be required.

5.5 Unburnt colliery spoil, Burnt colliery spoil and Spent oil shale

Unburnt and Burnt colliery spoil have a long history of use in the UK [70, 89, 90], and Spent oil shale in Scotland [70]; no reports of pollution caused by leaching from these materials have been found. All these materials are considered to be inherently variable [66, 70], in terms of engineering specifications and composition, suggesting variability in their leaching characteristics. Under the European Standards for aggregates [14-19], Unburnt colliery spoil would be considered a “natural aggregate” (see Section 5.9) and thus might be expected to be subjected to the same environmental qualification as primary aggregates.

The CIRIA “Handbook”[70] indicates that sulfates may be leached from Burnt colliery spoil. Unburnt colliery spoil has sulfides present within it, which form sulfates when burnt, and may form sulfates, available for leaching, upon exposure to air. Spent oil shale is noted to be similar to Burnt colliery spoil [70, 91], but also “CIRIA Report 167: Use of industrial by-products in road construction – water quality effects [33], recommended the unrestricted use of spent oil shale in road constructions. …This report found … no serious leaching despite utilising leaching tests designed to maximise the release of species”. However, see the concerns expressed in Section 5.2 regarding these conclusions.

A thorough review of the engineering and environmental properties of Unburnt colliery spoil has been published by Skarzynska [89]. Data concerning the contaminants present in surface waters surrounding embankments built of spoil indicate that the water would fail to meet the UK water quality standards, and in some instances the contaminant concentrations exceed the limiting values for inert landfilling. However, it should be noted that the paper describes two of the rivers sampled as “flowing through land heavily contaminated by coal mining”, suggesting that the Unburnt colliery spoil may not be the only source of pollution.

Skarzynska [89] does note that the environment must be protected when Unburnt colliery spoil is used in construction and recommends good compaction to minimize water ingress, along with a covering with soil and vegetation on embankments.

What does this tell us?
There is scant information on the risks of pollution from Unburnt and Burnt colliery spoil or Spent oil shale. The evidence that is available does indicate leaching of contaminants, but the level of leaching, and whether this is deleterious, is difficult to determine. The long history of use of Unburnt or Burnt colliery spoil and Spent oil shale indicates that it is a suitable aggregate for certain engineering applications, but that compositional variability may be reflected in the polluting potential of the material. The lack of relevant information and the variability of the materials suggest that these materials should be assessed on a project by project, or source by source, basis, probably on large projects where environmental risk assessments are required.

5.6 Foundry sand

Foundry sands are fine silica sands, also used as primary aggregates in construction, bound into shapes for casting metals. The sands are typically bound with bentonite clay binders (greensand) and chemical binders such as phenolic organic molecules. Greensand is common in iron foundries, chemically bound sand is more often used in non-ferrous casting processes [92].

The CIRIA “Handbook” [70] differentiates between the leaching potential of Foundry sands based on the metal casting process that they have been used in; “iron and aluminium casting sand generally have acceptable leaching characteristics, whereas brass is very poor. In such cases, the best uses of the foundry sand may therefore be within a binder of any specification, which will stabilize the metals and result in an inert material. Sand from brass foundries represents only a small proportion of the volume of foundry sand produced, the majority of which generally exhibits acceptable leaching characteristics... Experiences with the beneficial reuse of foundry sand have in general shown that potential levels of leachate generation are very low and unlikely to have any significant environmental impact.” The Recycled Materials Resource Center’s “Users Guidelines” [66] note that the presence of heavy metals is of greater concern with Foundry sands from brass and bronze foundries.
That Foundry sand is environmentally benign is supported by Lovejoy et al [93], who tested wastes from three iron or steel foundries using laboratory tests (TCLP test) and through monitoring water quality of embankments constructed of soils and Foundry sands. Winkler and Bol'shakov also conducted TCLP testing on Foundry sands and concluded that:

"Quantities of twelve heavy metals and a number of organic compounds extracted from foundry sand waste ... suggests that spent foundry sand can be beneficially used posing no environmental or human health risk. Only iron and manganese... showed increased leaching potential on a number of occasions.”

Bastian and Allemen [94] tested the impact on microbial activity of contaminants leached from Foundry sands from iron, steel and aluminium foundries, comparing the results to primary materials. Their research demonstrated that 7 out 11 Foundry sands from the iron foundries demonstrated equivalent or superior performance compared to the primary sands; the remaining 4 sands from iron foundries, and those from the steel and aluminium foundries, contained detrimental contaminants in the leachate. The research concluded that the contamination was associated with the type of mould and its chemical binders. The paper reports that an embankment built using Foundry sand from one of the 7 iron foundries that did not demonstrate leachate with a detrimental impact on microbial activity has shown no environmental impact on the surrounding ground water.

What does this tell us?
The use of Foundry sand within binder systems (such as cement or bitumen) appears to be considered relatively risk free. However, despite the case studies of acceptability, the variable nature of Foundry sands indicates that caution should be exercised when using Foundry sand as an unbound aggregate. The source of the Foundry sand, and hence its chemical binder type and associated metal processing, may all impact on the leaching of contaminants. It would seem responsible to assess the use of unbound Foundry sand on a project by project, or source by source, basis probably on large projects where environmental risk assessments are required.

It is important to note that, like Pulverized-fuel ash, Foundry sand is a fine material and if used on its own in embankments may be prone to water ingress by capillary suction. This would increase the likelihood of freeze/thaw deterioration of the embankment and of leaching from the Foundry sand. The consideration of such engineering properties should be made at the design stage of the construction project.

5.7 Recycled tyres

The use of recycled tyres in construction is still in its infancy in the UK. The recent report "Civil engineering applications of tyres”[95], notes that tyres are environmentally benign in most situations, a conclusion echoed by the Recycled Materials Resource Center’s "User guidelines" [66], although these guidelines note that "Shredded or chipped tires have been used as a lightweight fill material for construction of embankments. However, recent combustion problems at three locations have prompted a reevaluation of design techniques when shredded or chipped tires are used in embankment construction.”

Case studies on AggRegain demonstrate the use of baled Recycled tyres as replacements for road sub-base and fill materials, and as embankment fills in the UK, as well as coastal and fluvial engineering works. The web site for the project "Tyre re-use in coastal and river engineering”(www.tyresinwater.net), states "In the UK, previous civil engineering applications of tyres in the river and coastal environment include floating tyre breakwaters, embankments, walls and reefs. Other applications include road sub-base and drainage. These projects tend to be disperse and one-off without reporting or monitoring. This project aims to break the deadlock of lack of knowledge causing lack of use" [96]. The project aims to produce a guidance manual in July 2005.

The "Sixth Report Of The Used Tyre Working Group" notes that the University of Southampton's School of Ocean and Earth Sciences is responsible for an artificial reef constructed using tyres in Poole Harbour in 1998 and "are well on their way to proving that there is no significant pollution risk through the studies" [97]. This is supported by the TEKES review [71], which states that testing in Finland has shown no threat to the environment from shredded tyres. A field study of water close to trenches containing buried tyre shreds indicated that water in the trenches had elevated concentrations of iron, manganese, zinc and some organic compounds, but that water at a down-gradient to the trenches did not have contaminant levels above the background [98]. An AggRegain case study states that “zinc is used as the main indicator of tyre leaching” [99].

In the USA, recycling tyres into asphalt has been extensively practised [100] but use has declined since the Intermodal Surface Transportation Efficiency Act (ISTEA) no longer requires States to use quantities of asphalt containing recycled rubber. [101]. A paper by Azizian et al [102] notes that the leaching of aluminium, calcium, potassium, magnesium, strontium, phosphorous and mercury was detected, following 24 hours shaking of an asphalt containing recycled tyres in distilled water; aluminium and mercury were leached at 1.5 mg/l and 0.02 mg/l respectively. Vanadium, zinc, arsenic, barium, nickel, cobalt, iron, chromium, copper, antimony, lead, cadmium and selenium were not detected. In addition, noticeable leaching of a benzothiazole compound was detected but, despite the toxicity of this compound, it was expected to biodegrade and thus would have no impact on the environment. The paper concluded that the degradation
of the benzothiazole and the attenuation of contaminants should prevent transport to nearby soils and groundwater.

**What does this tell us?**

There is evidence to suggest that the use of Recycled tyres is not environmentally damaging. However, a number of UK research projects are ongoing and it can be expected that best practice guidance will be developed once these studies are completed. In the interim, it would be reasonable to assess the use of unbound Recycled tyres on a project by project basis, perhaps as part of fuller site environmental risk assessment.

### 5.8 Recycled glass

The USA guidelines [66], the CIRIA "Handbook" [70] and the TEKES review [71], all note that glass is chemically inert. The Tekes Review [71] also states that glass is environmentally safe if it does not contain lead, recommending source control to ensure lead is not present in significant quantities, particularly before use in environmentally sensitive areas. Dirty glass is noted to contain high contents of organic materials which may cause problems [71]. The British Standards Institution (BSI), in association with WRAP, have published guidance on the collection of container glass to ensure high quality Recycled glass, PAS 101 [103], effectively an agreed UK industry approach to source control.

There are many UK case studies of binder course and base asphalts containing Recycled glass available on the AggRegain web site (www.aggregain.org.uk) and no incidences of deleterious leaching have been reported. Research is underway to overcome the impact of deleterious alkali-silica reaction (ASR) that occurs when glass is used as a concrete aggregate. WRAP is currently working with BSI and industry to develop specifications for the use of Recycled glass in a number of market sectors but the use of Recycled glass in concrete is not considered to be sufficiently progressed to allow specification at this time [104].

**What does this tell us**

Recycled glass is considered environmentally inert where appropriate source control is in place. The use of Recycled glass in bituminous pavement layers is increasing in the UK and no environmental issues have been reported. There are still technical, rather than environmental, difficulties in using Recycled glass as a concrete aggregate. It is reasonable to assume that Recycled glass, collected in accordance with the PAS 101 specification [103], from a supplier implementing an FPC regime, will be suitable for use without extensive risk assessment in all but the most sensitive areas.

### 5.9 China clay sand, Slate aggregate and Primary aggregates

The European Standards for aggregates [14-19] provide the following definitions:

- **Aggregate:** granular material used in construction. Aggregates may be natural, manufactured or recycled.
- **Natural aggregate:** aggregate from mineral sources which have been subjected to nothing more than mechanical processing
- **Manufactured aggregate:** aggregate of mineral origin resulting from an industrial process involving thermal or other modification
- **Recycled aggregate:** aggregate resulting from the processing of inorganic material previously used in construction

These European Standards [14-19] do not differentiate between the aggregates based on their source, but define performance in terms of their physical, chemical and durability characteristics. It would be entirely in accordance with this philosophy to adopt a similar approach for recycled and secondary aggregates. As Hjelmar notes [8] "In principle, virgin materials and alternative materials to be used for the same purpose should meet the same requirements and be able to pass the same tests. This is, for a variety of reasons, not always the case, particularly in relation to environmental requirements. ...Traditional raw materials have, in addition, often been exempted from environmental testing."

The definitions from the European Standards demonstrate that China clay sand and Slate aggregate would be viewed as natural or primary aggregates. The CIRIA “Handbook” [70] does not indicate there are any specific environmental impacts associated with the use of China clay sand or Slate aggregates, stating "CIRIA Report 167: Use of industrial by-products in road construction – water quality effects [33], recommended the unrestricted use ...in road constructions. This report found ... no serious leaching despite utilising leaching tests designed to maximise the release of species". However, see the concerns expressed in Section 5.2 regarding these conclusions. Both China clay sand and Slate aggregate are by-products of quarrying operations whose primary product does not contain potential pollutants, indicating that few contaminants will be present in the by-products. The acceptance of these materials as "natural" aggregates means they can be used in the same manner as primary aggregates, and are thus, de facto, exempt from environmental leach testing.

A few studies have been found, through the literature review for this project, examining the leaching characteristics of primary aggregates. The most comprehensive study to date has been conducted by Tossavainen and Forssberg [69]. Nine primary aggregates were leach tested, using a two stage batch test process at a L/S ratio of 100/1 and at pH 7 and
then pH 4 during the two steps.

The paper [69] concludes that: “Gravels seem to be more unpredictable regarding both total content and leachability of elements compared to rock materials. The total content and the soluble fraction of heavy metals both can be high.” Although not scientifically robust, since the leaching results for the primary aggregates might be very different if the ‘NRA test’ [41], the European Standard two batch extraction test [52] or the European Standard leach test for aggregates [49] had been used, it is informative to compare the leach test results to the water quality standards given in Appendix 3. None of the aggregates, based on the test results alone, would have passed the most stringent water quality standards for soft freshwater discharge to areas containing salmonoid fish, and only one of the primary aggregates would pass the inert waste acceptance criteria.

This analysis, and the comparison to water quality standards and other limiting values, does confirm that Primary aggregates will have an environmental impact which may be greater than, or similar to, that of the proposed recycled or secondary aggregate. This conclusion is confirmed by Morse et al, who demonstrated leaching test results for natural materials may exceed limiting values local to Texas [105].

**What does this tell us?**

The evidence available suggests that both China clay sand and Slate aggregate pose minimal risk to the environment through leaching. However, the acceptance of these materials as “natural” aggregates, and thus, de facto, exempt from environmental leach testing, or environmental impact qualification, does highlight the disparity of current approaches to the use of recycled and secondary aggregates compared to primary aggregates.
6 Stakeholder interviews

This section highlights issues, raised through the stakeholder interviews, which may be of importance to WRAP.

6.1 Lack of guidance

All the stakeholder groups noted the lack of clear-cut guidance on testing, limiting values and associated decision making procedures. Reputable suppliers have taken a self-regulatory role in the use of their materials, essentially not supplying materials where they believe that there is a risk of poor engineering, or poor environmental, performance. This requires the suppliers to confirm the use to which the client will put the material; a requirement that it is beyond their control to enforce. Scientists/consultants use relatively complex procedures, often to demonstrate minimal risks; a procedure that could be simplified in all but the most sensitive areas. The current assessment practices were considered to mean that similar risk assessments were being conducted every time the use of recycled and secondary aggregates is proposed, replicating previous activity and incurring additional project expense (re-inventing the wheel).

Confusion existed over the leaching tests to be applied, such as the NRA test [41], the European Standard test for aggregates [49] and those for wastes [50-53], and the limiting values that could be used; environmental quality standards, surface water abstraction standards, drinking water standards or others. Straight-forward comparison of leach test data with water quality standards will frequently indicate an unacceptable level of leaching, but the measured value is one that would be reduced by dilution, attenuation and so on. The absence of a simple means of evaluating this reduction (albeit conservatively) is a knowledge gap that warrants addressing.

Solutions proposed by the stakeholder interviews included:

• A clear set of limiting values for recycled and secondary aggregates, perhaps allocated against the sensitivity of the area, similar to current water quality standards, or related to the leaching of primary aggregates.
• A simple risk assessment model for Local Authorities to allow them to use new materials or other innovative technologies with more confidence. This risk assessment procedure should allow the risks in decision making to be moved from the person/individual level to the corporate level. In particular, it should aim to stop a priori outright rejection. This could well be linked to the WRAP "procurement checklists" [106].
• Providing more information/tools to planning officers might be a good mechanism to alleviate concerns over recycled and secondary aggregates; and
• Education of potential users, particularly Local Authority engineers who often dismiss the use of recycled and secondary aggregates, particularly since they are currently considered to be wastes. The stakeholders are aware of the educational work WRAP is undertaking but question its effectiveness on such influencers. This may be addressed by WRAP’s "Training and information on the role of recycled and secondary aggregates in sustainable construction for influencers in the supply chain" [106].

6.2 Waste Management Licensing

The application of Waste Management Licensing (WML) was considered to be inconsistent across the UK, with a lack of expertise within the regulatory bodies often impacting on the decision-making process. There was confusion about the point at which ‘waste is recovered’ if it is used in an unbound form, this confusion exacerbated by a lack of published guidance or consistent interpretation.

Although stakeholders were aware of the WRAP activity to overcome legislative and regulatory barriers related to WML, there was a certain degree of pessimism towards the work. Several stakeholders did not believe that the Protocol [68] will have the desired outcome since it still will not provide the unambiguous guidance on the issue.

These concerns are linked to the use of the European Standards for characterization of wastes [50-53] as leaching tests for materials. Since recycled materials may not be portrayed in the environmental risk assessment as ‘waste’, testing them as such may be undermining the risk assessment and agreements made with the regulators. An environmental risk management strategy adopted primarily to stop an environmental impact might be viewed as a reason to prevent a material's use on the basis that it is a waste. The WML regulations then impinge with all that is subsequently entailed (see Section 2.1).
6.3 Landfill Directive

The ban on co-disposal and the reduction in the number of hazardous disposal sites, in July 2004, will probably lead to increased amounts of fly-tipping. Several stakeholders expressed concerns that this would have consequences for the priorities of the EA, and thus knock-on effects in dealing with the regulatory issues involved in using recycled and secondary aggregates in construction.

A positive outcome of this change in the Landfill Regulations may be the increased need for off-site recycling sites to deal with excavation wastes from contaminated land sites, as an alternative to ‘dig and dump’. There is also expected to be an increase in the use of remediation techniques such as solidification/stabilization.
7 Conclusions

The perceived risk of leaching from recycled and secondary aggregates is often overstated, particularly when used in unbound engineering applications. The risk of deleterious leaching is significantly reduced by binding aggregates in bitumen bound materials, hydraulically bound materials or concrete. The literature review demonstrates that the majority of recycled and secondary aggregates pose no significant risk to controlled waters when used in properly designed and constructed engineering applications that account for the sensitivity of the local environment. Where any doubt exists over the potential contaminants that could be leached from the recycled and secondary aggregates, or bound materials containing them, risk assessment on a project by project, or a source by source, basis may allay any concerns.

This review of the issues surrounding leaching from recycled and secondary aggregates highlights the complexity of assessing deleterious leaching, as no specific guidance on the topic is provided. The tests to be used and the limiting values applied are not clear. The increased use of recycled and secondary aggregates would be facilitated by simple, clear, decision-making procedures that would benefit users of such materials. Although such definitive guidance can only be provided by the regulatory authority, the Environment Agency (EA), this project has been able to highlight some of the issues related to the use of recycled and secondary aggregates, and thus provide the information sheets required by the WRAP AggRegain web site.

The summary nature of the information sheets will dictate that they include pointers to web-based information sources. It is not within the remit of these information sheets to provide authoritative guidance, but WRAP should consider working with the Environment Agency to develop guidance on acceptable leaching levels from recycled and secondary, and primary, aggregates.

Although this project has conducted an interview with the Environment Agency, it was noted at that time that the timescales for the project did not facilitate EA approval for the information presented in the final information sheets. WRAP may wish to seek this approval before publication (and may consider discussions with the Scottish Environment Protection Agency). WRAP can play a valuable role in working with the EA to develop the guidance desired by the supply industry and users.

Simple risk assessments concerning the use of recycled and secondary aggregates are possible, for example, comparing the results of appropriate leaching tests against water quality standards applicable to the place of use. This approach is reliant on the regulator accepting that leaching tests on monolithic materials (for bound recycled and secondary aggregates) and unbound aggregates in their inherent or processed grading (rather than aggregates ground to test requirements), are appropriate test regimes for these materials. Currently this would only be possible on a project by project basis.

There is a scientific-knowledge gap related to the comparative leaching performance of primary aggregates and recycled and secondary aggregates. If this information were available it would assist in the development of appropriate guidance for users and a research project to fill this information gap could be used to confirm appropriateness of leaching tests which reflect the behaviour of the aggregates in service, that is, monolithic and aggregate leaching tests, as opposed to waste characterization tests.
8 References

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Leaching from recycled and secondary aggregates – a review


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83 Arnold, GK, Dawson, AR and Muller, M; “Determining the extent of ground and surface water contamination adjacent to embankments comprising pfa”; University of Nottingham, Nottingham, 2002. [Available at www.ukqaa.org.uk]
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99 AggRegain; “Use of tyre bales as replacement for shingle in flood defence scheme at Pevensey Beach”, WRAP, 2003. [Available at www.aggregain.org.uk]


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Appendix 1

List I and II Substances

**Note:** This information reproduced out of context and will not be updated; the source documents should be referred to whenever comparisons are necessary.

List I includes:
- Organohalogen compounds and substances that form such compounds in an aquatic environment
- Organophosphorous compounds
- Organotin compounds
- Substances that possess carcinogenic, mutagenic or teratogenic properties in or via the aquatic environment (including substances which have these properties which would otherwise be in List II)
- Mercury and its compounds
- Cadmium and its compounds
- Mineral oils and hydrocarbons
- Cyanides.
A substance is not in List I if it has been determined by the Environment Agency to be inappropriate to List I on the basis of low risk of toxicity, persistence and bioaccumulation.

List II includes any substance that could have a harmful effect on groundwater and includes compounds of:

<table>
<thead>
<tr>
<th>List II includes any substance that could have a harmful effect on groundwater and includes compounds of:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc</td>
<td>Nickel</td>
</tr>
<tr>
<td>Copper</td>
<td>Chromium</td>
</tr>
<tr>
<td>Tin</td>
<td>Lead</td>
</tr>
<tr>
<td>Barium</td>
<td>Selenium</td>
</tr>
<tr>
<td>Boron</td>
<td>Arsenic</td>
</tr>
<tr>
<td>Vanadium</td>
<td>Cobalt</td>
</tr>
<tr>
<td>Tellurium</td>
<td>Silver</td>
</tr>
<tr>
<td>Antimony</td>
<td>Molybdenum</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>Titanium</td>
</tr>
<tr>
<td>Titanium</td>
<td>Beryllium</td>
</tr>
<tr>
<td>Beryllium</td>
<td>Uranium</td>
</tr>
<tr>
<td>Uranium</td>
<td>Thallium</td>
</tr>
<tr>
<td>Biocides and their derivatives not appearing in List I</td>
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</tr>
<tr>
<td>Substances which have a deleterious effect on the taste or odour of groundwater</td>
<td></td>
</tr>
<tr>
<td>Toxic and persistent organic compounds of silicon</td>
<td></td>
</tr>
<tr>
<td>Inorganic compounds of phosphorous and elemental phosphorous</td>
<td></td>
</tr>
<tr>
<td>Fluorides</td>
<td></td>
</tr>
<tr>
<td>Ammonia and nitrites</td>
<td></td>
</tr>
<tr>
<td>Other substances determined by the Environment Agency.</td>
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</table>
Appendix 2

Summary of EA policy on discharge to underground strata

Note: This table is reproduced out of context and will not be updated; the source documents should be referred to whenever comparisons are necessary.

Each of the assessments is clarified by a numbered note given below the table.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Zone I – Inner Zone</th>
<th>Zone II – Outer Zone</th>
<th>Zone III – Catchment Zone</th>
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<td>No objection - 5</td>
<td>No objection - 5</td>
</tr>
<tr>
<td>Impermeable areas:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public amenity</td>
<td>Not acceptable - 1</td>
<td>Acceptable - 4</td>
<td>Acceptable - 4</td>
</tr>
<tr>
<td>Large car parks</td>
<td>Not acceptable - 1</td>
<td>Acceptable (via interceptor) - 3/4</td>
<td>Acceptable (via interceptor) - 4</td>
</tr>
<tr>
<td>Lorry park</td>
<td>Not acceptable - 1</td>
<td>Presumption against - 2</td>
<td>Acceptable (via interceptor) - 3/4</td>
</tr>
<tr>
<td>Garage forecourt</td>
<td>Not acceptable - 1</td>
<td>Presumption against-2</td>
<td>Acceptable (via interceptor) - 4</td>
</tr>
<tr>
<td>Major roads</td>
<td>Not acceptable - 1</td>
<td>Presumption against (Acceptable only in exceptional circumstances) - 4</td>
<td>Acceptable only if investigation favourable and with adequate precautions - 4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Activity</th>
<th>Major aquifer</th>
<th>Minor aquifer</th>
<th>Non-aquifer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface water to soakaway</td>
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<td>No objection - 5</td>
<td>No objection - 5</td>
</tr>
<tr>
<td>Impermeable areas:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public amenity</td>
<td>Acceptable (with interceptor) - 4</td>
<td>Acceptable (with interceptor) - 4</td>
<td>Acceptable (with interceptor) - 4</td>
</tr>
<tr>
<td>Large car parks</td>
<td>Acceptable (with interceptor) - 4</td>
<td>Acceptable (with interceptor) - 4</td>
<td>Acceptable (with interceptor) - 4</td>
</tr>
<tr>
<td>Lorry park</td>
<td>Acceptable (with interceptor) - 4</td>
<td>Acceptable (with interceptor) - 4</td>
<td>Acceptable (with interceptor) - 4</td>
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<tr>
<td>Garage forecourt</td>
<td>Acceptable (with interceptor) - 4</td>
<td>Acceptable (with interceptor) - 4</td>
<td>Acceptable (with interceptor) - 4</td>
</tr>
<tr>
<td>Major roads</td>
<td>Acceptable (subject to investigation and with interceptor) - 3/4</td>
<td>Acceptable (subject to investigation and with interceptor) - 4</td>
<td>Acceptable (with interceptor) - 4</td>
</tr>
</tbody>
</table>

1 - Prohibit/object in principle – The Agency will normally object in principle to such activities which would involve a high risk of contamination to controlled waters or a source.

2 - Presumption against - The Agency will seek to prohibit this activity by serving an absolute prohibition notice wherever possible. An objection will only be withdrawn in exceptional circumstances or where detailed investigation can demonstrate that the activity does not represent a high risk of contamination to controlled waters and can be adequately controlled by conditions that form part of a statutory consent or agreement.

3 - Prohibition notice/Consent to discharge - The Agency will normally have no objection in principle to this type of discharge, providing it is controlled through the use of a prohibition notice with conditions and a consent to discharge is obtained where appropriate. Initial screening of a consent application will identify whether further investigation and assessment is required prior to consent being determined. Consent conditions may restrict the quality and quantity of effluent discharged and where assessment identifies a potential for significant change in groundwater quality, long term monitoring of both the discharge and remote observation points may be required. Principle to this discharge which it considers will have no discernible impact on water resources or quality. No conditions or monitoring are likely to be required.

4 - No objection subject to standard conditions - The Agency will normally have no objection in principle to this discharge subject to standard conditions on a prohibition notice or planning permission to protect the quality of controlled waters or a source. An investigation may be required to determine the risk of contamination and the formulation of appropriate conditions. Long term monitoring of controlled waters in the vicinity of such activities may be required.

5 – No objection - The Agency will normally have no objection in principle to this discharge which considers will have no discernible impact on water resources or quality. No conditions or monitoring are likely to be required.
### Appendix 3

Comparison of inert waste acceptance criteria and environmental quality standards

**Note:** These tables are reproduced out of context and will not be updated; the source documents should be referred to whenever comparisons are necessary.

Table showing limiting values in Parts Per Million (ppm)

<table>
<thead>
<tr>
<th>Component</th>
<th>Inert Waste (L/S at 10/1)</th>
<th>Environmental Quality Standards&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Surface Water Abstraction Imperative Standards&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Surface Water Abstraction Guideline Standards&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Combined Limiting Values</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Fresh-water&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Estuary</td>
<td>Marine</td>
<td>A1</td>
</tr>
<tr>
<td>pH</td>
<td>mg/kg</td>
<td>mg/l</td>
<td>mg/l</td>
<td>mg/l</td>
<td>mg/l</td>
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<tr>
<td>Asbestos</td>
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<td>0.05</td>
<td>0.025</td>
<td>0.025</td>
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<tr>
<td>Cadmium</td>
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<td>0.005</td>
<td>0.005</td>
<td>0.0025</td>
<td>0.005</td>
</tr>
<tr>
<td>Chromium (total)</td>
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<td>0.005</td>
<td>0.015</td>
<td>0.015</td>
<td>0.005</td>
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<td>0.0005</td>
<td>0.0003</td>
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</table>


<sup>d</sup> For soft water (0-50 µg/l CaCO₃) and for Salmonoid (game) fish.
Table showing limiting values in Parts Per Billion (ppb)

<table>
<thead>
<tr>
<th>Component</th>
<th>Inert Waste*(L/S at 10/1)</th>
<th>Environmental Quality Standardsb</th>
<th>Surface Water Abstraction Imperative Standardsc</th>
<th>Surface Water Abstraction Guideline Standardsd</th>
<th>Combined Limiting Values</th>
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<tr>
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<td>pH</td>
<td></td>
<td>6 - 9</td>
<td>6 - 8.5</td>
<td>6 - 8.5</td>
<td>6.5 - 8.5</td>
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<tr>
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<td>500</td>
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<td>25</td>
<td>25</td>
<td>50</td>
</tr>
<tr>
<td>Cadmium</td>
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<td>5</td>
<td>2.5</td>
<td>5</td>
</tr>
<tr>
<td>Chromium (total)</td>
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<td>5</td>
<td>15</td>
<td>15</td>
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<tr>
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<tr>
<td>Manganese</td>
<td>50</td>
<td>100</td>
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</table>


h) For soft water (0-50 µg/l CaCO₃) and for Salmonoid (game) fish.