Study on methodological aspects regarding limit values for pollutants in aggregates in the context of the possible development of end-of-waste criteria under the EU Waste Framework Directive

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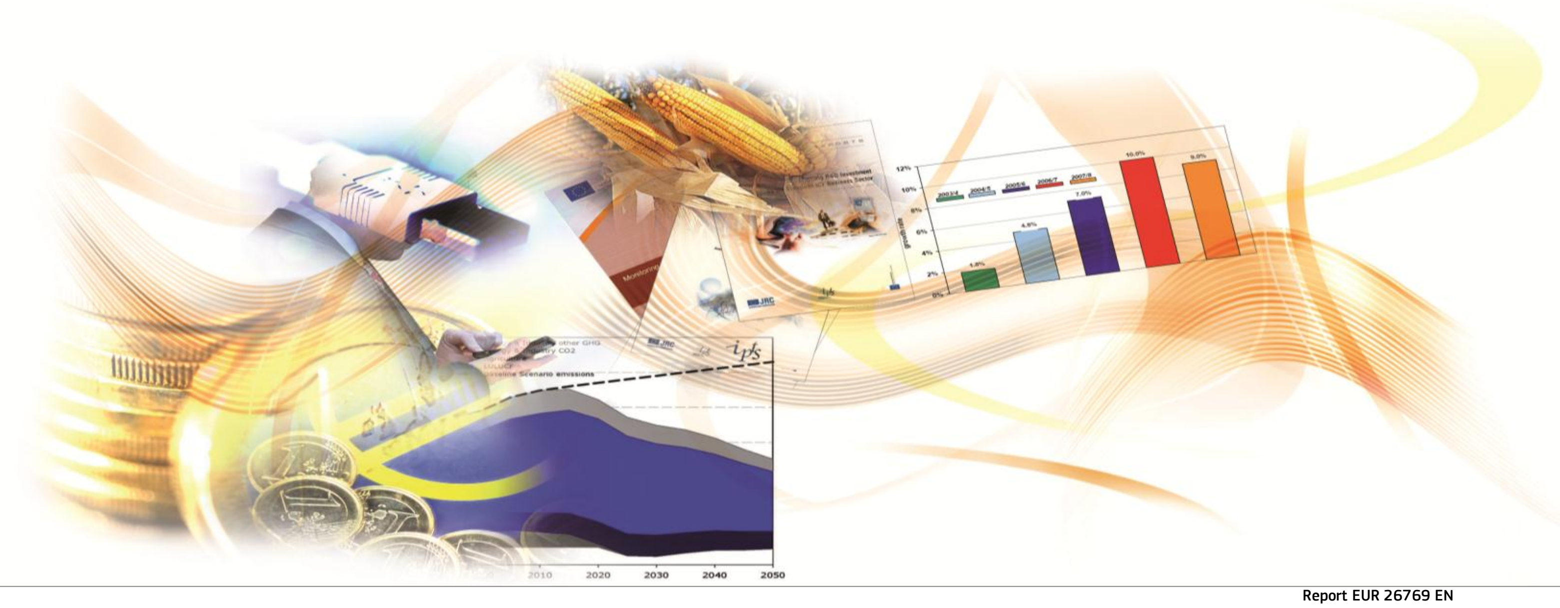

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Study on methodological aspects regarding limit values for pollutants in aggregates in the context of the possible development of end-of-waste criteria under the EU Waste Framework Directive

Final Report
September 2014

JRC-IPTS

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PREFACE

The present document represents an edited and reviewed version of the tendered study performed by DHI (Denmark) in cooperation with ECN and Hans van der Sloot Consultancy for the Joint Research Centre – Institute for Prospective Technological Studies.

Objectives of the study

The study was launched to provide a science-based analysis of how limit values for pollutants could be developed as part of end-of-waste criteria for aggregates in accordance with Article 6 of the Waste Framework Directive (2008/98/EC). In particular, the study had to:

- identify and assess the pollution risks of using aggregates derived from waste;
- review how the use of aggregates is regulated today in the EU with respect to avoiding pollution;
- assess the need for including limit values for pollutants in end-of-waste criteria;
- assess the suitability of different types of pollutant limit values;
- identify and assess the different methodological approaches for deriving pollutant limit values;
- identify the most suitable testing approaches and methods, including simplified modes of compliance;

The study had to take into account the information and analyses from the 'Aggregates Case Study' in the 'End-of-Waste Criteria' report (EUR 23990 EN) and from the related background report on aggregates.

Organisation of the study

This study was commissioned to DHI and its co-operation partners ECN and Hans van der Sloot Consultancy (Contract no. 151932-2010-A08-DK). The work was started in 2011 by Ole Hjelmar (DHI, project manager), Hans van der Sloot (Hans van der Sloot Consultancy), Rob Comans (ECN), André van Zomeren (ECN), Jiri Hyks (DHI) and Anke Oberender (DHI).

Several stakeholders and experts have contributed with data and information to the study. The work in progress was discussed by a limited group of representatives from environmental authorities, industry, consulting companies, research institutions and standardisation committees at a workshop held in Amsterdam on 7 July 2011, organised by the consultant consortium.

The final report was delivered to JRC-IPTS in the summer of 2012. Subsequently, JRC-IPTS has verified and discussed data internally. Member States representative experts were contacted with requests for additional information in 2013-2014.

Scope

The present study describes a possible way of establishing limit values for pollutants in waste-derived aggregates with a view of using such aggregates in a wide variety of construction projects. More specifically, the study focuses on aggregate substances that are subject to leaching and/or release through wear.

The study does not focus on other aspects of possible pollution from using waste-derived aggregates such as emission of volatile substances from aggregates or radiation from aggregates.

Moreover, the work centres on the possible use of recycled aggregates in construction projects. It does not envisage other applications, such as for instance the agricultural use of gypsum from recycled plasterboards.

Furthermore, the current study does not deal in detail with the use of recycled excavated soils and stones, for which other environmental considerations may apply apart from possible leaching phenomena.

Finally, it should be stressed that the current study concentrates on one, albeit important, condition for EU end-of-waste criteria, namely the possible adverse environmental or human health effects from using aggregate materials outside the waste legislative framework. Other end-of-waste conditions according to Article 6(1) of the Waste Framework Directive, such as the use, market conditions and technical requirements or legal standards are excluded from the scope of this preliminary study. In particular, requirements on geometry, durability and physical properties of waste aggregates are not being addressed in this document, but may be important when considering possible end-of-waste criteria for waste aggregates. Therefore, the present study should not be considered as a feasibility analysis for the establishment of EU end-of-waste criteria for aggregates.

Building blocks of the proposed methodology in this study

The proposed methodology to set leaching limit values, as outlined in this document is based on the steps outlined below and illustrated by examples:

Steps	*Illustrative examples**
Waste aggregates are classified in different groups according to their origin and composition.	Waste aggregates are classified into categories such as recovered concrete, recovered bricks, etc.
An initial detailed assessment of the leaching behaviour of a wide range of substances is made for every waste aggregate group by means of standardized tests (initial type testing). This assessment results in comprehensive information on the average leaching behaviour of every substance from materials belonging to a group, as well as on the spread of the leaching behaviour between different materials within the same group.	Many different recovered concrete material samples from a wide variety of suppliers are tested for leaching. This results in a database with leaching values for As, Cu, Pb, Hg, fluorides, chlorides, sulphates, etc. In the following sulphate is often used for the purpose of illustration, but it could be any other relevant substance of concern.
A scientifically sound risk-based approach is used to model several typical use scenarios for (waste) aggregates. These scenarios consider the transport of leaching substances from the source (the used aggregate) following a pathway (through its surrounding environment) towards the receptor (generally a surface or groundwater body). Model calculations result in time-dependent concentration curves of the transported leached substances, at the receptor, for the expected lifetime of the construction project.	Scenarios are modelled e.g. for recovered concrete used in pillars for a bridge spanning a river, for use in a highway road, for use in a warehouse, etc. Time dependent concentration levels for sulphate (or other substances of relevance) at a point of compliance in the nearby water body (river, underground aquifer, etc.) are calculated for a period of an appropriate length of time (which can exceed the lifetime of the construction project).
Leaching limits for (waste) aggregates at the source are then determined based on the quality	It is calculated that for a maximum leaching value of X for sulphate in an aggregate used in

Steps	*Illustrative examples**
requirements at the final receptor, viz. the maximum allowed concentration of substances at the receptor, at any time during or within a specified time after the lifetime of the construction project.	the highway road, the drinking water quality norm of Y mg/l sulphate in the underground aquifer will never be exceeded during a specified period of time (generally longer than the lifetime of the construction project).
As a result, various sets of leaching limits for (waste) aggregates may be established, depending on the typical pathway the leached substance will take in a given use scenario and the quality requirements at the receptor. The strictest leaching limits will be obtained for direct contact between the aggregate and the receptor, with more lenient limits for more shielded and remote uses of the aggregate. Specific shielding conditions may become part of conditions of use associated with end-of-waste status for various classes of materials associated with various sets of limit values.	For example rather strict sulphate leaching limits will be obtained for a pillar in direct contact with the water in a small lake or an aquifer. More lenient sulphate leaching limits will be obtained for an aggregate shielded e.g. by an asphalt cover in a highway road 20 m above the aquifer.
Through clustering all these various sets of leaching limits, a small number of distinct material classes may be defined at EU level, preferably in harmonised European standards under the Construction Products Regulation (305/2011). Apart from a set of leaching limits, a number of restrictions on the aggregate use are established for every material class, in line with the foreseen applications. These restrictions may thus range from none to very stringent. They may apply to the use during the service life of the aggregate as well as to the treatment and disposal at the end-of-life.	For example, four material classes could be established (Class 1, 2, 3, 4) Use scenarios involving direct contact between aggregates and surface water or groundwater could be grouped in Class 1 with very strict leaching limits for sulphate (and other substances). Use scenarios for covered base materials in roads at a safe distance from the groundwater table or similar construction projects could be clustered in Class 3 with more lenient leaching limits for sulphate (and other substances). No use restrictions might apply for Class 1 materials. An aggregate of Class 3 should for example not be used in construction projects with a distance to the nearest water body of less than 50 metres and it would have to be removed after the end of its service life).
Once material classes have been established from use scenarios and a waste aggregate group has been comprehensively characterized inter alia by collection and assessment of extensive leaching data, subsequent routine testing (factory production control) for a certain material in that group will focus on the most relevant substances for the specific group. Whether a substance is relevant for routine testing depends on its typical leaching behaviour (average and spread) in that	The initial leaching assessment for the group of recovered concrete aggregates may have indicated that many waste concrete materials are not likely to meet the strict sulphate limits for Class 1 (direct water content). Waste concrete materials might therefore have to undergo routine sulphate leaching testing when applying for Class 1 use. Nonetheless, a waste concrete material may e.g. be exempt from routine testing on sulphate leaching for use in Class 3, given the

Steps	*Illustrative examples**
waste aggregate group and the leaching limits imposed by the material class. If the candidate material passes the routine tests it may receive end-of-waste status and be categorized in the corresponding material class. In principle, this would allow the end-of-waste aggregate material to be used for the purposes described in its material class, provided the corresponding conditions on use and end-of-life treatment are respected. If the material does not pass the tests for the envisaged material class, it may be subject to further treatment before undergoing renewed tests or it may be classified in a different material class with less strict conditions. A certain level of routine testing should be required to uphold the end-of-waste status for a given waste-derived aggregate.	less strict sulphate leaching requirements compared to Class 1 seen in view of the initial type testing. A waste concrete material may not pass the routine sulphate tests for Class 1, but pass the test for Class 2 and be declared end-of-waste for use as a Class 2 material. Alternatively, the waste concrete material may undergo additional treatment and be retested to check whether it meets Class 1 requirements.
Even though material classes may exist at EU level, Member States might be given the possibility to impose additional restrictions on the use of certain materials or to exclude certain classes, e.g. in order to protect sensitive areas.	Member State Z may decide to exclude any waste derived aggregates for use in wetlands declared as protected natural reserves.

* These examples just serve to illustrate the corresponding steps and in some cases may be completely fictive. Hence, they should not be seen as having any scientific or legal validity.

Strengths and limitations of the proposal in this study

The methodology proposed in this study for the establishment of leaching limits for waste aggregates in the context of possible end-of-waste criteria has a number of clear strengths as well as some limitations.

Strengths

- The proposed methodology mimics the existing EU methodology used for acceptance of waste at landfills and is largely compatible with the current views and approaches to waste aggregates in many Member States.
- The methodology is comprehensive and could provide an EU level playing field that reaches beyond the end-of-waste scope, as it is built on harmonized European standards under the Construction Products Regulation that may also apply to natural or industrially manufactured aggregates. The current document indicates that several non-waste aggregates may exhibit pronounced leaching behaviour as well, whereas few Member States currently have comprehensive regulations in place to control leaching from non-waste aggregates.
- The methodology is risk based and hence provides a clear scientific background for proposing limit values, in line with Article 6(1)(d) of the Waste Framework Directive.

- Referring directly to harmonized European standards applicable for aggregates could help simplify any possible end-of-waste legislation for aggregates, therefore minimizing possible administrative and legal burden.
- A better insight in long term leaching behaviour and factors controlling leaching can be obtained from more extended initial type testing or characterization tests. In addition, the proposed tests also provide the potential for modelling release under conditions beyond the scope of the laboratory tests.
- By categorizing aggregates into a limited number of classes, each with their own set of limits, the methodology provides for limit values that are in accordance with the foreseen use of the aggregates. On the one hand, it is more flexible than a single set of robust but extremely strict "all-purpose" limits that would be impossible for most waste aggregates to meet and might thus enable more materials to receive end-of-waste status. On the other hand, once established, it provides for a relatively simple and workable approach to the wide variety of (waste) aggregate materials and applications that exist, while ensuring appropriate environmental and human health protection.

Limitations

- Unless direct reference could be made to relevant harmonized European standards under the Construction Products Regulation regulating the leaching limits and use conditions of aggregates for different purposes, end-of-waste criteria would have to provide for detailed leaching limits and possible use restrictions for various applications of different waste aggregates. Moreover, without such clear product standards under the Construction Products Regulation, the shift in aggregate status from waste to product could be hampered by possible adverse environmental or human health impacts. It has to be noted indeed that current requirements in many Member States are much less stringent for natural or industrial aggregates with product status than for waste aggregates. As such, current waste legislation for aggregates often provides better environmental and human health safeguards than existing product legislation for aggregates. In this context, it should be noted as well that the development of uniform harmonized European standards for aggregates under the CPR may take several years to be completed.
- Extensive initial type testing for every type of aggregate and performing routine leaching tests could be resource-intensive and costly. Moreover, an independent body might be needed to guard the data quality and maintain a centralized Community database on leaching data for different (waste) aggregate material groups in order to ensure a level playing field across Member States.
- For the development of material classes, it might be very challenging to cluster the wide spectrum of possible use scenarios into a limited series of material classes with matching restrictions. Moreover, this clustering exercise should take into account differences in climatic conditions (e.g. rainfall and temperature patterns) as well as geological differences across Europe.
- Monitoring and enforcing the correct use of end-of-waste aggregates, including checking whether certain restrictions with regard to shielding such aggregates from water bodies have been respected, could possibly pose practical challenges.
- Monitoring and enforcing any prescribed end-of-life treatment and disposal actions for end-of-waste aggregates could possibly pose organisational and legal challenges, especially given the long life time of many construction projects (e.g. change of ownership, bankruptcy, etc.).

Disclaimer

It should be stressed that, at this point, the European Commission has not undertaken any steps for the preparation of end-of-waste criteria for waste aggregates. Therefore, the following should be noted:

- the present document does not constitute the opinion of the European Commission regarding the feasibility of end-of-waste criteria for waste aggregates and its required methodology, nor regarding feasibility and methodology for setting limit values for pollutants as part of possible end-of-waste criteria for waste aggregates;
- the present document does not constitute any commitment by the European Commission to start work on the development of end-of-waste criteria for waste aggregates or related preparatory work.

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TERMS AND DEFINITIONS

adsorption	Adherence of the atoms, ions, or molecules of a gas or liquid to the surface of another substance, called the adsorbent.
aggregate	Granular material used in construction. Aggregates may be natural, manufactured or recycled (from EN 13242).
anoxic	In the absence of oxygen.
attenuation	The reduction of the concentrations of chemical species in a solution by means of physical, chemical and biological reactions as it migrates through a solid medium.
anion	Any ion with a negative charge.
batch tests	Leaching tests which are carried out on a single portion of material using a single portion of leachant i.e. there is no renewal of leachant during the test.
bound use	Bound use refers to a monolithic use of an aggregate material whereas unbound use refers to its use in granular form, e.g. after crushing of bigger lumps.
buffer	A solution containing both a weak acid and its conjugate weak base whose pH changes only slightly on addition of acid or alkali.
cation	An ion with a positive charge.
cation exchange	A reversible chemical reaction between a solid (cation exchanger) and a fluid (usually a water solution) by means of which cations may be interchanged from one substance to another.
complexation	The formation of an ion into a molecular structure consisting of a central atom bonded to other atoms by coordinate covalent bonds
congeners	Related chemicals (e.g. the 209 PCB congeners)
demineralised water (DMW)	Water from which minerals/ions have been removed e.g. by ion exchange (deionised water), reverse osmosis and/or distillation. When prescribed in test standards, a maximum conductivity is often specified.
desorption	The process of removing an adsorbed material from the solid on which it is adsorbed
diagenesis	The set of processes, including solution, that alter sediments at low temperatures after burial
diffusion	The spontaneous mixing of one substance with another when in contact or separated by a permeable membrane or microporous barrier
dissolution	Molecular dispersion of a solid in a liquid
E_H	A measure of the oxidation reduction potential. See **oxidation/reduction**.
eluate	As **leachate** but usually in the context of a laboratory test.
emission	Release of substances from one environment, medium or phase to another.
equilibrium	Chemical equilibrium is a condition in which a reaction and its opposite or reverse reaction occur at the same rate resulting in a constant concentration of reactants. Physical equilibrium is exhibited when two or more phases of a system are changing at the same rate so the net change in the system is zero.
extraction	A separation operation that may involve three types of mixture: (1) a mixture composed of two or more solids (2) a mixture composed of a solid and a liquid - as in this context (3) a mixture of two or more liquids. One or more components of such a mixture are removed (extracted) by exposing the mixture to the

	action of a solution or solvent in which the component to be removed is soluble.
heterogeneous	Any mixture or solution comprising two or more substances which are not uniformly dispersed.
homogeneous	Any mixture or solution comprising two or more substances which are uniformly dispersed.
hydraulic head	The pressure exerted by a fluid expressed as metres above a reference point.
hydraulic conductivity	The **permeability** of a material to water.
infiltration	The movement of water (usually rainwater) into and through a solid material.
inorganic	Chemicals that are generally considered to include all substances except hydrocarbons and their derivatives or all substances which are not compounds of carbon with the exception of carbon oxides and carbon disulphide.
ionic strength	A measure of the concentration of ions in solution.
kinetic	Chemical phenomena can be studied from two fundamental approaches: (1) **thermodynamics**, a rigorous and exact method concerned with equilibrium conditions of initial and final states of chemical changes and (2) **kinetics**, which is less rigorous and deals with the rate of change from initial to final states under non equilibrium conditions. The two methods are related. Thermodynamics, which yields the driving potential - a measure of the tendency of a system to change from one state to another - is the foundation on which kinetics are built.
labile	Descriptive of a substance that unstable and is readily inactivated for example by high temperature or radiation
leachant	Liquid in contact with or which will be brought in contact with a solid which extracts soluble components of the solid.
leachate	Liquid containing soluble components extracted from a solid.
leaching	The process by which the soluble components of one phase (usually a solid) are transferred to another phase (usually a liquid).
ligands	A molecule, ion or atom that is attached to the central atom of a coordination compound, a chelate or other complex. Ligands are also called complexing agents.
L/S	L/S (the Liquid to Solid ratio) describes the ratio between the amount of liquid (in a leaching test normally demineralised water) measured in litres and the amount of solid (e.g. aggregate measured as dry mass) measured in kg, which are brought into contact with each other in a leaching test. In a batch leaching test L/S is based on the total amount of water added to the solid, whereas L/S in a column or percolation leaching test is based on the amount of eluate collected at any time during the test
natural aggregates	Natural aggregates are produced from mineral sources and include e.g. sand and gravel resulting from rock erosion and crushed rock extracted from quarries.
organic	Chemicals that are generally considered to include all compounds of carbon except carbon oxides and sulphides.
oxidation/reduction potential	A measure of the ability of a system to cause oxidation or reduction reactions. Oxidation and reduction are reactions in which electrons are transferred. Oxidation and reduction always occur simultaneously (redox reactions).The substance that gains the electrons is termed the oxidizing agent and the substance that loses the electrons is termed the reducing agent.
partitioning	The distribution of molecules in different states or phases in a system for example as solid, liquid or gas.

pE	A measure of the redox potential.
percolation	The movement of a liquid through a solid.
permeability	A measure of the ability of a material to transmit fluid under a hydraulic gradient.
pH	pH is a value taken to represent the acidity or alkalinity of an aqueous solution. It is the negative logaritm of the H^+ activity.
porosity	The relative volume of void space to the total volume occupied by a material.
precipitation	The settlement of small particles out of a liquid or gaseous suspension by gravity or as the result of a chemical reaction.
redox	See **oxidation/reduction potential**
recycled aggregates	Aggregates obtained from reprocessing of materials previously incorporated in construction.
secondary aggregates	Aggregates obtained from other (e.g. industrial) processes that have not previously been used in construction.
solubility	The ability or tendency of one substance to blend uniformly with another e.g. solid in liquid, liquid in liquid, gas in liquid, gas in gas. Solids vary from 0% to 100% in their degree of solubility in liquids depending on the chemical nature of the substances.
sorption	A surface phenomenon that may be either absorption, adsorption, or a combination of the two. The term is often used when the specific mechanism is not known
speciation	Determination of the precise chemical form of a substance present in a material.
standard	A documented method or specification to which activities should conform.
thermodynamic	See **kinetic**.
unbound use	See **bound use**
validation	Confirmation of soundness and defensibility (of a method or procedure).

ABBREVIATIONS AND ACRONYMS

ANC	Acid Neutralisation Capacity
ArtAggr	Artificial Aggregates
Avg	Average
BFSlag	Blast Furnace Slag
BMD	Building Materials Decree (The Netherlands)
BOFSlag	Basic Oxygen Furnace Slag
BTEX	Benzene, toluene, ethylbenzene and xylene(s)
CEN	European Committee for Standardisation
CEN/TR	European Committee for Standardsation Technical Report
CEN/TS	European Committee for Standardisation Technical Specification
CBA	Coal Bottom Ash
CBoiSlag	Coal Boiler Slag
CFA	Coal Fly Ash
CFBCA	Coal Fluid Bed combustion Ash
CGLT	Compacted Granular Leaching Test (part of TS-2 from CEN/TC 351)
COD	Chemical Oxygen Demand
CPD	Construction Products Directive (89/106/EEC)
CPR	Construction Products Regulation (Regulation (EU) No 305/2011 of the European Parliament and of the Council)
CSTR	Continuously Stirred Tank Reactor
C&D	Construction and Demolition
DOC	Dissolved Organic Carbon
DMLT	Dynamic Monolithic Leaching Test
DMW	Demineralised water (see also Terms and Definitions)
DSLT	Dynamic Surface Leaching Test (TS-2 from CEN/TC 351)
DWQC	Drinking Water Quality Criteria
EAFSlag	Electric Arc Furnace Slag
EC	Electrical Conductivity (also European Commission)
ECHA	European CHemicals Agency
EINECS	European Inventory of Existing Chemical Substances
ELT	End-of-Life Tyres
EN	European Standard
EoL	End of Life
EOTA	European Organisation for Technical Approvals
EoW	End of Waste
ER3	Essential Requirement No. 3: Hygiene, health and the environment (in CPD)

EWC	European Waste Catalogue (now List of Wastes (see LOW) as defined by Commission Decision 2000/532/EC and subsequent amendments)
FGD	Flue Gas Desulphurisation
FPC	Factory Production Control
FT	Further Testing
GranTyre	Shredded and Granulated Tyres
GWQC	Groundwater Quality Criteria
ISO	International Standardisation Organisation
ITA	Initial Type Assessment
I-TEQ	International Toxicity Equivalents
ITT	Initial Type Testing
LD slag	Steel slag from the Linz-Donawitz process (one type of BOF slag)
LFD	Landfill Directive (1999/31/EC)
LOW	(European) List of Waste (see also EWC)
L/S	Liquid to Solid Ratio (see also Terms and Definitions)
MixC&D	Mixture of Concrete, Tiles and Ceramics
MPA	Maximum Permissible Addition (in the Dutch SQD)
MSWI	Municipal Solid Waste Incinerator
MSWIBA	Municipal Solid Waste Incinerator Bottom Ash
MSWIBoiA	Municipal Solid Waste Incinerator Boiler Ash
MSWIFA	Municipal Solid Waste Incinerator Fly Ash
NatAggr	Natural Aggregates
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated biphenyls
PCDD	Polychlorinated dibenzodioxins
PCDF	Polychlorinated dibenzofurans
POC	Point of Compliance
POP	Persistent Organic Pollutants
PSlag	Phosphorous Slag
QA	Quality Assurance
QC	Quality Control
REACH	European Community Regulation on chemicals and their safe use (EC 1907/2006) - **R**egistration, **E**valuation, **A**uthorisation and Restriction of **Ch**emical substances.
RecAsph	Recycled Asphalt
RecBrick	Recycled Bricks
RecCer	Recycled Ceramics
RecCon	Recycled Concrete
RecGls	Recycled Glass
RecTile	Recycled Tiles

RDS	Regulated Dangerous Substance
RNC	Risk of Non-Compliance
SIWAP	Sickerwasserprognose (German research project)
SQD	Soil Quality Decree (The Netherlands)
Stdev	Standard Deviation
TC	Technical Committee
TDA	Tyre Derived Aggregates
TDS	Total Dissolved Solids
TR	Technical Report
TS	Technical Specification
TOC	Total Organic Carbon
UK	United Kingdom
UVCB	Unknown or Variable composition, Complex reaction products or Biological materials
WAC	Waste Acceptance Criteria
WHO	World Health Organisation
WFD	Waste Framework Directive (2008/98/EC) – not to be confused with the Water Framework Directive (2000/60/EC)
WFT	Without Further Testing
WQC	Water Quality Criteria
WRAP	Waste and Resources Action Programme (UK)
WT	Without Testing

Executive Summary

Background

The **Waste Framework Directive** (WFD) 2008/98/EC includes the option to set so-called **end-of-waste (EoW) criteria** under which specified waste fractions shall cease to be waste. If these criteria are fulfilled, the material will no longer be classified as a waste but it will instead become a product subject to free trade and use (albeit for specific purposes). In accordance with Article 6 (1) of the WFD, a waste material (substance or object) may cease to be waste as defined in the WFD when it has undergone a recovery, including recycling, operation and is commonly used for specific purposes, has a market value, fulfils the technical requirements for the specific purpose and meets existing standards and legislation applicable to products. In addition, criteria shall be set to ensure that the use of the material will **not lead to overall adverse environmental or human health impacts** (indent (d) in Article 6 (1)). These criteria shall include limit values for pollutants where necessary and shall take into account any possible adverse environmental effects of the material.

The **European Commission's Joint Research Centre, Institute for Prospective Technological Studies** (EC JRC-IPTS) has established general guidelines for the development of EoW criteria for waste materials. Furthermore, the JRC-IPTS has carried out a number of studies leading to proposals for European end-of-waste criteria for certain waste streams and it has launched a number of **preliminary studies** to collect in-depth background information about certain important aspects of possible future candidate materials for end-of-waste. In this context, the JRC-IPTS had launched a call for tender for a study on the methodological aspects regarding limit values for pollutants in aggregates in the context of the development of end-of-waste criteria, i.e. addressing the above mentioned requirement to prevent adverse environmental or human health impacts. More specifically, the study had the following objectives:

- to identify and assess the **pollution risks** of using aggregates derived from waste;
- to review how the use of aggregates is **regulated today** in the EU with respect to avoiding pollution;
- to assess the **need for including limit values** for pollutants in possible end-of-waste criteria;
- to assess the **suitability** of different types of limit values;
- to identify and assess the different **methodological approaches for deriving** pollutant limit values; and
- to identify the most suitable **testing** approaches and methods, including simplified modes of compliance.

The study focuses primarily on environmental risks and limit values associated with ***leaching*** of substances from aggregates in relation to EoW whereas the prevention of environmental and human health impacts related to the *composition* of the aggregates is discussed more briefly. The study was started in 2011 by DHI (Denmark) in cooperation with ECN and Hans van der Sloot Consultancy and this report describes the study and the resulting findings and proposals.

Aggregates and potential pollution in relation to EoW

In the context of this study, aggregates constitute **granular materials used in construction works**. In principle, waste-derived aggregates with EoW status at EU level could be used and traded freely unless some restrictions are included in the EoW approval procedure. At this stage, it is unclear whether it would be feasible to **impose conditions** on the use/type of application of the recycled aggregates as part of the EoW criteria.

The environmental protection aspects of the use of a recycled waste-derived aggregate that would achieve possible EoW status at EU level and become a construction product would no longer be regulated by waste legislation. It would only be subject to compliance with the **Construction Products Regulation** and **national environmental criteria** for the use of aggregate products in construction works. However, currently only the Netherlands and Germany have implemented or are implementing environmental protection legislation on the use of construction products, including aggregates, which includes leaching testing and leaching limit values. In the other Member States such legislation does not (yet) exist. With this in mind and in consideration of I Article 6 (1), indent (d) of the WFD, in this study it is assumed that EoW criteria should ensure the following:

- a high degree of **certainty** that aggregates used under possible EoW status actually fulfil the EoW criteria to be developed. This implies sufficient proof (e.g. in the form of a dossier) of absolute compliance with the criteria up front and effective subsequent quality control (factory control) measures.

- that the generally acknowledged underlying source-pathway-receptor scenarios should clearly reflect the presence or absence of any **restrictions or conditions on the use** of waste derived aggregates with EoW status, taking into account that most EU Member States have no legislation that regulates the potential environmental impact of construction products..

- that the underlying source-pathway-receptor scenarios should not only address the service life situation (i.e. the period during which the aggregate serves an intended and useful purpose) but rather the **entire lifecycle**, and in particular the end-of-life (EoL) situation where the aggregate, if left unattended, may disintegrate and become exposed over a long time period to ambient conditions that may favour the release of potentially polluting substances. This implies the inclusion of source term scenario(s) that reflect maximum and long term exposure conditions and includes the effects of potential chemical changes (e.g. carbonation of alkaline materials).

The **methodology** proposed for the setting of EoW criteria and limit values for waste-derived aggregates to protect the environment and human health from adverse impacts is largely independent of the aggregate in question. The methodology follows a **conceptual risk assessment model** that considers a chain of events that include the potential contamination **source**(s), i.e. the aggregate in question, and **receptor**(s) as well as the potential migration **pathways** between them. For a risk or impact to occur, the chain must remain unbroken, and an undesired effect must occur at the receptor.

The receptor may be soil, groundwater or surface water below or downstream of the aggregate application, and the primary quality criteria to be complied with at the point of compliance should be **water** quality criteria that are acceptable in all EU Member States. The leaching-related criteria mainly include **inorganic** substances since reliable leaching standards for organic substances have not yet been developed at EU level.

The impact on human health of substances in the aggregates through exposure routes such as inhalation, ingestion, direct contact and occupational exposure is not addressed in detail in this study. It is assumed that existing national legislation on maximum content of (dangerous) substances in materials that can be used without restrictions (e.g. waste aggregates and soil) sufficiently reflect and protect against the risks associated with these exposure routes. Member States without such legislation may have to develop or adopt it. The development of such limit values in various EU Member States has already been the subject of another European study on soil screening values (Carlon, 2007).

Release of substances from aggregates

In general, **leaching tests** rather than analysis of total composition (content) should be used to assess the release or potential release of substances from aggregates to groundwater, surface water and soil, because the leaching properties of an aggregate are directly related to risk of such impacts. There is seldom a direct relationship between the content of a substance in an aggregate and the leaching behaviour of that substance, because elements may be incorporated into the aggregate matrix and may not become accessible upon contact with water, and because solubility limitations by minerals and sorption processes may prevent the elements from leaching at levels proportional to their content. The fraction of a substance that is available for leaching may thus be a very minor portion of its total content, even under the most extreme conditions (acidic conditions and size-reduced to a fine granular material). If under such conditions leachability is still very limited, then a constituent may often be regarded as non-critical with respect to release.

For substances for which no standardised leaching tests exist or for which leaching tests cannot be performed, assessments based on **content** may nevertheless be necessary. This is in particular the case for organic substances. Although content in general is a poor indicator of the potential risk of an impact on the environment (groundwater, surface water, soil), such results may be used in the evaluation of potential health effects caused by contact with or ingestion or inhalation (as dust) of the aggregates.

It has been shown to be particularly functional to describe the leaching of inorganic substances from aggregates as a function of the **liquid-to-solid ratio (L/S)** and as a function of **pH** under equilibrium-like conditions. For constant or average long term flow or percolation conditions, L/S is proportional to time (S = the amount of material in question will remain constant, and L, the amount of water that has been in contact with the material, will, at any time, correspond to the accumulated amount of water that has percolated through the material), and for modelling purposes the L/S scale may therefore be converted to a time scale for a given physical scenario. Other influences that affect the leachability of substances such as redox potential and complexation processes may also be taken into account.

Standards and guidance on sampling and pre-treatment of aggregates, performance of leaching tests and chemical analysis of aggregates and eluates from leaching tests on aggregates have been developed by the European standardisation committees CEN/TC 292: “Characterisation of waste” and CEN/TC 351: “Construction products – Assessment of the release of dangerous substances”. Additional guidance on sampling has been provided by some of the CEN product technical committees, e.g. CEN/TC 154 on aggregates, as part of the product standards.

The following small “tool kit” of leaching tests is proposed for assessment of the leaching properties of aggregates in relation to EoW considerations:

- pH dependence tests (CEN/TS 14429 and CEN/TS 14997) – leaching as a function of pH
- Percolation test (CEN/TS 14405 and CEN/TC 351/TS-3) – leaching as a function of L/S
- Batch leaching test (EN 12457-1, 2 or 3), to be included when used for compliance or factory production control (FPC) – leaching as a function of L/S but only determined at one L/S value (EN12457-1 and 2) or two L/S values (EN 12457-3)

The above tests are all performed on **granular or size reduced material** in order to account for the more critical parts of the lifecycle of the waste-derived aggregates with EoW status (used with or without restrictions). The application of the pH dependence leaching test is particularly important also in relation to the Construction Products Regulation (CPR, 305/2011/EU)) which, in contrast to the Construction Products Directive (89/106/EEC) it replaced in 2013, in its Basic Requirements on protection of the environment and human health addresses the **entire lifecycle** of a product (see below). CPD only addressed the service life of a product.

In order to facilitate the use of test methods as part of legislative systems and to avoid excessive or redundant testing, both CEN/TC 292 and CEN/TC 351 have developed so-called **hierarchic test** structures based on a comprehensive **initial characterisation** that may e.g. comprise all of the above leaching tests as well as chemical composition analyses which then become the reference for subsequent day-to-day or recurring routine testing, using e.g. only the batch test. The assessment of a waste-derived aggregate in relation to fulfilment of possible EoW criteria will be based on the initial characterisation and compliance could then be checked regularly by the simpler **routine testing**. It is proposed to adopt the system developed by the CEN product standardisation committees and CEN/TC 351 in the context of implementing the so-called Essential Requirement 3 (ER3) of the Construction Products Directive (CPD) which aims to ensure that materials used in construction works will not be a threat to the environment or the hygiene or health of humans. The initial characterisation (Initial Type Assessment (ITA)) involves the development of a dossier which will be evaluated by a competent body. The subsequent routine testing is generally referred to as Factory Production Control (FPC).

For the purpose of assessing the compliance of test results for waste-derived aggregate with possible test limit values for achievement of EoW status, a statistical approach based on calculation of a so-called **k-value** is proposed. The k-value, which is calculated from the (EoW) limit value and the average and standard values of the normally distributed test results for a specified number of observations (samples), quantifies the risk of exceeding the limit value for a specified reliability and an accepted risk of exceeding the limit value. It should be noted that leaching test results generally are log normally distributed and therefore will have to be transformed to and from logarithmic representation before and after the conformity analysis. Using this approach, the calculated k-value obtained from the test results for a specific material can be compared to a tabled set of limits values which depend on the desired reliability, the percentage of the material that must comply with the EoW criterion and the number of samples considered. If the calculated k-value is larger than the quantified k-value limit, the risk that the material will exceed the regulatory limit value is unacceptably high. What is unacceptable is defined when choosing the boundary conditions for the k-value, in particular the fraction of the material for which non-compliance can be accepted.

Properties of some waste aggregates

Leaching **data were collected** for a number of waste-derived aggregates, including recycled concrete, recycled bricks, recycled glass, recycled C&D waste, mixed C&D waste, recycled asphalt, blast furnace slag, basic oxygen furnace slag, electric arc furnace slag, phosphorous slag, coal fly ash, coal bottom ash, MSWI bottom ash, MSWI fly ash, artificial aggregate and shredded and granulated tyres. The list is not exhaustive, and the materials were selected partly because they have been used or their use has been suggested for construction purposes under waste legislation, partly on the basis of availability of leaching data. In addition, leaching data were collected for two natural reference aggregates, limestone and natural (rock) aggregate. Both percolation and pH dependence leaching data were available for a substantial number of samples of most of the aggregates from several EU Member States and for a wide range of primarily inorganic substances. The data are used to illustrate various ways of interpreting leaching test results and to compare laboratory leaching results to field observations. It is also shown that useful lessons can be learned from past mistakes made when using waste aggregates for construction purposes. Two Separate Appendices provide L/S and pH dependent leaching data on several waste-derived aggregates.

Although it is not recommended to merely adopt the EU leaching limit values for acceptance of waste at landfills for inert waste (inert LFD WAC), a preliminary comparison of the available leaching data for the aggregates with the inert LFD WAC was carried out for the purpose of identifying substances that may potentially be problematic in relation to the achievement of EoW status for the various waste-derived aggregates. An overview of the results is given in Table A, where leaching test results based on the L/S dependence test and the pH dependence test for each of the aggregates considered have been ranked in terms of substances that are close to the limit (results are consistently close to the inert LFD WAC), partially exceeding the limit (some samples exceed the inert LFD WAC, others do not), and consistently exceeding the limit (practically all samples exceed the inert LFD WAC). This overview has been based on the availability of existing leaching results, and although it does represent a substantial amount of data, it is not necessarily representative of the entire range of leachability and potentially critical substances for all of the aggregates presented.

The number of samples upon which the lists in Table A are based varies substantially from one aggregate to another. For several of the aggregates, the number of individual samples exceed 100 to 200 (for mixed C&D waste the number of samples exceeds 700), and for nearly all the aggregates, data for at least 20 samples have been available. For phosphorous slag only 14 samples and for limestone only 4 samples have been included. Since the quality and properties of limestone may vary from one quarry to another, the absence of potentially critical substances in Table A cannot be taken as proof that limestone will always comply with the inert LFD WAC. It should also be noted that data have been collected from numerous sources and studies, and although in general there is a broad coverage of inorganic substances, there is a certain variation between datasets in the number of substances included.

The substances listed in Table A should therefore be taken as indications of substances that may **possibly be problematic** if the aggregates are assessed for the purpose of achieving EoW status, and the leaching of the substances on the list should most definitely be included in the assessment which should, however, cover a much broader spectrum of substances than those identified here as potentially critical. The results in Table A show that when compared to inert LFD WAC, the leaching of one or more substances from practically all the aggregates listed may possibly be critical and may require some attention if and when the aggregates are assessed for achievement of EoW status.

The data presented here may thus contribute to but cannot alone replace the efforts that will be required to produce a full dossier on a waste-derived aggregate to be assessed for EoW status. They may also serve as a reference for benchmarking of new EoW candidate aggregates.

Table A

Overview for the aggregates included in the study of the substances for which the leachability, determined by the L/S dependence test or the pH dependence test, is close to, partially exceeding or consistently exceeding the EU leaching limit values for acceptance of waste at inert waste landfills.

Aggregate	**L/S dependence test (L/S = 10 l/kg)**			**pH dependence test (L/S = 10 l/kg)**		
	Close to the limit	Partially exceeding	Consistently exceeding	Close to the limit	Partially exceeding	Consistently exceeding
Recycled concrete		Ba, Cr, Pb		Ba	Cu, Mo, Ni, Pb, Sb, Se, Sn, V	Cr, SO4
Recycled bricks		SO4		Pb, Sb, Se	As, Cr	
Recycled glass		Cu, Pb	Sb	Ba	As, Cd, Cr, Ni	Pb, Sb
Mixed C&D waste		Cd, Cl, Pb		V	Cd. Cl, Cr, Pb, Sb, SO4, V	
Recycled asphalt				Se		
Blast furnace slag		SO4			Cl*, Sb**, Se**, SO4, V	
Basic oxygen furnace slag			V		Cd, Mo, Sb, Se,	V
Electric arc furnace slag					Ba	Cr, Mo, V
Phosphorous slag		Mo, Pb, Sb, Se			Cd, Sb, Se	
Coal fly ash		As, Ba, Cd, Cl, Cr, Mo, Ni, Pb V, Zn	SO4		As, Cd. Cr, Mo, Ni, V	Sb, Se, SO4
Coal bottom ash	As	Cd, Cr, Mo, Ni		As	Cd, Cr, Ni, SO4	
MSW incinerator fly ash		As, Cu, Cr, Ni, Sb, Se, Zn	Cd, Cl, F, Mo, Pb, SO4		As, Ba, Cu, Ni	Cd, Cl, Cr, F, Mo, Pb, Sb, Se, SO4, Zn
MSW incinerator bottom ash	Cd, Se, Zn	Cr, Mo, Ni, Pb, Sb, SO4	Cl, Cu		Cd. Cr, Ni, Pb, Se, Zn	Cl, Cu, Mo, Sb, SO4
Artificial aggregate	Cd, Mo. Pb, SO4, Zn	As, Cr, Mo, Se		Pb, Zn	As, Cr, Mo, Se	
Natural aggregate	Cd, Ni, V			As, Cd, Ni, Pb, Sb, Se, V		
Limestone						
Granulated tyres		Zn				

*: Seawater quenching **: Older data, possibly overestimation

Relevant Member State and EU legislation

The situation in several EU Member States concerning regulation of the use of waste-derived aggregates for construction purposes is summarised in Table B. The selection of Member States for the overview was aiming to cover the range across the EU, but also based on availability of information.

The UK is actively assessing waste-derived aggregates for consideration of **end-of-waste** status at national level.

Two Member States, the Netherlands and Germany, have or are developing test-based criteria and limit values for the use of **construction products**, including waste-based aggregates, which means that the use of these materials will subject to leaching criteria whether the aggregates are still waste materials or whether they have achieved EoW status and become products.

In most of the Member States listed in Table B (Austria, Belgium, Czech Republic, Denmark, Finland, France, Hungary, Italy, Poland, Portugal, Spain and Sweden) the use of waste-derived aggregates is governed by **waste legislation**.

Several Member States have regulations or guidelines that include criteria on **leaching** and performance of leaching tests on the aggregates to be used as construction materials, e.g. for road construction. This is the case in Austria, Belgium (Flemish region), Czech Republic, Denmark, Finland, France, Germany, Italy, The Netherlands, Spain (regional) and Sweden. With the exception of Italy, all of these Member States also have criteria based on total content of organic and/or inorganic substances.

Several Member States have adopted the EU leaching **Waste Acceptance Criteria** (WAC) for landfilling of inert waste as the basis for their leaching criteria for use of waste aggregates. This indicates that these Member States have not carried out a specific risk or impact assessment for the application scenarios but rely on the risk/impact assessment that was carried out when the EU LFD WAC for inert waste were developed. The Member States relying fully or partly on the EU LFD WAC for inert waste are Austria, Czech Republic, Finland, France and Spain (Cantabria).
The Member States which have carried out specific **scenario-based risk/impact assessments** as a basis for their leaching criteria for the use of waste-derived aggregates include Belgium (Flanders), Denmark, France (partly), Germany (for pending legislation), The Netherlands and Sweden. In the UK, scenario-based risk assessment is also the basis for approval of utilisation of waste-derived aggregates for construction purposes.

In some Member States, one of the sets of criteria refers to **free or nearly free use** of the unbound aggregate without restrictions. This is the case in Austria (class A+), Denmark (Category 1), France (type-3 without use restriction), Germany (the old type Z0), Sweden (free use) and The Netherlands (granular, open), so those criteria cover a situation that could be close to an EoW scenario. It should be noted that all of these criteria, with the exception of the old German Z0, which is more pragmatic and not based on an actual risk assessment, have been developed using pathway scenarios that take some degree of attenuation of released substances into account. This may, however, not be sufficient for general EoW criteria without any restrictions on the use of the products.

Table B
Overview of the situation with respect to development of EoW criteria and regulation of utilisation of waste-derived aggregates in some selected EU Member States.

Member State	EoW criteria?	Regulation of the use of waste aggregates?	Criteria on total content?	Criteria on leaching?	Type(s) of leaching tests required
Austria	No	Guidelines	Yes	Yes	EN 12457-4 (L/S = 10 l/kg)
Belgium	No	Yes, in the Flemish region	Yes	Yes	CEN/TS 14405 (L/S = 10 l/kg)
Czech Republic	No	Based on Landfill legislation*	Yes	Yes	EN 12457-4 (L/S = 10 l/kg)
Denmark	No	Yes	Yes	Yes	EN 12457-1
Finland	No	Yes	Yes	Yes	CEN/TS 14405; EN 12457-3 (L/S = 10 l/kg)
France	No	Yes	Yes	Yes	EN 12457-2 and 4**
Germany	No	Yes guidelines – new regulation in preparation	Yes	Yes	EN 12457-2 and DIN 19528 (new legislation)
Hungary	No	Some	No	Yes	Not known
Italy	No	Yes	No	Yes	EN 12457-2 (L/S=10 l/kg)
The Netherlands	No	Yes	Yes	Yes	CEN/TS 14405 (L/S=10

					l/kg)
Poland	No	No	No	No	
Portugal	No	Some guidance	No	No	
Slovakia	No	No	No	No	
Spain	No	Yes, regional	No	Yes	EN 12457-4 & DIN 38414-S4
Sweden	No	Guidelines	Yes	Yes	CEN/TS 14405
United Kingdom	Yes	Guidance, case by case	No	No	Variable, no routine testing

*: Considering adoption of the Austrian guidelines
**: For compliance testing (CEN/TS 14405 for basic characterization)

Several EU Directives and Regulations should be considered for a possible development of EoW criteria and limit values for waste-derived aggregates. These include:

- The **Waste Framework Directive** (WDF) which sets the basic rules determining when waste materials can cease to be waste and become products or by-products at EU or national scale, including the requirement that the use of the materials with EoW status must not lead to overall adverse environmental or human health impacts, and that criteria that include limit values for pollutants when necessary shall be set to prevent such impacts;
- The **REACH** Regulation (1907/2006) which specifies the conditions of registration and whether or not a given waste-derived aggregate with EoW status can be exempted from REACH registration. Guidance provided by ECHA (2010) seems to indicate that each stream of waste-derived aggregates that obtains EoW status will have to be considered separately concerning obligations in relation to REACH. Most likely, some additional guidance will be required;
- The **Construction Products Regulation** (CPR, 305/2011/EU), which provided the regulatory and logistic framework for management of waste-derived aggregates with EoW status as well as pristine aggregates used for construction purposes. Although the CPR, which replaced the Construction Products Directive in 2013, extends the considerations of environment and health from concerning only the service life in the CPD to the entire lifecycle, the associated product standards still only prescribe the harmonized test methods to be used in environmental and health assessments – the actual criteria to be met by construction products are still a matter for the individual Member States. As mentioned above, only the Netherlands and to some extent also Germany have set leaching limit values for construction products to be used for different applications. If such general criteria were to be imposed at EU level for waste-derived aggregates with EoW status, they would have to be incorporated as part of the development of the EoW criteria and conditions;
- The **Water Framework Directive** (2000/60/EC) and its daughter directive, the **Groundwater Directive** (2006/118/EC) which set requirements on protection of groundwater and surface water and oblige EU Member States to improve the quality of natural water bodies, in particular groundwater. Both the general EU requirements and the national requirements arising from their implementation in Member States must be taken into account if and when setting the environmental protection criteria for EoW assessment for waste-derived aggregates.

Assessment of the need to include limit values in EoW criteria for aggregates

Most of the aggregates considered in the context of this study (see Table A) are classified as waste materials and currently regulated under waste legislation as laid out in the Waste Framework Directive. Several EU Member States have regulations on the use of recycled waste-derived aggregates for construction purposes (see Table B), and several Member States have taken steps to protect the environment and human health by requiring testing and setting limit values for the leachability and content of several substances considered dangerous or undesired in the environment as a condition for various types of applications. In addition, specific limitations are often placed on the conditions of the use of waste-derived aggregates, e.g. on height, area, cover and location of the application. Some of the Member States without direct legislation on the use of waste-derived aggregates will instead require site-specific risk assessments on a case-by-case basis to permit beneficial use of waste materials.

It has further been shown that for several of the examples of waste-derived aggregates discussed in this study, there may be a risk that they will not even comply with the EU WAC for inert waste landfills. Some of the waste aggregates, e.g. some of the steel slags, are produced under very controlled conditions and aimed at specific uses, but many of the other waste aggregates are produced under less controlled or controllable conditions and may therefore vary considerably with respect to leachability and content of substances and other properties.

Based on substantial experience, **several European Member States** thus seem to have concluded that **testing and associated limit values or risk assessments** will be required to provide adequate environmental and human health protection in association with beneficial use of waste-derived aggregates in general. This is very much in line with the requirement in Article 6 (1) of the Waste Framework Directive that the use of aggregates with EoW status must not lead to overall adverse environmental or human health impacts, and that the criteria shall include limit values where necessary and shall take into account any possible adverse environmental effects. Limit values may further be required to ensure that possible future European EoW criteria would not conflict with other European and national environmental policy and legislation. There must be a high degree of certainty that waste-derived products that are traded and used for construction purposes or stored or otherwise placed or spread in the landscape do not give rise to an unanticipated increase in the local or general pollution level. The Water Framework Directive (2000/60/EC) and its daughter directive, the Groundwater Directive (2006/118/EC) set rather strict limits on the allowable impact on water bodies in the Member States and directly forbid the discharge of certain substances.

It is therefore **recommended** that if EoW criteria for assessment of waste-derived aggregates would be developed, such criteria should include **leaching tests** and associated **limit values** aimed at the protection of soil, surface water and groundwater. Similarly, limit values should be set on the **content** of certain substances to prevent impacts on human health.

The purpose and function of EoW limit values for aggregates

The primary purpose of establishing EoW limit values for the leaching and content of substances are, of course, to ensure that the aggregates that are tested and comply with the limit values cannot cause “any overall adverse impacts” to the environment or human health when used in accordance with the conditions associated with the EoW status gained. The assessment of the acceptability and the quantification of “overall adverse impacts” on the environment have already been carried out and are expressed in EU and national legislation in terms of surface water and groundwater (and soil) quality criteria for a number of relevant substances. The remaining job is to establish a rational, scenario- and risk-based relationship between the **primary water quality criteria (WQC)** at the receptor and the results of a leaching test performed on the aggregate in question. This relationship must ensure that when the aggregate complies with the limit values for EoW, then the impact from any application possible under the EoW criteria will not cause the water (or soil) quality at the point of compliance (POC) at the receptor to exceed the primary WQC for any substance considered. The relationship between the leaching limit values, and the primary WQC must be established in such a way that compliance with the limit values actually does ensure compliance with the WQC.

In principle, the **most restrictive** primary WQC in any EU Member State should be applied when setting limit values, since the EoW status of a waste-derived aggregate most likely will be European-wide and in principle will allow free trade of waste-derived aggregates with EoW status across borders. The criteria/limit values and the conditions of use associated with the EoW status must ensure the appropriate protection of all European water bodies.

The primary WQC as such are independent of the nature of the potential source of pollution, including the type of waste-derived aggregate in question. The primary WQC should represent the **substances** against which it is considered necessary to protect the groundwater, soil and surface water, and in principle, the general list of substances for which leaching limit values are to be defined should match the list of primary WQC. Following the **initial type assessment (ITA)** of an aggregate, a (shorter) material-specific list may be drawn up for **routine testing**. For ITA and the dossier upon which a decision on EoW status could be based, a fairly broad range of substances corresponding at least to the primary WQC should, however, be included. If there is knowledge or suspicion of the presence of potentially harmful substances not included in the WQC, then the producer should be obliged to include such substances in the testing programme and the dossier (precautionary principle).

It is important to realise that a leaching limit value is closely associated with the **test method** to which it refers. This is e.g. why the leaching limit values for landfilling of waste in Council Decision 2003/33/EC expressing the same risk or degree of protection of the environment are different, depending on whether they are measured at L/S = 0.1 l/kg, 2 l/kg or 10 l/kg. A leaching limit value is meaningless without reference to a specific leaching test (or specific test conditions). The choice of leaching test and L/S value(s) may depend on whether short term (L/S = 0.1 l/kg and to some extent 2 l/kg) or longer term (average) releases (L/S = 10 l/kg) are considered most important. In many cases the choice will simply be matter of convenience, using the same test method and L/S value used for other purposes (e.g. testing for comparison with landfill WAC or waste utilisation criteria). It is generally recommended to use the same tests and test specifications for all purposes in order to avoid redundant and unnecessary testing.

Even though the **EU inert waste landfill WAC** were used in this study to obtain a first impression of the likelihood that some of the waste aggregates considered would be potential candidates for EoW status, and even though some EU Member States have proposed the use of these WAC as EoW criteria, it is strongly recommended not to simply adopt the EU inert landfill WAC directly as leaching limit values for EoW. It is, however, equally strongly recommended to adopt **the principles of the methodology** used in developing the EU inert landfill WAC, but the scenario(s) to be applied shall be adjusted to the EoW situation and will hence be different from the landfill scenario. In addition, the list of substances considered should in all likelihood be increased (there are international or national WQC for several substances not included in the EU landfill WAC which were established 10 years ago). The Water Framework Directive also requires development of WQC for some substances which are not covered by the EU landfill WAC, such as e.g. ammonia.

Proposed principles for development of EoW limit values for aggregates

A number of basic principles upon which the selection of a methodology for establishing (leaching) limit values for pollutants as part of EoW criteria for waste-derived aggregates should be based are proposed:

- The methodology should be **risk-based**, and follow the source-pathway-receptor chain as outlined above.
- The main principles of the methodology should be **scientifically** sound and the process of development of leaching limit values should be transparent and discussed with all stakeholders, including Commission and Member State legislators, experts on leaching, modelling, environmental impact and risk assessment and criteria-development, representatives of CEN/TC 351, CEN/TC 154, CEN/TC 227 and CEN/TC 292, producers and manufacturers of waste-derived aggregates, and users of aggregates.
- The necessary impact modelling that is required for this purpose should be carried out by **experts** who can understand, interpret and explain the implications of chosen boundary conditions and parameters. The transparency of both this process and the derived limit values is mandatory to obtain acceptance among regulators and stakeholders.
- The methodology should be **generally** recognised and preferably applied previously for development of leaching limit values both at EU and Member State level.
- The **methodology** is **independent** of the type of aggregate it is applied to, and it is valid also for the setting of criteria under waste regulation (or for by-products, for that matter).
- The **primary WQC** imposed at the point of compliance are **independent** of the source and pathway scenarios and also applicable to the setting of criteria for beneficial use under waste regulation.
- The **test methods** required should be the same as required for any evaluation of the aggregate under waste legislation (beneficial use, landfilling) to avoid the risk of double testing.

- The primary WQC should reflect **EU and national Member State requirements** on water quality in terms of substances to be regulated and thresholds to be complied with. They should also be consistent with the requirements of the Water Framework Directive and the Groundwater Directive (or other relevant directives).
- **If no restrictions or conditions** are placed upon the use of a waste-derived aggregate with EoW status, both the source and pathway have to be chosen very conservatively, i.e. they must describe **worst case scenarios**, because the aggregate can be traded and used freely and may end up anywhere in the environment.
- Aggregates used in bound applications should be tested in a **granular state** (i.e. after size reduction), because the release of substances during the intended service life of bound aggregates is not critical in relation to EoW. The critical impacts may occur if and when the material (unintentionally) crumbles or otherwise disintegrates. This requirement will also prevent the use of materials which may constitute a major management problem at the end of the service life. Aggregates used in bound applications should be tested as part of the bound product, after appropriate maturing/ageing and subsequent size reduction.
- **If it is possible to place restrictions or conditions** on the use of a waste-derived aggregate with EoW status and require that the material is removed and managed at the end of its service life, these restrictions/conditions can be taken into account in the development of the limit values, and it may be possible to choose source and pathway scenarios that are **less conservative** and lead to less stringent EoW limit values. Examples of such conditions could be minimum distance to groundwater and surface water bodies, maximum thickness of application, maximum allowed rate of infiltration through top cover, obligation to remove aggregates at the end of the service life, etc.

Proposal of a methodology for development of EoW leaching limit values for aggregates

With or without conditions?

At this point it is **unclear whether or not it would be practically possible to impose conditions** on the use of waste-derived aggregates with possible EoW status. Hence the current study considers the development of leaching limit values in both cases, i.e. without and with conditions/restrictions on the use. In both cases the risk assessment principle is based on source – pathway – receptor considerations, but in the case with no conditions imposed a near worst case approach is required, leading to relatively stringent leaching limit values that few – if any – waste-derived aggregates are likely to comply with (see Table 7.1). More moderate leaching limit values are likely to result if the (recommended) methodology based on the adoption of certain conditions on the use of waste-derived aggregates with EoW status is applied (see Table D). Each situation is briefly described below. See also Figure 1.

EoW leaching limit values without restrictions or conditions on the use

The source term

If it is not possible to place any restrictions on the use of waste-derived aggregates which have obtained EoW status, the environmental and health criteria to be fulfilled must take this into account, i.e. must be based on relatively conservative (if not worst case) application scenarios. In order to take "any (potential) adverse environmental effects" into account, the entire life cycle of the product, including the End-of-Life (EoL) situation, should be taken into consideration. This approach will probably differ most from the in-use situation for aggregates used in bound applications. The release of substances from bound materials during the service life, when they are fully or nearly intact, will probably be small (and hence not restrictive with respect to potential environmental impact) compared to the potential release of substances when the products disintegrate/crumble sometime in the future. When that happens, the products may be anywhere in the environment if the use is uncontrolled and unrestricted. This means that the critical release of substances from bound use of waste-derived aggregates to be compared to appropriate limit values should be determined on size reduced material under conditions that represent an initial release and a long term exposure scenario.

In many cases the concentrations of the substances of interest that occur in the **porewater** in an application with a granular or size reduced aggregate will represent the highest and hence the critical values to be used in the source term. Since there are no restrictions, it should be assumed that the application (or heap) could be relatively high (5 to 10 m or more) and that the rate of infiltration of precipitation into the application (or heap) and hence the rate of production of leachate could be substantial (e.g. 300 to 350 mm/year or more). For most substances the highest concentrations are seen in the initial porewater (i.e. at low L/S), but some substances, particularly those that are solubility controlled, may show increasing concentrations when the L/S ratio increases over a certain range, e.g. due to removal of other substances or due to changes (decreases) in pH as a result of carbonation. Many relevant waste-derived aggregates will have a relatively high starting pH (typically 10 – 12.5) that may be reduced over time to more neutral values by natural carbonation). The testing should reflect the effects of the possible change of pH over time.

The pathway

In this case of unrestricted use the pathway is simple: Due to the lack of restrictions, it is necessary to assume that the material can be placed in **direct contact** with the receptor, which can be groundwater or surface water, so there is no pathway along which attenuation of released substances can take place. The source is discharged directly into the receptor. Calculations during development of the limit values for the Dutch SQD have shown that, for the Dutch WQC, the groundwater pathway is generally more restrictive than the surface water pathway, when dilution in a (water body specific) mixing zone is considered.

The receptor

The receptor will be **groundwater or surface water**. It is proposed to use either national values or European values as the primary water quality criteria (WQC). It is the responsibility of the appropriate environmental authorities to determine the primary water quality criteria, taking into account existing legislation at EU and national level.

Calculation of leaching criteria

The present study describes how leaching criteria may be “translated” from one L/S value to another for a given material and substance. If it is assumed that the pore water in a water-saturated aggregate corresponds to a certain L/S value (e.g. 0.2 l/kg), the condition that the pore water concentration must not exceed the primary WQC can be used to calculate the corresponding limit value for a leaching test for example at L/S = 2 l/kg or 10 l/kg. The limit values calculated in this way can be compared to results of the percolation leaching test CEN/TS 14405 (accumulated leached amounts) at the corresponding L/S = 0.2 l/kg, L/S = 2 l/kg and L/S = 10 l/kg. They can also be compared to the results of the batch leaching tests EN 12457-1 (L/S = 2 l/kg), EN 12457-2 (L/S = 10 l/kg) and EN 12457-3 (L/S = 2 and 10 l/kg). And at L/S = 10 l/kg they can be compared to the results of the pH dependence tests CEN/TS 14997 and CEN/TS 14429 at L/S = 10 l/kg carried out at relevant pH values. Compliance with the limit values at the higher L/S ratios of 2 and 10 l/kg ensures that the WQC will also be met at the End-of-Life/crumbled/carbonated state of the aggregates as discussed above.

EoW leaching limit values with restrictions or conditions on the use

Conditions that can modify EoW limit values

Some of the conditions that could be imposed on the use of a given waste-derived aggregate with EoW status are listed in Table C which also indicates which parts of the source-pathway-receptor chain will be affected (in terms of modelling conditions) by the measures taken. The two most basic requirements that will set the scene for the proposed methodology for development of leaching limit values as part of EoW criteria are:

1) The aggregate can only be used for **specified purposes**, and
2) The aggregate must be **taken back** by the user/owner at the end of its service life.

The first of these requirements is already implied in indent a) in Article 6 (1) of the WFD, but it should be further specified and refer to one or more specific scenario type(s), e.g. use as sub-base in a road or a filling material in an embankment. This requirement could then lead to more than one set of limit values (corresponding to different application purposes) or, if that is considered impractical, to the adoption of the most restrictive of these for all the relevant purposes.

The second requirement, which is for example already part of the Dutch Soil Quality Decree (SQD), will, together with the first requirement, ensure that the risk assessment only has to be performed for specific, relevant in-use scenarios (as opposed to the very conservative scenario applied in the case of free or unrestricted use), albeit always assuming that the material is granular. However, this requirement would still need consideration of aggregate alterations (e.g. carbonation) that may enhance the leaching of substances during the service life. The practical implementation of this requirement will probably require some careful consideration of measures to ensure that the responsibility remains with someone, if ownership and other conditions change in the course of a long service life.

Table C
Overview of conditions that may be imposed on the use of waste-derived aggregates as part of End-of-Waste criteria. A general ranking of the conditions is not useful since the relevance and effect of the different conditions will vary from one scenario to another.

Imposed condition	Source	Pathway	Receptor
The material can only be used for specified purposes	Can be influenced	Can be influenced	May determine which receptors are relevant
Take back the material after service life	Reduction in the time span to be considered	Not affected	Not affected
Minimum distance to groundwater level	Not affected	Attenuation in the unsaturated zone may be taken into account	Depends on POC
Minimum distance to surface water	Not affected	Attenuation in the unsaturated zone and the aquifer may be taken into account	Depends on POC
Restrictions on height of application	May reduce source term	Not affected	Not affected
Restrictions on the length and width of the application	May reduce the source term	Not affected	Not affected
Restrictions on allowed rate of infiltration	Reduction of the flux (the load per time unit)	Not affected	Not affected

Stepwise modelling procedure
It is proposed to apply a **generic stepwise (iterative) modelling approach** that can be used to develop leaching limit values for EoW for waste-derived aggregates, taking into account the conditions described in Table C above. The approach is in agreement with the principles described in EN 12920: “Characterisation of waste – Methodology for the determination of the leaching behaviour of waste under specified conditions”, and it is also applicable to the setting of criteria for utilisation of the materials under waste legislation. It is based on the same fundamental principles that have been applied in the setting of the EU leaching criteria for acceptance of waste at inert waste landfills and in the development of leaching criteria for application of virgin and waste materials under the Dutch Soil Quality Decree. The stepwise procedure which is shown and commented in Table D could in fact also be applied to the setting of limit values for the use of waste-derived aggregates without conditions, and this case is therefore included in Table D for the purpose of illustration.

The procedure should be performed by experts and be subject to involvement of and discussion with stakeholders. The results obtained may possibly be modified due to other considerations.

This study recommends using this methodology to develop leaching criteria for EoW assessment of waste-derived aggregates for specific applications under specified conditions as opposed to the development of leaching criteria for EoW use without conditions or restrictions.

Table D
Description of the first seven steps of the stepwise procedure for the development of leaching limit values for EoW assessment for waste-derived aggregates to be used for specific purposes under specified conditions (see Table C). For the sake of comparison, the case of development of leaching limit values for EoW use without conditions is also shown.

Stepwise procedure	EoW use with conditions imposed	EoW use without conditions or restrictions
Step 1: Description of the application and the imposed conditions (if any)	The specified application and the conditions imposed are described (see table C).	In this case description of a worst case scenario (e.g. high application without top cover placed directly in or close to the receptor) would be appropriate.
Step 2: Description of the relevant receptor(s) and the primary water quality criteria	The receptor (groundwater or surface water) is selected and appropriate water quality criteria are chosen (based on European or lowest national values).	The receptor (groundwater or surface water) is selected and appropriate water quality criteria are chosen (based on European or lowest national values).
Step 3: Description and modeling of the source term	Modelling of the flux of substances as a function of time based on the chosen application, the imposed conditions, and the assumed climatic conditions.	Calculation of the concentration of the initial porewater from the aggregate in question.
Step 4: Description and modeling of the migration of substances from the source to the point of compliance (POC)	Modelling of the transport of substance from the source to the receptor, taking into account the mitigating effects of the imposed conditions and the attenuation/dilution effects in soil, groundwater and surface water.	Since the application is placed directly in or at the receptor, no changes will occur in the source strength, and the volume is assumed to be large compared to the size and capacity of the receptor.
Step 5: Assessment of the impact at the receptor and reverse modeling or iteration to adjust the source term to the primary WQC	The peak values of the substances at the POC are calculated, and the relationship between peak value and initial concentration at the source is established by reverse modelling or iterative modelling. The source term concentration corresponding to a peak value substituted by the WQC is established.	Because of the assumptions under step 4, the porewater concentrations of the substances are compared directly to the primary WQC. No reverse modelling is necessary.
Step 6: Transformation of source term criteria to specific limit values	The resulting initial source term concentration (C_0) corresponding to the WQC at the POC can be converted to corresponding limit values at L/S = 2 l/kg and 10 l/kg, assuming an exponential decrease of the concentration with L/S.	The WQC are assumed to correspond to porewater concentrations, which are again assumed to correspond to L/S = 0.2 l/kg which can be converted to released amounts (mg/kg) e.g. in a percolation test. Assuming an exponential decrease of the concentration with L/S, this can be converted to corresponding limit values at L/S = 2 l/kg and 10 l/kg.
Step 7: Assessment of the resulting limit values and possible repetition of the stepwise procedure	For the same receptor and the same WQC, the limit values calculated for use with conditions imposed are likely to be considerably less stringent than for the case without conditions. If the leaching limit values calculated for a given set of conditions are considered too restrictive, the procedure can be repeated with additional or more effective conditions to find new limit values.	This procedure is very conservative because of the lack of restrictions on the use of the aggregate which in principle can be placed anywhere. This will lead to rather stringent EoW limit values (see Table 7.1), and few or none of the waste aggregates considered in this study are likely to comply.

The procedure shown in Table D should be followed by an eighth step in which a possible adjustment of the limit values based on impact on groundwater or surface water could take place due to **consideration of other issues** such as e.g. consistency with other legislation, interference between substances, corrosion effects, particular exposure conditions, etc. For large construction projects the establishment of maximum permissible additions of selected substances to the soil below the application could be considered (see e.g. the Dutch SQD in Annex 5).

Proposal of a methodology for development of health-related limit values

While the limit values on leaching are necessary to protect the environment, it will most likely also be necessary to apply limit values on the **content** of a number of substances to provide protection against human health hazards e.g. from ingestion, inhalation and direct contact with the aggregates. Since no standardised leaching tests are available for organic substances, such limit values could also provide a certain degree of protection against release and migration of organic substance into soil, groundwater and surface water, despite the lack of relationship between content and leachability.

If EU-wide EoW criteria for aggregates were to be developed, it would be necessary to consider the **regulations in all Member States** as well as a **broader range of substances**. Since the criteria would be applicable in all EU Member States, it would probably be necessary to choose the lowest limit values found in the Member States as EoW limit values (unless the use conditions prevent human contact with the material throughout the entire life-cycle). New legislation on utilisation of soil and waste aggregates that include limit values on content of both inorganic and organic substances is underway in some Member States. Specifically for recycled crushed concrete, for example, special attention should be paid to the possible content of PCB, and care should be taken to specify exactly to which congeners and analytical methods limit values for PCB refer (PCB is a group of substances consisting of 209 different congeners).In general, it should be ensured that the content of persistent organic pollutants (POP) is sufficiently low (see the POP Regulation), and that the content of any substance does not cause the aggregate to be classified as a hazardous waste.

Testing and documentation requirements

It is proposed that a **dossier** should be prepared to document compliance with the requirements on leaching and content of substances and any other requirements of the aggregate to be considered for EoW status. To be approved for EoW status, it should be shown that a number of samples of the aggregate, representing a **realistic cross-section** of the material in question in the form it will have when it is to be used, comply with the criteria established for leaching as well as for the content of substances. Already existing data of sufficiently good quality should also be included in the dossier. A convention should be established for the statistical requirements for compliance with the limit values. If the dossier indicates a reasonable degree of compliance with the limit values at the level of characterisation or **initial type testing (ITT)**, rules for routine testing (compliance testing) or **factory production control (FPC)** in terms of frequency, sampling requirements, test methods and pass/fail conventions should be established. ITT and FPC are procedures established within CE marking under the Construction Products Regulation, CPR (Regulation (EU) No 305/2011).

It is recommended that for a given waste-derived aggregate, the appropriate Technical Committee should define different **classes** according to different levels of restrictions of or conditions on the use and associated different sets of limit values for EoW classification. Member States can then decide which classes they allow to be used on their territory.

It is proposed that the leaching testing under ITT for the dossier should include a percolation test (CEN/TS 14405 or CEN/TC 351/TS-3), a pH dependence test (CEN/TS 14429 or CEN/TS 14997) and a batch leaching test EN 12457-part 1, 2 or 3 (for future compliance/FPC purposes). The analytical programme considered should as a minimum for ITT include all major substances (mainly salts) and all substances for which water quality criteria exist in the EU Member States. Any substance that may be of concern and known to be present in the aggregate, but not included in the above, should also be part of the analytical programme. Dissolved organic carbon (DOC) should be analysed in the eluates (because of its ability to enhance the leaching of metals and POPs). ITT Testing should also include determination of the total content of a number of substances. Minimum requirements for ITT analysis of content should account for at least 95 % of the mass of the material and include TOC, PCB, BTEX, PAH and hydrocarbons and any inorganic substances of concern (unless they can be excluded on the basis of the origin of the aggregate). The analytical programmes for testing of leaching and content during FPC should be based upon the findings in the ITT and may be substantially reduced as compared to the ITT programme.

The leaching criteria set should be met at L/S = 0.2 l/kg, L/S = 2 l/kg as well as L/S = 10 l/kg by the column/percolation test results and they should also be met by the batch test results and the results of the pH dependence test (at L/S = 10 l/kg) for pH between 7.0 and the materials own pH (often alkaline, as mentioned before). If a discrepancy of compliance occurs between the percolation test and the batch test, the results of the percolation test should take precedence, as the latter provides a better representation of percolation-based release. A producer should have the choice to use the percolation test (recovering a single eluate at L/S = 2 l/kg or L/S = 10 l/kg) instead of the batch test for FPC purposes. Appropriate environmental authorities (such as the Environmental Protection Agencies in the Member States and/or the EU Commission) should be responsible for approval/refusal of dossiers. The control of the FPC compliance with regulatory requirements could be placed at national level.

For some waste-derived aggregates, particularly those resulting from highly variable or one-of input streams, it will be necessary to place strict controls on the quality of the input materials. One example is the production of crushed concrete from C&D waste, where procedures for selective demolition, depollution of buildings and sorting of C&D waste/concrete will be required to ensure a good quality input material.

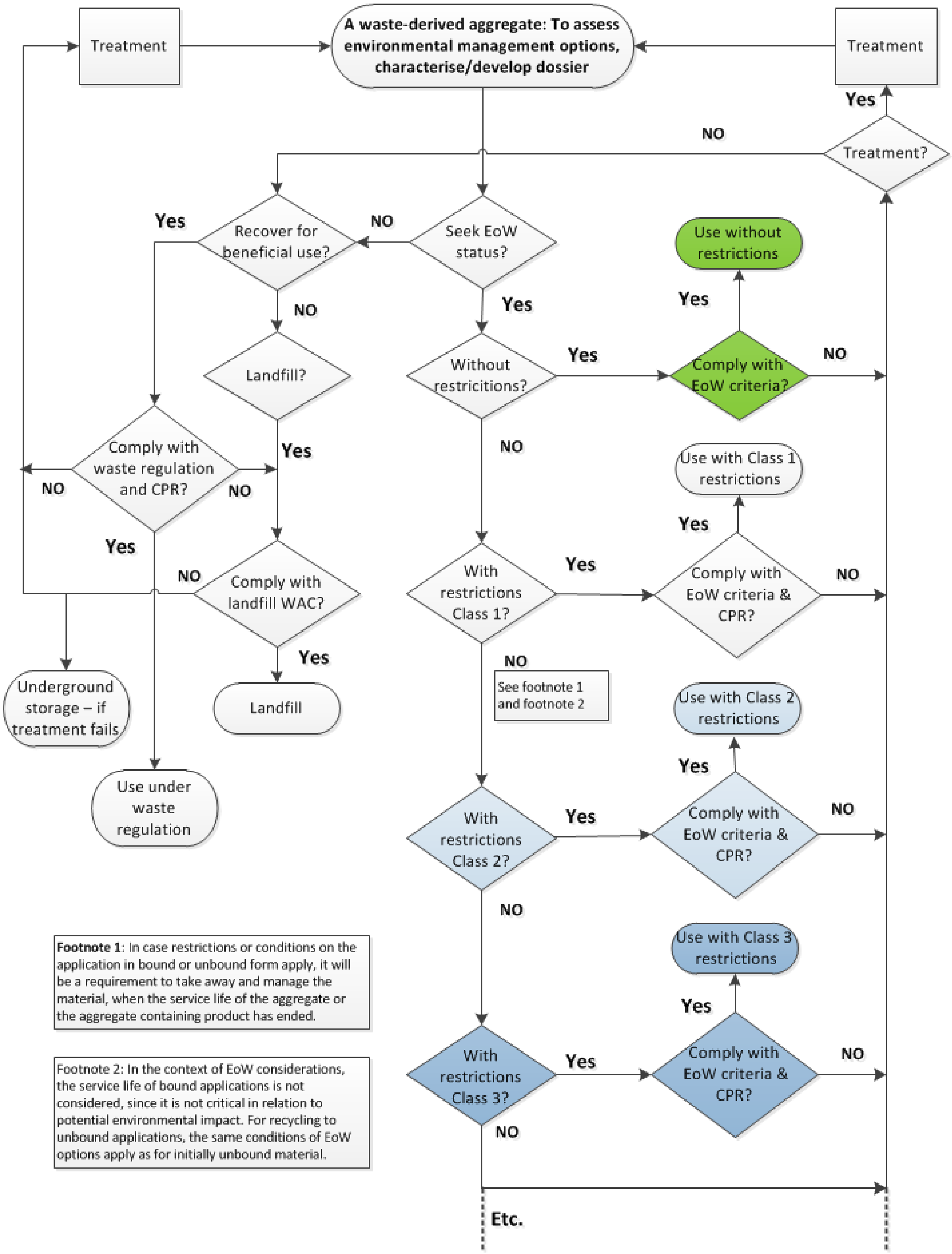
Compatibility of the proposed methodology

The proposed methodology for development of EoW criteria for use of waste-derived aggregates with restrictions/conditions is basically **compatible** with the approach to environmental protection and development of risk-based limit values for utilisation of waste and product aggregates taken in several EU Member States, including Belgium, Denmark, France, Germany, The Netherlands and Sweden. The scenario-based risk assessment methodology is also largely in agreement with the risk assessments carried out in the UK as part of the WRAP procedures for EoW assessment. At European level, the basic principles of the methodology are similar to those applied in the setting of EU waste acceptance leaching criteria for landfilling which is incorporated into Council Decision 2003/33/EC, and both the application of leaching tests and the proposed procedures correspond to those prescribed by and applied in the Construction Products Regulation as well as the associated product standards.

This supports the possible use of the above described methodology to develop EoW limit values for aggregates, and to set conditions on the use of waste-derived aggregates with EoW status.

Overview

Figure 1 on the next page shows an overview of the assessment framework in which the proposed methodology for development of EoW criteria will result. The figure also illustrates the fact that the same testing and characterisation results that are obtained for EoW assessment of a waste-derived aggregate can be used to assess the **management options** under waste legislation if the results do not comply with the EoW limit values. The different levels of restrictions shown in Figure 1 correspond to the different classes that may be defined in the product standards by the appropriate Technical Committees (see above). The possible registration under REACH is not indicated in the figure.



Footnote 1: In case restrictions or conditions on the application in bound or unbound form apply, it will be a requirement to take away and manage the material, when the service life of the aggregate or the aggregate containing product has ended.

Footnote 2: In the context of EoW considerations, the service life of bound applications is not considered, since it is not critical in relation to potential environmental impact. For recycling to unbound applications, the same conditions of EoW options apply as for initially unbound material.

Figure 1
Overview of the proposed framework for assessment of possible EoW status of waste-derived aggregates, including options under waste legislation. The levels of restriction may correspond to different classes.

1. Introduction

1.1 Background

The Waste Framework Directive (WFD) 2008/98/EC includes the option to set so-called End-of-Waste (EoW) criteria under which specified waste fractions shall cease to be waste. If these criteria are fulfilled, the material will no longer be classified as a waste but it will instead become a product subject to free trade and use (albeit for specific purposes). According to Article 6 (1) of the WFD, a waste material (substance or object) may cease to be waste as defined in the WFD when it has undergone a recovery, including recycling, operation and complies with specific criteria to be developed in accordance with the following conditions:

The end-of-waste criteria for a specific type of waste must be developed according to the conditions set out in Article 6 (1) of the Waste Framework Directive (WFD):

(a) the substance or object is commonly used for specific purposes;

(b) a market or demand exists for such a substance or object;

(c) the substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products;

(d) the use of the substance or object will not lead to overall adverse environmental or human health impacts.

Additionally, the criteria shall include limit values for pollutants where necessary and shall take into account any possible adverse environmental effects of the substance or object.

In Article 6 (2) of the WFD it is stated that “End-of-Waste specific criteria should be considered, among others, at least for aggregates, paper, glass, metal, tyres and textiles.” Article 6 (4) of the WFD states that “where criteria have not been set at Community level under the procedure set out in paragraphs 1 and 2, Member States may decide case by case whether certain waste has ceased to be waste taking into account the applicable case law. They shall notify the Commission of such decisions….”

On request by the EU Commission’s DG Environment, the Joint Research Centre, Institute for Prospective Technological Studies (JRC-IPTS) carried out two studies where the first was aimed at defining the concept of EoW and developing a general classification methodology (Delgado et al., 2009) and the second was aimed at identifying waste streams suitable for non-waste classification (IPTS, 2009). The latter study has identified three different types of waste streams:

I. Streams that are in line with the basic principles of EoW and suited for further EoW criteria assessment;

II. Streams that may be in line with the principles;

III. Streams that are not considered appropriate for EoW classification.

The first category of waste streams has been further divided into two sub-categories, namely:

I.1): Streams used as feedstock in industrial processes, a pathway that controls the risks of health and environmental damage. These streams include metal scrap of iron and steel, aluminium, copper, plastics, paper, textiles, glass, metal scrap of zinc, lead and tin, other metals;

I.2) Streams used in applications that imply direct exposure to the environment. In these cases, the EoW criteria to be developed in the further assessment shall include where necessary limit values for leaching pollutants, taking into account any possible adverse environmental and health effects. The streams in this subcategory are: Construction and demolition (C&D) waste aggregates, ashes and slag, and biodegradable waste subject to biological treatment.

Steps have been taken by the EU Commission to initiate the development of EoW criteria for waste fractions belonging to waste stream I.1, i.e. wastes that are not used in direct contact with soil and the environment.[1]

In view of the possible establishment of EoW criteria for waste streams of sub-category I.2 under the EU Waste Framework Directive (WFD), including aggregates that are produced from waste, the JRC-IPTS launched a call for tender for a study on the methodological aspects regarding limit values for pollutants in such aggregates. Following evaluation of the offers, DHI (Denmark) and its co-operation partners, ECN (The Netherlands) and Hans van der Sloot Consultancy (The Netherlands) were retained in 2011 to perform the study. The rationale for this preliminary study was that when aggregates are used, they may release pollutants into the environment, in particular to soil, groundwater or air, depending on their composition and manner of utilisation. This may make it necessary to include limit values on release and/or content of pollutants in possible end-of-waste criteria for these materials. This report describes the study and the resulting findings and proposals made by the contracted consortium.

1.2 Objectives

The overall objective of the study was to provide a science-based analysis of how limit values for pollutants may be developed as part of possible end-of-waste criteria for aggregates in accordance with article 6 of the WFD. In particular, the study had to:

- Identify and assess the pollution risks of using aggregates derived from waste;
- Review how the use of aggregates is regulated today in the EU with respect to avoiding pollution;
- Assess the need for including limit values for pollutants in end-of-waste criteria;
- Assess the suitability of different types of limit values;
- Identify and assess the different methodological approaches for deriving pollutant limit values;
- Identify the most suitable testing approaches and methods, including simplified modes of compliance.

Health risks related to occupational or incidental hazards associated with the aggregate materials themselves are not included in the study.

It should be noted that this report only addresses indent (d) and the two subsequent lines associated with indent (d) in Article 6 (1) of the WFD. It does not address whether or not the aggregates in question are commonly used for specific purposes (indent (a)), whether or not there is a market for the aggregates (indent (b)) or whether or not the aggregates fulfil the technical requirements for the specific purposes or meets existing requirements of relevant legislation and standards (indent (c)). Therefore, the current report does not provide an analysis of the feasibility of end-of-waste criteria for aggregates. Moreover, the methodology described in this report may only become relevant if and when a given aggregate meets the requirements of indents (a), (b) and (c) in Article 6 (1) of the WFD.

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[1] On 8 April 2011, Council Regulation (EU) 333/2011 of 31 March 2011 establishing criteria determining when certain types of scrap metal cease to be waste under Directive 2008/98/EC of the European Parliament and of the Council, was published in the Official Journal.

2. Aggregates and potential pollution in relation to EoW

2.1 Aggregates for consideration in the study

Aggregates are granular materials used in construction. Natural aggregates are produced from mineral sources and include e.g. sand and gravel resulting from rock erosion and crushed rock extracted from quarries. Secondary aggregates arise from industrial processes, and recycled aggregates are produced from processing of materials previously used in construction (Delgado et al., 2009). In this report, “recycling” refers to both the use of secondary and recycled aggregates. Table 2.1 presents a list of waste aggregates that are or have been used or considered for use for construction purposes. A few natural aggregates are also listed. While the list is by no means exhaustive, it is believed to be fairly representative and span a range that encompasses the properties of materials that may possibly be considered for EoW assessment. As indicated in the table, several aggregates may be used in bound and unbound form in construction applications. The type of aggregate used in construction usually involves a specific particle size gradation of the aggregate. Specific types of aggregates may be fit for one specific purpose and not for another.

Table 2.1
Aggregates for consideration in the context of this study. Unbound/bound use is indicated where information has been found.

Aggregate	EWC/LOW Code	Abbreviation	Unbound use	Bound use
Waste aggregates				
Recycled concrete	17 01 01	RecCon	X	X
Recycled bricks	17 01 02	RecBrick	X	X
Recycled tiles and ceramics	17 01 03	RecTile, RecCer	X	X
Recycled glass	17 02 02 19 12 05 20 01 02	RecGls		X
Mixture of concrete, bricks, tiles and ceramics	17 01 07	MixC&D	X	X
Recycled asphalt	17 03 02	RecAsph	X	X
Blast furnace (BF) slag	10 02 01/02	BFSlag	X	X
Basic oxygen furnace (BOF) slag	10 02 01/02	BOFSlag	X	X
Electric arc furnace (EAF) slag	10 02 10/02	EAFSlag		X
Phosphorous slag	06 09 01	PSlag		X
Fly ash (from coal combustion)	10 01 02	CFA	X	X
Bottom ash (from coal combustion)	10 01 01	CBA	X	
Boiler slag (from coal combustion)	10 01 01	CBoiSlag		
FBC ash (from coal combustion)	10 01 24	CFBCA		
Fly ash from incineration of household waste	19 04 14	MSWIFA		X
Bottom ash from incineration of household waste	19 01 12	MSWIBA	X	X
Boiler ash from incineration of household waste	19 01 16	MSWIBoiA		X
Shredded and granulated tyres	16 01 03 19 12 04	GranTyre	X	X
Artificial aggregate		ArtAggr		X
Reference material				
Natural aggregate		NatAggr	X	X
Limestone		LimeStone	X	
Soil and stones	20 02 02	Soil, Stone	X	

The characteristics of each of the aggregates and their environmental properties in terms of content and release of potentially relevant substances are discussed in Chapter 4.

2.2 The basic conditions and concepts of the assessment of the pollution potential of aggregates in relation to EoW

2.2.1 Basic safety conditions dictated by EoW status of aggregates

Article 6 (1) (d) of the WFD requires that the use of a waste material that obtains EoW status must not lead to overall adverse environmental or human health impacts. The development of EoW criteria for aggregates must therefore include an assessment of the potential risks that any possible use of the aggregate may pose to the environment and human health.

At this point, it is unclear whether or not it would be practically possible to impose conditions on the use/type of application of the recycled aggregates as part of possible end-of-waste criteria. In practice, such conditions would imply that control measures must exist to guarantee that the materials will be used properly – this would to some extent resemble the existing control under waste legislation already in place in several Member States. To a certain extent the technical requirements of the aggregates for specific uses are likely to control the use of a given aggregate with EoW status for a given type of application, but in principle, the aggregate can be placed anywhere where such controls are not applicable.

An aggregate that would achieve EoW status at EU level would cease to be a waste and become a construction product that will be subject to compliance with EU-wide environmental quality criteria (to be determined) and will be subject to compliance with national environmental criteria for the use of aggregates in construction works. However, only the Netherlands and Germany have implemented or are implementing environmental protection legislation on the use of construction products, including aggregates, which includes leaching testing and limit values. In the other 25 Member States such regulation did not seem to exist yet at the time of the study.

From the above the study consortium finds that it follows logically that EoW criteria to be set at EU level in accordance with Article 6 (1) (d) of the WFD should ensure:

1. A high degree of certainty that aggregates used under the EoW status actually fulfil the EoW criteria to be developed. This implies sufficient proof (e.g. in the form of a dossier) of absolute compliance with the criteria up front and effective subsequent quality control (factory control) measures.

2. That the source-pathway-receptor scenarios upon which the EoW environmental and health protection criteria shall be based must reflect the absence of any restrictions on the use of waste derived aggregates with EoW status, as well as the fact that their use in construction applications is without environmental criteria in most EU Member States. This must be taken into account both in the source and pathway scenarios.

3. That the source-pathway-receptor scenarios address not only the service life situation but the entire lifecycle, and in particular the end-of-life (EoL) situation of the aggregates to be granted EoW status. This implies the inclusion of source term scenario(s) that reflect maximum and long term exposure conditions and includes the effects of potential chemical changes (e.g. carbonation of alkaline materials).

The development of EoW criteria and limit values shall be based on a scientifically sound basis.

It should be noted that the methodology used to set EoW criteria for waste derived aggregates in relation to environmental protection is independent of the aggregate in question – except for the fact that the types of substances that may be critical may and will vary from one aggregate to another.

2.2.2 Conceptual risk assessment model

The risks or impacts posed by aggregates (natural, secondary or recycled) to the environment or human health can be conceptually described as a chain of events, see Figure 2.1. The chain consists of the identified potential contamination source(s) and receptor(s) as well as the potential migration pathways between them. A risk or impact only arises if the chain remains unbroken and there is a negative effect at the receptor. The conceptualisation of risk/impact as a chain can be seen as a descriptive tool and will be used as such in this context, but the chain of events can be much more formalised with event-oriented risk assessment models. From a systematic perspective it seems useful to consider each part of the chain separately as the basis for impact assessment scenarios and the associated models.

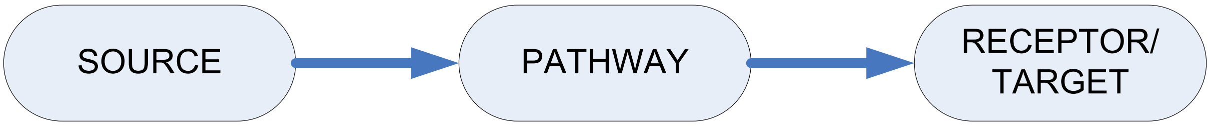


Figure 2.1
The concept of risk/impact illustrated as a chain of events. For a risk or impact to occur, the chain must remain unbroken, and an undesired effect must occur at the receptor.

In this context, the main emphasis will be on evaluation of relevant combinations of sources, pathways and receptors associated with the release of substances from aggregate applications by leaching, direct contact with or transport through soil and aquifers or surface water bodies to points of evaluation or compliance in soil, surface water or groundwater (primary receptor). The actual or final receptor will be the humans or the ecosystem that by use of or contact with the primary receptor are affected by the impact. The relevant quality criteria to be set and complied with at the primary receptor are reflected by and should be based on existing EU or national legislation on groundwater, surface water and soil quality.

Exposure routes such as inhalation, ingestion, direct contact and occupational exposure will not be addressed in detail. It will be assumed that existing national legislation on maximum content of (dangerous) substances in materials (e.g. waste aggregates and soil) that can be used without restrictions sufficiently reflect and protect against the risks associated with these exposure routes. However, the possible use of bioavailability tests will be addressed. The potential use of data on ecotoxicology in the setting of criteria/limit values at the primary receptor will also be discussed.

The conceptual model described above will be relevant in relation to any use of secondary or recycled aggregates regulated under waste legislation as well as for the use of aggregates in general regulated by environmental and health protection measures under construction product legislation. It will therefore also be applicable to the assessment of the potential risks associated with the use of waste aggregates that have obtained EoW status.

In the following, the source, pathway and receptor concepts and their application to the development of EoW criteria aimed at the protection of the environment and human health will be discussed separately. The description of the source, pathway and receptor will be focused on the potential risks to the environment associated with release (leaching) of substances. Health risk issues will be briefly addressed separately in section 2.2.6.

2.2.3 Source term scenarios

General source term conditions

Numerous source term scenarios are possible for the service life of recycled aggregates used in construction applications. The output from a source term assessment based on a source term scenario should be the *flux*, i.e. the amount per unit time of relevant substances released from the application as a function of time over a relevant timeframe. As such, the flux for leached substances is determined by the amount of leachate and concentration of substances as a function of time. The output from the source term assessment will be the input for the pathway/transport assessment. The

source term assessment generally involves modelling based on the scenario description and the behaviour of the aggregate in question (based on tests performed on the aggregate).
In general, a description of a leaching source term scenario should include both normal and exceptional conditions that may influence the leaching conditions, and it should include:

- the physical layout of the application, including mechanical and geotechnical conditions
- the hydrogeological and climatic conditions
- biological conditions (if relevant)
- conditions for the use of the site at different points in time

It is important to describe the expected timeframe of an application (in this case the entire lifetime, including the EoL situation), and the description of the conditions should be related to the timeframe. Another very important issue is the mode of contact between the reused material and water, which should also be described as a function of time. The mode of contact may depend both on the nature of the material (granular (unbound), monolithic (bound)) and on the scenario conditions such as physical layout, rate of precipitation and (for percolation systems) rate of infiltration or other ingress of water. The release of substances from an aggregate in contact with immobile or stagnant water is different from that from a granular material in contact with percolating water (and the leaching tests to be applied in each case are also different). For monolithic (bound) systems it is important to assess the effective surface, including cracks and fissures. The mode of contact with water in combination with the nature of the material to be reused largely determines the release mechanism for the contaminants and hence the test method(s) to be applied. In its simplest form the (bound/unbound) aggregate – water contact mode may be reduced to three basic scenarios (see Figure 2.2).

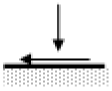
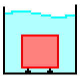
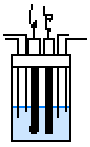
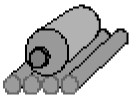
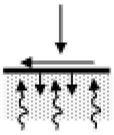
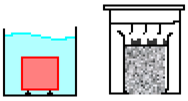
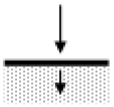
General water contact scenario		**Relevant test methods** **Applicable to a large range of materials**		
	Non-permeable material. Water is flowing over the surface of the product	**Tank test (DSLT/DMLT)**		**pH dependency test**  or 
	Low permeable material. Water is transported into the matrix by capillary forces; contribution of core to surface	**Tank test (DSLT/DMLT, including the CGLT)**		
	Permeable material. Water may infiltrate into the matrix driven by gravity (typically granular materials)	**Percolation (column) test** **Batch test (for QC/FPC or compliance)** **CGLT for coarse granular material**		
Note: The tests shown only address inorganic and a few organic substances				

Figure 2.2
The three basic water contact scenarios. DSLT is the dynamic surface leaching test (TS-2 from CEN/TC 351) and CGLT is the compacted granular (tank) leaching test which is a special version of TS-2. QC is quality control and FPC is factory production control. See section 3.7.2 for further description of test methods.

In addition to the leaching properties, the source term scenario description should ideally include the following information on the aggregate in question (unless irrelevant in view of the use application):

- nature and origin of the aggregate;
- total chemical composition (it should be possible to account for at least 90 to 95 % of the composition in terms of oxides or other likely compounds of main constituents;
- chemical properties such as pH and redox potential upon contact with water, acid neutralisation capacity (ANC), thermodynamic stability, oxidising/reducing capacity, degradable organic matter content;
- mineralogy, chemical speciation;
- physical and geotechnical properties (e.g. density, porosity, particle size distribution, water content, mechanical strength, permeability) that are necessary to determine the materials status as fine granular, coarse granular or monolithic as well as the mode of contact with water.

If an aggregate is to be recycled as part of another material (e.g. in hydraulically bound materials or bituminous mixtures) then the tests and risk assessments ideally should be carried out on the material containing the mixed-in aggregates and not on the "pure" aggregates. This is obviously not possible in the context of EoW criteria since the free mobility and free use allows too many options for different uses.

For alkaline aggregates such as steel slags and many combustion residues it will be important to know how the leaching properties will change when the aggregates are carbonated on contact with air/CO_2 and how fast this will happen. Carbonation will start on the surface of alkaline materials and (in most cases slowly) move inwards. Carbonation – in which hydroxides are transformed into carbonates through the uptake of CO_2 - will shift the pH on contact with water from the original pH of e.g. 11 to 12 to approximately 7.5 to 9. This will change the solubility and leachability of several trace elements/contaminants, for some in the direction of increased solubility and release but for others the solubility may decrease. Therefore knowledge of the release of potentially contaminating substances as a function of pH is important.

It is also important to determine whether or not an aggregate is in a reduced state (not thermodynamically stable under ambient/atmospheric conditions). Reducing conditions in slag (or other aggregates) have a beneficial effect on the leachability of some contaminants. Cr leachability is, for example, reduced in slag blended cements containing reducing slag; the chromate (Cr(VI)) present in Portland cements is reduced to the less soluble Cr(III) upon blending. Reducing conditions can e.g. be identified from the increased leachability of Fe and Mn at neutral pH. If or when the reduced material become oxidised, e.g. due to exposure to atmospheric oxygen in the presence of water and possibly over a longer period of time, the less soluble reduced species may change to their more oxidised states and become more soluble. This could for example happen after the end of the service life, if the material is crushed or allowed to crumble and recycled or discarded under oxidising conditions in contact with atmospheric air. For aggregates containing sulphides, oxidation may result in acidification, if the aggregate does not have sufficient acid neutralisation capacity (ANC). As is outlined in section 3.12, the utilisation of aggregates with reducing properties may also lead to environmental problems such as oxygen depletion in certain types of applications.

Aggregates with EoW status may be used in bound and unbound applications in and above groundwater or surface water. When aggregates are bound in cementitious materials, the presence of the aggregate will most often not lead to a significant change in leaching behaviour of the intact monolithic specimen and may only be recognised in the leaching behaviour of the size-reduced materials in a pH dependence test. Even rather high loadings of metals cannot necessarily be traced back in the release behaviour of intact products when tested under conditions corresponding to the service life situation.

Relevant or possible generic service life use/recycling scenarios for aggregates in unbound form include the following:

- Unbound application in a road as base coarse or sub-base material
- Unbound application in embankments

- Unbound application in structural fill above groundwater
- Unbound application of structural fill in ground - or surface water
- Unbound application as a soil modifier

As indicated above, the end-of-(service)life (EoL) situation must also be considered since a material which has been granted EoW status may no longer be subject to any environmental protection regulation after the expiration of its service life. EoL considerations are important because an aggregate with EoW status may remain in place after its primary service life has expired and hence not return to waste status, or it may deteriorate and physically disintegrate during (the later) stages of its service life. Appropriate scenarios based on small particle size and long term exposure (including oxidation and pH neutralisation through carbonation) should be developed for this situation.

Source term conditions relevant for the development of EoW criteria

If there are no restrictions or measures to control the use of waste derived aggregates with EoW status, and since both the service life situation and the EoL situation, i.e. the entire life-cycle, must be taken into account, the source term scenario must reflect this in terms of maximum potential release of substances. Based on experimental evidence it seems safe to assume that the leaching of most substances from an intact bound material will be less extensive than the leaching of the same substance from the same material in a crushed or crumbled state. Since a bound material (and a coarse unbound material) may eventually end up in a crumbled stage with small particle size in the EoL stage, aggregates used in bound applications should be tested in that crumbled state, and the source term scenario(s) for these materials should be based on this and include the potential effects of ageing, carbonation and changes in pH and redox potential. This means that the same physical source term scenarios can be used to describe the release of substances from both bound and unbound conditions.

The maximum release per unit time of several substances from an aggregate in an unbound application will occur during the initial part of the leaching period, i.e. at lower liquid-to-solid (L/S) ratios. Hence the highest concentrations of many substances in the leachate will be seen during this period. Other substances, however, in particular substances whose releases are solubility controlled in this phase, may show constant or increasing concentration levels over a broader L/S or time range. In order to truly represent the potentially critical source terms, one scenario should therefore represent an unbound application of aggregate of small particle size exposed to critical ambient conditions (in terms of percolation of infiltrated precipitation) over a longer period of time (a large L/S range). The thickness of the layer should be relatively high (the flux of released substances usually increases or is prolonged with increasing height of the application). Both the amount and the concentration of the initially released substances (at an L/S value corresponding to the pore volume of the application) and the accumulated release as a function of L/S and time should be assessed on the basis of leaching tests and scenario calculations. The influence of carbonation and changes in pH should be assessed, as these processes may both increase and decrease the release of specific substances.

Another potentially critical source term scenario will be one that represents an EoL situation where a bound or unbound material has crumbled or been broken into particles of smaller size and is exposed to critical leaching conditions (high rate of infiltration, relatively high thickness of layer). The material may have been protected from or exposed to percolation, weathering/carbonation/oxidation and leaching during the service life and maybe also during the first period of the EoL stage. An assessment of the potentially critical source term should be made in a way similar to that described above, but on material with smaller particle size (< 1 mm) using the pH dependence test (see section 3.7.2) and with more emphasis on the effects of ageing reactions.

The two types of source term scenarios will also cover any effects that may occur during storage prior to the use of aggregates for a given application. One of the scenarios is likely to describe the most critical source term situation and will then become determining in relation to the assessment of impact and criteria. It may sometimes be feasible to combine the two scenarios into one, e.g. by assuming that the full contamination potential is still present in an aggregate in the beginning of the EoL situation.

For a given (chosen) source term scenario, the source term should describe the release of relevant substances as a function of time over the relevant timeframe in terms of quantity and quality of the leachate, i.e. the amount of leachate and the concentration of the substances in the leachate. If conditions are set for the use of the aggregate with EoW status, the effect of these conditions should be reflected in the scenario and the source term. This information would also provide the flux of released substances as a function of time. The source term description for a given aggregate will generally be based on a combination of leaching test results, assumed scenario conditions and modelling.

2.2.4 Pathway/transport scenarios

The pathway/transport scenarios will form the basis for modelling the transport of substances from the application to the primary receptor using the output from the source term assessment, e.g. in terms of amounts of substances and leachate as a function of time, as input. If there are no restrictions and control of where waste derived aggregates with EoW status will be placed, the pathway/transport scenarios should also be chosen to include representation of relatively critical conditions.

In the calculation of the EU waste acceptance criteria (WAC) for inert waste landfills, for example, the pathway scenario included modelling of the transport through the unsaturated zone below the landfill to the groundwater level and subsequent transport through the aquifer to the point of compliance downstream of landfill, taking into account both hydrodynamic dilution and dispersion and retention of the substances in the soil/aquifer (see Annex 4). The combined effect of dilution/dispersion and retention (often referred to as attenuation) will have a substantially mitigating effect on the resulting impact at the receptor, and this pathway can therefore not be considered critical in relation to the EoW situation.

The most critical pathway scenario that would not provide any protection or modification of the receptor from the impact of the source term will be to place the source in direct contact with the receptor, which could be soil, groundwater or a surface water body. If no restrictions are placed on the use of the waste-derived aggregate, this situation may very well occur and should be taken into account.

Other pathway/transport scenarios which take into account the modifying effects of an unsaturated zone, an aquifer and transport/dilution in a surface water body and assess the impact or effect at various points of compliance downstream of the application should also be included in the evaluation procedures for the sake of comparison and to allow an evaluation of the potential effect of placing certain limitations on the use of a waste-derived aggregate as part of the conditions for achievement of EoW status (even if such limitations are not envisaged).

In the risk or impact assessment, appropriate mathematical/computer models should be used to describe the transport of substances along the pathway, unless the source is in direct contact with the receptor. The models should represent state-of-the-art knowledge in the field. They may be more or less sophisticated and should be able to account for the issues decided upon at the conceptual level. The output of the transport model or series of models will e.g. be the concentration of the substances in question as a function of time at one or more points of compliance at the receptor.

2.2.5 Receptor scenarios and primary quality criteria at the point of compliance

The receptor is simply the point of compliance at the end of the pathway (in soil, groundwater or surface water) where some quality criteria must be fulfilled. Since these are the environmental protection criteria from which all other leaching criteria and limit values will be derived, it seems reasonable to use the term “primary quality criteria” for them. Typically such criteria could be the maximum acceptable concentrations in the groundwater or surface water at the point of compliance (POC). The primary quality criteria are totally independent of the nature of the source, and in principle also of the pathway.

In the development of the EU leaching criteria for acceptance of waste at e.g. inert waste landfills, the POC was the groundwater at a distance of 20 m or, for some soluble and mobile substances, 200 m downstream of the landfill (Hjelmar et al., 2001) where the concentrations of various substances must not exceed certain values (the primary quality criteria). In general, this means that these primary criteria will be exceeded in the groundwater between the landfill and the POC, and this groundwater is more or less “written off”, i.e. it is accepted that it may have a lower quality, whereas the groundwater downstream of the POC will not exceed the primary quality criteria. If the receptor is a surface water body and the POC is located at the upstream boundary of the water body but downstream of the source, the water in the surface water body will not exceed the primary quality criteria at any place, at least not because of the source in question. However, if the POC is located somewhere off-shore or (for a river) downstream, and part of the surface water body constitutes the last part of the pathway and dilution in the surface water body is required to comply with the quality criteria at the POC, then part of the surface water body (between the point of entry of the pathway into the surface water body and the POC) may also exhibit concentration levels of the substances in question that exceed the primary quality criteria.

For the development of leaching limit values in the context of assessing EoW criteria for aggregates at EU level, it might theoretically be useful to apply EU-wide groundwater or surface water quality criteria as primary quality criteria. Unfortunately, such criteria do not exist to date. Instead, one could use the EU drinking water criteria (Directive 98/83/EC), keeping in mind that their primary goal is to protect human consumers of water, not the ecosystem which may be more vulnerable to certain substances than humans are.

During the development of the EU leaching criteria for acceptance of waste at landfills, slightly modified criteria based on the WHO guideline for drinking water quality were used as primary quality criteria (Hjelmar et al., 2005; Hjelmar 2012). It might also be considered to adopt the national groundwater quality criteria from a Member State relying heavily on good quality groundwater as the source of drinking water. Similarly, relatively stringent national surface water quality criteria could be applied as primary quality criteria for surface water bodies. Table 2.2 shows some examples of water quality criteria for mainly inorganic substances that might be relevant in the context of the development of EoW criteria for aggregates.

With very few exceptions (DOC and phenols), the leaching based waste acceptance criteria (WAC) for landfilling only include inorganic substances. The main reason for this is that whereas there are standardised and well proven leaching tests for inorganic substances at EU level, leaching tests for organic substances are much less developed, and at present, the experience with leaching tests for organic substances is probably not sufficient for these to be applied in general to regulatory systems. As a substitute, the total content of organic substances of concern should be determined as the basis for an assessment. Many waste aggregates will only contain traces of organic substances, and many of these, e.g. polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs), are relatively immobile in soil and groundwater. The transport may, however, be facilitated by the presence of dissolved organic carbon DOC in the leachate from the aggregates. Since DOC can also enhance the mobility of inorganic substances (e.g. Cu), there is good reason to set limits on the release of DOC from aggregates when assessing EoW criteria.

The lists with water quality criteria referred to in Table 2.2 (EU Directive 98/83/EC and EU Directive 2008/105/EC as well as WHO Guidelines (WHO 1996 and 2011) and national regulation) also contain criteria for a large number of organic substances. They will not be shown here, since they cannot be directly related to the leaching properties of the aggregates through the risk or impact assessment procedure. It should be noted that for several substances, drinking water criteria may not provide sufficient protection for groundwater and/or surface water bodies. This is the reason why, for example, although drinking water criteria were used as the starting point when selecting groundwater quality criteria for the setting of EU leaching limit values for landfilling (Hjelmar et al., 2001), the values were lowered for some substances (e.g. Cu from 1 mg/l (WHO, 1996) and 2 mg/l (Directive 98/83/EC) to 0.05 mg/l and Zn from 3 mg/l (WHO, 1996) to 0.1 mg/l).

Since the purpose of the risk/impact assessment and the subsequent development of leaching criteria for aggregates to obtain EoW status in this case is to protect groundwater and surface water, the first step in the procedure should be to determine from which substances the water bodies should be protected (the primary quality criteria). This could be done on the basis of lists like those shown in Table 2.2. The next step would then be to find out to which extent these substances are present in and leached from the aggregates in question. On this basis an appropriate match between the primary quality criteria and the substances leached from the aggregates can be made, resulting in a list of substances for which the leachability criteria must be developed.

Table 2.2
Examples of primary water quality criteria. Where no value is shown for a substance it means that the legislation or guideline in question does not define a limit value for that substance.

Substance	**EU DWQC**	**GWQC EU LFD**	**WHO 2011**	**GWQC DK LF**	**Surface WQC DK**	
					Fresh	Marine
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Bromide	0.010					
Chloride	250	250		150		
Fluoride	1.5	1.5		1.5		
Sulphate	250	250		250		
NH_4-N	0,50					
Nitrate	50					
Nitrite	0,5					
Cyanide	50					
Na	200					
Al	0.20					
As	0.010	0.010	0.010	0.0080	0.0043	0.00011
Ba		0.70		0.70	0.0093	0.0058
Cd	0.0050	0.0040	0.003	0.0020	0.00008-0.00025	0.0002
Co					0.00028	0.00028
Cr(tot)	0.050	0.050	0.050	0.020		
Cr(III)					0.0049	0.0034
Cr(VI)					0.0034	0.0034
Cu	2.0	0.050	2.0	0.10	0.012	0.0029
Fe	0.20					
Hg	0.0010	0.001	0.006	0.001		
Mn	0.050				0.15	0.15
Mo		0.070		0.020	0.067	0.0067
Ni	0.020	0.020	0.070	0.010	0.003	0.003
Pb	0.010	0.010	0.010	0.0050	0.00034	0.00034
Sb	0.0050	0.0050	0.020	0.0020	0.113	0.0113
Se	0.010	0.010	0.040	0.010		
Sn						
V					0.0236	0.0236
Zn		0.10		0.100	0.0031-0.0078	0.0078
DOC		10		3.0		
Phenol		0.10*		0.0005	0.0077	0.00077

EU DWQC:	Drinking water criteria from EU Directive 98/83/EC on the quality of water intended for human consumption (not exhaustive).
GWQC EU LFD:	Groundwater quality criteria used as primary quality criteria when developing the EU WAC for landfilling - based on WHO (1996) and EU Directive 98/83/EC but slightly modified for some substances.
WHO 2011	From Guidelines for drinking-water quality (WHO, 2011).
GWQC DK LF:	Groundwater quality criteria used in the setting of Danish WAC for landfilling as part of implementing Directive 1999/31/EC and Council Decision 2003/33/EC (Hjelmar et al., 2005).
Surface WQC DK:	Danish surface water quality criteria from Statutory Order No. 1022 of 25 August 2010 on environmental quality criteria for waters and criteria for discharge of contaminating substances to rivers, lakes and the sea (partly implementing Directive 2008/105/EC). Not exhaustive.

*: Phenol index

2.2.6 Health related criteria (not based on leaching)

As mentioned in section 2.2.2, exposure routes related to inhalation, ingestion, direct contact and occupational exposure will not be addressed in detail. Instead, existing legislation on content of inorganic and, in particular, organic substances is referenced. Ideally, the leaching, transport and impact of certain organic substances should have been included in the scenario and impact calculations described in the previous sections, but as described above, this is not possible at this time due to lack of appropriate leaching test methods for organic substances and due to lack of data. Instead it is assumed that the restrictions on the content of organic substances do provide some, albeit non-quantifiable, protection also against the leaching, migration and impact on the primary receptor of organic substances. This situation should be reviewed when appropriate methods and data are available.

Table 2.3 shows some examples of limit values based on the content of various (inorganic and organic) substances in waste materials and products that may be used freely without restrictions. For comparison, EU limit values on the content of some organic substances in waste to be accepted at landfills for inert waste are also shown (Council Decision 33/2003/EC).

Table 2.3
Examples of criteria for acceptance of inert waste for landfilling and free use of soil/waste materials in terms of content. Where no value is shown for a substance or parameter it means that the legislation or guideline in question does not define a limit value for that substance or parameter.

Substance	**LFD inert**	**Austria A$^+$ (free use)**	**Denmark Category 1 (free use)**	**Sweden free use**
	mg/kg	**mg/kg**	**mg/kg**	**mg/kg**
As		20	20	10
Cd		0.5	0.5	0.2
Cr (total)		40	500	40
Cr (VI)			20	
Cu		30	500	40
Hg		0.2	1	0.1
Ni		30	30	35
Pb		30	40	20
V		100		
Zn		100	500	120
TOC	30,000		30,000	
BTEX	6			
PCB (7 congeners)	1			
PAH		4		
PAH low ring number				0.6
PAH medium ring number				2
PAH high ring number				0.5
Hydrocarbons (C10-C40)	500			
Hydrocarbons (C6–C40)				

LFD inert waste: Council Decision 2003/33/EC on criteria and procedures for acceptance of waste at landfills.

Austria: Free use of C&D waste (Austrian Construction Materials Recycling Association (2007) and Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (2006)

Denmark: Free use of MSWBA, CFA, CBA (Ministry of the Environment: Statutory Order 1662 of 21 Dec. 2010). The waste (or soil) must not be contaminated with organic substances..

Sweden: Free use of waste materials (Guidelines from the Swedish EPA: Handbook of recycling of waste in construction work, 2010)

Carlon (2007) has carried out a review and evaluation of derivation methods of soil screening values in Europe for the European Commission, JRC-IES. This study presents the actual screening limit values (generally in terms of content of substances) in 15 EU Member States and discusses how they were derived using various risk assessment methodologies and various source, pathway and receptor scenarios. This study could be useful if and when content-based European EoW criteria for aggregates are to be set to protect human health.

2.2.7 Summary of basic conditions and scenarios

As part of the methodology for development of criteria that will ensure that the achievement of EoW status for a waste-derived aggregate will not lead to overall adverse environmental or human health impacts, it is strongly recommended to use risk or impact assessments that follow the source-pathway-receptor approach. It seems advantageous to consider each part of this chain separately before they are combined. It should be noted that the methodology for development of EoW criteria or limit values is independent of the type of aggregate (or other material) in question. The main conditions to be considered in the various steps of the impact assessment are summarised in Table 2.4.

Table 2.4
Summary of the proposed approach to risk assessment upon which to base the setting of EoW criteria..

Type of risk/impact	Main scenarios/conditions to be considered
Impact on the environment	
Source (leaching)	The source term scenario should reflect the fact that an aggregate with EoW status can be used with or without restrictions. It should reflect the most critical parts of the service life and EoL situations, which without restrictions could correspond to initial porewater/high application and small particle size (also for bound applications) and/or long term exposure as well as potential chemical changes, in particular changes in pH and redox potential. If restrictions are imposed, some of these may influence and mitigate the source term during the various life-cycle stages.
Pathway (transport)	If no restrictions on the use exist, the most critical pathway will represent the situation where the source is in direct contact with the receptor (i.e. no pathway). To assess the effect of imposing various conditions or assumptions on the use of a waste-derived aggregate as a product, other pathways including attenuation of substances should also be investigated.
Receptor (impact)	The receptor may be soil, groundwater or surface water below or downstream of the aggregate application, and the primary quality criteria to be complied with at the point of compliance should be water quality criteria that are acceptable in all EU Member States. The leaching-related criteria will mainly include inorganic substances since reliable leaching standards for organic substances have not yet been developed at EU level.
Impact on human health	The impact on human health of substances in the aggregates through exposure routes such as inhalation, ingestion, direct contact and occupational exposure will not be addressed in detail. It may be reasonable to assume that existing national legislation on maximum content of (dangerous) substances in materials (e.g. waste aggregates and soil) that can be used with or without restrictions sufficiently reflects and protects against the risks associated with these exposure routes. Member States without such legislation may have to develop or adopt it. See also the study mentioned above.

3. Release of substances from aggregates

3.1 Leaching versus content

There is seldom a direct relationship between the content of a substance in an aggregate and the leaching behaviour of that substance. Firstly, because elements may be incorporated into the aggregate matrix and may not become accessible upon contact with water. Secondly, because solubility limitations by minerals and sorption processes may prevent the elements from leaching at levels proportional to their content. The fraction of a substance that is available for leaching may thus be a very minor portion of its total content, even under the most extreme conditions (acidic conditions and size-reduced to a fine granular material). If under such conditions leachability is still very limited, then a constituent may often be regarded as non-critical with respect to release. This could for instance be established by carrying out a single batch of the pH dependence test CEN/TS 14429 or CEN/TS 14997 at pH = 2 (see section 3.7.2). In cases where the total content of a substance is below the critical limit for leachability, content may be used for evaluation instead of leaching. For substances for which no standardised leaching tests exist or for which the performance of a leaching test is impossible, assessments based on composition may be necessary. This is in particular the case for organic substances. In general, content is a poor indicator of the potential risk of an impact on the environment (groundwater, surface water, soil), while the leaching properties of an aggregate are directly related to these types of impacts.

In Figure 3.1 the actual leaching of a substance is shown in comparison with the total content and the potential leachability from a material. It is clearly seen that there is no simple relationship between content and leachability, nor is there one between potential leachability (i.e., availability under extreme environmental conditions) and actual leaching behaviour. In addition, several influencing factors can change the actual leaching substantially.

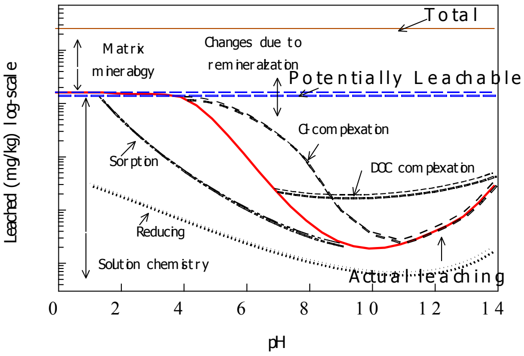


Figure 3.1

Comparison of total content with potentially leachability (i.e., availability under extreme environmental conditions) and actual leachability showing factors influencing leachability.

3.2 Leaching and release controlling mechanisms

Leaching may be defined as the dissolution of a soluble substance from a solid phase into a solvent (the leachant). Accumulated dissolved substances in the leachant eventually comprise a leachate (or an eluate, as the liquid resulting from a leaching test is called). Leaching of inorganic substances from largely inorganic (mineral) granular materials such as aggregates can be a complex process and many factors influence the release of specific substances both in the short and long term. A granular leaching system may be at or near equilibrium or it may be kinetically controlled. Kinetically controlled release can be associated with slow chemical dissolution or remineralisation reactions or with physical diffusion processes. For aggregates, in particular under the conditions stipulated in the critical scenarios described in section 2.2.3, the material will be percolated by water (see also Figure 2.2). In such systems, equilibrium conditions may exist if the rate of release of a substance from the individual particles is fast compared to the advective velocity of the percolating water. Conversely, non-equilibrium or kinetically controlled leaching conditions are likely for substances in systems where the advective velocity of water through the material is high compared to the release rate of that substance from the particles (often relevant for larger particle sizes). For such systems, test methods aimed at the determination of the mass transfer rate through the surface of the material (tank leaching tests), will be appropriate. Tank leaching tests will only be discussed briefly, since the release of substances from aggregates in the critical scenarios identified in section 2.2.3 is likely to be equilibrium or near-equilibrium controlled.

3.3 Presentation of leaching data

Leaching test results may be expressed either as

- Eluate concentration of substances in [mg/l]
- Substance release in [mg/kg of material] for granular materials or
- Substance release in [mg/m^2] for monolithic materials.

Leaching test results are frequently expressed as eluate concentrations, as this is the form in which results become available after eluate analysis. Subsequent data conversion may be necessary for different purposes. The eluate concentration as measured is used for geochemical modelling. Some regulations use concentrations expressed in mg/l. Others use leached quantities (mg/kg dry matter) or other derived units, such as mg/m^2.

Conversion of measured leachate concentrations into constituent release is necessary for the comparison of data obtained in different leaching tests at different liquid to solid (L/S) ratios. The conversion between substance release and eluate concentration is:

Substance release [mg/kg] = substance concentration in eluate [mg/l] x L/S ratio [l/kg] (3.1)

Presentation of data as measured eluate concentrations or as substance release can be necessary for the determination of the general leaching mechanism. Some examples (illustrated in Figure 3.2) are:

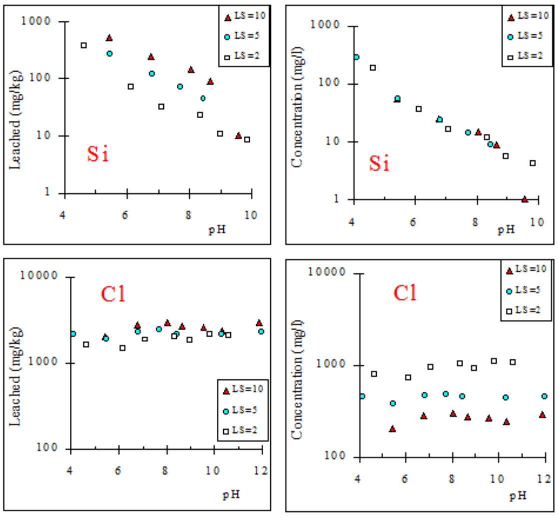


Figure 3.2
Distinction between solubility control (Si) and availability control (Cl) in the presentation of leaching test results.

- Chlorine (Cl) represents an availability controlled element. Data from tests at different L/S ratios expressed in [mg/l] lead to apparent differences, while data presented in [mg/kg] show that in all cases the whole fraction available for leaching is released.

- Silicon (Si) represents a solubility controlled element. Here, presentation of leaching data in [mg/kg] leads to differences, whereas data presented in [mg/l] show the solubility control in the pH region of 3 to 8 (constant concentration irrespective of L/S).

3.4 Leaching as a function of L/S

The liquid to solid ratio was defined in section 2.2.3. For leaching systems under equilibrium or near-equilibrium conditions, the expression of results of leaching tests as concentrations of a substance in the eluate or as accumulated leached amounts of a substance as a function of L/S is very convenient and allows the comparison of results from different test methods, in particular percolation tests and batch leaching tests (see section 3.6.2). This is illustrated in Figure 3.3 which shows accumulated leached amounts of Mo from an aggregate (bottom ash from incineration of hazardous waste) as function of L/S from a percolation test (CEN/TS 14405) and a two-step batch leaching test (EN 12457-3). The figure also shows the total content of Mo in the aggregate. It can be seen that the batch test results represent two points on the leaching curve described by the percolation test results. Also note the substantial difference between the total content and the leachable amounts of Mo.

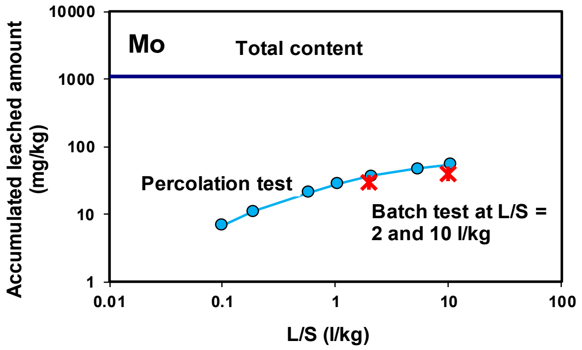


Figure 3.3
Results of percolation and batch leaching tests on an aggregate shown as a function of L/S.

In most cases where the difference in pH and redox conditions over the column experiment is limited, the results from batch tests and cumulative results from a column test will most likely be the same. An example of a situation where a difference is likely to develop is where, for instance, the pH changes during the column test, and as a result the leachability of some substances also changes, while the batch result represent only one pH value. This can happen either when the initial condition is acidic and then becomes neutral or alkaline, or when the initial pH is alkaline and then lowered due e.g. to carbonation. In other situations high concentrations of easily soluble salts such as chlorides may influence the leaching results for substances that can form chloride complexes. One such example is the increased leachability of Cd that may occur due to complexation with chloride. Chloride washes out fast and may be present in the first fraction(s) of eluate from the column test in concentrations high enough to form complexes with Cd and cause release of Cd in relatively high concentrations, whereas the average chloride concentration in the eluate from the batch test will be too low to form complexes with Cd, and the release of Cd will therefore remain low in the batch leaching test.

In some cases when sufficient information is available, results from observation of full scale applications of aggregates in the field may also be described as a function of L/S and compared to results of leaching tests performed on the same material in the laboratory. It is therefore sometimes possible – with considerable caution - to predict certain aspects of the leaching behaviour of an aggregate under field conditions on the basis of laboratory leaching tests, using relatively simple modelling tools, although supplementary hydrogeochemical equilibrium modelling is often required to account for longer term effects. It is, of course, important to validate such prediction methods to the extent possible by appropriate comparisons between lab and field results (see section 3.11). Most laboratory leaching tests on granular materials performed under equilibrium-like conditions are accelerated in time compared to the actual duration of leaching under field conditions.

Under certain conditions, and when the physical layout and hydraulic/water balance situation for a full scale application is known, the L/S scale may be converted to a time scale for that particular utilisation scenario. This can be done by means of the following equation (Hjelmar, 1990):

$$t = (L/S) \times d \times H/I \qquad (3.2)$$

where

t is the time since the production leachate from the application started (years)
L is the total volume of leachate produced at time t (m^3)
S is the total mass of aggregate used in the application (tonnes, dry mass)
d is the average dry bulk density of the aggregate in the application (tonnes/m^3)
H is the average height of the application (m)
I is the annual net rate of infiltration of precipitation (m^3/m^2)

It is assumed that percolation of the infiltrated precipitation is the sole source of leachate in the application.

The relationship between L/S and time is illustrated in Table 3.1 for an unbound application of an aggregate with a bulk density of 1.5 tonne/m^3, heights of 0.5 m and 5 m, and annual rates of infiltration of precipitation of 50 mm and 200 mm, respectively.

Table 3.1
Illustration of the relationship between L/S and time, using equation (3.2).

Height H m	**Infiltration I** mm/year	**L/S** l/kg	**Time t** Years	**Height H** m	**Infiltration I** mm/year	**L/S** l/kg	**Time t** Years
0.5	50	1	15	0.5	200	1	3.8
0.5	50	2	30	0.5	200	2	7.5
0.5	50	5	75	0.5	200	5	19
0.5	50	10	150	0.5	200	10	38
5	50	1	150	5	200	1	38
5	50	2	300	5	200	2	75
5	50	5	750	5	200	5	188
5	50	10	1500	5	200	10	375

When using leaching data as input to transport and behaviour models, it is often convenient to be able to quantify the leaching process in terms of simple mathematical formulas. The leaching of several (but not all) inorganic contaminants in an equilibrium controlled system, including a percolation test, may be described as resulting in an initial or early peak concentration of the substance in the leachate followed by an exponential decrease of the concentration with time (or L/S). If it is assumed that a continuously stirred tank reactor (CSTR) model (see e.g. van der Sloot et al., 2003) can be used to interpret the results of a column leaching test on the granular waste material, the leaching of several components may be expressed by a simple decay function:

$$C = C_0 * e^{-(L/S)\kappa} \qquad (3.3)$$

where C is the concentration of the contaminant in the leachate as a function of L/S (mg/l), the constant C_0 is the initial peak concentration of the contaminant in the leachate (mg/l), L/S is the liquid to solid ratio corresponding to the concentration C (l/kg) and where κ is a kinetic constant describing the rate of decrease of the concentration as a function of L/S for a given material and a given substance (kg/l). κ values may be estimated from column, lysimeter or serial batch leaching data (see van der Sloot et al., 2003).

By integrating the above expression, the amount of the substance, E (in mg/kg), released over the period of time it takes for L/S to increase from 0 l/kg to the value corresponding to C, can be calculated:

$$E = (C_0/\kappa)(1 - e^{-(L/S)\kappa}) \qquad (3.4)$$

Even if it is not entirely true, it is assumed that κ is independent of the material leached, but specific for each substance. The larger κ is, the faster will the concentration in the eluate decrease as a function of L/S. This is illustrated in Figure 3.4 which shows C/C_0 as a function of L/S for different values of κ.

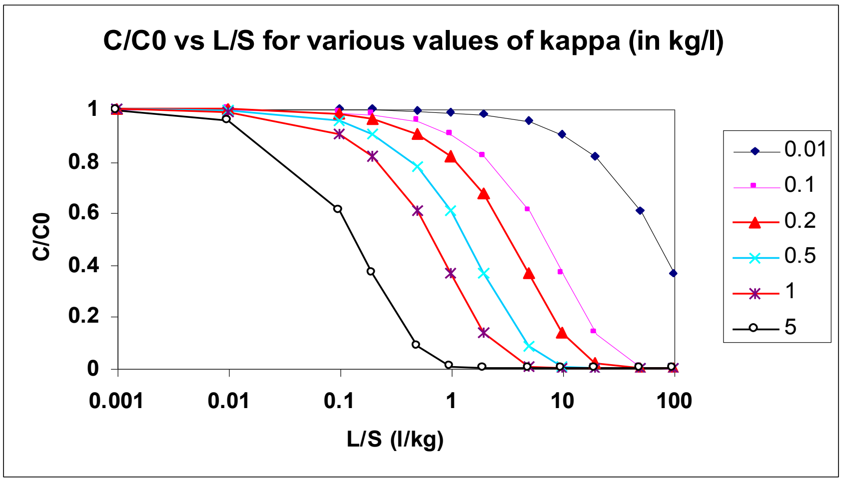


Figure 3.4
C/C_0 as a function of L/S for different values of κ.

For substances for which the leaching from an aggregate progresses as described by equation (2.3), the equation can be used to “translate” a leaching result (or a limit value associated with a percolation or batch leaching test) from one L/S value to another. If E1 is the amount leached of the substance at $(L/S)_1$, the amount E2 leached at $(L/S)_2$ can be calculated as follows:

$$E2 = E1 * (1 - e^{-(L/S)2\ \kappa})/(1 - e^{-(L/S)1\ \kappa}) \qquad (3.5)$$

This method was used when setting equal limit values (= values on the same leaching curve) at L/S = 2 l/kg and L/S = 10 l/kg for acceptance of waste for landfilling in Council Decision 2003/33/EC.

Annex 1 shows an example of how equations (3.3) and (3.5) may be used to estimate the pore water concentrations in aggregates of initially released substances from leaching tests performed at higher L/S values.

3.5 Leaching as a function of pH

It is generally accepted that pH is the major chemical variable that controls the leachability of both major and minor substances from most aggregates. Relatively small changes in pH can either increase or decrease leached concentrations by several orders of magnitude for many substances, among which both (cationic) metals and oxyanions. The influence of pH is based on the strong dependency on this parameter of the solubility of important minerals that may occur in aggregates, such as oxides, hydroxides and carbonates. In addition to these mineral precipitation/dissolution processes, both cationic and anionic constituents are bound to the solid residues by adsorption/desorption on reactive mineral and/or organic surfaces with a pH-dependent charge. Both types of processes (solubility and sorption) result in general terms in the same pH-dependency of release process in that the leaching of cationic constituents increases towards low pH and the leaching of anionic constituents increases towards high pH. This general leaching behaviour can be further modified by the effect of other chemical parameters, as discussed below. For alkaline aggregates, changes in pH may for example occur as a result of exposure to carbon dioxide (CO_2) in atmospheric air as a result of maturation prior to use or as part of the ageing processes in the field. For this reason the leaching properties of a freshly produced alkaline aggregate may be completely different from those of the same material in a carbonated/aged state.

3.6 Other influences on leaching (redox potential, complexation, particle size)

Other important chemical properties that may influence the leaching of substances from aggregates, in addition to pH, are redox potential and complexation by inorganic and organic substances. A physical property that has a substantial influence on the leaching of an aggregate is the particle size or the particle size distribution.

The state and leachability of several substances (e.g. Cr, Fe, Mn, SO_4^{2-}) are sensitive to changes in the redox-potential. Oxidation may occur for reduced materials, e.g. aggregates containing sulphides, as a result of exposure to atmospheric oxygen and give rise to the production of sulphuric acid and associated release of harmful substances. Reduction may occur for oxidised aggregate, e.g. as a result of biological degradation of organic material and give rise to release of e.g. Fe, Mn and other potentially harmful substances associated with these oxidised minerals. A typical example is the release of As from dissolving Fe-oxides under reducing conditions. Under slightly acidic conditions, the reduction of sulphate may cause the formation and release of hydrogen sulphide which is a toxic gas.

The formation of dissolved complexes enhances the solubility and leaching of major and minor elements. Examples of inorganic complexation reactions in leachates from waste aggregates are the complexation of cations with hydroxide (also called hydrolysis) and carbonate ions. These reactions cause the typical V-shaped solubility-curves of amphoteric elements such as Fe, Al, Zn, Cu, and Pb, as a function of pH (Stumm and Morgan, 1981), which are also reflected in their pH-dependent leaching from many aggregates.

Some waste-derived aggregates, e.g. MSWI bottom ash, contain residual organic matter (TOC). Various amounts of dissolved organic carbon (DOC) may be produced in leachates from such aggregates by the dissolution and/or (bio)degradation of the organic residues (Chandler et al., 1997; Meima and Comans, 1997). Several studies have shown that dissolved organic carbon (DOC) can substantially enhance the leaching of for example Cu from e.g. MSWI bottom ash (e.g. Comans et al., 1993; Johnson et al., 1995; Chandler et al., 1997; Meima et al., 1999).

All other conditions equal, reduction of the particle size will decrease the resistance against diffusion of substances out of the particle and increase the rate of release of substances that are not otherwise affected. The leachability is therefore generally assumed to increase, when the particle size decreases. Kosson et al. (2002) have, for example, estimated that the achievement of an equilibrium condition equal to that obtained for aggregates of a particle size of 2 mm in 48 hours would take 13 days for aggregates of a particle size of 5 mm and 41 days for aggregates of a particle size of 9 mm.

Besides particle size the porosity is a relevant factor, particularly if closed porosity (i.e. non-connected porosity) is involved. For dense, non-porous matrices, the release can be very much reduced as the contribution by diffusion out of the matrix is minute. However, since the alkalinity of for example steel slags often becomes less accessible with increased particle size (thus preventing a decrease in pH when exposed to water) and since the leachability for some elements increases when pH decreases, the net effect of a larger particle size may actually be no difference or even an increase in leachability with particle size depending on the extent of the leachability increase with decreasing pH. These counteracting effects can only be quantified by experimental verification. Current on-going robustness work on leaching tests adopted in CEN/TC 351 will most likely provide some insight and conclusions on the net effect for a few different materials with different particle sizes, pH and porosities (see also Annex 2).

3.7 Protocols for sampling and determination of leaching and content of substances for aggregates

3.7.1 Sampling protocols

When testing waste materials or products, the first step will always be to obtain a “representative” sample of the material to be tested. When sampling a waste aggregate for the purpose of assessment of compliance with possible of EoW criteria, it is particularly important that the sample(s) to be tested represent(s) all possible variations of the quality of the product. If it is a routine testing of a specific batch of the material, then the sample(s) collected should be representative of that particular batch. It is always a challenge to ensure that the small amount of material which is eventually tested is truly representative of the population from which it is sampled, and the importance of employing proper sampling (and pre-treatment) procedures has often been underestimated. However, during recent years the focus on sampling has increased, and several sampling protocols for waste aggregates have been developed, in particular by CEN.

CEN/TC 292: Characterisation of waste has produced a standard and five technical reports that are relevant for sampling waste aggregates, see Table 3.2.

Table 3.2
Sampling standard and guidance documents produced by CEN/TC 292.

Standard/Technical Report	Objective/Content
EN 14899:2005. Characterisation of waste – Sampling of waste materials – Framework for the preparation of a sampling plan.	The objective of the sampling programme is to provide general guidance on the content of a sampling plan. The sampling plan translates the sampling programme into specific and concrete technical instructions for the sampler.
CEN/TR 15310-1:2006. Characterisation of waste – Sampling of waste materials – Part 1: Guidance on the selection and application of criteria for sampling under various conditions.	Discussion of statistical principles in sampling and description of statistical tools for designing testing programmes.
CEN/TR 15310-2:2006. Characterisation of waste – Sampling of waste materials – Part 2: Guidance on sampling techniques.	General description of sampling techniques for various wastes found in a variety of locations.
CEN/TR 15310-3:2006. Characterisation of waste – Sampling of waste materials – Part 3: Guidance on procedures for subsampling in the field.	Description of procedures for reducing the size of waste materials in the field to aid practical transport of a sample to the laboratory.
CEN/TR 15310-4:2006. Characterisation of waste – Sampling of waste materials – Part 4: Guidance on procedures for sample packaging, storage, preservation, transport and delivery.	Description of procedures for packaging, preservation, short-term storage and transport of samples.
CEN/TR 15310-5:2006. Characterisation of waste – Sampling of waste materials – Part 5: Guidance on the process of defining the sampling plan.	Guidance on important steps in sampling including illustrative examples on how to define technical goals.

The standard on sampling in the field and the connected Technical Reports provide the tools to define the scale of production for which the sampling is representative and the number of increments and samples to take (and how to take them) to get a result that is representative for the batch with a certain reliability.

The CEN product technical committee on aggregates, CEN/TC 154, has included guidance or prescriptions on sampling of aggregates for testing as part of or in relation to the product standards, but mostly in relation to testing for functional criteria (e.g. EN 932-1:1996. Tests for general properties of aggregates – Part 1: Methods for sampling). To compensate for this, CEN/TC 351: "Construction products – Assessment of release of dangerous substances" has produced a technical report: CEN/TR 16220: Construction products – Assessment of release of dangerous substances – Complement to sampling. This CEN/TR covers the specific requirements for sampling construction products to determine the release or emission of dangerous substances in their intended use. It is complementary to existing sampling standards and sampling instructions in product standards or test methods for construction products of CEN product TCs and EOTA committees which fall under the CPD. The scope of the CEN/TR covers all activities related to product sampling, starting with the initial planning of sampling until the delivery and formal transfer of the laboratory sample at the laboratory. It does not deal with sub-sampling in the laboratory as a step towards the preparation of the test portion, it does not deal with the second sampling domain in which a sample is to be taken from the eluate of a leaching test and it does not deal with the statistical testing of a construction product against (legislative) limit values, nor does it deal with the definition of repetitive sampling, suitable for fulfilling requirements with respect to a minimum level of uncertainty in a series of test results. CEN/TR 16220 focuses on obtaining a single sample. Repetitive sampling is outside the scope as the boundary conditions for routine testing against a limit are not yet defined (e.g. the necessary reliability). Despite the fact that repetitive sampling is not covered, the conditions provided in the CEN/TR apply for an individual sample, as well as for a sample that is part of a series. CEN/TC351/TG7 covers the statistical testing and assessment of a construction product against (legislative) limit values and has been preparing technical reports providing guidance on evaluation and assessment of conformity.

The preparation of the test portions from the laboratory samples in the laboratory are covered partly by the individual test standards or procedures and by the standard EN 15002:2006: Characterisation of waste – Preparation of test portions from the laboratory sample. It has been produced by CEN/TC 292. The standard provides guidance and prescriptions for choosing sample pre-treatment techniques in the laboratory and e.g. information on the relationship between particle size and minimum sample mass.

3.7.2 Leaching protocols

Leaching tests are basically carried out for the purpose of providing answers to questions, such as "What is the initial concentration of the eluate/leachate from an aggregate being percolated by infiltrating rainwater?" or "What is the total leachable amount of various substances from an aggregate?" or "How does the leachability of various substances vary with pH?" or "Does this aggregate comply with the regulatory limit values for this or that purpose?"– and many others. Several questions are relevant for an assessment of the compliance of an aggregate with possible leaching requirements for the achievement of EoW status. Clearly, one single test cannot provide all the necessary answers, but a few, carefully selected leaching tests will be sufficient. The tests should be selected on the basis of the nature of the questions to be answered and the leaching mechanisms involved.

Historically, numerous leaching tests have been developed within different fields with slightly different purposes and slightly different test conditions for different materials. There is, however, a strong movement towards harmonisation of leaching standards and test methods. As already shown in section 2.2.3 and Figure 2.2, most leaching conditions for most materials can be assessed by means of a little handful of test methods. Table 3.3 presents this limited number of test types and the most important international leaching standards relevant to testing of aggregates.

Within the European Standardisation Organisation, CEN, test methods have different status according to their stage of development. Fully developed European test methods are called standards and labelled EN XXXXX if the method is validated, i.e. its robustness (sensitivity to changes in test conditions) and performance (repeatability and reproducibility) have been determined. If a method is developed but not yet validated, it is called a CEN technical specification, CEN/TS XXXXX. A draft standard or technical specification which has been submitted to voting within CEN but has not yet been fully processed in the system is often labelled prEN or prCEN/TS (preliminary standards or technical specifications).

It is widely accepted that the testing tools for waste materials and products within the different legislative regimes for different evaluations – landfilling in accordance with the Landfill Directive/Council Decision, beneficial use in accordance with national waste regulations or the CPD/CPR and potential future regulation on EoW criteria – should be the same to the extent possible to avoid double testing of the same material or product falling under different regulatory regimes.

Table 3.3
Relevant international leaching standards and standards under development.

Test type	Soil, sediments, compost and sludge	Waste	Construction products
pH dependence test	ISO/TS 21268-4	CEN/TS 14429	CEN/TS 14429**
	EPA 1313*	CEN/TS 14997	CEN/TS 14997**
			EPA 1313*
Percolation test	ISO/TS 21268-3	CEN/TS 14405	CEN/TC351/TS-3
	EPA 1314*	EPA 1314*	EPA 1314*
Batch test	ISO/TS 21268-1 and 2	EN 12457-1 to 4	EN 1744-3 (CEN/TC 154) and EN 12457**
Tank test	EPA 1315*	EPA 1315*	EPA 1315*
		CEN/TS 15863	CEN/TC351/TS-2
		CEN/TS 15864	
Acid generation behaviour		EN 15875	

* US EPA drafts for inclusion in SW846 (US EPA guideline on test methods for solid waste).
** Has been applied but is not (yet) a method approved by CEN/TC 351.

In the following, the proposed "tool kit" for EoW assessment of the leaching properties of aggregates, i.e. the most important of the leaching protocols listed in Table 3.3, are presented in more detail.

The proposed tool kit for assessment of the leaching properties of aggregates contains the following tests:

- pH dependence tests (CEN/TS 14429 and CEN/TS 14997)
- Percolation test (CEN/TS 14405 and CEN/TC 351/TS-3)
- Batch leaching test (EN 12457-1, 2 or 3), to be included when used for compliance or FPC

The above tests are all performed on granular or size reduced material in accordance with the discussion of the most critical EoW scenarios to be assessed (section 2.2.3). Even though the testing of intact bound materials cannot be recommended in relation to the EoW use and EoL scenarios with or without conditions or restrictions, two methods for determination of surface/diffusion related release will also be briefly described to complete the toolbox:

- Tank leaching test for monolithic materials (CEN/TS 15863 and DSLT CEN/TC 351/TS-2)
- Tank leaching test for compacted granular materials (option in DSLT, CEN/TC 351/TS-2)

These latter tests can only be considered in relation to EoW, when a material is very durable (i.e. retains its physical integrity) and even under extreme exposure conditions does not deteriorate appreciably during service life, recycling or EoL conditions. See Annex 2.

pH dependence leaching tests

The pH dependence tests (CEN/TS 14429 and CEN/TS 14997) are used to characterize the pH dependent leaching behaviour of granular materials and size reduced stabilised/bound materials. Both are size reduced (to < 1 mm) prior to testing to minimise diffusion resistance to release and formation of equilibrium. In short, this leaching test involves leaching the size reduced material at (typically) eight pH values ranging from pH 4 to 12 (the range can be expanded if necessary), each at a liquid to solid ratio (L/S) of 10 l/kg. Nitric acid and sodium hydroxide are used to adjust the pH to the desired value. In CEN/TS 14429 the different pH values are obtained through initial addition of acid or base and subsequent check of pH and adjustment after 6 hours of equilibration. In CEN/TS 14997 the different pH values are pre-set and maintained by feedback control and continuous addition of acid or base. After 48 hours, the final pH and electrical conductivity (EC) are measured, and the eluates are filtered (0.45 µm) and analysed chemically. The amount of acid or base added equivalents added at the different pH values provides a measure of the acid/base neutralisation potential of the material. Results are reported as concentrations or leached amounts as a function of pH. The test is generally applicable to assessment of the release of inorganic substances (and DOC) from largely inorganic or mineral aggregates and products. For organic substances special attention must be given to the type of container used to prevent sorption losses. For highly reactive materials (e.g. materials containing significant amounts of $Ca(OH)_2$ and CaO) the acid addition must proceed slowly to prevent too strong reactions to the base/acid addition.

Percolation tests

The percolation or column leaching test on granular or size reduced material (95% < 4 mm) is carried out on waste materials according to CEN/TS 14405 (2004), which is similar to ISO 21268-3 (for soil). In this column test 7 eluate fractions are collected within the range of L/S = 0.1-10 l/kg (L/S = 0-0.1, 0.1-0.2, 0.2-0.5, 0.5-1.0, 1.0-2.0, 2.0-5.0 and 5.0-10.0 l/kg). In some cases, some or all of the eluate fractions are collected together or combined prior to analysis for practical or economic reasons (a deviation from the technical specification). The total test duration is approximately 21 days following a 2 to 3 day pre-equilibration period under saturated conditions. The leachant is demineralised water (DMW). The test material is leached in a column operated in up-flow (15 cm/day), typically using a column height of 30 cm and a diameter of 5 or 10 cm. pH is generally controlled by the waste itself in this test. If necessary, the eluates can be collected under nitrogen or argon to prevent e.g. oxidation of reduced species and/or uptake of atmospheric CO_2 which could lower the pH of alkaline eluates. The eluates are filtered through 0.45 µm membrane filters and analysed. Results are reported as concentrations or leached amounts as a function of L/S. It is assumed that the test conditions cause the test to be operated under conditions (particle size and flow velocity) approaching local equilibrium between the matrix of the aggregate and the leachant. ISO 21268-3 for soil uses a 0.001 M $CaCl_2$ solution instead of demineralised water, and it can be applied to the leaching both of inorganic substances and non-volatile organic substances when proper precautions are taken. The experience with leaching of organic substances is, however, very limited. The harmonized percolation test CEN/TC351/TS-3: “Generic horizontal up-flow percolation test for determination of the release of substances from granular construction products” is based on and very similar to the two other percolation tests. This test is currently undergoing robustness validation to assess the influence of particle size distribution, flow velocity, temperature and pre-equilibration on the test results and adjust the test description accordingly (CEN, 2011).

Batch leaching tests

The batch leaching test on granular or size reduced material (95% < 4 mm) should be carried out according to EN 12457-1 (single batch test at L/S = 2 l/kg), EN 12457-2 (single batch test at L/S = 10 l/kg) or EN 12457-3 (two stage batch test at L/S = 2 and 8 l/kg to an accumulated L/S of 10 l/kg). The granular material is placed in a closed bottle with demineralised water and agitated for 24 hours (6 and 18 hours for the two stage test). The eluates are filtered through 0.45 µm membrane filters and analysed. Results are reported as concentrations or leached amounts as a function of L/S. The batch tests provide information similar to that obtained from the percolation test but averaged over larger L/S ranges and thus showing much less detail (one point on the leaching curve for the one-stage tests, see e.g. Figure 3.3). Only the two-stage test may provide limited information on the development of the release as a function of L/S (two points on the curve). Some EU Member States apply the test EN 12457-4 which is similar to EN 12457-2, except for the fact that it does not require size reduction of particles up to 10 mm. Since the interpretation of the test results are based on the assumption that near equilibrium conditions are achieved during the test, there is a risk that the leaching in EN 12457-4 will be controlled by diffusion instead of equilibrium (and therefore different) if the amount of fines in the material is small. The EN 12457 tests are applicable mainly measure the release of inorganic substances (and DOC) from predominantly inorganic or mineral aggregates.

Tank leaching test
The tank leach test is performed on monolithic (or bound) products of regular shape above a minimum size according to the new dynamic monolith leach test CEN/TS 15863: "Characterisation of waste – Leaching behaviour test for basic characterisation – Dynamic Monolithic Leaching Test with periodic leachant renewal, under fixed conditions" currently being developed by CEN/TC 292 WG6. A similar, more generally applicable tank test, CEN/TC351/TS-2: "Generic horizontal dynamic surface leaching test (DSLT) for determination of surface dependant release of substances from monolithic or plate-like or sheet-like construction products", is under development in CEN/TC 351. The specimen (minimum size in any dimension = 4 cm) is subjected to leaching in a closed tank. Demineralised water is used as the leaching solution at a liquid-to-surface area ratio, (L/A) of 8 cm^3/cm^2. The leaching solution is renewed after 0.08, 1, 2.25, 8, 14, 15, 28, 36 and 64 days. The pH, electrical conductivity (EC) and, optionally, Eh are measured in all eluates before filtration (0.45 µm) and chemical analysis. A special variation of the tank leaching test incorporated into CEN/TC351/TS-2 is the compacted granular tank test (based on the Dutch Standard NEN 7347) where the material to be tested is placed in a beaker in the tank with the surface exposed to the water. In view of its applicability to coarse granular materials in forward assessments of environmental impact, the compacted granular tank leaching test is discussed further in Annex 1. Results are reported as a flux (e.g. $mg/m^2/day$) as a function of time or as leached amounts per unit surface area as a function of time. CEN/TC351/TS-2 has been undergoing robustness validation to assess the influence of the L/A ratio, water renewal time schedule and temperature on the test results for both inorganic and non-volatile organic substances and adjust the test description accordingly (CEN, 2011).

Tank leaching test EN 1744-3 (not recommended)
CEN/TC 154: Aggregates has developed a tank leaching test in which the tested aggregate of particle size up to 32 mm is suspended in a vessel with demineralised water for 24 hours. After this the eluate is filtered and analysed chemically. The test does not reflect leaching behaviour in a specified scenario, nor does it give insight into the leaching behaviour of aggregates. In practice, due to the way it is interpreted (not taking surface related, diffusion controlled release into account and comparing test data directly with criteria for batch test data on granular material), it underestimates release. It is not possible to relate test results to exposure risks and thus provides no basis to link test results to a current regulatory approach. Due to poor definition of particle size, the repeatability is questionable. In terms of release, the method provides an undefined mix between dissolution and diffusion phenomena (van der Sloot and Mulder, 2002). In view of this, the limited amount of available test data, to avoid double testing, and in the interest of harmonisation, it is strongly recommended NOT to apply this test in assessments in relation to EoW criteria (or other assessments, for that matter).

Developments in the USA
Currently, US-EPA is in the process implementing new characterisation leaching tests in SW-846 to provide more appropriate alternatives for cases where TCLP is not scientifically appropriate. This implementation of a pH dependence leaching test, a percolation test a tank leach test and a compacted granular leach test in SW 846 was realized in 2013 (http://epa.gov/wastes/hazard/test-methods/sw846/new_meth.htm).

3.7.3 Methodology framework for application of leaching tests – EN 12920

CEN/TC 292 has developed a framework, EN 12920: "Characterisation of waste – Methodology for the Determination of the Leaching Behaviour of Waste under Specified Conditions", which can be very useful in designing scenarios, testing strategies and impact assessments for the development of EoW criteria and limit leaching limit values. EN 12920 establishes the essential principles to be applied and is, beyond that, actually nothing more than a very useful checklist outlining all the important issues that should be considered. A brief outline of the procedures described by EN 12920 is given below.

The methodology consists of the following steps:

1. Defining the problem and the solution sought
2. Describing the scenario
3. Describing the material
4. Determining the influence of material properties and specified conditions on the leaching behaviour of the waste/performing the leaching tests
5. Modelling the leaching behaviour
6. Validating the behavioural model
7. Drawing the conclusions
8. Reporting on the procedure and the results/conclusions

Figure 3.5 illustrates how the stepwise procedure may be used in decision-making related e.g. to assessment of the environmental impact or acceptability of reuse of aggregates/steel slag. In the discussion, BS EN 12920 is adjusted (and improved) slightly to cover aggregates/steel slag in unbound and bound applications.

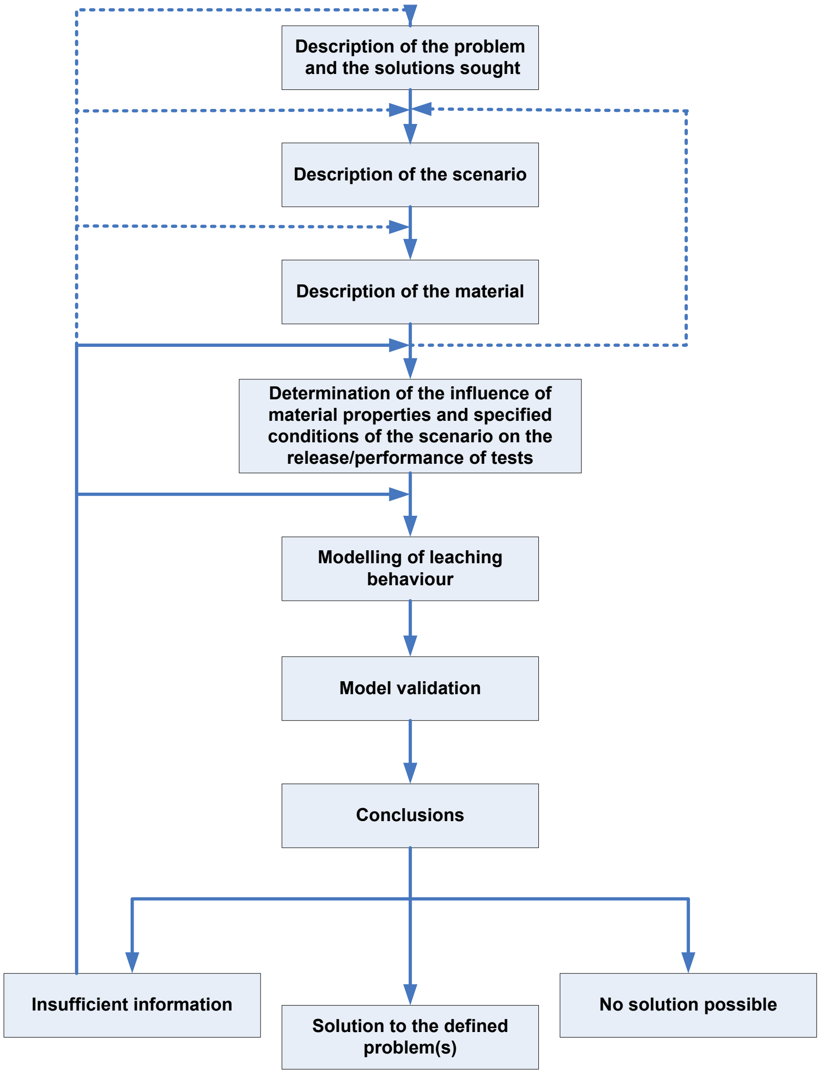


Figure 3.5
Principle of the methodology described in EN 12920.

3.7.4 Determination of total content

Methods for determination of the content of both inorganic and organic substances will also be required, particularly to enable comparison to existing limit values related to health risks. Risks associated with the release of substances from an aggregate (or any other material) and subsequent transport of the substances in an aqueous phase should always be evaluated on the basis of leaching tests, since there is no direct relationship between the content of a substance in an aggregate and the leaching of that substance from the aggregate.

In the context of the work carried out by CEN/TC 351 in support of the Construction Products Directive (CPD; 1989), a technical report has been written (CEN/TR16045, 2010) to evaluate the availability of digestion methods and subsequent analytical methods to assess inorganic and organic substances in the full spectrum of construction products falling under the CPD and its successor, the Construction Products Regulation (CPR, 2011). In view of the broad range of construction products to be covered, the report specifies a preference for multi-matrix, multi-substance methods for digestion/extraction as well as for the subsequent analytical quantification.

If content is needed, the proposed methods for inorganic substances (major, minor and trace elements) are aqua regia digestion followed by quantification using ICP-OES or ICP-MS. For a subgroup of the inorganic substances, namely anions, the recommended methods are dissolution by alkali fusion followed by quantification using Ion chromatography (IC). For non-polar organic substances, the proposed approach is to develop a horizontal method based on separate methods developed for individual organic substances or substance groups (CEN/TC292 and CEN/TC 400) consisting of extraction, clean-up and quantification by GC-MS. Similarly, for polar organic substances it is proposed to develop a horizontal method based on separate methods developed for individual polar organic substances or substance groups (CEN/TC292, CEN/TC 400 and CEN/TC139) consisting of extraction (other extractants), clean-up and quantification by GC-MS.

The development of these methods in CEN/TC351 started in 2011.

In the context of EoW and testing of waste materials to obtain EoW status, it should be noted that there are some specific issues concerning analysis of aggregates (and other materials) for the content of polychlorinated biphenyls (PCBs) that should be addressed. EU legislation does not provide a detailed definition of the limit values for content of PCB in waste. Regulation (EC) No. 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures refers to the substance as “polychlorobiphenyls, PCB”, setting a limit value on content of 0.005 % (50 mg/kg) for content that will render a waste hazardous. However, it is important to note the fact that PCB is a group name for 209 different congeners. In the “Commission Regulation (EC) No. 756/2010 of 24 August 2010 amending Regulation (EC) No. 850/2004 of the European Parliament and of the Council on persistent organic pollutants as regards Annexes IV and V” – “the POP Regulation” – there is a reference to the measurement of the content of PCBs: “Where applicable, the calculation method laid down in European standards EN 12766-1 and EN 12766-2 shall be applied”. These standards which refer to determination of PCB in petroleum products and used oils (and not in solid waste) prescribe two methods for the calculation of the PCB content: 1): Determine all congeners analytically and sum them; 2): Determine the sum of 6 congeners PCB 28, 52, 101, 153, 138 and 180 and multiply the result by 5 to get an estimate of the total content of PCB. The Council Decision 2003/33/EC on criteria and procedures for acceptance of waste at landfills specifies under limit values on content of PCB in section 2.1.2.2 only “(polychlorinated biphenyls, 7 congeners)” and a limit value, not mentioning any factor. The standard EN 15308 developed by CEN/TC 292 for use e.g. in Council Decision 2002/33/EC specifies the determination of 7 congeners (PCB 28, 52, 101, 118, 138, 153 and 180) but does not mention any factor or how to estimate the total content of PCB, and it is not clear whether the limit values for PBC given in Council Decision 2003/33/EC refer to the sum of the seven specified congeners or to the total content of PCBs. It is therefore important that any criteria set on the content of PCB specifies both the congeners to be measured and the factor to be applied to estimate the total content corresponding to a criterion. Alternatively, the criterion could refer to the sum of the congeners to be measured.

3.8 Testing hierarchies and simplified procedures

3.8.1 Basic purpose of testing hierarchies

Different systems aimed at reducing the amount of testing necessary and avoid redundant testing have been developed. The systems most relevant to the assessment of compliance with future EoW criteria for aggregates are probably those developed by CEN/TC 292: Characterisation of waste and CEN/TC 351: Construction products – Assessment of the release of dangerous substances. They are both based on the principle of performing one thorough characterisation of the environmental properties of a given waste material or product which then only have to be repeated if the material changes. Simpler test methods which can be related to the initial characterisation and to compliance with criteria are then applied routinely at certain intervals. The principle of this tiered approach is illustrated in Figure 3.6.

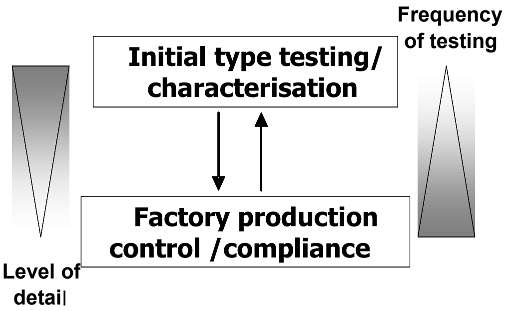


Figure 3.6
Tiered approach in testing – detailed when needed, simple when possible.

The two systems from CEN/TC 292 and CEN/TC 351 which are both embedded in or associated with EU Directives, are described in more detail below.

3.8.2 CEN/TC 292: Characterisation of waste

To avoid unnecessary or redundant testing, CEN/TC 292 has developed a test hierarchy, consisting of basic characterisation, compliance testing and on-site verification. The hierarchy, which is included in all standards and technical specifications issued by CEN/TC 292, may be described as follows:

Basic characterisation tests are used to obtain information on the short and long term leaching behaviour and characteristic 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.

Compliance (or conformity) tests are used to determine whether the material complies with specific reference values. The tests focus on key variables and leaching behaviour identified by basic characterisation tests.

On-site verification is a rapid check to confirm that the material received at the site of application is the same as that which has been subjected to the characterisation and compliance test(s).

Basic characterisation may be quite comprehensive and will generally consist of more than one leaching test. Apart from producing information on the leaching behaviour under various conditions, it should also produce information on the variation of the leaching properties of a material. In addition to the leaching characteristics, basic characterisation should also include information on the origin of the material, the process and the raw materials from which it is generated, its composition, its functional/geotechnical properties, etc. A given material of a given origin will only have to be subjected to basic characterisation once; when the information obtained by basic characterisation is available, the performance of **compliance testing**, which generally consists of fewer (often just one) and simpler leaching tests, will be sufficient. If major changes occur in the processes that produces the material or if material of another origin is introduced, a new basic characterisation will be required. The test(s) chosen for compliance testing must be included in the basic characterisation programme. The results of the basic characterisation will determine the frequency of the compliance testing. **On-site verification** will generally not require actual testing, but rather consist of visual checks and verification of the accompanying certificates and papers. It could include collection and storage of samples.

The hierarchy developed by CEN/TC 292 has been adapted and incorporated into the EU Landfill Directive (1999/31/EC) and forms the basic structure of the accompanying Council Decision on criteria and procedures for acceptance of waste at landfills (2003/33/EC).

3.8.3 CEN/TC 351: Construction products – Release of dangerous substances

As part of the fulfilment of the obligation of producers of construction products, including aggregates, to provide information on the release of regulated substances to soil, groundwater and surface water (and indoor air), CEN/TC 351 and the Product TCs regulated by the CPR are adopting and developing a system aimed at minimising the level of testing and avoid unnecessary testing while still ensuring that sufficient information is available. This is done in cooperation with DG Enterprise from the EU commission.

A procedure is described in the Technical Report CEN/TR 15858: "Construction Products – Assessment of the release of regulated dangerous substances from construction products based on the WT/WFT/FT procedures". It describes how Regulated Dangerous Substance classes (RDS classes) for each mandated Regulated Dangerous Substance (RDS) are developed and how sets of these RDS classes may be grouped for user convenience. It introduces the idea of an Initial Type Assessment (ITA) as the first step in the technical process. Where the ITA identifies that the construction product satisfies the criteria set out in the product standard with either no, a limited amount or in specific cases more extensive testing using European test methods, the construction product may be deemed-to-conform to one or more RDS classes. Where all relevant RDS classes are satisfied by these procedures, the construction product may be deemed-to-conform to a set of RDS classes. The technical procedure(s) for establishing a deemed-to-conform approach (based on assessment of conformity with relevant criteria), and its informational requirements, is described in CEN/TR 15858.

In the technical procedure, there is a hierarchy of testing using reference test methods for the determination of release/emission, alternative test methods and screening tests. These may be used in the Initial Type Testing (ITT) and in the further testing (factory production control and evaluation of conformity) to assess the constituents or materials and approve the construction product. The overall objective of the system is to set out a framework for an effective, appropriate and cost effective system for providing, when required, information on the release/emission of RDSs from construction products.

It should be noted that the WT (without testing) procedure is likely to disappear since it creates the misunderstanding that a product can be approved without consideration of any test results. During the ITA, existing data may be sufficient for an evaluation of a material and if not, such data must be produced. Both will be entered into an ITA dossier together with other information. Regardless of the source of information, the evaluation of the dossier will result in further procedures of WFT (without further testing) if there is strong evidence of compliance with criteria, and in FT (further testing) if it is found that non-compliance with criteria may sometimes occur. The further testing procedure consists of (often simpler) routine tests carried out at production level, often referred to as Factory Production Control (FPC).

The form of the ITA dossiers is currently being developed by CEN/TC 351, and a draft example of such a dossier is shown in Annex 3.

It is suggested to adopt the dossier approach (and the FPC approach as well) to the assessment of compliance of various waste-derived aggregates with possible future EoW criteria on leaching and (for organic substances) content. It is, however, too early to develop the details of the dossier, since the methodology and criteria for achievement of EoW status have not yet been determined.

3.8.4 Practical application of the waste hierarchy

The testing hierarchy for a given material can be seen as consisting of the following decision steps:

The release behaviour of any (granular) material type needs to be characterised properly using pH dependence (see section 3.7) and percolation test (see section 3.7) to ensure that the full spectrum of possible exposure scenarios for the material can be addressed (Landfill, EoW declaration, Beneficial use, recycling and coming full circle End of Life aspects). By requiring the same type of tests to be performed for any of the regulations related to the mentioned scenarios, double testing of a material possibly falling under different regulations or specification will be avoided. For more specific requirements, see chapter 7.

There needs to be a sufficient understanding of the bandwidth of cumulative release and leaching concentrations under the range of conditions of relevance in exposure scenarios (see statistical data for a range of material types Separate Appendix Part 2). This characterisation data set will allow identification of the relevant substances for compliance testing (defined by the chance of exceeding the regulatory or class limit) as well as the frequency of testing, when the regulatory criteria or class limits for a given use are identified (see section 3.9).

Once adequate characterisation data is available and assessable for a given material type, simplified testing by analysing specific eluate fractions from the characterisation tests or performing a simpler, suitable batch leaching test will suffice to demonstrate compliance with limit values or class limits. The simplified test data then need to be placed in conjunction with such more extended data to adequately substantiate this. From this description it is clear the reference tests in case of dispute will be the full characterisation tests and simplified tests (like a batch procedure) are allowed for compliance conformity testing. When a compliance test shows significant deviation from the available bandwidth of test data, then additional checks are needed to verify that the deviation is not caused by the analysis itself (dilution factor, inadequate calibration, interference, unit conversion mistake). If that check does not lead to conformity/compliance, then a full characterisation is called for to identify what has caused the deviation (e.g. other source materials, changes in processing, handling), which may lead to the identification of a new subcategory.

The hierarchy in testing as laid out here satisfies the needs from a regulatory perspective to ensure compliance with health and environmental quality targets, but at the same time provides an efficient means of complying with requirements by industry without carrying out more tests and analysing more substances than strictly necessary. For several major material streams substantial data sets are available to be used as a reference base for compliance verification purposes. In the Separate Appendices 1 and 2, both raw test data as well as aggregated data for specific material types are given. The latter would be most relevant for comparison of single test data from a dedicated compliance/conformity test. Such a comparison is illustrated in Figure 3.7 for leaching data on Cr and Zn from MSWI bottom ash.

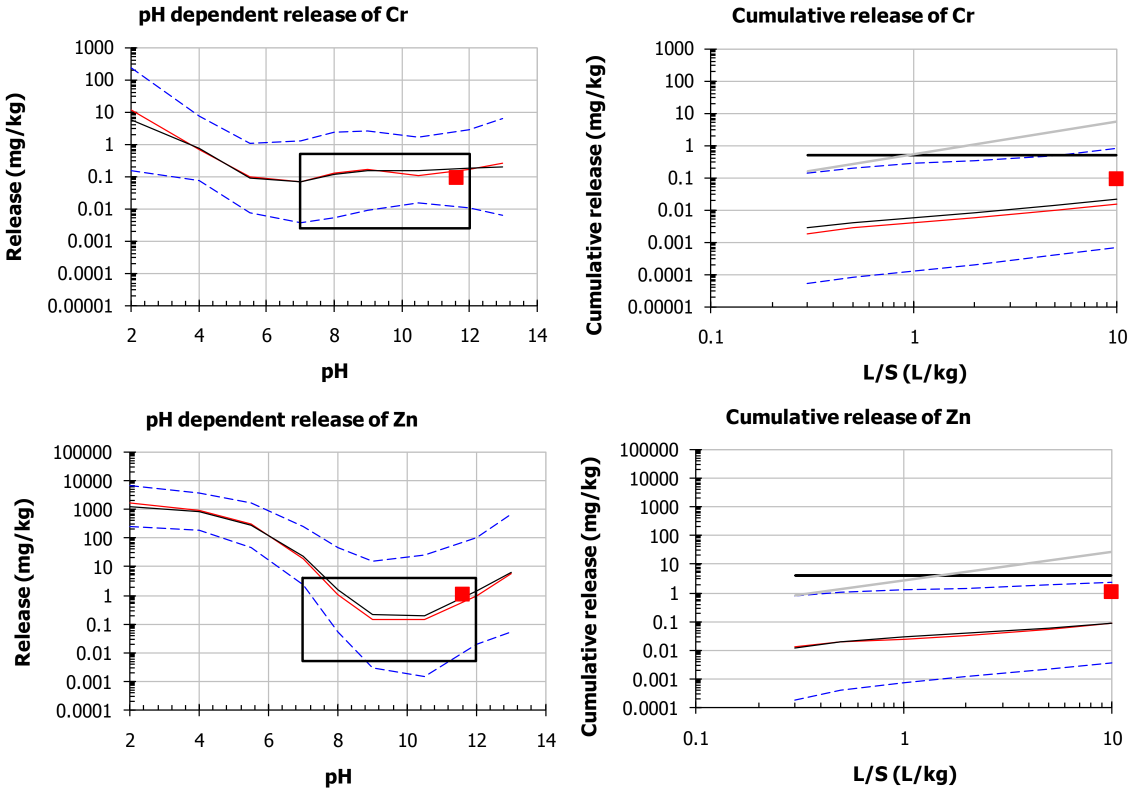


Figure 3.7

Compliance test data for Cr and Zn in comparison with bandwidth data form MSWI bottom ash and associated domain for regulatory or class judgment. Black line – average leaching of log transformed data; red dotted line – median leaching of log transformed data; broken blue lines – 90 % confidence interval of log transformed data.

3.9 Assessment of conformity of test results with limit values

In connection with the testing hierarchy an approach is needed to determine if test results obtained for a material meet the requirements. The reference base of test data as discussed in 3.8 can be used as basis for such evaluation.

In most cases, judgment needs to be made on a limited number of data. Only when assumptions can be made about the statistical distribution of the data, and then only when it concerns a normal distribution, will it be possible to draw conclusions with only a limited number of observations. Leaching test data are skewed and that requires a logarithmic transformation to be able to treat the data as a normal distribution. What ultimately needs to be determined is the chance of exceeding the (regulatory) limit value or a class limit.

For Dutch legislation (BMD, 1995; SQD, 2007), a simple statistical test method has been developed to determine the risk of exceeding a limit value with a small number of observations, which is known as the k-value.

The k-value quantifies the risk of exceeding the limit value for normally distributed data, a specified number of observations, a specified reliability and an accepted chance of exceeding the limit value (leaching test results are generally log normally distributed and will therefore have to be transformed to and from logarithmic representation before and after the conformity analysis). Within these conditions, the k-value sets limit values against which a calculated k-value can be compared. The calculated k-value is obtained from test results of a specific material. If the calculated k-value is larger than the quantified k-value limit, the chance that the material will exceed the regulatory limit value is

unacceptably high. What is unacceptable is defined when choosing the boundary conditions for the k-value, specifically the fraction of the material that is accepted not to comply.
For normal data, the k-value is calculated in accordance to:

k = (Limit value – Avg) / Stdev (3.6)

With:

k = the calculated k-value

Limit value = the (regulatory) limit value

Avg = the mean value calculated over a specified number of observations

Stdev = the standard deviation over a specified number of observations

As leaching data often require a logarithmic transformation to meet the boundary condition of a normal distribution, the k-value can be calculated with the following formula:

k = (log(Limit value) — (Avg(log normal data))/(log (Stdev(log normal data)) (3.7)

The values against which the calculated k-value is to be tested are given in Table 3.4.

Table 3.4
Values for comparison with k for different numbers of observations and different reliabilities.

Reliability of the test	**Number of observations**	**Percentage of the material that has to comply with the limit value or class limit**		
		99%	**95%**	**90%**
90%	5	4.67	3.40	2.74
	10	3.53	2.57	2.07

The k-value can either be calculated for a set of data with a variable number of samples (e.g. from a historical data set) or it can be used in a situation with repetitive sampling, where after each sample the earliest observation is discarded and the k- value is repeatedly recalculated. In the latter situation, the value of k is based upon a moving average and standard deviation over the last 5 or 10 observations.

The frequency of testing is linked to the k-value and consequently with the accepted level of non-compliance which is usually determined by the regulator.

Limits to the k-value can be calculated for any chosen set of reliability, number of observations and percentage of the material that has to comply.

In Figure 3.8 an illustration of this approach is provided for Pb leaching from MSWI bottom ash. In case of adequate characterisation, this evaluation can be based on a single step compliance test verification. Here a set of complete pH dependence tests an percolation tests has been used as an example. When varying numbers of samples per test condition are used, the k-value may not be the best representation, then the risk of non-compliance (RNC) would be better.

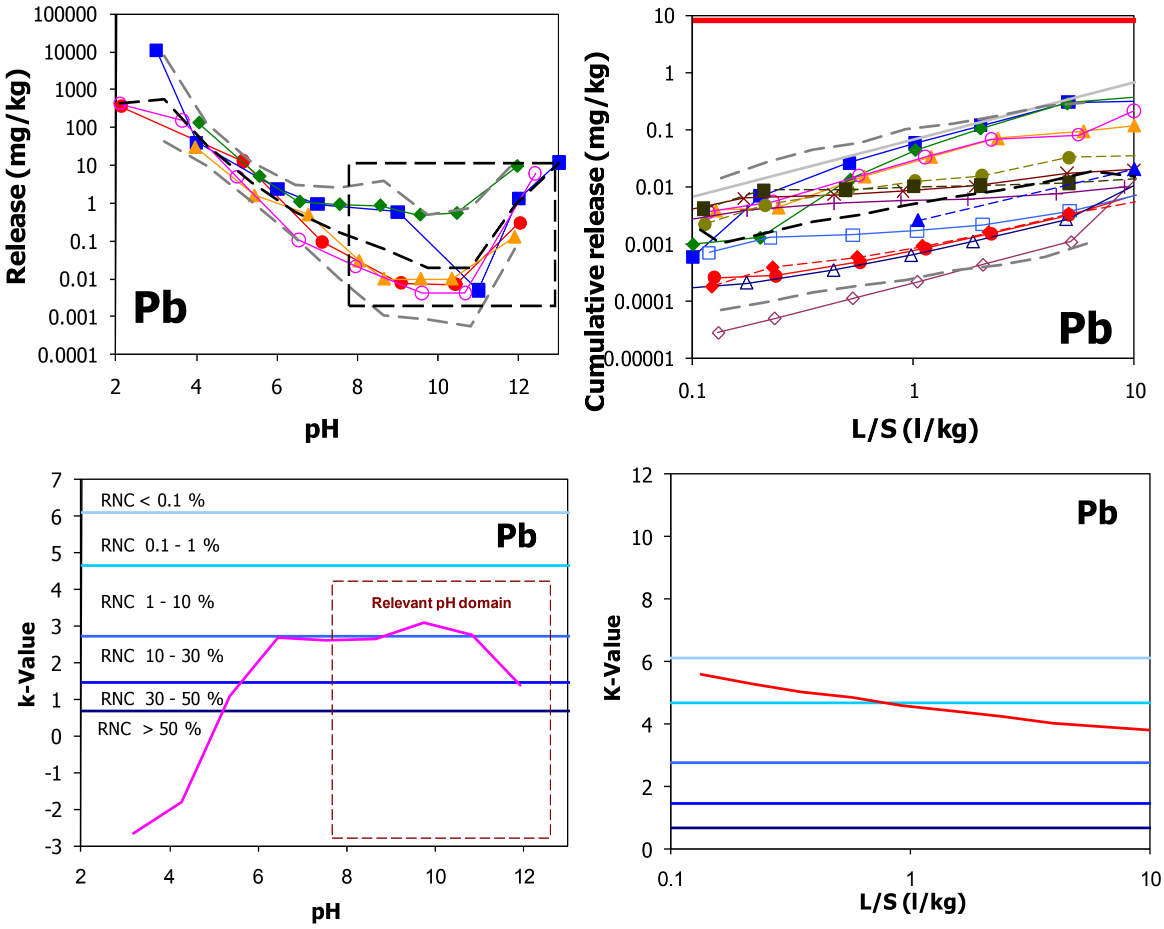


Figure 3.8

Application of the k-value approach to characterisation leaching data for Pb leaching from MSWI bottom ash to illustrate a statistically based decision on the risk of non-compliance, which can be linked to a decision on frequency of testing (to be decided by authorities). Top left: pH dependence test data for a series of measurements, box denotes the relevant evaluation domain in terms of pH; top right: percolation test data; bottom left: result of k-value evaluation for pH dependence; bottom right: result of k-value evaluation for percolation test data. RNC = risk of non-compliance.

3.10 Evaluation and interpretation of leaching data

The Separate Appendix Part 1 presents a large amount of leaching data on the aggregates considered in this context. This section explains the manner in which the data are presented and discusses how they are interpreted. Several aspects of the leaching behaviour of aggregates have already been discussed in the previous sections. A few additional key aspects are of relevance to leaching of any substance from aggregates in different end uses. This is on the one hand the issue of particle size distribution, as that property has a significant impact on the release behaviour of substances from different size classes used in construction applications. On the other hand, the role of pH in release of substances from cementitious and other alkaline materials is an important issue, as the high initial pH of such products does not stay high due to carbonation taking place after prolonged exposure to the atmosphere. Since pH has a substantial effect on release of several trace substances, it is crucial to be aware of this fact, as otherwise undesired release may develop in time. This type of behaviour is more relevant for oxyanions like As, Sb, Se, Mo, V and sulphate than it is for metals, since metal leachability is generally low in the pH range from 7 – 10 (see Separate Appendix Part 1). When a material contains sulphide, the potential for acidification may occur, if the neutralising capacity of the material is insufficient to compensate the acid produced from oxidation of sulphide to sulphate.

Increased leaching of metals is associated with this form of pH change (CEN/TC292 WG8 Guidance document, 2011).

For any type of granular material, the relevant leaching tests for characterisation of leaching behaviour are the pH dependence test (CEN/TS 14429 or 14497) and the percolation test (CEN/TS14405). The pH dependence test is used to assess the sensitivity to small pH changes (steep concentration – pH curves) and the release behaviour over the pH range the material may become exposed to during its application, recycling or end of life. The percolation test (CEN/TS14405) provides the time-dependent release behaviour of the material to be assessed and in addition, provides insight in porewater composition, which is close to the first leachate released (in the context of the EU LFD referred to as C_0) from the material in any given application. Both methods in combination allow judgment of exposure conditions outside the range of actual conditions tested. This is important for judgment of long term impact. Expressing results in mg/l and in mg/kg dry matter addresses different aspects of leaching (see also section 3.3).

All data presented in Separate Appendix Part 1 (see section 4.2) are given in the same layout, unless data for one of the tests are lacking. All data are presented in log scale, as presentation of leaching data in linear scale will not show the release behaviour at low concentrations. In Figure 3.9 an example is given of the leaching of V from crushed cement mortars with results expressed in mg/l and mg/kg. Crushed cement mortar can be seen as being representative for recycled concrete.

- In the top left figure concentration of the substance is given as a function of pH. For V it is clear that all cements from worldwide origin follow the same general trend with a minimum in leachability around pH 5 and a maximum leachability at mild alkaline pH (pH 9 -10). The lowest leaching for V is found at high pH, which is the condition corresponding to fresh crushed material. At this pH solubility is most likely by incorporation in ettringite as a solid solution (Van der Sloot et al., 2001 and 2011; Meeussen et al., 2009). Upon carbonation leachability will increase significantly.

- The top right figure gives the release in the percolation test expressed in concentration units. This illustrates for the full tests that the concentration is virtually constant, which is indicative of solubility control. The different levels (2 orders of magnitude) reflect different stages of carbonation. The cluster of data points at L/S=10 l/kg reflects the data from column tests, in which only the final fraction is analysed (Aalbers et al., 1998). Batch test data at L/S=10 or 2 l/kg will form a cluster of data points which lack insight in the reason for the observed range. The combination with the pH dependence test provides an important part of such understanding. The concentration at L/S = 0.2 l/kg reflects the concentration that may be expected in porewater, which is of relevance in judging large volume applications of the material.

- In the bottom left graph release is expressed in mg/kg. In the graph the relevant pH domain for the material is indicated. Here from pH 12 to pH 7 (as a result of carbonation). The vertical lines in the box denote the pH range of relevance, the upper horizontal line reflects the regulatory criterion (here the EU Landfill Directive leaching limit values for acceptance of inert waste), while the lower line reflects the average detection limit for the substance.

- The bottom right graph shows the data for the column test as cumulative release in mg/kg. The continuous line reflects a slope 1, which indicates solubility control, which in the case of V is clearly the case. The broken line is the regulatory criterion for inert waste. The data as presented forms the basis for the statistical evaluations presented in Separate Annex Part 2.

In the following part a number of examples and typical observations will be presented to illustrate observed release behaviour from aggregates.

In Figure 3.10 the release behaviour of Zn from mixed C&D waste is given, which illustrates the lack of full column data for this materials stream. There are some 449 measurements in the cluster at L/S=10 l/kg, which match in range with the range observed in pH dependence test results. The data do not provide insight in the release pattern as a function of L/S, as depending on the application the relevant L/S may not be as high as 10 l/kg. In addition the release pattern has consequences for the initial porewater concentration.

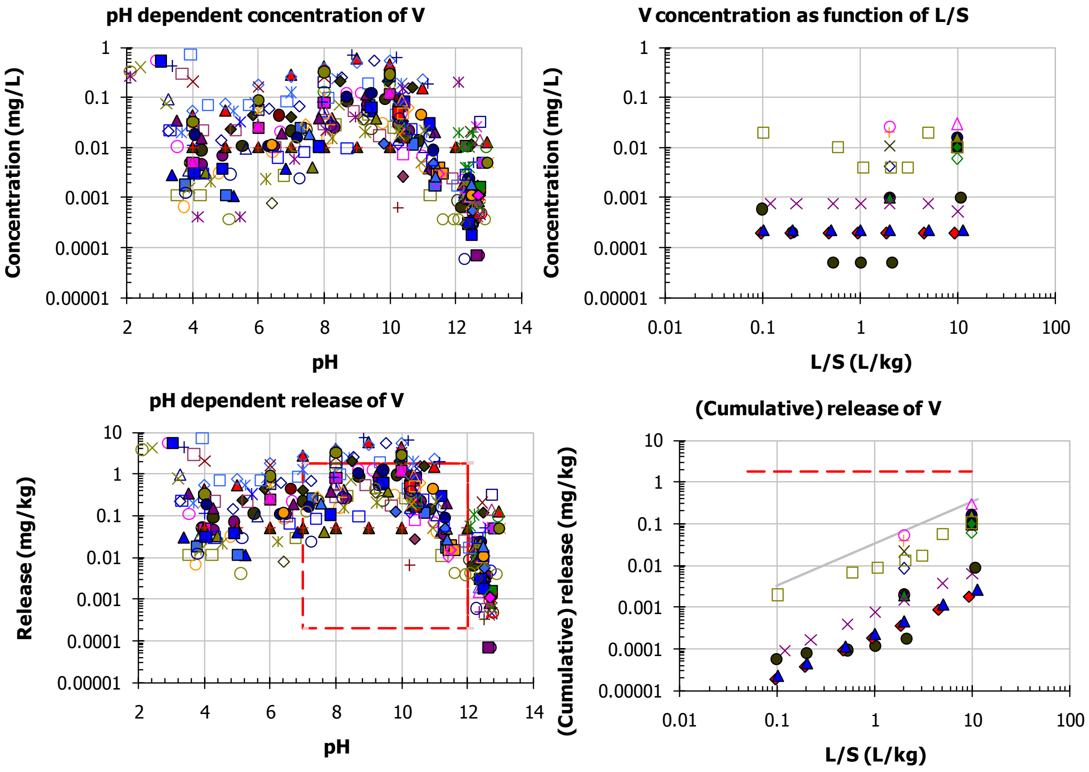


Figure 3.9
Release of V from crushed cement mortar in pH dependence test and percolation test expressed in mg/l and in mg/kg. Top left: pH dependence in mg/l; top right: percolation in mg/l; bottom left: pH dependence in mg/kg with the relevant pH domain and regulatory criteria embedded; bottom right: cumulative release with regulatory limit; continuous line reflects solubility control.

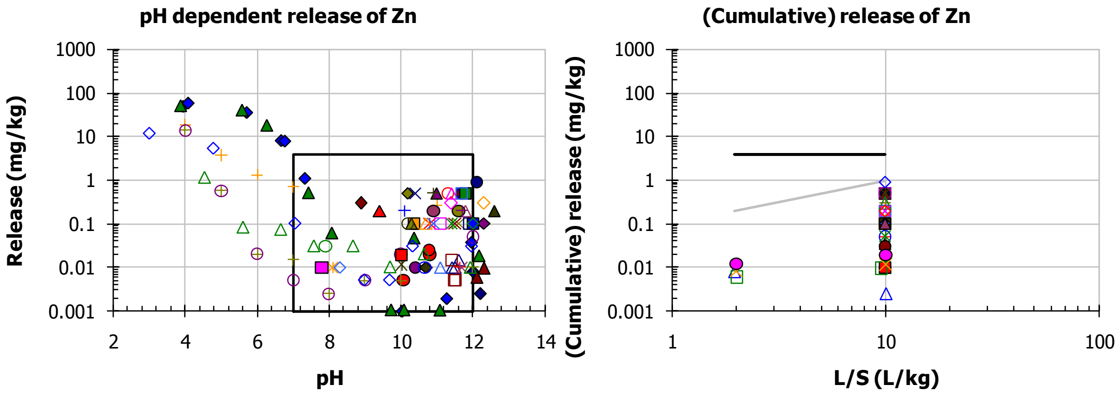


Figure 3.10
Release of Zn from Mixed C&D illustrating the limitation of single data point measurements.

In some cases, serial batch tests (RecBrick) and multiple batch tests (CFA) have been applied extending beyond L/S=10 l/kg. In general, these tests form a logical extension of the observations until L/S=10 l/kg. It should be realized, however, that the regulatory criteria are based on L/S=10 of recalculated to an L/S=10 l/kg condition. In Figure 3.11 an example is given for Cr and SO4 from RecBrick.

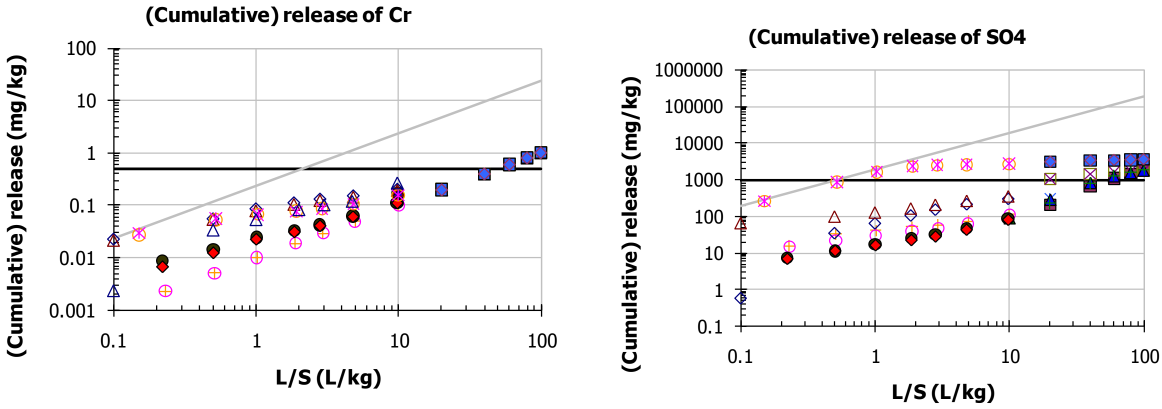


Figure 3.11

Cumulative release for Cr and sulphate from RecBrick illustrating consistency between column and serial batch test data beyond L/S=10 l/kg.

In Figure 3.12 an example is given of possible acceptance at or close to the regulatory limit for Cr release from CFA, where the Cr is 100 % leachable as chromate up to concentrations in porewater of 2 to 5 mg/L. This is typically a situation, where it is important to evaluate both aspects of release: the cumulative release as defined by impact modelling and the porewater concentration in case of high volume applications. If the Cr remains in its oxidized state, this may clearly lead to unacceptable releases in the environment in spite of acceptance at the Inert landfill limit.

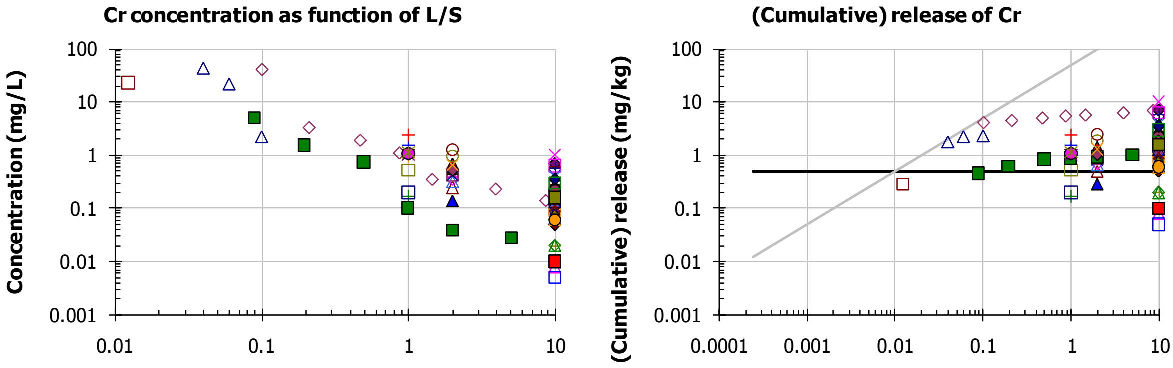


Figure 3.12

Release of Cr from CFA as example of possible unacceptable release of Cr in spite of being at or close to the limit.

In a number of cases, the first fraction of a column test may be decisive for the release observed in a percolation test. This may occur if the first leachate is acidic and later on the pH increases due to delayed release of alkaline components from the material. This effect on metal release may take place in flue gas dust, when acids (H_2SO_4, HCl) which are washed out readily are deposited on the surface of particles. In field conditions such initial acidity peaks may not occur at all or could be avoided easily and thus the judgment might be faulty, if that aspect is not taken into consideration. Alternatively, this effect may also occur in highly alkaline materials, where the first flush has a very high pH, which then decreases rapidly. A substance that leaches at high pH, but then decreases in leachability (e.g. Pb) will show an initial high release, which may not occur in the field. In Figure 3.13 this effect is shown for release of Pb from recycled concrete. The pH recorded during the percolation test can flag this possible occurrence.

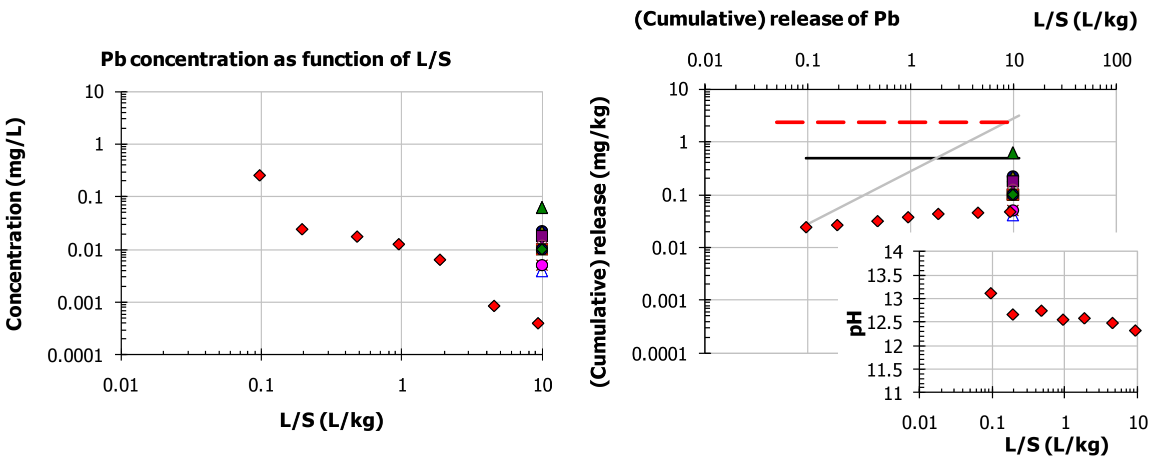


Figure 3.13

Release of Pb from RecCon showing domination of cumulative release by the first eluate from the column.

In Figure 3.14 the data from extensive quality control on MSWI bottom ash compared with characterisation data for MSWI BA from many different sources. This illustrates that the production of bottom ash in a full scale incinerator from household waste dictates a certain release behaviour that is comparable between installations from different locations. This provides a basis of reference for compliance as well as a basis for making improvements in material behaviour. However, that can not be done without a more detailed understanding of the underlying release controlling processes and chemical speciation aspects.

Carbonation has an effect on leaching of substances. The main effect is visible for Ba, Ca, Sr, which are substantially affected. The effect on many other substances is limited as the carbonation's main effect is a pH change. Leachability then follows the pH curve as observed in the pH dependence test. In the case of sulphate, the formation of ettringite disappears, so the carbonation effect is mainly noticeable at high pH. The disappearance of ettringite has consequences for substances incorporated in ettringite, as they will be released in the dissolution process (ettringite is not stable below pH = 10). Figure 3.15 shows the effect of full carbonation on Ba, Ca, Sr and sulphate.

It should be realised that leachability of substances from natural aggregates generally comply with inert criteria, but are not necessarily negligible, as shown in Figure 3.16 for As, Ni, Cu and Sb.

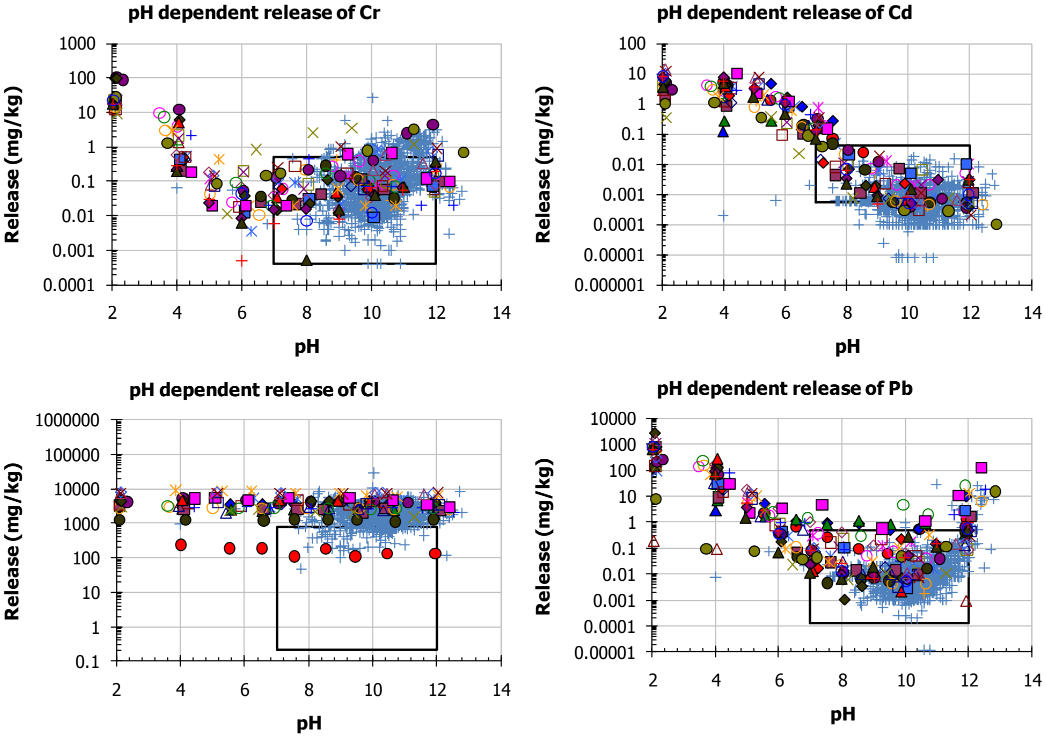


Figure 3.14
Comparison of quality control data for MSWI BA (DK) with characterisation data for Cr, Cd, Cl and Pb from different sources illustrating the systematic release behaviour and data consistency for this material type.

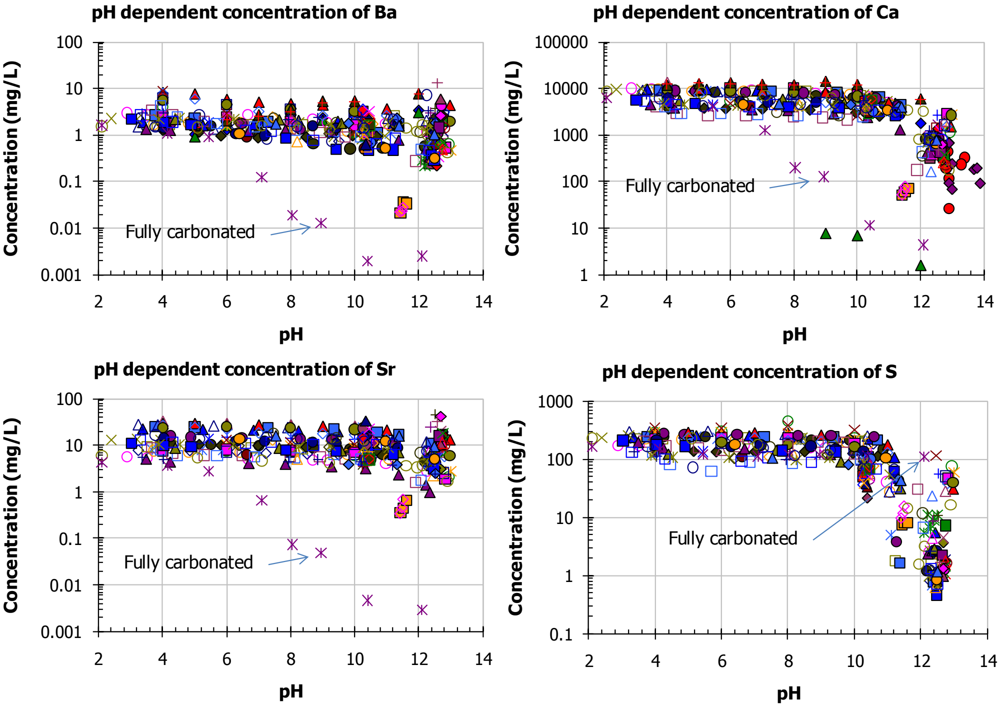


Figure 3.15
The effect of carbonation on release of Ba, Ca, Sr and SO4 as S from RecCon.

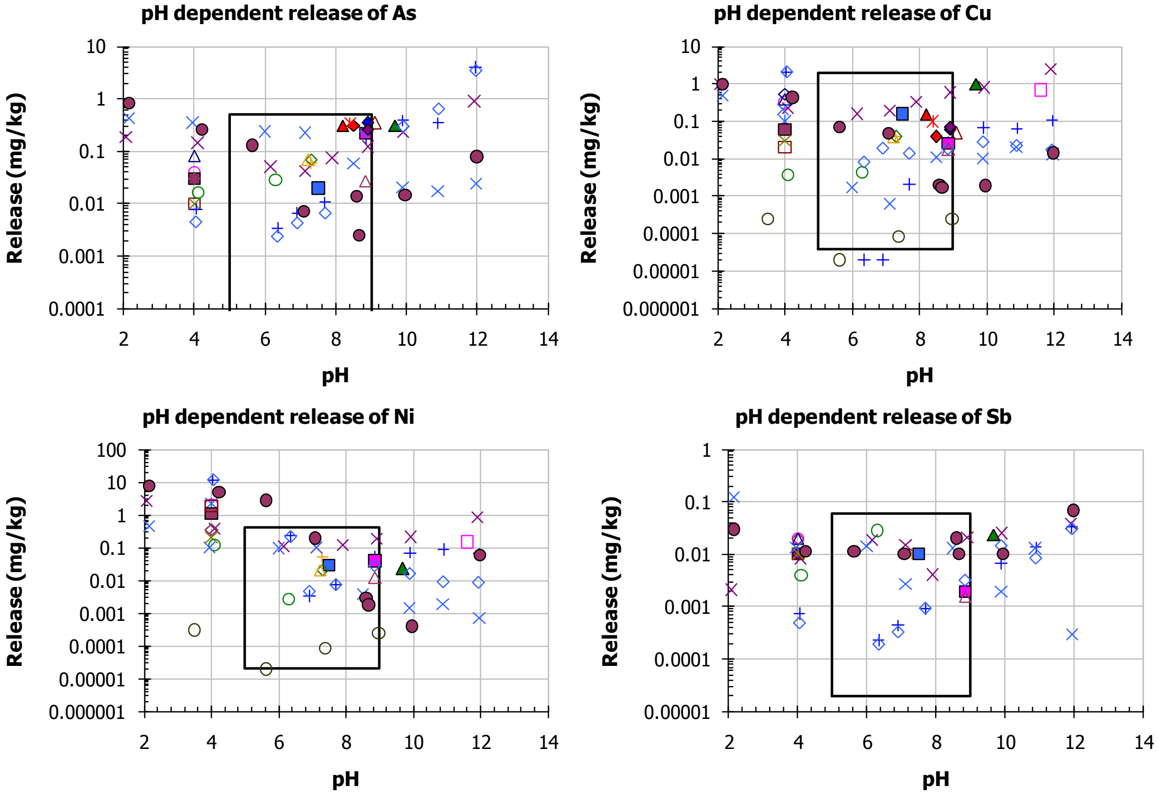


Figure 3.16

Release of As, Ni Cu and Sb from natural aggregates in comparison with inert landfill criteria.

3.11 Relationship between laboratory leaching test results and field leaching behaviour of aggregates

3.11.1 Overview

Laboratory tests are one of the important means to answer the main interesting question, namely, how does a material behave in full application. Field verification is, however, complicated and quite costly. Understanding the relationship between laboratory test results and field observations is therefore highly relevant. Simulation of field conditions in laboratory tests is a fruitless effect as a multitude of variations is possible without ever capturing the right condition. A standardised test with data interpretation based on understanding the release controlling factors, possibly in combination with modelling, is a better alternative, as it results in comparability of test data. From experiences gained in performing leaching studies, it has been found that a very important distinction to be made between release behaviour of substances is whether the substance of interest is fully soluble (like Na or Cl) or is limited by solubility/sorption constraints in the source material itself. In the latter case, concentrations in the laboratory and the field (i.e. interface between material and soil, so representing a field source term) can be the same in spite of differences in liquid to solid ratio. The concentrations may change, when the pH conditions between laboratory and field change. The pH dependence test then gives a good indication of the direction and magnitude of possible change. In case a substance is fully soluble it washes out just as readily as other mobile salts. Within L/S = 0 – 1 l/kg more than 90 % of the leachable substance is released. Under field conditions preferential flow becomes a significant factor, as stagnant zones in the application may contribute only limited to the mass flux, as such zones release substances by diffusion.

On three types of materials used in road construction field work has been carried out to a significant degree to verify the performance in the field relative to laboratory test data. This concerns MSWI bottom ash (Schreurs et al,1997; Bendz et al, 2009; Susset and Leuchs, 2008 ; DWW, 2002), coal fly ash (Hjelmar , 1990; Hjelmar et al, 1991; Schreurs and van der Sloot, 1997) and recycled construction debris (Susset, and Leuchs, 2008). In most of the older studies, pH dependence was not covered and comparison was only made based on percolation test data. It is clear that, the significant pH changes occurring in the field after a certain period of contact with the atmosphere cannot be addressed by a percolation test on relatively fresh material only, particularly, when such materials are initially alkaline. More recent studies take this aspect into account.

3.11.2 MSWI bottom ash

In Rotterdam (The Netherlands) a section of road was monitored, in which a layer of 0.5 m of MSWI bottom ash was applied as road stabilisation material (Schreurs et al, 1997). About 8 years after placement samples were taken from the stabilisation layer and the underlying soil. Laboratory tests were performed on material sampled from the field and soil core samples were tested for increases in concentration as a function of depth. The main conclusion from this work was that a layer of 0.5 m becomes fully carbonated and shows leaching behaviour reflecting this pH change. For instance, initial high Pb leaching is very soon reduced to rather low release levels as pH drops below pH 10. This also explained why Pb was not really elevated in the first soil layers.

In Sweden a road-base, in which MSWI bottom ash had been applied was sampled in detail (Bendz et al, 2009). On composite samples pH dependence and percolation tests were carried out, while also single step tests were carried out to obtain insight in the spatial distribution. In Figures 3.17 and 3.18, results from this study are given for a small selection of substances analysed. For a mobile substance like Cl, it is clear that values covering a wide range of concentrations were obtained, which indicates almost non-leached samples in sections covered by the asphalt top cover and section that have been fully depleted of soluble Cl. This reflects the point made before on the importance of preferential flow aspects in full scale applications. For many other substances (e.g. Al, Cd, Ni, Zn), the data from the individual samples show a good agreement with the more extended pH dependence and percolation test results as well as with fresh bottom ash samples from other sources, which indicates that the solubility control exerted on these substances is the same for bottom ashes from different sources.

Geochemical modelling work on MSWI ashes from different locations also points in the same direction (Dijkstra et al, 2006 and 2008). In the case of Cu, the data show a range of values covering an order of magnitude. This reflects wash out of soluble Cu-DOC from the stabilisation layer. Carbonation of a range of more exposed samples is reflected in the Ca leaching behaviour. The leaching curve shifts in accordance with calcite solubility.

The work by LANUV (Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen) in the Sickerwasser Prognose project (Susset and Leuchs, 2008) has been focused on lysimeters with a 0.5 m of bottom ash on top of 1 m of soil. The eluate was collected and analysed for a range of substances at the bottom of the soil column. This is thus an example of release in which attenuation by the soil column is taken into consideration. The neutralisation of the leachate, the retention of substances in the soil column and the preferential flow aspects under field conditions (derived from salt release) are typical aspects covered in this work. Data evaluation in terms of verification of impact assessment by geochemical modelling is still in progress. These studies provide a very valuable verification of impact modelling, when more data on the soil properties are available (leaching characterisation of soil by pH dependence and percolation test).

As a result of the need for reconstruction of a road section in Highway 15 by the study by the Dutch Water Directorate an opportunity presented itself to study the condition of MSWI bottom ash in an embankment of a highway at about 10 years after placement of the MSWI bottom ash (DWW, 2002). This study has shown that carbonation has not progressed deep into the core of the embankment. In fact in the bottom of the embankment reducing conditions were observed. The release behaviour under these circumstances appeared to be lower for some substances (Mo, Cu), but is increased for others (Mn, Fe, As, Ba).

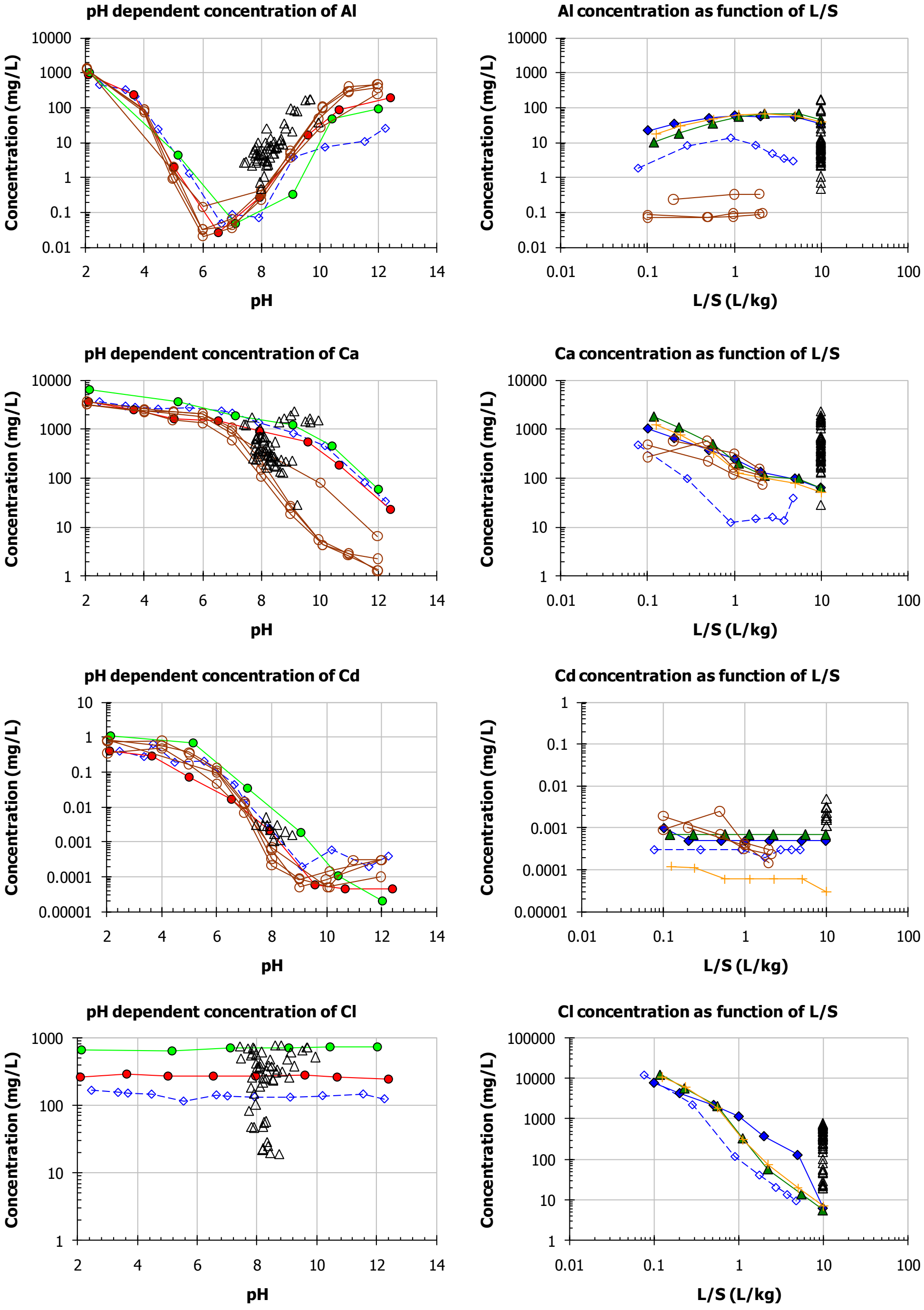


Figure 3.17
Comparison of laboratory leaching tests on a composite of samples taken from a roadbase stabilisation with MSWI bottom ash after x years of field exposure with single step laboratory extraction data on spatially distributed core samples and leaching tests on MSWI bottom ash from other sources aged for at least 3 month (for legend see Figure 3.18).

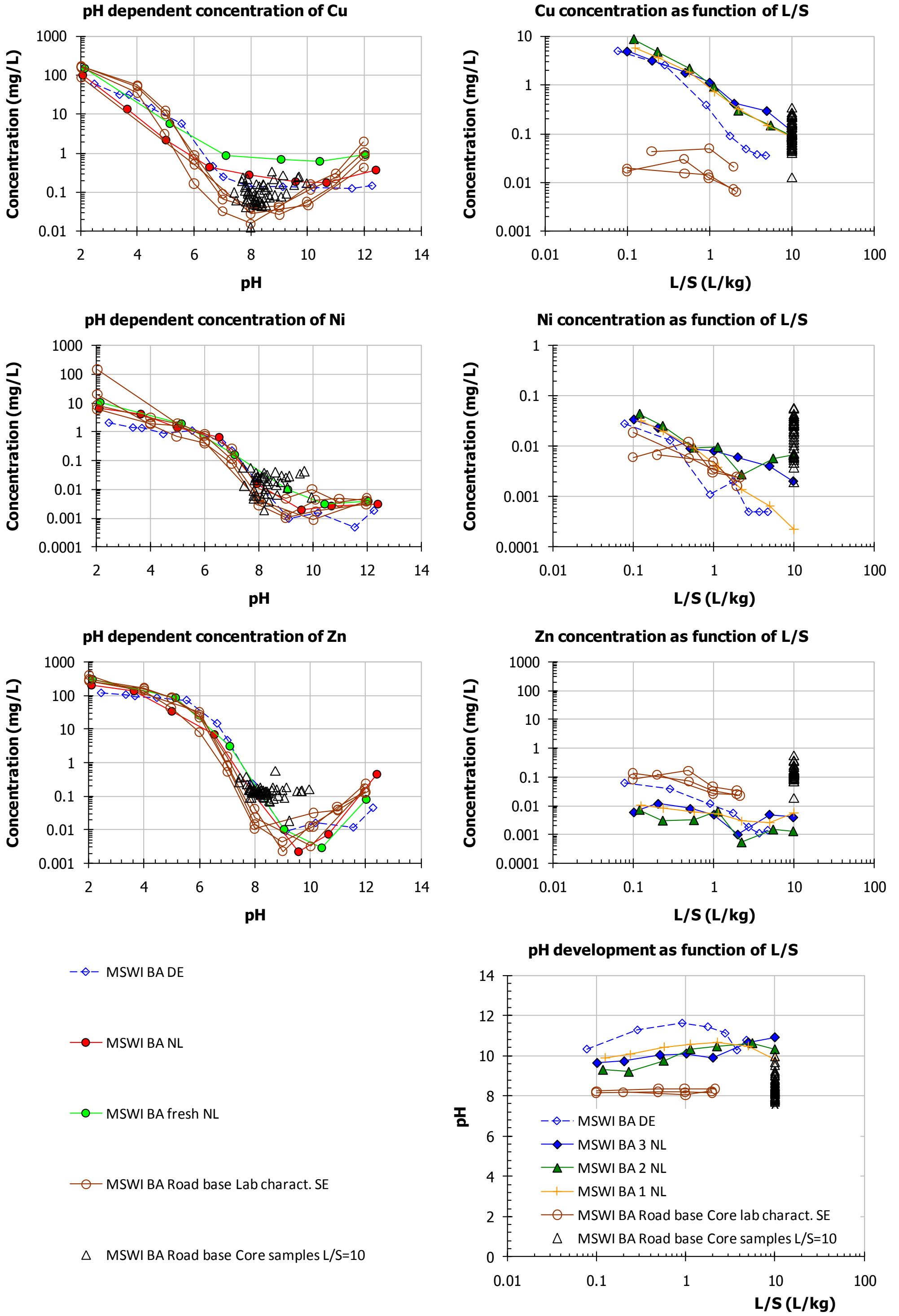


Figure 3.18
Comparison of laboratory leaching tests on a composite of samples taken from a road-base stabilisation with MSWI bottom ash after x years of field exposure with single step laboratory extraction data on spatially distributed core samples and leaching tests on MSWI bottom ash from other sources aged for at least 3 months.

3.11.3 Coal fly ash

In the same study that addressed the field sampling of MSWI bottom ash, also a roadbase containing MSWI fly ash was sampled (Schreurs et al, 1997). About 10 years after placement samples were taken from the stabilisation layer and the underlying soil. Laboratory tests were performed on material sampled from the field and soil core samples were tested for increases in concentration as a function of depth. The release of anions like Mo was clearly noted in the shoulder of the roadbase, where also full carbonation was observed. In the stabilisation layer under the asphalt cover the pH had remained high. In contrast to the MSWI bottom ash the coal fly ash stabilisation had hardened to a monolithic layer, which was less permeable than the granular MSWI bottom ash.

Hjelmar et al (1991) carried out laboratory experiments and lysimeter studies on alkaline coal fly ash. In Figure 3.19 the results of the comparison are shown. In this case, the match between a source term description from the laboratory and from the field is quite good when simply compared on the basis of L/S. The column experiments were run on 8 kg samples of fly ash over a somewhat longer time than currently used in percolation tests (due to a slower water flow velocity), reaching L/S = 10 l/kg in 2-3 months as compared to the 18 to 25 days typically used in CEN/TS 14405, see section 3.7.2). The lysimeters contained 12 and 19 tonnes of coal fly ash, respectively, and had surface areas of 9 m^2 exposed to natural weather conditions for 7 years and reaching an L/S of up to 1.9 l/kg during that period. The results indicated that presenting leaching data as a function of L/S is a valid basis for comparison, not only of results from different types of laboratory leaching tests, but also for comparison of laboratory leaching test results on inorganic, mineral materials with the leaching behaviour of the same materials in field scale, provided they are not sensitive to redox conditions or undergoing redox reactions.

Parallel column and lysimeter tests were run on flue gas desulphurisation (FGD) waste from coal fired power plants, mixed with coal fly ash, produced by the semidry gas cleaning process without preliminary removal of fly ash. The main component in the FGD part of the waste was calcium sulphite which was gradually oxidised to sulphate in the lysimeters. Due to this oxidation reaction, which does not occur to any significant extent in the column tests, the match between laboratory and lysimeter leaching data for this type of waste was much poorer than for the coal fly ash, particularly for substances sensitive to redox conditions.

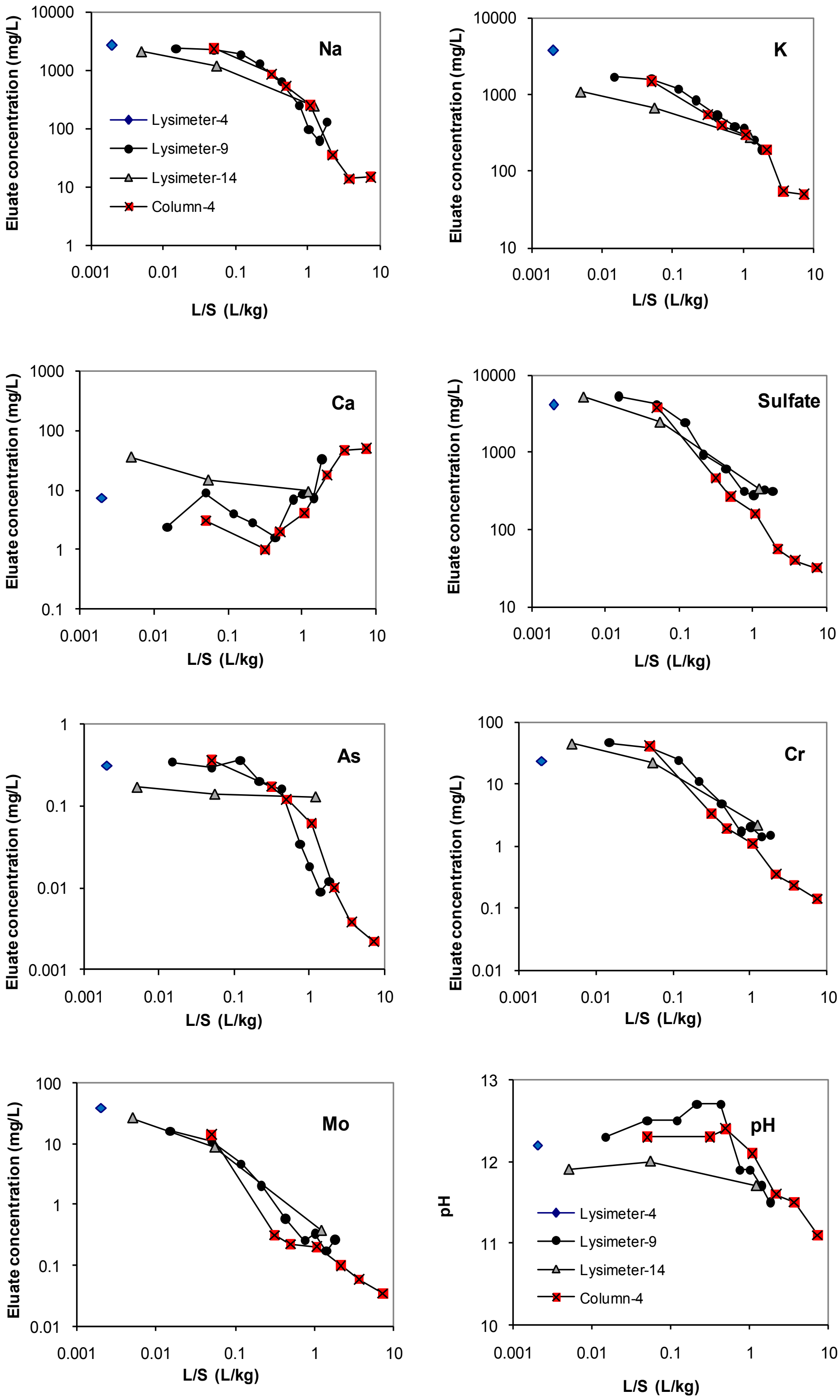


Figure 3.19
Comparison of laboratory column experiments (up to L/S = 10 l/kg in 2 – 3 months) with field lysimeter studies on alkaline coal fly ash (9 - 18 tonnes, 9 m^2, natural infiltration running over 7 years).

3.11.4 Recycled construction debris and MSWI bottom ash

In the framework of the SIWAP work (Susset and Leuchs, 2008) also lysimeters with recycled construction waste and MSWI bottom ash were studied. The lysimeters had a layer of 0.5 m of recycled construction debris on top of 1 m of soil. The eluate was collected and analysed for a range of substances at the bottom of the soil column. In this case also release with attenuation by the soil column was taken into consideration. The release of soluble salts (e.g. Cl, Na, K) indicated that due to preferential flow only a fraction (~ 20 %) of the leachable mass is released in comparison with the corresponding L/S condition in an up-flow column experiment (no or minimal preferential flow). The release from soil affected by overlying layers must not be neglected. Increased concentrations of substances can be the result of a high pH solution entering soil and mobilising DOC (dissolved organic carbon) and substances associated with it. In layers of limited height, carbonation proceeds fairly quickly, which differs considerably from applications with substantial height (> 5 m), where the carbonation front progresses much more slowly. In the translation of lab results to field conditions, such factors need to be considered.

Since the submission of the draft report an extensive study of 10 disposal and beneficial use scenarios have been evaluated for US EPA. The report "*Leaching Test Relationships, Laboratory-to-Field Comparisons and Recommendations for Leaching Evaluation using the Leaching Environmental Assessment Framework (LEAF)",* EPA-600/R-14 is expected to be available on line in the summer of 2014. In this study, cases have been selected where full characterization test data (including geochemical modelling) were available together with data on lysimeter or pilot scale and data from full scale operations. The comparison at these different scales of testing has revealed valuable relationships and possibilities to predict release under conditions beyond the scope of the laboratory tests. Changes occurring during field exposure could be identified and subsequently modelled.

In summary the above reviewed relationships between laboratory leaching test results and the leaching behaviour of aggregates in the field demonstrate that information on release at different scales of testing (lab – lysimeter – field) is crucial for a proper long term prediction of release from unbound use.

3.12 Review of actual pollution problems caused by the use of waste aggregates

Mistakes and accidents are generally unavoidable, and the use of waste aggregates for construction purposes is no exception. While mistakes and accidents are unfortunate and should be avoided or minimised, there are sometimes lessons to be learned when they happen. Therefore, a number of known accidents or problems related to the use of recycled waste aggregates have been reviewed. It should be noted that only a few such incidents have been reported, mainly in the Netherlands which has a long tradition for recycling of waste aggregates as well as for monitoring and control. In addition, this type of information is not always released voluntarily by the involved parties. In some cases, the application was not carried out according to the specifications, and in such situations the applicant is at fault. In other situations, the development of unacceptable conditions was not foreseen, as the material was applied fully in line with the regulations. In this case, additional rules or guidance to users are called for. Such cases can also help improving the understanding of factors that play a role in full application but often cannot be covered by laboratory leaching tests.

Application of LD steel slag as filling material

At the end of 2004, a total amount of 105416 tons of granular LD steel slag (0-40 mm) was used as a filling and hardening/paving material in an industrial park (over an area of 80,000 m^2). In January 2005, increased pH levels were found in drained (discharge) water and in the nearby surface water killing fish. When the groundwater below the application was monitored in early February 2005, high pH values (up to pH 13,4) were found (van der Sloot et al., 2007). Although the material conformed the 0-40 mm gradation, the main portion of the material was closer to the lower than to the higher range of this particle size range. This resulted in a high release of alkalinity from the slag caused by the high surface area. At the same time sulphides were leached, probably in the form of polysulphides, which resulted in oxygen depletion.. Since pH and reducing properties were not regulated in the BMD

(1995) or SQD (2007), this is a typical example of learning by experience. For now there is a recommendation to the sector to be aware of these phenomena under field conditions.

Application of LD steel slag on the bottom of a pond in a residential area
In 2001, the bottom of a pond in the middle of a small residential area was reinforced and made less permeable with LD steel slag (7-32 mm). This was done to prevent upward "seepage" of groundwater (a common problem in the Netherlands). The pond was I- shaped and had an area of about 46,000 m^2. An amount of about 110,000 m^3 steel slag was used on the bottom of this pond, a layer with a thickness of about 2.40 metres. All the fish in the pond died only shortly after the application of the slag in the pond. A combination of high pH and low redox potential was measured. The problem here was the small volume of water that was not refreshed regularly to allow neutralisation by the buffering in surface water, CO_2 from the air, soil and organic matter. In addition, the access of O_2 from the atmosphere was insufficient to prevent the temporary development of reducing conditions (like in a canal or big lake); van der Sloot et al., (2007). In this case, the application did not conform to the specifications to only apply the material in situations with sufficient water flow.

Utilisation of blast furnace slag in direct contact with water
Application of BFS in direct contact with ground/ surface water has resulted in discolouring of water bodies due to release of sulphides and at the same time release of hydroxide, which turned the water body alkaline (van der Sloot et al, 1995, van der Sloot et al., 2007). Application of BFS as a fill material behind a steel sheet protection in a lock In Burlington (Ontario, Canada) resulted in green, yellowish colouring of the seawater caused by sulphides released from the slag. The ultimate action has been to remove the material from that application. Application of BFS slag in road stabilisation in an area with a high groundwater table in Giethoorn (The Netherlands) resulted in similar releases of yellow, greenish liquid flowing out of the application. BFS directly in contact with ground or surface water is leading to such releases. In closed confinement (limited water flow), the high pH imposed by the slag will also affect water quality. Observed release of substances may not be coming from the slag material, but a secondary effect resulting from mobilising substances associated with soil underlying the application by the high pH imposed on the soil. A high pH mobilises dissolved organic matter (DOC), mainly in the form of humic and fulvic substances, which have the tendency to bind metals and organic contaminants.

Issues with slag stability
The application of monolithic slag (armour stone) in coastal protection has been practiced in the Netherlands already for a long time (van der Sloot et al, 1995). With the application of different types of slag, it has been found that slag stability can be an issue as upon contact with water, unreacted lime inclusions can create expansive forces leading to slag deterioration and undesirable environmental impacts. To ensure that the slag is sufficiently stable, a boiling test (EN 1367-3: Test for thermal and weathering properties of aggregates – Part 3: Boiling test for "Sonnenbrand basalt". CEN-CMC, Brussels, Belgium, 2001) needs to be applied. In a waterworks project in Biesbosch (Netherlands) the poor slag quality was caught just in time, as the delivered slag started to deteriorate in storage. In water bodies with sufficient flow of water (rivers, canals and estuaries), the initial release of hydroxyl ions can locally result in an increased pH and release of reducing species (sulphides). The effect is very temporary (months) and, provided the water circulation is adequate, does not pose a risk to the environment.

Application of shredded tires at tennis courts
The application of shredded tires as a base material for tennis courts, which are designed to drain well, has led to increased levels of Zn release from the tire component. In several studies, this phenomenon has been observed (Hofstra, 2006 and 2007; Smolders and Degryse, 2002; Westenberg and Máscik, 2001). The key question is still whether the release is environmentally acceptable.

Application of MSWI bottom ash in embankment
Municipal solid waste incinerator bottom (MSWI) ash has been used as road subbase and embankment in many instances in Europe, but always with additional requirements, such as application with measures to reduce net infiltration, with a requirement of use at least 0.5 m above the highest recorded groundwater level and removal of the material, when the service life is finished. Over

the years there have been instances where any of these specifications were not fulfilled or were fulfilled initially, but with time changes resulted in situations no longer fulfilling the criteria. In such circumstances, measures were taken to remedy the non-compliance. An example of such a situation is the faster settling of a roadbed at a location where formerly a canal cut through the planned road section. In a few cases, local failures in the top cover placed to ensure low net infiltration have been observed and mitigated.

Lessons learned

The experience gained in these cases can be used as guidance for end users. Firstly, that the specifications associated with particular uses should always be followed, and secondly that new experiences should find their way to the user community in the form of adjusted regulation and/or as guidance in practice. Clearly, pH and redox conditions resulting from use of an alternative material were not regulated and need to be considered besides substances of direct regulatory concern. This is particularly relevant in cases where the release of leachate with a high pH can mobilise substances from underlying “natural” soil layers. Based on these observations there are further lessons to be learned. Namely, that overlying a material with potentially leachable substances with a layer of “reactive” soil that can generate DOC with a humic and fulvic acid component capable of mobilising metals as DOC complex and organic contaminants as DOC associated species. We are not aware of any cases yet, but this is likely to happen at some point. An issue to consider in practice is also that testing is often carried out at relatively high L/S values, whereas in an application, especially in applications of some height, the release of substance will occur at rather low L/S values during the first years. This condition can prove critical in field applications. The low L/S in the column test can forewarn for such potential situations.

4. Properties of waste aggregates

4.1 General properties of waste aggregates

In the following, the general characteristics of the waste aggregates presented in Table 2.1 are briefly presented. The presentations include information on content of some specific substances, particularly substances of concern in relation to EoW. The information and data on the leaching properties of the aggregates are discussed separately in subsequent sections.

Parts of the material descriptions below are taken from the compilations of Böhmer et al. (2008), en Delgado et al. (2009). The reader is referred to those reports for more detailed descriptions of the properties of the individual materials. Where possible, the material descriptions do also include a first impression of the leaching properties and potentially critical substances, from reviews of Aalbers et al. (1998) and De Wijs and Cleven (2008) of quality control data of aggregates (over the period 1993-1997, and 2003-2006, respectively) for their possible utilisation in construction in The Netherlands. The reader is referred to those studies for the underlying quantitative details and statistics regarding the leaching of individual materials and substances.

Recycled (crushed) concrete

Most of the recycled concrete (RecCon) arises as one of several types of waste collectively referred to as construction and demolition (C&D) waste. RecCon can be reprocessed into coarse or fine aggregates. Prior to crushing and grading, the concrete must be separated from impurities and other materials such as steel reinforcement, insulation, wood, gypsum plaster boards, sealants and potentially contaminated parts. This can be done in-situ by mobile units or at centralised processing sites. A main application for recycled coarse concrete aggregates is road construction, other applications are e.g. use as backfilling material, use in earthwork constructions, foundations, and in the production of new concrete. Fine aggregates may be used in place of natural sand in mortars (Monier et al., 2011). The major concern in relation to environmental and health risks from RecCon aggregates would be associated with the potential contamination with other materials (e.g. sealants, paints, plaster boards) due to insufficient sorting, with substances taken up from other materials (e.g. PCB from sealants and paints) and with substances originally present in the concrete (e.g. coal fly ash – during several years Portland cement in some Member States contained at least 25 % of coal fly ash added to the rotary kiln as a substitute for clay – and additional amounts of fly ash could be added as a substitute for cement in the concrete production process). The sources of RecCon will generally be very diverse and the environmental/health quality therefore difficult to predict without testing. Newly produced RecCon aggregates will normally have a very alkaline reaction with water. This is likely to move towards a neutral pH due to carbonation (uptake of CO_2) as a result of exposure to ambient conditions.

Recycled concrete has been reported to comply structurally with the leaching criteria of the Dutch Building Materials Decree for Category-1 materials (i.e. application height of 0.2 m without isolating measures; Aalbers et al., 1998).

Recycled bricks

Recycled bricks are a sub-category of construction and demolition waste and are obtained from selective demolition. Leaching data for granular tiles and ceramics have not been reported by Aalbers et al. (1998) and De Wijs and Cleven (2008).

Recycled tiles and ceramics

Recycled tiles and ceramics are a sub-category of construction and demolition waste and are obtained from selective demolition. Leaching data for granular tiles and ceramics have not been reported by Aalbers et al. (1998) and De Wijs and Cleven (2008).

Recycled glass

Waste glass consists of a number of waste glass streams including container glass, flat glass, automotive windows etc. The origin of the glass waste is reflected by its code in the European Waste Catalogue (EWC): 17 02 02 is glass from C&D waste, 19 12 05 is glass from mechanical treatment of waste and 20 01 02 is separately collected glass fraction from household waste. The largest component is container glass, particularly mixed or coloured glass which is of less value than clear glass. Waste container glass can be crushed and graded into an aggregate suitable for use in bound and unbound applications specifically for highway applications (WRAP, 2010). Experience from e.g. Denmark indicates that thermal insulation windows from the period 1965 to 1976 have a considerable content of PCB in the glue (Ingeniøren, 2011). The period during which PCB was used in the manufacture of insulation windows is likely to vary from Member State to Member State, depending on national PCB legislation, but it is typically from the period 1965 to 1975. Other types of glass, usually in smaller quantities, stems from coloured glass, screen glass and electronic devices. Coloured glasses can contain several types of metals that cause the coloration, which may be more or less leachable. The glasses from electronic devices can be seriously contaminated with surface coatings and should be kept out of the glass stream for recycling purposes. Older glass types may have high contents of lead.

Mixture of concrete, bricks, tile and ceramics

Mixture of concrete, bricks, tile and ceramics is a sub-category of construction and demolition waste. This C&D fraction is well suited to being crushed and recycled as a substitute for newly quarried (primary) aggregates in certain lower-grade applications, most notably engineering fill and road sub-base (Delgado et al., 2009). This practice has been common (though not necessarily widespread) in several Member States for many years. Inert materials from construction and demolition waste can be reused as (Böhmer et al., 2008): fill on-site for constitution of landscape hillocks and anti-noise banks; sub-grade or sub-base and base courses of roadways with the addition of binders; wearing courses which can be regenerated in place, hot or cold; pavement which can be treated in place by mixture with binders; pavement which can be treated on the spot by crushing or screening before reemployment; fill with or without treatment.

Aalbers et al. (1998) consider a mixture of concrete and masonry aggregate (“mix granulate”), which contains at least 45% (m/m) concrete granulate. This material is generally used in The Netherlands as either unbound or bound (sub)base in road constructions. The (unbound) mixture does generally comply with the Category-1 leaching limits of the Dutch Building Materials Decree at an application height of 0.2 m.

Recycled asphalt

Recycled asphalt granulate originates from the scraping of asphalt pavements prior to renewal of the top layer, and/or from the demolition and grinding of such pavements. It can be re-used for the production of new asphalt, in The Netherlands only if the total PAH content is below 75 mg/kg. Otherwise it is classified as tar-containing asphalt granulate which can only be recycled without heating as a bound foundation layer with isolation measures. In Denmark, the use of tar-containing asphalt ceased in 1973, and it has largely been phased out.

Aalbers et al. (1998) report that (non tar-containing) recycled asphalt complies with the Category-1 leaching limits for inorganic substances. Tar-containing asphalt granulate does not comply with the limits for the content of total and individual PAH.

Blast furnace slag

Blast furnace slag (BFSlag) is formed when iron ore or iron pellets, coke and a flux (either limestone or dolomite) are melted together in a blast furnace. When the metallurgical smelting process is complete, the lime in the flux has been chemically combined with the aluminates and silicates of the ore and coke ash to form a non-metallic product called blast furnace slag. During the period of cooling and hardening from its molten state, BFSlag can be cooled in several ways to form any of several types of BFSlag products. For details on the production of BFSlag, see Delgado et al. (2009) or Böhmer et al. (2008). BFSlag aggregates are e.g. used in ground form in the production of slag cement, concrete, mortar and grout, and in unground form as a structural filler in concrete and as a base layer in road construction (Böhmer et al., 2008). On its website (www.environment-agency.gov.uk) the UK Environment Agency has posted the message that blast furnace slag waste has been assessed and that it was subsequently successfully proven to be a by-product rather than a waste based on Community guidance (CEC, 2007). See also section 5.2.

Aalbers et al. (1998) report that 43% of tested granular blast furnace slag complies with the Category-1 limits of the Dutch Buildings Materials Decree, and the remaining 57% with the Category-2 limits (utilisation with isolation measures), the critical substances being Ba and SO_4. These results are qualitatively consistent with the few observations reported by De Wijs and Cleven (2008) that confirm Ba and SO4 leaching higher than the Category-1 BMD limits for some tested samples.

Basic oxygen slag

Basic oxygen furnace (BOF) slag is formed when steel is produced from pig iron, direct reduced iron or scrap. The amount of slag depends on the amount of silicon in the pig iron, because this is connected with the amount of lime added. The BOF is used to produce steel. The objective in oxygen steelmaking is to burn (oxidise) the undesirable impurities contained in the metallic feedstock. The main elements thus converted into oxides are carbon, silicon, manganese, phosphorus and sulphur. Undesirable impurities are removed with the off-gas or the liquid slag. Usually the slag is cooled and crushed, after which the metallic iron is recovered by magnetic separation. There are three main different kinds of the BOF-process, the LD (Linz-Donawitz) and LD/AC processes (Linz-Donawitz/Arbed-CRM), BOP processes (bottom-blown oxygen process) and combined processes. The LD process is normally used for phosphorus poor pig iron while the LD/AC process is used for phosphorus rich pig iron. LD slag is a firm, grey, stone-like material that is less porous than blast furnace slag. Because of its structure, LD slag has a high abrasion resistance and is therefore often used for road construction. However, due to risks of volume expansion, the slag cannot be used as building aggregate when its content of free lime (CaO) is greater than 7 % (Böhmer et al., 2008). It is further used in civil and hydraulic engineering (because of its high bulk density), the cement industry or disposed of in landfills.

Aalbers et al. (1998) report that LD slag is generally compliant with the Category 1 leaching limits of the Dutch Building Materials Decree (up to application heights of 0.7 m). Occasionally, Ba and F leaching exceeds these limits.

Electric arc furnace slag

The direct smelting of iron-containing materials such as scrap is usually performed in electric arc furnaces (EAF) which play an important and increasing role in modern steel work design. The major feed stock for EAF is ferrous scrap which may include scrap from inside the steelworks (e. g. off-cuts), cut-offs from steel product manufactures (e. g. vehicle builders) and capital or post-consumer scrap (end of life products). Also, direct reduced iron is used as feedstock. The different input materials, such as the scrap, additives and alloy elements, determine the chemical composition of the EAF slag. A distinction between carbon steel making slag (EAFc) and stainless steel/ high alloy steel making slag (EAFs) can be made. The slags from the latter in particular, can reflect the presence of specific additions such Mo, Cr and V. As in the BOF, the slag is formed from lime to collect undesirable components in the steel. EAF-slag has a lower amount of free CaO than BOF-slag. In the EU, EAF slags from carbon steelmaking and high alloyed steelmaking are used in stabilisation and solidification (e.g. landfill cover, filling of abandoned mines), as raw material for cement production and as constituent in bound construction products. EAFc has been used as constituent for hydraulic binders, as soil conditioner and for sand blasting (Kobesen et al, 2010).

For unbound applications in construction, Aalbers et al. (1998) report that only 33% of tested EAF slag complied with the Category-1 and 33% with Category-2 leaching limits of the Dutch Building Materials Decree, for application heights of 0.2 m, the critical substances being Ba, Cr and Mo.

Phosphorous slag

Phosphorus slag is a secondary product formed from the electro-thermal recovery of phosphorus from phosphate ores. In the EU, it is only produced at the Hoechst phosphorus plant in Vlissingen, NL. It is a grey dense stony material that is used as a ballast material in waterworks and as mineral aggregate in asphalt. The major beneficial application in The Netherlands, however, is hydraulic phosphorus slag, a mixture of 87% phosphorous slag, 9 % LD slag and 3% granulated blast furnace slag, which is used as a bound pavement layer in road construction.

Aalbers et al. (1998) indicate that hydraulic phosphorus slag in bound pavement layers can be considered a monolithic material of which 30% (data prior to 1998) complies with the Category-1A (i.e. permanent water contact) leaching limits of the Dutch Building Materials Decree and 70% with the Category 1B,2 (intermittent water contact) limits, Cl and Br being the critical substances. The material does, however, fully comply with the BMD Category-1 criteria when utilised in brackish or seawater, where no Cl and Br limits apply.

Coal fly ash

Coal fly ash is the fine size fraction of the ash formed from the combustion of finely ground coal at temperatures between 1400 and 1600 ^{o}C, and which is recovered from the flue gasses with electrostatic precipitators. The nature and properties of fly ash are dependent on a variety of factors that include the type and fineness of coal and the conditions of combustion. The chemical composition of ashes from coal and lignite combustion is oxides, silicates and aluminium silicates of the elements contained in the coal. The utilisation of fly ash across European Member States is different and is mainly based on national experience and tradition. Fly ash is the most important coal combustion residue and accounts for nearly 70% of the total amount of coal combustion residues. Approximately 33 % of the total fly ash produced in the EU-15 is used as cement raw material, as a constituent in blended cement and as an addition in the production of concrete. In 2003, about 21 million tons of fly ash were utilised in the construction industry and in underground mining. Most of the fly ash produced in 2003 was used as a concrete addition, in road construction and as a raw material in cement clinker production. Fly ash was also utilised in blended cements, in concrete blocks and for in-fill, i.e. for filling voids, mine shafts and subsurface mine workings. 48 % of the generated bottom ash was used as fine aggregate in concrete blocks, 33 % in road construction and about 14 % in cement and concrete (Böhmer et al., 2008).

When applied in concrete, coal fly ash is expected to comply fully with the leaching criteria of the Dutch Building Materials Decree for Category-1A materials (i.e. monolithic, in permanent contact with ground- or surface water; Aalbers et al., 1998). However, in unbound form, a variety of oxyanions and metals may be of environmental concern, in particular Arsenic, Boron, Cadmium, Chromium, Copper, Mercury, Molybdenum, Nickel, Lead, Selenium, Vanadium, Thallium, Antimony, Manganese, Tin and Zinc (Böhmer et al., 2008). The major potentially critical substances for alkaline ashes are oxyanions such as Cr, As ,Se V, Mo, while for acidic ashes metals like Cd, Zn, Cu are of greater relevance.

Coal bottom ash, including boiler slag

During coal combustion, coarser particles from the mineral content of the fuel remain in the bottom of the boiler. It is removed directly or by jets of water. The bottom ash particles are irregularly shaped with a rough surface. According to the type of application, bottom ash may be further processed, dewatered, ground or graded before being stored. Delgado et al. (2009) report that about 6 million tonnes of bottom ash were produced in Europe in 2003. About 2.7 million tonnes were used in the construction industry, of which 48 % as fine aggregate in concrete blocks, 33 % in road construction and about 14 % in cement and concrete. Boiler slag is a glassy material produced when the fuel is burned in slag-type furnaces at 1500-1700 ºC. The slag is removed from the furnace in a molten state and is cooled with water solidifying and resulting in glassy granules. About 55 % of boiler slag was used in road construction in 2003, for example as a drainage layer. Another 31 % was used as blasting grit and smaller amounts as aggregates in concrete and grout. In 2003, about 2.1 million tonnes of boiler slag were produced in Europe (EU-15; Delgado et al., 2009).

Aalbers et al. (1998) report that about 20% of tested coal bottom ash did not comply with the Category-2 limits of the Dutch Buildings Materials Decree, with Se and Mo as the critical substances. The authors report, however, developments that after quality improvement by washing, the Category-1 limits can be met. Indeed, the more recent quality control data reported by De Wijs and Cleven (2008) show that coal bottom ash does generally comply with the Category-1 BMD limits, with only a few % of tested samples occasionally exceeding the limits for varying (oxy)anionic substances and/or heavy metals.

Coal fluid bed combustion ash

Coal fluidised bed combustion ash belongs together coal fly ash, bottom ash, and boiler slag to the main coal combustion residues. As for all of the solid residues generated by fossil fuel combustion, their amounts depend on the content of non-combustible substances in the fuel, i.e. ashes and sulphur. Fluidised bed combustion ashes are rich in lime and sulphur due to the desulphurisation process, so their application as aggregate, inert material is limited (Delgado et al., 2009). As a likely consequence of these limitations, no information was found on the leaching properties of this material.

Municipal solid waste incinerator fly ash

Fly ash consists of relatively fine ash particles, which are entrained in the flue gas from the boiler and recovered in electrostatic precipitators or fabric filters (Hjelmar et al., 2010). In incinerators equipped with wet scrubbing systems for removal of acid gases, the fly ash is always collected upstream of the scrubber(s) and constitutes a separate residue stream. In some cases, the separately collected fly may subsequently be mixed with the sludge from treatment of the wastewater from the wet scrubber as part of the residue management system prior to landfilling. In incinerators equipped with semidry or dry lime injection air pollution control processes, the fly ash and the acid gas cleaning residues may or may not be collected separately, depending on residue management systems or local regulation. The amount of fly ash produced varies from one incinerator to another and is, of course, difficult to estimate when the fly ash occurs in an admixture of acid gas cleaning residues. The amount of fly ash will normally constitute 10 to 30 kg/tonne of incinerated waste, depending on the properties of the waste, the firing technology and the particulate collection system. Chandler et al. (1997) estimates the average amount of fly ash produced at a state-of-the-art mass burn incinerator at approximately 20 kg/tonne of incinerated waste. Most MSWI fly ashes react with water to produce neutral to alkaline solutions (typically pH = 7 to 11.5). Hjelmar et al. (2010) reports contents of 0.2 to 10 µg/kg of PCDD/PCDF (I-TEQ), 6 – 250 µg/kg of PCB, 28 to 2000 µg/kg of PAH and < 500 to 4300 µg/kg of phthalates in MSWI fly ashes. The content of various minor and trace elements is generally high, e.g. 6300 to 15000 mg/kg for Pb, 2.3 to 10 mg/kg for Hg, 240 to 480 mg/kg for Cd, based on MSWI fly ashes from several Member States (Hjelmar et al., 2010).

Municipal solid waste incinerator bottom ash

The bottom ash (or slag as it is sometimes called) is formed and transported through the combustion chamber on the moving grate and in some cases continues from the grate through a rotary kiln to the quencher. The bottom ash constitutes by far the largest stream of residues from the incinerator - typically 150 to 300 kg/tonne of waste incinerated with an average of 200 kg/tonne of waste. The bottom ash generally has a very inhomogeneous appearance and it may – partly depending on the quenching technology – be a granular material, or it may contain larger fused lumps. It is usually mixed with scrap metal and in some cases also with incompletely combusted material. However, most state-of-the-art MSW incinerators should be able to produce bottom ash with a content of total organic carbon, TOC below 1 % /w/w).

When the bottom ash leaves the grate or the rotary kiln, it must be cooled. Most commonly, the bottom ash drops from the grate or the kiln directly into a quenching tank with water from where it is moved to the ash bunker and/or treatment and storage facilities. MSWI bottom ash is used for road construction in several EU Member States, typically as an unbound material as sub-base. Prior to utilisation the MSWIBA undergoes considerable treatment: ferrous iron (scrap iron) is recovered by means magnetic separators, and often other metals (e.g. aluminium and copper) are recovered by means of eddy current separation. Sometimes the bottom ash is washed and soluble salts (chlorides) are removed as part of the quenching operation. The bottom ash is then screened and crushed, usually to a particle size of < 40 mm. Most MSWI bottom ashes are moderately to strongly alkaline when produced, and they are typically stored for 1 to several months prior to use. During this period pH is generally reduced to between 8 and 9 due to carbonation resulting from uptake of atmospheric carbon (Hjelmar et al., 2010). The leaching of some metals (e.g. Pb and Zn) is substantially reduced by the lower pH which may, on the other hand, mobilise some of the oxyanion-forming elements such as Cr and Sb. The exposure during storage usually also reduces the leaching of DOC which in turn gives rise to a lower release of Cu. Hjelmar et al. (2010) reports contents of dioxins and furans (PCDD/PCDF) of 0.005 to 0.018 µg/kg, of PCB of < 5 to 110 µg/kg, of PAH of < 5 to 380 µg/kg, and of phthalates of 20 to 4000 µg/kg in MSWI bottom ashes.

Aalbers et al. (1998) report that MSWI bottom ash does generally not comply with the Category-2 limits of the Dutch Buildings Materials Decree (utilization with isolation measures), with Cu, Mo, Sb, Cl and SO4 as the critical substances. Although an exception has been made in the Decree for the application of this material, and the quality of MSWI bottom ash has been substantially improved in recent years, De Wijs and Cleven (2008) show that these substances, and particularly Cu, are still of concern.

Municipal solid waste incinerator boiler ash

Boiler ash consists mostly of material that is removed from the flue gas or the cooler surfaces of the boiler and other heat transfer equipment (Hjelmar et al., 2010). The material that condenses on the surfaces acts as an insulator, reducing heat transfer rates and must be removed at regular intervals to maintain process efficiency. When removed, e.g. by steel balls, the boiler ash, which is relatively fine (but coarser than economizer ash and fly ash), is collected in hoppers and often mixed with the bottom ash stream before or after the quencher. In some Member States, e.g. Germany, separate collection of boiler ash is required by legislation, based on the assumption that the environmental quality of boiler ash is poorer than that of bottom ash. One source reports that the annual production of boiler ash at one incinerator corresponded to 1 % (w/w) of the amount of bottom ash produced (Ludvigsen and Hjelmar, 1992). The above mentioned German source reports that the amount of boiler ash produced at a MSW incinerator corresponds to 3 % (w/w) of the bottom ash (Vehlow, 1991). Chandler et al. (1997) estimates the average production of boiler ash from a modern MSW incinerator at approximately 5 kg per ton of waste.

End-of-life tyres used as granulates (GranTyr)

In Europe, about 3.3 million tonnes of used tyres are managed annually. After sorting out the data of those tyres going for reuse (second-hand market) or rethreading, an estimated 2.7 million tonnes of end-of-life tyres (ELTs) are left to be treated. This material flow goes into a variety of recycling, public works and civil engineering applications (totalling 1.3 million tonnes) or is used as a fuel substitute in cement kilns, boilers and power plants (1.2 million tonnes). Amongst material recovery, the use of tyre rubber granulate and powder is the main route (80% of the tonnage), followed by civil engineering applications and public works (18%), dock fenders, blasting mats (<2%) and steel mills and foundries (<1%).

As regards the use of ELTs in construction as granulates, shreds or whole tyres, one can mainly distinguish the following applications:

- the use of ELTs as whole tyres or shredded tyres / tyre chips in civil engineering and geotechnical applications (Edeskär, 2006; Aliapur EEDEMS EOS, 2005 and 2006). Note: In the ELT area, the concept of aggregates is commonly related to TDA (tyre derived aggregates) and is defined in ASTM D6270 – 08.

- the use of ELTs as granulate/powder in asphalt rubber (dry or wet process).

- the use of ELTs as granulate in synthetic turf and children playgrounds, sport tracks.

Based on ingredients present in tyres, Nilsson et al. (2008) indicate several substances which may be expected to leach from ELT rubber granulates in artificial turf. Amongst those substances, zinc is frequently observed in the leachates (MCPA, 1990; Downs et al, 1996; Blic, 2005; Eedems, 2005; Hofstra, 2006; Edeskär, 2006; Hofstra, 2007; ETRMA, 2011). Verschoor (2007) reports that the leaching of zinc from granulated tyre infill will show an increasing trend as a consequence of the ageing of the rubber. It is assessed in that study that the zinc release from such infill material will be 800 mg/m^2/year, implying that the leaching limit for zinc in the Dutch Building Materials Decree (i.e. 2100 mg/m^2/100yr) will be exceeded after approximately 3 years. After publication of that report, which estimated an upper limit for the leaching of zinc from granulated tyre infill, a follow-up study was completed on the effect of ageing on the leaching of zinc and other substances (Hofstra, INTRON 2008). The study was performed by SGS INTRON and reviewed by Verschoor and Cleven from RIVM. The results from this study show that the limit values from the present Dutch Soil Quality Decree will be reached after more than 60 years for a sports system consisting of artificial turf with rubber infill, lava sub-layer and sand base layer and after 7 to 70 years for a sport system consisting of only the artificial turf with rubber infill and the lava sub-layer. An additional study (Hofstra Intron (2009)) was performed on the actual absorption capacity of the sand layer, which showed that the previous calculated results were too conservative. Only after 230 years the zinc emission will reach the limit value, and therefore infill from recycled cars complies fully with Dutch Soil Quality Decree. The concentration build-up in the underlying soil layer may render this layer unfit for unrestricted use, but does leave possibilities for its use as a bound material. According to this study zinc does not leach from artificial turf fields beyond acceptable levels into groundwater. In Appendix 17 in Separate Appendix Part 1 GranTyr additional data from various studies are given on inorganic and organic substances illustrating the relationship of Zn and PAH release with pH. The latter illustrates the possible role of dissolved organic matter (DOC) as a mobilising agent for PAH's, when the pH increases. When sulphide (present in rubber) oxidation results in a decrease of pH, Zn leachability is likely to increase. In addition, several organic contaminants have been observed to leach from ELT granulates, particularly PAHs, phthalates, amines and phenols (Blic, 2005; Eedems, 2005; Edeskär, 2006; ETRMA, 2011). From that perspective, the Aliapur EEDEMS study (2007) analysed total cyanide, phenolic index, total hydrocarbons (THC), 16 PAHs, TOC, Al, As, Ba, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se, Sn, Zn, fluorides, nitrates, ammonium, chlorides and sulphates as well as pH and conductivity of percolates (4 lab pilots + "in-situ" field tests with lysimeter). These results show that over time and irrespective of the type of filling material, the cyanide, phenol and total hydrocarbon concentrations were very low, most often below the analytical detection limits (cyanide concentration inferior to 60 µg/l, phenol concentration below 20 µg/l and total hydrocarbon concentration below 50 µg/l). Similarly, the sum of the concentrations of 6 PHAs proves to be below the guide value from French Decree no. 2001-1220 concerning water used for human consumption (1 µg/l).

Artificial aggregate

Artificial aggregates or synthetic aggregates have been produced by sintering a pure material stream (Coal fly ash: Lytag, 2011) or a mixture of (waste) materials (Wainwright and Cresswell, 2001; Barton et al, 2001; Minergy, 2011;) after a pelletising process to produce green pellets ready for firing. Cold bonding is also practiced (Aardelite, 2011). Generally, these materials are intended for replacement of natural aggregate in concrete. Aalbers et al. (1998) mention the utilisation of expanded clay as light-weight filling material in (road) construction. A wide range of waste materials have been studied (Wainwright et al, 2001) and the full engineering process requirements from pre-treatment through to incorporation of the product in concrete have been studied (Barton et al, 2001). The leaching properties of artificial aggregate have been investigated by van der Sloot et al. (2000), who indicate that oxyanions such as Mo, Sb and Se are of particular concern relative to the leaching criteria of the Dutch Building Materials Decree. The authors also point at the low acid neutralising capacity (ANC) of artificial aggregate, which makes the leaching properties of these materials sensitive to the external pH. When artificial aggregate is used to replace natural gravel in concrete, oxyanion leaching is reduced, with the exception of molybdenum. For this utilisation scenario, van der Sloot et al. (2000) indicate that the leaching properties of in the concrete recycling and end-of-life stages require particular attention. Aalbers et al. (1998) indicate that 50-70% of produced expanded clay complies with the Category-1 limits of the Dutch Building Materials Decree, for an application height of 0.2 m, with sulphate being the critical component. The remainder complies with the Category-2 limits (for application with isolation measures).

Natural aggregate

Natural aggregate consists of crushed natural (generally igneous) rocks, such as basalt, gneiss and granite and is used for a variety of road and coastal construction applications. Aalbers et al. (1998) were unable to report leaching data for these aggregates, but De Wijs and Cleven (2008) reviewed more recent quality control data over the period 2003-2006 and did not find any substances leached at levels higher than the Category-1 limits of the Dutch Building Materials Decree at an application height of 0.2 m. These authors do not provide specific information as to the type of rocks that the tested natural aggregates originated from. Ekvall et al. (2006) have reported leaching data for a range of natural aggregates. It should be stressed, that natural aggregates are not automatically fulfilling all criteria on inert waste. Natural aggregates containing sulphides may be subject to acidification and hence leach metals at a rate not in compliance with inert waste criteria.

Limestone

Limestone consists mainly of calcium carbonate (calcite) and has a variety of uses that include the production of lime for Portland cement, utilisation as unbound base layers in road construction, as aggregate and filler in asphalt, and production of lime-sandstone. Aalbers et al. (1998) were unable to report leaching data for these aggregates. It is unclear whether limestone aggregate was included as natural aggregate in the more recent review of De Wijs and Cleven (2008), who did not find any substances leached from natural aggregate at levels higher than the Category-1 limits of the Dutch Building Materials Decree at an application height of 0.2 m.

Soil

Soil materials are widely excavated and (re)used in a variety of construction applications. The leaching properties of soils vary strongly and depend on the source rocks from which the soil originated, its (secondary) mineral composition, its use and/or vegetation cover (e.g. agriculture, forestry) and possible secondary sources of (potentially contaminating) substances, of which particularly diffuse (airborne) contamination is not generally obvious. These different conditions and properties have a major effect on both the potential availability (i.e. the exchangeable fraction as opposed to the non-leachable fraction occluded in mineral lattices) and the leaching at ambient conditions. The latter is also strongly determined by the natural soil pH, which may typically range between approximately pH 3 - 8.5, and the amount and quality of both particulate and dissolved organic matter, all of which are strongly determined by the origin and utilisation of the soil.

Leaching tests of soils are most frequently performed for contaminated and remediated soils. Aalbers et al. (1998) report that 88% of tested remediated soil complies with the Category-1 leaching limits of the Dutch Soil Quality Decree, at an application height of 2 m, potentially critical contaminants being As, Cd, Cu, Hg, Ni and Zn.

4.2 Leaching data on aggregates

For the mutual comparison of leaching test data and the comparison with regulatory criteria, LeachXS Lite™ has been used because of its readily accessible data format and the capability to compare results from different leaching test with one another.

A significant number of leaching datasets on various types of aggregates, including both pH dependence test data and data on release as a function of L/S (primarily column leaching data, but also a substantial number of batch leaching data), have been identified in the LeachXS database. Data from acquired sources have been uploaded in the database in connection with this study.

LeachXS Lite™ (see e.g. van der Sloot et al., 2008) is a data management and visualisation tool that is a part of the Leaching Environmental Assessment Framework (LEAF). The tool allows the user to evaluate leaching data and characterize the release of constituents in materials under various conditions based on comparisons derived from leaching test results. LeachXS Lite is freely available at www.vanderbilt.edu/leaching with user registration required to obtain a free-of-charge license key.

Table 4.1 provides an overview of the leaching data on the aggregates described in section 4.1 that are already present and additionally imported in LeachXS. The table shows the datasets describing both release as a function of pH (pH dependence test, results of other tests like batch tests and field data are shown as single points in the graphs) and release as a function of L/S (percolation or column tests and batch tests). The origin of the data is also referenced. Many of the datasets are Dutch, German and Danish but the database includes data on aggregates from a wide range of EU Member States (Belgium, Finland, France, Italy, Slovenia, Sweden, UK) and countries outside Europe (Taiwan, USA, Australia). The Dutch data refer to a large extent to data generated in the context of the development of the Building Materials Decree (BMD, 1995), for which the raw data were available. The German data refer to DIN 38414 DEV S4 results from the Abanda dataset (Nord-Rhein Westfalia) and data from the SIWAP project (Sickerwasser Prognose), which forms the basis for the current regulatory developments in Germany. The datasets listed in Table 4.1 includes both data that are publicly available and data that are not publicly available, but were made available in aggregated form within the framework of the contract between JRC-IPTS and the consultant.

Data presented as averages, minimum, maximum and percentiles are not very useful in this context as the context of the information is missing. High values for Pb are associated with high (or low) pH which may not be the relevant condition(s) to consider for an aggregate, and thus such a high value could be eliminated because an alkaline material will be readily carbonated to a condition below pH = 11 where Pb release often is a non-issue. In addition, averages are biased by the highest values, which conveys an unbalanced impression. The use of the median value is far better in such cases. In view of the variation of concentrations over orders of magnitude, normal linear statistics is unsuitable, and log transformation of data is necessary to obtain statistically meaningful results.

In Separate Appendix Part 1, graphical presentations of these leaching data are shown both as concentration (mg/l) and accumulated release (mg/kg) as a function of both pH and L/S for a number of substances. Where applicable, the graphs also indicate the limit values for landfilling at inert waste landfills in accordance with Council Decision 2003/33/EC and in one case for comparison also with the limit values for use in accordance with the Dutch Soil Quality Decree (SQD, 2007). In a few cases, limit values from the SQD were also used for specific material types where the key substances for leaching were not covered by EU WAC for inert waste landfills (e.g. V in slags).

The number tests performed on each material, the number of substances that are analysed in the eluates and the number of eluates produced and analysed per test vary between the different materials and datasets in LeachXS which are listed in Table 4.1 and shown in the separate Appendix. In order to assist an assessment of the representativity of datasets listed, they are further described in Tables 4.2a to 4.2e and Tables 4.3a to 4.3e. Tables 4.2 a to e shows for each material the total number of samples subjected to pH dependence and L/S dependence (mainly percolation) tests and the number of each of these tests in which the listed individual substances have been analysed. Table 4.3a-e shows for each material the total number of pH and L/S dependence tests carried out for each material and total number of analyses of each substance that has been carried out for each test type, including all fractions. In the data evaluation to assess potentially critical substances, also batch test data and percolation test data in which only the cumulative amount leached was analysed, were considered.

Table 4.1
Number of leaching datasets (pH dependence test data, data on release as a function of L/S – primarily column leaching data) currently available. The number of substances measured will vary from one dataset to another. Some of the datasets may not be publicly available.

Aggregate	**Abbreviation**	**Current number of available datasets**		**Reference**
		Release as a function of pH	**Release as a function of L/S**	
Waste aggregates				
Recycled concrete	RecCon	109	146	5,12
Recycled bricks	RecBrick	13	20	11,12
Recycled tiles and ceramics	RecTile, RecCer	na	na	
Recycled glass	RecGls	34	11	11,14
Mixture of concrete, bricks, tiles and ceramics	MixC&D	75	703	11,12,26
Recycled asphalt	RecAsph	10	38	12,18
Blast furnace (BF) slag	BFSlag	58	67	11,12,19
Basic oxygen furnace (BOF) slag	BOFSlag	51	131	4,11,12,20
Electric arc furnace (EAF) slag	EAFSlag	23	4	11,12,15
BF,BOF and AEF dust	BFBOFEAFDst	na	na	
Phosphorus slag	PSlag	4	14	12,25
Fly ash (from coal combustion)	CFA	99	107	1,2,3,11,21
Bottom ash (from coal combustion)	CBA	na	106	11,12
Boiler slag (from coal combustion)	CBoiSlag	13	167	11,12
FBC ash (from coal combustion)	CFBCA	na	Na	
Fly ash from incineration of household waste	MSWIFA	10	19	6,12 ,24, 32, 33
Bottom ash from incineration of household waste	MSWIBA	38	175 (+1300 at L/S = 2 l/kg)	8,9,10,11,12,13,16,17,22, 23,27, 31
Boiler ash from incineration of household waste	MSWIBoiA	na	na	
Granulated tyres	GranTyre		5	28,29,30
Artificial aggregate	ArtAggr	20	40	6,12
Reference material				
Natural aggregate	NatAggr	65	15	11,12,14,25
Limestone	LimeStone	3	4	14
Soil and stones	Soil, Stone	18	3	

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Full characterisation data for several matrices are missing or insufficient. This concerns in particular column data for EAF slag, pH dependence and column test data for CBA, pH and percolation test data for limestone, full column data for natural aggregates, pH dependence and percolation data for recycled glass (possibly here vitrified material can be used), adequate number of full column tests on MixC&D (exists but not received for implementation in the database), column test on RecAsph (too limited data), column data on BFSlag (expected to exist, not received), limited data on pH dependence for PSlag.

The current report gives a wide overview of environmental behaviour of a large number of substances in some possible streams of waste used as aggregates. It summarizes work on leaching, based on Dutch, Danish, German, British, French, Swedish, Austrian, Belgian, American and Slovenian experiences including work carried out in several EU projects. Many other sources could have been beneficial, such as proceedings of international conferences WASCON 1997, 2000, 2003, 2006 and 2009, WasteEng’ 2005 and 2008, EUROSLAG 2000, 2002, 2004, 2007 and 2010. In part such conferences are covered already. However, in many cases the data that can be obtained from papers at conferences are inadequate for the presentation mode used here as key information is often missing. Data presented in bar graphs and tables with aggregated information cannot be used without access to the detailed background information and data, for which resources were lacking in this project.

The single pH dependence test on BOF slag that has been provided by FEHS matches very well with the data from the LeachXS database as reported Separate Appendix Part 1. As we have seen for other large material streams produced in large facilities, the leaching behaviour as presented as a function of pH and as a function of L/S is rather systematic and leads to a bandwidth within which almost all of the produced materials fall.

Data presented in reports like the INTRON reports (2003-2004 and 2005), which provide averages and percentiles are not sufficient, when dealing with long term effects (e.g. carbonation, oxidation). In spite of that the ranges generated from the percolation and batch test data in this work match well with the ranges presented in the INTRON reports for three main materials (Separate Appendix Part 1). For the pH dependence test focused on a relevant pH domain for the application wider ranges have been observed as expected. As indicated in Separate Appendix Part 1, raw test data form the basis of the comparisons presented here and in our opinion are the only way forward when questions as arising from EoW and CPR need to be addressed.

Table 4.2a

Total number of samples (NoS) subjected to pH and L/S dependence tests and the number of each of these tests in which the listed individual substances have been analysed, evaluated on the basis of leaching data from pH-dependence and percolation tests listed in Table 4.1 and shown in the Separate Appendix Part 1. CN = CNT = total cyanide, CNC = complexed cyanide, CNV = free cyanide.

Material	Test	NoS	Ag	Al	As	Au	B	Ba	Be	Bi	Br	Ca	Cd	Ce	Cl	CN	CNC	CNT	CNV
Artificial aggregate	LS	40		12	25		12	22			1	14	17		12				
	pH	20		20	20		20	20				20	20						
Asphalt aggregate	LS	38			24			28			19		23		25				
	pH	10		5	9		3	5			1	5	7		3				
BFS	LS	67		24	38		22	37			11	27	38		38		4		4
	pH	58		32	31		29	31				34	32		31				
BOF EoW	LS	131		12	65		12	103			58	14	65	3	77				
	pH	51		19	24		15	21			4	24	27		12	3			
Coal fly ash	LS	107	9	70	67		21	52	13		40	88	47		76	17			13
	pH	99	1	62	88		63	23	5		1	73	92		55	8			5
EAF	LS	4		3	3			3				4			4	1			
	pH	23	1	21	15		1	22	1			22	7		11	2			1
Coal bottom ash	LS	167		2	90			100			56	1	87		91	4			
	pH	13		2	12			7				1	13		13	4			
Glass	LS	12		11	6			11				11	2		4				
	pH	36		35	24		3	35				35	18		7				
Limestone	LS	4	2	2	1	2	2		2	2		2		2	1				
	pH	3	2	2	1	2	2		2	2		2		2	1				
Mix C&D derived aggr	LS	774		10	417		4	489			384	11	404		490	2			
	pH	4		4	4		1	4				4	4		2				
MSWI fly ash	LS	19		1	9			6				8	11		11				
	pH	10		4	4			4				4	5		4				
MSWIBA	LS	175		26	56		22	60	4		117	30	71		113				
	pH	38		34	34		27	33			4	38	37		23				
Natural aggregate	LS	15	15	15		15	15		15	15		15		15					
	pH	65	34	52	26	33	42	18	34	34		52	16	34	17				
P slag	LS	14		10	13		4	12			5	11	13		6			1	1
	pH	4		4	3		4	4				4	4						
Recycled bricks	LS	20		3	12			10				11	9		9				
	pH	13		11	13		2	9				11	4		4				
Recycled C&D waste	LS	91		4	71			20			20	5	67		82	2			
	pH	75		14	59		5	10				15	53		63				
Recycled concrete	LS	146		11	91		3	119	9		79	16	90		100				
	pH	109		101	101		84	98	18		2	101	95		22				
Granulated Tyres	pH																		
	LS	27		2	7			19				6	10						

Table 4.2b
Total number of samples (NoS) subjected to pH and L/S dependence tests and the number of each of these tests in which the listed individual substances have been analysed, evaluated on the basis of leaching data from pH-dependence and percolation tests listed in Table 4.1 and shown in the Separate Appendix Part 1. DIC = Dissolved Inorganic Carbon. DOC = Dissolved Organic Carbon.

Material	Test	NoS	Co	CO32-	Cr	Cr(III)	Cr(VI)	Cs	Cu	DIC	DOC	Dy	Er	Eu	F	Fe
Artificial aggregate	LS	40	13		17				18						22	12
	pH	20	20		20				20							20
Asphalt aggregate	LS	38	20		24				25		4				25	
	pH	10	3		9				9	3	1					3
BFS	LS	67	37		41				42	1	1				38	25
	pH	58	31		34				35	6	6				29	33
BOF EoW	LS	131	65		65		21		65	2	2				92	14
	pH	51	22		26		24		28	6	5				10	23
Coal fly ash	LS	107	66		102	3	20		42	1	10				71	35
	pH	99	18	1	95	3	13		88	4	4				73	30
EAF	LS	4			3				4						1	2
	pH	23	13		23		5		19		1				2	18
Coal bottom ash	LS	167	74		106				80		6				70	2
	pH	13			13				6		6				11	2
Glass	LS	12	3		3				12							3
	pH	36	22		23				36							27
Limestone	LS	4						2	1			2	2	2		2
	pH	3						2	1			2	2	2		2
Mix C&D derived aggr	LS	774	364		400		47		524		13				415	4
	pH	4	2		4				4		3					4
MSWI fly ash	LS	19	1		11				11		1					1
	pH	10	1		4				4		1					4
MSWIBA	LS	175	57		75				175	18	18				52	26
	pH	38	29		34				38	32	28					33
Natural aggregate	LS	15						15				15	15	15		15
	pH	65	16		25			34	26	7	6	34	34	34		52
P slag	LS	14	12		13				13						7	10
	pH	4	4		4				4							4
Recycled bricks	LS	20	1		11				12							
	pH	13	6		10				11							6
Recycled C&D waste	LS	91	20		26		47		69		13				20	
	pH	75	6		14		45		57		14				1	8
Recycled concrete	LS	146	89		101				107	2	3				87	4
	pH	109	94		101				101	2	2				3	93
Granulated Tyres	pH															
	LS	27	9		16				8							7

Table 4.2c

Total number of samples (NoS) subjected to pH and L/S dependence tests and the number of each of these tests in which the listed individual substances have been analysed, evaluated on the basis of leaching data from pH-dependence and percolation tests listed in Table 4.1 and shown in the Separate Appendix Part 1.

Material	Test	NoS	Ga	Gd	Ge	Hf	Hg	Ho	I	Ir	K	La	Li	Lu	Mg	Mn	Mo	N	Na	Nb	Nd
Artificial aggregate	LS	40					2				14		12		14	12	17		14		
	pH	20									20	2	20		20	20	20		20		
Asphalt aggregate	LS	38					19										27		1		
	pH	10					3				5		3		3	3	3		5		
BFS	LS	67					13				27		22		27	24	36		27		
	pH	58			1		3				33	1	29		33	32	29		32		
BOF EoW	LS	131					51				12		12		14	14	89		12	1	
	pH	51					10				15		15		20	25	15		17	1	
Coal fly ash	LS	107					31		37		88		9		82	76	50		88		
	pH	99					23				26		12		71	28	69		26		
EAF	LS	4									1				1	4			1		
	pH	23					12				1				5	23	4		1		
Coal bottom ash	LS	167					84										154				
	pH	13					13														
Glass	LS	12					1									12		1			
	pH	36					7				3		3		3	36	3	1	3		
Limestone	LS	4	2	2	2	2		2		2	2	2	2	2	2				2	2	2
	pH	3	2	2	2	2		2		2	2	2	2	2	2				2	2	2
Mix C&D derived aggr	LS	774					352				10		4		5	4	461		10		
	pH	4					2				4		1		4	4	2		4		
MSWI fly ash	LS	19					9				1				1	1	10		1		
	pH	10					1				4				2	2	4		4		
MSWIBA	LS	175					55				26	2	22		26	22	173		30		
	pH	38					6		4		32		27		31	33	27	4	32		
Natural aggregate	LS	15	15	15	15	15		15		15	15	15	15	15	15				15	15	15
	pH	65	34	34	34	34	7	34		34	42	34	42	34	42	19	8	1	42	34	34
P slag	LS	14					1				11		4		11	10	13		11		
	pH	4			1						4	1	4		4	4	4		4		
Recycled bricks	LS	20					1				10					1	9		10		
	pH	13					3				8		2		2	7	2		8		
Recycled C&D waste	LS	91					18				4				1		20		4		
	pH	75					2				14		5		9	8	6		14		
Recycled concrete	LS	146					86				13		3		4	14	102		8		
	pH	109					41				100		82		94	94	95		99		
Granulated tyres	pH																				
	LS	27					6				6				6	12			6		

Table 4.2d
Total number of samples (NoS) subjected to pH and L/S dependence tests and the number of each of these tests in which the listed individual substances have been analysed, evaluated on the basis of leaching data from pH-dependence and percolation tests listed in Table 4.1 and shown in the Separate Appendix Part 1.

Material	Test	NoS	NH3	NH4	Ni	NO2	NO3	P	Pb	Pd	PO4	Pr	Pt	Rb	Re	Rh	Ru	S	S2-	Sb	Sc
Artificial aggregate	LS	40			18			12	16		1							13		15	
	pH	20			20			20	20									20		20	
Asphalt aggregate	LS	38			24				23									2		27	
	pH	10			7			3	9									3		5	
BFS	LS	67			38		3	22	39									23		37	
	pH	58			33		3	29	33									29		30	
BOF EoW	LS	131			65			12	65									12		63	
	pH	51	3		27	3	4	15	24									17		17	
Coal fly ash	LS	107	19	1	45	14	15	13	47		12							16	1	62	
	pH	99	11	1	48	10	57	15	94		5							15	5	64	
EAF	LS	4	1		2	1	1		3		1									3	
	pH	23	2		18	2	1		18		1									17	
Coal bottom ash	LS	167	5		87	11	7		87										7	154	
	pH	13	5		13	11	7		13										7		
Glass	LS	12			9				12											11	
	pH	36			32			3	36									3		34	
Limestone	LS	4								2		2	2	2	2	2	2				2
	pH	3								2		2	2	2	2	2	2				2
Mix C&D derived aggr	LS	774			419			4	417									6		364	
	pH	4			4			1	4									2		1	
MSWI Fly ash	LS	19			11			1	10									2		9	
	pH	10			4			1	4									1		2	
MSWIBA	LS	175			69			22	112									26		167	
	pH	38			30			31	38									31		30	
Natural aggregate	LS	15								15		15	15	15	15	15	15				15
	pH	65			20			8	21	34		34	34	34	34	34	34	8		17	34
P slag	LS	14			13			4	13		1							5	4	12	
	pH	4			4			4	4									4		4	
Recycled bricks	LS	20			12				12		8							1		1	
	pH	13			9			2	11									2		6	
Recycled C&D waste	LS	91			71				71									2		20	
	pH	75			59			5	59									8		5	
Recycled concrete	LS	146			93		10	3	94									5		90	
	pH	109			100		10	93	100									93		95	
Granulated tyres	pH																				
	LS	27			7				7									14			

Table 4.2e

Total number of samples (NoS) subjected to pH and L/S dependence tests and the number of each of these tests in which the listed individual substances have been analysed, evaluated on the basis of leaching data from pH-dependence and percolation tests listed in Table 4.1 and shown in the Separate Appendix Part 1.

Material	Test	NoS	Se	Si	Sm	Sn	SO3	SO4	Sr	Tb	Te	Th	Ti	Tl	Tm	U	V	W	Y	Yb	Zn	Zr
Artificial aggregate	LS	40	13	12		13		21	12				12				28				16	
	pH	20	20	20		20			20				20				20	2	2		20	
Asphalt aggregate	LS	38	21			19		24									23				24	
	pH	10	3	3		3		1	3				3				3				7	
BFS	LS	67	37	22		35		64	22				22	2			38	22			38	
	pH	58	29	29		29		55	29				29	2			30	27	1		33	
BOF EoW	LS	131	63	12		63		63	12				12				84	12			65	
	pH	51	15	15		15		15	15				15	1			18	12			28	
Coal fly ash	LS	107	58	13		18	3	89	10				8	15			81	37	1		97	
	pH	99	70	65		13	7	81	19				13	10		46	71	52	1		92	
EAF	LS	4						2													4	
	pH	23	1	4		1		9						1			9				23	
Coal bottom ash	LS	167	154			56	7	167	7					7			100				91	
	pH	13					7	13	7					7			7				13	
Glass	LS	12						3													11	
	pH	36		3		3		6	3				3				3				35	
Limestone	LS	4			2			1	2	2	2	2	2	2	2	2			2	2	1	2
	pH	3			2			1	2	2	2	2	2	2	2	2			2	2	1	2
Mix C&D derived aggr	LS	774	357	4		355		607	4				6				374				408	
	pH	4	3	4		1		2	4				1				4				4	
MSWI Fly ash	LS	19	5	1				8	5								6				11	
	pH	10	1	2				4	2												5	
MSWIBA	LS	175	67	22		69		79	26				17				65	12			83	
	pH	38	23	31		23		20	30				23	1			27	17			38	
Natural aggregate	LS	15			15				15	15	15	15	15	15	15	15			15	15		15
	pH	65	8	8	34	8		17	42	34	34	34	42	34	34	34	8	8	34	34	29	34
P slag	LS	14	12	4		11		6	10				4				13	4			13	
	pH	4	3	4		4			4				4				4		1		4	
Recycled bricks	LS	20	1			8		9									1				12	
	pH	13	2	2		2		4	2				2				6				11	
Recycled C&D waste	LS	91	20			20		69					2				22				71	
	pH	75	7	8		5		51	8				5				10				59	
Recycled concrete	LS	146	79	4		86		128	3				3	10			89	3			94	
	pH	109	94	94		94		23	93		10		93	19		1	97	70			101	
Granulated tyres	pH																					
	LS	27																			27	

Table 4.3a
Total number of samples (NoS) subjected to pH and L/S dependence tests and the total number of analyses of each substance that has been carried out for each test type (including all eluate fractions), evaluated on the basis of leaching data from pH-dependence and percolation tests listed in Table 4.1 and shown in the Separate Appendix Part 1. CN = CNT = total cyanide, CNC = complexed cyanide, CNV = free cyanide.

Material	Test	NoS	Ag	Al	As	Au	B	Ba	Be	Bi	Br	Ca	Cd	Ce	Cl	CN	CNC	CNT	CNV
Artificial aggregate	LS	40		58	106		58	74			7	82	91		40				
	pH	20		95	95		95	95				95	95						
Asphalt aggregate	LS	38			47			51			19		35		25				
	pH	10		34	38		18	32			6	34	20		18				
BFS	LS	67		25	62		23	44			11	39	62		50		4		4
	pH	58		57	49		54	56				59	57		42				
BOF EoW	LS	131		94	147		94	185			70	96	147	14	159				
	pH	51		101	99		97	117			27	106	109		57	3			
Coal fly ash	LS	107	9	147	130		32	59	13		63	180	94		142	17			13
	pH	99	1	188	184		123	79	5		24	198	183		148	8			5
EAF	LS	4		3	3			3				4			4	1			
	pH	23	1	65	15		1	66	1			66	7		11	2			1
Coal bottom ash	LS	167		2	90			100			56	1	87		91	4			
	pH	13		2	12			7				1	13		13	4			
Glass	LS	12		11	6			11				11	11		13				
	pH	36		56	24		24	56				56	39		7				
Limestone	LS	4	3	3	1	3	3		3	3		3		3	1				
	pH	3	2	2	1	2	2		2	2		2		2	1				
Mix C&D derived aggr	LS	774		54	506		22	521			384	56	467		561	2			
	pH	4		32	32		3	32				32	32		24				
MSWI Fly ash	LS	19		25	91			44				74	103		69				
	pH	10		28	34			34				28	43		34				
MSWIBA	LS	175		154	128		146	188	8		171	182	199		247				
	pH	38		217	213		175	209			35	248	238		158				
Natural aggregate	LS	15	15	15		15	15		15	15		15		15					
	pH	65	34	83	57	33	73	49	34	34		83	47	34	24				
P slag	LS	14		38	64		16	52			23	50	64		35			7	7
	pH	4		22	14		22	22				22	22						
Recycled bricks	LS	20		3	106			104				99	103		97				
	pH	13		39	49		16	37				39	18		4				
Recycled C&D waste	LS	91		8	75			20			20	9	67		84	2			
	pH	75		78	123		25	70				79	99		94				
Recycled concrete	LS	146		50	136		21	143	9		91	55	119		117				
	pH	109		447	450		334	428	66		23	451	400		57				
Granulated Tyres	pH																		
	LS	27		2	7			19				6	10						

Table 4.3b

Total number of samples (NoS) subjected to pH and L/S dependence tests and the total number of analyses of each substance that has been carried out for each test type (including all eluate fractions), evaluated on the basis of leaching data from pH-dependence and percolation tests listed in Table 4.1 and shown in the Separate Appendix Part 1. DIC = Dissolved Inorganic Carbon. DOC = Dissolved Organic Carbon.

Material	Test	NoS	Co	CO32-	Cr	Cr(III)	Cr(VI)	Cs	Cu	DIC	DOC	Dy	Er	Eu	F	Fe
Artificial aggregate	LS	40	65		91				99						50	58
	pH	20	95		95				95							95
Asphalt aggregate	LS	38	26		36				48		48				25	
	pH	10	18		38				38	18	6					18
BFS	LS	67	44		65				66	2	2				50	26
	pH	58	56		59				60	17	17				40	58
BOF EoW	LS	131	147		147		21		147	14	14				144	96
	pH	51	104		108		24		110	48	40				27	119
Coal fly ash	LS	107	88		129	3	39		89	7	16				131	86
	pH	99	84	6	155	3	32		179	30	25				138	130
EAF	LS	4			3				4						1	2
	pH	23	13		67		49		19		1				2	62
Coal bottom ash	LS	167	74		106				80		6				70	2
	pH	13			13				6		6				11	2
Glass	LS	12	3		12				21							12
	pH	36	43		44				57							48
Limestone	LS	4						3	1			3	3	3		3
	pH	3						2	1			2	2	2		2
Mix C&D derived aggr	LS	774	382		444		92		611		24				422	22
	pH	4	8		32				32		27					32
MSWI Fly ash	LS	19	7		96				103		16				11	25
	pH	10	6		34				43		6				6	22
MSWIBA	LS	175	159		203				327	117	118				132	154
	pH	38	177		213				248	187	156					206
Natural aggregate	LS	15						15				15	15	15		15
	pH	65	47		56			34	57	37	29	34	34	34		83
P slag	LS	14	52		64				64						42	38
	pH	4	22		22				22							22
Recycled bricks	LS	20	7		105				106							
	pH	13	20		38				39							20
Recycled C&D waste	LS	91	20		30		47		73		13				20	
	pH	75	30		78		45		121		38				8	54
Recycled concrete	LS	146	113		146				152	14	20				87	27
	pH	109	397		451				451	23	23				23	391
Granulated Tyres	pH															
	LS	27	9		16				8							7

Table 4.3c
Total number of samples (NoS) subjected to pH and L/S dependence tests and the total number of analyses of each substance that has been carried out for each test type (including all eluate fractions), evaluated on the basis of leaching data from pH-dependence and percolation tests listed in Table 4.1 and shown in the Separate Appendix Part 1.

Material	Test	NoS	Ga	Gd	Ge	Hf	Hg	Ho	I	Ir	K	La	Li	Lu	Mg	Mn	Mo	N	Na	Nb	Nd
Artificial aggregate	LS	40					19				82		58		82	58	104		82		
	pH	20									95	16	95		95	95	95		95		
Asphalt aggregate	LS	38					19										39		7		
	pH	10					8				34		18		18	17	18		34		
BFS	LS	67					13				39		23		39	25	54		54		
	pH	58			8		3				58	8	54		58	57	54		66		
BOF EoW	LS	131					51				94		94		96	96	171		94	7	
	pH	51					10				97		97		102	121	97		113	8	
Coal fly ash	LS	107					53		37		178		16		156	120	143		178		
	pH	99					45				149		63		194	121	195		149		
EAF	LS	4									1				1	4			1		
	pH	23					12				1				49	67	48		1		
Coal bottom ash	LS	167					84										154				
	pH	13					13														
Glass	LS	12					1									21		10			
	pH	36					7				24		24		24	57	24	1	24		
Limestone	LS	4	3	3	3	3		3		3	3	3	3	3	3				3	3	3
	pH	3	2	2	2	2		2		2	2	2	2	2	2				2	2	2
Mix C&D derived aggr	LS	774					352				54		22		24	22	479		54		
	pH	4					24				32		3		32	32	8		32		
MSWI Fly ash	LS	19					41				25				25	25	103		25		
	pH	10					6				28				14	14	34		28		
MSWIBA	LS	175					59				154	12	146		154	146	325		182		
	pH	38					36		34		215		175		203	209	171	31	215		
Natural aggregate	LS	15	15	15	15	15		15		15	15	15	15	15	15				15	15	15
	pH	65	34	34	34	34	7	34		34	73	34	73	34	73	50	39	1	73	34	34
P slag	LS	14					7				50		16		50	38	64		50		
	pH	4			8						22	8	22		22	22	22		22		
Recycled bricks	LS	20					1				98					1	103		98		
	pH	13					3				44		16		16	21	16		44		
Recycled C&D waste	LS	91					18				8				1		20		8		
	pH	75					24				78		25		55	54	30		78		
Recycled concrete	LS	146					86				52		21		27	37	131		47		
	pH	109					89				447		325		392	400	401		443		
Granulated tyres	pH																				
	LS	27					6				6				6	12			6		

Table 4.3d
Total number of samples (NoS) subjected to pH and L/S dependence tests and the total number of analyses of each substance that has been carried out for each test type (including all eluate fractions), evaluated on the basis of leaching data from pH-dependence and percolation tests listed in Table 4.1 and shown in the Separate Appendix Part 1.

Material	Test	NoS	NH3	NH4	Ni	NO2	NO3	P	Pb	Pd	PO4	Pr	Pt	Rb	Re	Rh	Ru	S	S2-	Sb	Sc
Artificial aggregate	LS	40			99			58	96		12							65		80	
	pH	20			95			95	95									95		95	
Asphalt aggregate	LS	38			47				35									14		50	
	pH	10			36			18	38									18		20	
BFS	LS	67			56		3	23	63									30		50	
	pH	58			58		3	54	58									54		55	
BOF EoW	LS	131			147			94	147									94		145	
	pH	51	3		109	3	11	97	106									113		99	
Coal fly ash	LS	107	19	16	96	14	56	24	99		12							43	1	136	
	pH	99	11	16	143	10	98	70	190		5							70	5	187	
EAF	LS	4	1		2	1	1		3		1									3	
	pH	23	2		18	2	1		18		1									17	
Coal bottom ash	LS	167	5		87	11	7		87										7	154	
	pH	13	5		13	11	7		13										7		
Glass	LS	12			18				21											11	
	pH	36			53			24	57									24		55	
Limestone	LS	4								3		3	3	3	3	3	3				3
	pH	3								2		2	2	2	2	2	2				2
Mix C&D derived aggr	LS	774			508			22	506									30		382	
	pH	4			32			3	32									8		3	
MSWI Fly ash	LS	19			96			25	96									40		86	
	pH	10			34			8	43									8		14	
MSWIBA	LS	175			197			146	240									174		295	
	pH	38			184			207	248									207		185	
Natural aggregate	LS	15								15		15	15	15	15	15	15				15
	pH	65			51			39	52	34		34	34	34	34	34	34	39		48	34
P slag	LS	14			64			16	64		7							23	16	52	
	pH	4			22			22	22									22		22	
Recycled bricks	LS	20			106				106		96							7		7	
	pH	13			23			16	39									16		20	
Recycled C&D waste	LS	91			75				75									4		20	
	pH	75			123			25	123									34		25	
Recycled concrete	LS	146			138		10	21	139									34		114	
	pH	109			448		10	391	428									391		401	
Granulated tyres	pH																				
	LS	27			7				7									14			

Table 4.3e

Total number of samples (NoS) subjected to pH and L/S dependence tests and the total number of analyses of each substance that has been carried out for each test type (including all eluate fractions), evaluated on the basis of leaching data from pH-dependence and percolation tests listed in Table 4.1 and shown in the Separate Appendix Part 1.

Material	Test	NoS	Se	Si	Sm	Sn	SO3	SO4	Sr	Tb	Te	Th	Ti	Tl	Tm	U	V	W	Y	Yb	Zn	Zr
Artificial aggregate	LS	40	65	58		66		43	58				58				109				96	
	pH	20	95	95		95			95				95				95	16	16		95	
Asphalt aggregate	LS	38	33			19		24									35				42	
	pH	10	18	18		18		6	17				18				16				36	
BFS	LS	67	44	23		36		82	23				23	2			56	23			62	
	pH	58	47	54		54		66	54				54	2			55	38	8		58	
BOF EoW	LS	131	145	94		145		145	94				94				166	94			147	
	pH	51	90	97		97		51	97				97	1			114	83			110	
Coal fly ash	LS	107	131	28		25	3	171	17				15	15			90	110	36		150	
	pH	99	176	129		64	7	174	70				64	10		46	124	147	36		194	
EAF	LS	4						2													4	
	pH	23	1	48		1		9						1			53				67	
EC Boiler slag	LS	167	154			56	7	167	7					7			100				91	
	pH	13					7	13	7					7			7				13	
Glass	LS	12						3													20	
	pH	36		24		24		6	24				24				24				56	
Limestone	LS	4			3			1	3	3	3	3	3	3	3	3			3	3	1	3
	pH	3			2			1	2	2	2	2	2	2	2	2			2	2	1	2
Mix C&D derived aggr	LS	774	375	22		373		668	22				24				398				497	
	pH	4	27	32		3		24	32				3				32				32	
MSWI Fly ash	LS	19	61	25		25		43	25								88				103	
	pH	10	14	14		5		34	8								8				43	
MSWIBA	LS	175	177	146		197		138	154				103				193	68			211	
	pH	38	140	207		140		134	196				140	8			173	107			247	
Natural aggregate	LS	15			15				15	15	15	15	15	15	15	15			15	15		15
	pH	65	39	39	34	39		24	73	34	34	34	73	34	34	34	39	39	34	34	60	34
P slag	LS	14	52	16		45		35	38				16				64	16			64	
	pH	4	14	22		22			22				22				22		8		22	
Recycled bricks	LS	20	7			96		97									7				106	
	pH	13	16	16		16		4	16				16				42				39	
Recycled C&D waste	LS	91	20			20		69					2				24				75	
	pH	75	49	54		25		87	54				25				58				123	
Recycled concrete	LS	146	103	27		104		146	21				21	10			118	21			139	
	pH	109	392	392		395		58	391		58		391	67		1	414	234			451	
Granulated tyres	LS	27																			27	
	pH																					

4.3 Preliminary evaluation of aggregates based on leaching data

The performance of waste derived (and natural) aggregates in relation to potential future leaching limit values for the achievement of EoW status cannot be determined before the methodology for development of such limit values is in place and the values have been determined. It is therefore not possible beforehand to provide any material with immediate EoW status. It is, however, possible on the basis of the available leaching data to obtain a preliminary indication of the substances that are likely to be become most critical in relation to an EoW assessment by comparing them to the limit values for acceptance of waste at inert waste landfills (the EU LFD inert WAC). It should be noted that the potential final EoW criteria may be more stringent than the EU LFD inert WAC criteria which have been derived under the assumption of a certain effect of attenuation and that additional health related criteria on the content of various substances have not (yet) been considered.

Based on the data listed in Table 4.1 and shown in the Separate Appendices, compliance with the EU LFD WAC has been evaluated and the potentially most critical substances (on this basis) have been identified for the aggregates under consideration in Tables 4.4a and 4.4 b.

Table 4.4a
Identification of the potentially most critical substances, evaluated on the basis of a comparison of leaching data from the pH-dependence and percolation tests shown in the Separate Appendices with the leaching limit values from the EU LFD inert WAC (for RecCon also the Dutch SQD). Empty cells indicate either compliance with these leaching limit values or no data (check with tables 4.2 or 4.3).

Substance	**RecCon**		**RecBrick**		**RecGls ***		**MixC&D**		**RecAsph**		**BFSlag**		**BOFSlag**		**EAFSlag**	
	pH	L/S	pH	L/S	pH	L/S	pH	L/S	pH	L/S	pH	L/S	pH	L/S	pH	L/S
As			p		p											
Ba	b	p			b										p	
Br																
Cd					p		p	p					p			
Cl							p	p			p **					
Co																
Cr	e	p	p		p		p								e	
Cu	p					p										
F																
Hg																
Mo	p												p		e	
Ni	p				p											
Pb	p	p	b		e	p	p	p								
Sb	p		b		e	e	p				p #		p			
Se	p		b						b		p #		p			
Sn	p															
SO4	e			p			p				p	p				
V	p						b						e	e	e	
Zn																

p = partially exceeding (some samples comply, others do not)

b = at the limit (the data are consistently close to the limit value)

e = exceeding (the data consistently exceed the limit values)

l = possibly exceeding at low end of pH range

* if not waste glasses, then no exceeding substances

** Seawater quenching

\# older data, possibly overestimation

Table 4.4b

Identification of the potentially most critical substances, evaluated on the basis of a comparison of leaching data from the pH-dependence and percolation tests shown in the Separate Appendices with the leaching limit values from the EU LFD inert WAC. Empty cells indicate either compliance with these leaching limit values or no data (check with tables 4.2 or 4.3).

Substance	**Pslag**		**CFA**		**CBA**		**MSWIFA**		**MSWIBA**		**ArtAgg**		**NatAggr**		**Limestone**		**GranTyre**	
	pH	L/S	pH	L/S	pH	L/S	pH	L/S	pH	L/S	pH	L/S	pH	L/S	pH	L/S	pH	L/S
As			p	p	b	b	p	p			p	p	b					
Ba				p			p											
Br																		
Cd	p		p	p	p	p	e	e	p	b		b	b	b				
Cl				p			e	e	e	e								
Co																		
Cr			p	p	p	p	e	p	p	p	p	p						
Cu							p	p	e	e								
F							e	e										
Hg																		
Mo		p	p	p		p	e	e	e	p	p	b						
Ni			p	p	p	p	p	p	p	p			b	b				
Pb		p		p			e	e	p	p	b	b						
Sb	p	p	e				e	p	e	p			b					
Se	p	p	e				e	p	p	b	p	p	b					
Sn																		
SO4			e	e	p		e	e	e	p		b						
V			p	p									b	b				
Zn				p			e	p	p	b	b	b						p

p = partially exceeding (some samples comply, others do not)

b = at the limit (the data are consistently close to the limit value)

e = exceeding (the data consistently exceed the limit values)

l = possibly exceeding at low end of pH range

* if not waste glasses, then no exceeding substances

** Seawater quenching

older data, possibly overestimation

Based on the data available and the analysis of the data shown in Tables 4.4a and 4.4b, the potentially most critical substances leached from the various types of aggregates are summarised in table 4.5. Only the recycled asphalt, the natural aggregate and limestone do not exceed the EU leaching limit values for landfilling of inert waste, and only for the limestone, none of the measured inorganic substances are leached in amounts approaching the limit values.

Table 4.5
Overview for the aggregates included in the study of the substances for which the leachability, measured in the L/S dependence test or the pH dependence test, is close to, partially exceeding or consistently exceeding the EU leaching limit values for acceptance of waste at inert waste landfills (for RecCon also the limit values in the Dutch SQD).

Aggregate	**L/S dependence test (L/S = 10 l/kg)**			**pH dependence test (L/S = 10 l/kg)**		
	Close to the limit	Partially exceeding	Consistently exceeding	Close to the limit	Partially exceeding	Consistently exceeding
RecCon		Ba, Cr, Pb		Ba	Cu, Mo, Ni, Pb, Sb, Se, Sn, V	Cr, SO4
RecBrick		SO4		Pb, Sb, Se	As, Cr	
RecGls		Cu, Pb	Sb	Ba	As, Cd, Cr, Ni	Pb, Sb
MixC&D		Cd, Cl, Pb		V	Cd. Cl, Cr, Pb, Sb, SO4, V	
RecAsph				Se		
BFSlag		SO4			Cl*, Sb**, Se**, SO4, V	
BOFSlag			V		Cd, Mo, Sb, Se,	V
EAFSlag					Ba	Cr, Mo, V
PSlag		Mo, Pb, Sb, Se			Cd, Sb, Se	
CFA		As, Ba, Cd, Cl, Cr, Mo, Ni, Pb V, Zn	SO4		As, Cd. Cr, Mo, Ni, V	Sb, Se, SO4
CBA	As	Cd, Cr, Mo, Ni		As	Cd, Cr, Ni, SO4	
MSWIFA		As, Cu, Cr, Ni, Sb, Se, Zn	Cd, Cl, F, Mo, Pb, SO4		As, Ba, Cu, Ni	Cd, Cl, Cr, F, Mo, Pb, Sb, Se, SO4, Zn
MSWIBA	Cd, Se, Zn	Cr, Mo, Ni, Pb, Sb, SO4	Cl, Cu		Cd. Cr, Ni, Pb, Se, Zn	Cl, Cu, Mo, Sb, SO4
ArtAgg	Cd, Mo. Pb, SO4, Zn	As, Cr, Mo, Se		Pb, Zn	As, Cr, Mo, Se	
NatAggr	Cd, Ni, V			As, Cd, Ni, Pb, Sb, Se, V		
Limestone						
GranTyre		Zn				

*: Seawater quenching **: Older data, possibly overestimation

5. Control of pollution from aggregates in EU Member States

5.1 Legislation and practice in individual EU Member States

A survey has been conducted of the environmental regulation of the use of waste-derived aggregates in several EU Member States. The situation in several individual Member States is described in Annex 5 and partly summarised in Table 5.1. The information in "Aggregates Case Study" (Böhmer et al., 2008) has been helpful in getting information for some of the Member States in the table. Additional information on the regulatory practice in EU Member States can be found in Böhmer et al. (2008).

The leaching criteria for use of waste-derived aggregates in Austria, Belgium (Flanders), Denmark, Finland, France, Germany, Italy, The Netherlands, Spain and Sweden as well as the LFD WAC for inert waste are shown in Tables 5.2a to 5.2e with reference to the L/S value of the prescribed test methods and in the units in which they are expressed in the legislation or guidelines. In order to render all the data comparable, all criteria have been converted to a basis of L/S = 10 l/kg and expressed as released amounts (in mg/kg) using equations (3.1) and (3.5). The results are shown in Tables 5.3a to 5.3 e.

Table 5.1
Overview of the situation with respect to development of EoW criteria and regulation of uitilisation of waste-derived aggregates in several EU Member States.

Member State	**EoW criteria?**	**Regulation of the use of waste aggregates?**	**Criteria on total content?**	**Criteria on leaching?**	**Type(s) of leaching tests required**
Austria	No	Guidelines (1)	Yes	Yes	EN 12457-4 (L/S = 10 l/kg)
Belgium	No	Yes, in the Flemish region (2)	Yes	Yes	CEN/TS 14405 (L/S = 10 l/kg)
Czech Republic	No	Based on Landfill legislation* (3)	Yes	Yes	EN 12457-4 (L/S = 10 l/kg)
Denmark	No	Yes (4)	Yes	Yes	EN 12457-1
Finland	No	Yes (5)	Yes	Yes	CEN/TS 14405; EN 12457-3 (L/S = 10 l/kg)
France	No	Yes (6)	Yes	Yes	EN 12457-2 and 4
Germany	No	Yes guidelines – new regulation in preparation (7)	Yes	Yes	EN 12457-2 and DIN 19528 (new legislation)
Hungary	No	Some (8)	No	Yes	Not known
Italy	No	Yes (9)	No	Yes	EN 12457-2 (L/S=10 l/kg)
The Netherlands	No	Yes (10)	Yes	Yes	CEN/TS 14405 (L/S=10 l/kg)
Poland	No	No (11)	No	No	
Portugal	No	Some guidance (12)	No	No	
Slovakia	No	No (13)	No	No	
Spain	No	Yes, regional (14)	No	Yes	EN 12457-4 & DIN 38414-S4
Sweden	No	Guidelines (15)	Yes	Yes	CEN/TS 14405
United Kingdom	Yes	Guidance, case by case (16)	No	No	Variable, no routine testing

*: Considering adaptation of the Austrian guidelines

1. Federal Ministry of Agriculture and Forestry, Environmental and Water Management, 2006 (Austria).
2. EMIS (2011). See also Böhmer et al. (2008).
3. Order No. 294/2005 and Order No. 61/2010, Czech Republic.

4. Statutory Order No. 1662 of 21 December 2010 on recycling of residual products and soil in building and construction works and on recycling of sorted, unpolluted C&D waste. Danish Environmental Protection Agency.
5. Finnish Government Decree 591/2006 on reuse of some waste materials in earth construction, amended by 403/2009 and 1825/2009.
6. Sétra (2011), Sétra (2012a), Sétra (2012b), Ministry of Environment, France (2011): order of 18 November 2011 on the use of bottom ash from non dangerous waste incineration for road construction. Note that basic characterization relies on CEN 14405 (L/S=10 l/kg), whereas compliance testing relies on EN 12457-2 and 12457-4
7. LAGA (2004).
8. EIONET (2011) Country fact sheet – fact sheets waste policies – Hungary, http://scp.eionet.europa.eu/facts/factsheets_waste/2006_edition/Hungary
9. Ministry of Environment, Italy (1997): Decree 22/97. See also Böhmer et al. (2008).
10. Soil Quality Decree. Staatscourant 20 December 2007, Nr. 247, 67-90. The Netherlands.
11. Böhmer et al. (2008).
12. Coelho, A.D., Brito, J. de (2008): Construction and demolition waste management in Portugal, part of: SB07 Lisbon – Sustainable Construction, Materials and Practices: Challenges of the Industry for the New Millenium, http://www.irbdirekt.de/daten/iconda/CIB11754.pdf
13. Act No. 223/2001 on Waste as amended in Act No. 409/2006. Slovakia.
14. Decree of February 15, 1996, Catalonia, Spain. See also Böhmer et al. (2008).
15. Swedish EPA (2010).
16. http://www.environment-agency.gov.uk

Several Member States have regulations or guidelines that include criteria on leaching and performance of leaching tests on the aggregates to be used as construction materials, e.g. for road construction. This is the case in Austria, Belgium (Flemish region), Czech Republic, Denmark, Finland, France, Germany, Italy, The Netherlands, Spain (regional) and Sweden. With the exception of Italy, all of these Member States also have criteria based on total content of organic and/or inorganic substances. In some Member States the criteria are set for specific types of aggregates, in other Member States the criteria are more general. Many of the Member States have more than one set of leaching criteria, reflecting different conditions of use, e.g. with respect to thickness of the application, requirements on cover and rate of infiltration of precipitation, area of application, distance to groundwater level, distance to drinking water extraction wells or the hydrogeological vulnerability of the environment at the site of application. This is the case for Austria, Denmark, Finland, France, Germany, The Netherlands and Sweden.

From Tables 5.3a to 5.3e it can be seen that several Member States have adopted the EU leaching WAC for landfilling of inert waste as the basis for their leaching criteria for use of waste aggregates. This indicates that these Member States have not carried out a specific risk or impact assessment for the application scenarios but rely on the risk/impact assessment that was carried out when the EU LFD WAC for inert waste were developed (described in Annex 4). The Member States relying fully or partly on the EU LFD WAC for inert waste are Austria, Czech Republic, Finland, France and Spain (Cantabria).

The Member States which have carried out specific scenario-based risk/impact assessments as a basis for their leaching criteria for the use of waste-derived aggregates include Belgium (Flanders), Denmark, France (partly), Germany (for pending legislation), The Netherlands and Sweden. In the UK, scenario-based risk assessment is also the basis for approval of utilisation of waste-derived aggregates for construction purposes.

In some Member States, one of the sets of criteria refers to free or nearly free use of the unbound aggregate without restrictions. This is the case in Austria (class A+), Denmark (Category 1), France (type-3 without use restrictions), Germany (the old type Z0), Sweden (free use) and The Netherlands (granular, open), so those criteria cover a situation that would be close to an unrestricted EoW scenario. It should be noted that all of these criteria, with the exception of the old German Z0, which is more pragmatic and not based on an actual risk assessment, have been developed using pathway scenarios that take some degree of attenuation of released substances into account. This may, however, not be sufficient for general EoW criteria without any restrictions on the use of the products.

In most of the Member States listed in Table 5.1 (Austria, Belgium, Czech Republic, Denmark, Finland, France, Hungary, Italy, Poland, Portugal, Spain and Sweden) the use of waste-derived aggregates is governed by waste legislation. In the Netherlands, the use of waste-derived aggregates is governed by generic legislation that covers and applies the same limit values to both waste and construction products. The Dutch Soil Quality Decree (SQD, 2007) which has replaced the earlier

Building Materials Decree (BMD, 1995) sets scenario-based leaching criteria for free (and restricted) use of both virgin and waste-derived aggregates used for construction purposes (see Annex 5). In this case the level of protection of the environment from the release of undesirable substances is the same regardless of whether the waste-derived aggregate has achieved EoW status or remains under waste legislation. It is important to notice that the modelling period used to set criteria in the SQD was limited to 100 years which led to relatively high modelled limit values for some substances (several of which were subsequently lowered politically) The BMD was also common for products and waste, but was more complicated to use than the SQD by which it has been replaced (see Annex 5).

Tables 5.2c and 5.3c show the old German leaching limit values for application according to the Länderarbeitsgemeinschaft Abfall (LAGA, 2004) which appear still to be used by some of the Federal States. Germany is, however, preparing new legislation on the use of secondary construction materials based on leaching and risk assessment. The leaching limit values are material-specific and refer to specific application and receptor scenarios. Due to the large number of materials and scenarios, the proposed new German limit values are not listed in Tables 5.2 and 5.3. It should be mentioned that a guideline for the assessment of effects of construction products on soil and groundwater has been developed in Germany (DIBt-Merkblatt "Grundsätze zur Bewertung der Auswirkungen von Bauprodukten auf Boden und Grundwasser, Mai 2008").

France has issued a guide that defines the procedure to assess the acceptance of waste, including waste aggregates, as alternative road construction materials (Sétra, 2011). It uses the LFD WAC for inert waste as the starting point. For general use, 80 % of the samples tested must comply with the LFD leaching WAC for inert waste (Level 1A in Table 5.2a), 95 % must comply with Level 1B values which are less restrictive and 100 % must comply with Level 1C values which are even higher. Another set of leaching criteria which is identical to the EU WAC for acceptance of waste at landfills for non-hazardous waste accepting stable, non-reactive hazardous waste (CEC, 2003) must be complied with, otherwise utilisation is not possible (Level 1, Exclusion in Tables 5.2 and 5.3). Finally two sets of leaching criteria (Level 2A and Level 2B) corresponding to specific road and earth construction with certain conditions on the use attached have been developed using risk-based scenario calculations (Sétra, 2011, Chateau, 2007). If Level 2 criteria (but not the exclusion criteria) are exceeded, then a site-specific assessment based on the same principles as used to set the Level 2 criteria can be applied.

The United Kingdom is defining national EoW criteria for waste-derived aggregates with reference to the Waste Framework Directive. The methodology used is different from the methodology applied to the setting of leaching criteria for the use of waste-derived aggregate in most other European Member States. In the UK a waste aggregate under consideration for EoW status will undergo an extensive study of the content and release of a selection of substances from a broad range of samples of the waste material in question to provide an overview of the general leaching behaviour (and composition) of the material. Based on this, a series of environmental impact assessments will be carried out using the leaching characterisation data as input to assessment models which includes several source scenarios, pathways and receptors reflecting the relevant service life scenarios. The number of substances considered may vary from one material to another. For coal fly ash, for instance, it includes chloride, fluoride, sulphate, Si, Ca, Mg, Na, K, Al, As, B, Ba, Cd, Co, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Sb, Se, Sn, V, Zn, DOC and ammonia. For leaching, the local groundwater or surface water quality criteria (often dictated by the Water Framework Directive and its daughter directives) generally apply as primary quality criteria. The organisation responsible for EoW assessments is the Waste Protocols Programme under the Environment Agency (http://www.environment-agency.gov.uk/business/topics/waste/32154.aspx). A panel under the Waste Protocols Programme reviews the results and determines whether or not the waste material in question can be granted EoW status. If it can, then a quality protocol for the material is produced. The quality protocol specifies the conditions for use of the material and which (functional) tests have to be performed to ensure the compliance with functional criteria. No further environmental testing is required. Beneficial use of waste aggregates under waste legislation may require testing and impact/risk assessment on a case by case basis.

Table 5.2a

Leaching limit values for utilisation of waste-derived aggregates in several EU Member States. Limit values are shown in the units in which they are expressed in the regulation.

Country:	**Austria**	**Austria**	**Austria**	**Belgium**	**Denmark**	**Denmark**	**Denmark**
Region:				Vlandern			
Category:	A+	A	B	Unbound	Cat 1	Cat 2	Cat 3
Materials:	C&D W	C&D W	C&D W	General	Residues	Residues	Residues
Test:	EN 12457-4	EN 12457-4	EN 12457-4	CEN/TS 14405	EN 12457-1	EN 12457-1	EN 12457-1
L/S (l/kg):	10	10	10	10	2	2	2
Unit:	mg/kg	mg/kg	mg/kg	mg/kg	µg/l	µg/l	µg/l
Bromide							
Chloride	800	800	1000		150000 (1500000)	150000 (1500000)	3000000
Fluoride	10	10	15				
Sulphate	1500	2500	5000		250000 (2000000)	250000 (2000000)	4000000
NH4-N	1	4	8				
Nitrate							
Nitrite-N	0.5	1	2				
Cyanide							
Na					100000 (1000000)	100000 (1000000)	1500000
As	0.5	0.5	0.5	0.8	8	8	50
Ba	20	20	20		0.3	0.3	4
Be							
Cd	0.04	0.04	0.04	0.03	2	2	40
Co							
Cr tot	0.3	0.5	0.5	0.5	10	10	500
Cr(VI)							
Cu	0.5	1	2	0.5	45	45	2000
Hg	0.01	0.01	0.01	0.02	0.0001	0.0001	1
Mn					150	150	1000
Mo							
Ni	0.4	0.4	0.6	0.75	10	10	70
Pb	0.5	0.5	0.5		0.01	0.01	100
Sb	0.06	0.06	0.1				
Se	0.1	0.1	0.1		10	10	30
Sn							
V							
Zn	4	4	18	2.8	100	100	1500
TDS							
DOC	500	500	500				
Phenol indx	1						
HC indx	1	3	5				
PAH (EPA)	4	12	20				
COD							
Asbestos							
pH	7.5 - 12.5	7.5 - 12.5	7.5 - 12.5				
EC (mS/m)	150 (200)	150 (200)	150 (200)				
TDS	4000	4000	8000				
Sources:	A	A	A	B	C	C	C

A Böhmer, S., Moser, G., Neubauer, C., Peltoniemi, M., Schachermayer, E., Tesar, M., Walter, B., Winter, B. (2008): AGGREGATES CASE STUDY, Final Report referring to contract n° 150787-2007 F1SC-AT "Aggregates case study – data gathering" (study commissioned by JRC-IPTS), Vienna. PAH refers to total content of US EPA PAH_{16}. In addition, total content limitations exist for As, Pb, Cd, Cr, Cu, Ni, Hg and Zn

B The same as A.

C Statutory Order No. 1662 of 21 December 2010 on recycling of residual products and soil in building and construction works and on recycling of sorted, unpolluted C&D waste. Values in parentheses are "temporarily" increased limit values for MSWI bottom ash.

Table 5.2b

Leaching limit values for utilisation of waste-derived aggregates in several EU Member States. Limit values are shown in the units in which they are expressed in the regulation.

Country:	**Finland**	**Finland**	**Finland**	**Finland**	**France**	**France**	**France**
Region:							
Category:	Covered	Paved	Covered	Paved	Level 1A 80%	Level 1B 95%	Level 1C 100%
Materials:	C&D W	C&D W	Ashes	Ashes			
Test:	CEN/TS 14405	CEN/TS 14405	CEN/TS 14405	CEN/TS 14405	EN 12457-2 EN 12457-4	EN 12457-2 EN 12457-4	EN 12457-2 EN 12457-4
L/S (l/kg):	10	10	10	10	10	10	10
Unit:	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Bromide							
Chloride	800	800	800	2400	800	1600	2400
Fluoride	10	50	10	50	10	20	30
Sulphate	1000	6000	1000	10000	1000	2000	3000
NH4-N							
Nitrate							
Nitrite-N							
Cyanide							
Na							
As	0.5	0.5	0.5	1.5	0.5	1	1.5
Ba	20	20	20	60	20	40	60
Be							
Cd	0.02	0.02	0.04	0.04	0.04	0.08	0.12
Co							
Cr tot	0.5	0.5	0.5	3.0	0.5	1	1.5
Cr(VI)							
Cu	2.0	2.0	2.0	6.0	2	4	6
Hg	0.01	0.01	0.01	0.01	0.01	0.02	0.03
Mn							
Mo	0.5	0.5	0.5	6.0	0.5	1	1.5
Ni	0.4	0.4	0.4	1.2	0.4	0.8	1.2
Pb	0.5	0.5	0.5	1.5	0.5	1	1.5
Sb	0.06	0.06	0.06	0.18	0.06	0.12	0.18
Se	0.1	0.1	0.1	0.5	0.1	0.2	0.3
Sn							
V	2.0	2.0	2.0	3.0			
Zn	4.0	4.0	4.0	12	4	8	12
TDS					4000	8000	12000
DOC	500	500	500	500			
Phenol indx							
HC indx							
PAH (EPA)							
COD							
Asbestos							
pH							
EC (mS/m)							
TDS							
Sources:	D	D	D	D	F	F	F

D Finnish Government Decree 591/2006 on reuse of some waste materials in earth construction, amended by 403/2009 and 1825/2009.

F Sétra (2011): Acceptabilité de matériaux alternatifs en technique routière. Évaluation environmentale. Guide Méthodologique. Service d’etudes sur les transports, les routes et leurs aménagements. Bagneux Cedex, France.

Table 5.2c

Leaching limit values for utilisation of waste-derived aggregates in several EU Member States. Limit values are shown in the units in which they are expressed in the regulation.

Country:	**France**	**France**	**France**	**France**	**Germany**	**Germany**	**Germany**
Region:							
Category:	Level 1C 100%	Level 1 Exclusion	Level 2A	Level 2B	Z0/Z1.1	Z1.2	Z2
Materials:					Soil	Soil	Soil
Test:	EN 12457-2 EN 12457-4	EN 12457-2 EN 12457-4	EN 12457-2 EN 12457-4	EN 12457-2 EN 12457-4	EN 12457-2	EN 12457-2	EN 12457-2
L/S (l/kg):	10	10	10	10	10	10	10
Unit:	mg/kg	mg/kg	mg/kg	mg/kg	µg/l	µg/l	µg/l
Bromide							
Chloride	2400	15000	10000	5000	30000	50000	100000
Fluoride	30	150	60	30			
Sulphate	3000	20000	10000	5000	20000	50000	200000
NH4-N							
Nitrate							
Nitrite-N							
Cyanide					5	10	20
Na							
As	1.5	2	0.8	0.5	14	20	60
Ba	60	100	56	28			
Be							
Cd	0.12	1	0.32	0.16	1.5	3	6
Co							
Cr tot	1.5	10	4	2	12.5	25	60
Cr(VI)							
Cu	6	50	50	50	20	60	100
Hg	0.03	0.2	0.08	0.04	0.5	1	2
Mn							
Mo	1.5	10	5.6	2.8			
Ni	1.2	10	1.6	0.8	15	20	70
Pb	1.5	10	0.8	0.5	40	80	200
Sb	0.18	0.7	0.4	0.2			
Se	0.3	0.5	0.5	0.4			
Sn							
V							
Zn	12	50	50	50	150	200	600
TDS	12000	60000					
DOC							
Phenol indx					20	40	
HC indx							
PAH (EPA)							
COD							
Asbestos							
pH					6.5-9.5	6-12	5.5-12
EC (mS/m)					25	150	200
TDS							
Sources:	F	F	F	F	G	G	G

F Sétra (2011): Acceptabilité de matériaux alternatifs en technique routière. Évaluation environmentale. Guide Méthodologique. Service d'etudes sur les transports, les routes et leurs aménagements. Bagneux Cedex, France. Note that basic characterization of level 2A and 2B is based on CEN/TS 14405, from which different sets of compliance limit values for batch testing according to EN 12457-2/4 are determined for different waste derived material streams in so-called "Application guides". The values above are given in ADEME (2012) "Etude de caractérisation des matériaux alternatifs issus de plateformes de tri et valorisation des dechets du BTP"

G LAGA (2004): Working Group of the German Länder under Waste Issues: Länderarbeitsgemeinschaft Abfall, Eckpunkte (EP) der LAGA für eine "Verordnung über die Verwertung von mineralischen Abfällen in technischen Bauwerken", Stand 31.08.2004.

Table 5.2d
Leaching limit values for utilisation of waste-derived aggregates in several EU Member States (the limit values for The Netherlands also cover products). Limit values are shown in the units in which they are expressed in the regulation.

Country:	**Italy**	**Netherlands**	**Netherlands**	**Spain**	**Spain**	**Spain**	
Region:				Cantabria	Basque Con	Catalonia	
Category:		300 mm/y	6 mm/y				
Materials:	Residues	All materials	All materials	Slags	Slags	Slags	
Test:	EN 12457-2	CEN/TS14405	CEN/TS14405	EN 12457-4	EN 12457-4	IN 38414-S4	
L/S (l/kg):	10	10	10	10	10	10	
Unit:	mg/l	mg/kg	mg/kg	mg/kg	mg/kg	mg/l	
Bromide		20	34				
Chloride	100	616	8800	800			
Fluoride	1.5	55	1500	10	18		
Sulphate	250	1730	20000	1000	377		
NH4-N							
Nitrate	50						
Nitrite-N							
Cyanide	0.05						
Na							
As	0.05	0.9	2	0.5		0.1	
Ba	1	22	100	20	17		
Be	0.01						
Cd		0.04	0.06	0.04	0.009/0.6	0.1	
Co	0.25	0.54	2.4				
Cr tot	0.05	0.63	7	0.5	2.6	0.5	
Cr(VI)						0.1	
Cu	0.05	0.9	10	2		2	
Hg	0.001	0.02	0.08	0.01		0.02	
Mn							
Mo		1	15	0.5	1.3		
Ni	0.01	0.44	2.1	0.4	0.8	0.5	
Pb	0.05	2.3	8.3	0.5	0.8	0.5	
Sb		0.16	0.7	0.06			
Se	0.01	0.15	3	0.1	0.007/0.2		
Sn		0.4	2.3				
V	0.25	1.8	20		1.3		
Zn	3	4.5	14	4		2	
TDS				4000			
DOC				500			
Phenol indx				1			
HC indx							
PAH (EPA)	30						
COD	30						
Asbestos							
pH	5.5-12						
EC (mS/m)							
TDS							
Sources:	A	H	H	A	A	A	

A Böhmer, S., Moser, G., Neubauer, C., Peltoniemi, M., Schachermayer, E., Tesar, M., Walter, B., Winter, B. (2008): AGGREGATES CASE STUDY, Final Report referring to contract n° 150787-2007 F1SC-AT "Aggregates case study – data gathering" (study commissioned by JRC-IPTS), Vienna.

H SQD (2007): Soil Quality Decree. *Staatscourant* 20 December, Nr. 247, 67 – 90, The Netherlands.

Table 5.2e

Leaching limit values for utilisation of waste-derived aggregates in several EU Member States. Limit values are shown in the units in which they are expressed in the regulation. The table also shows the European limit values for acceptance of inert waste at landfills for inert waste.

Country:	**Sweden**	**Sweden**	**EU LFD Inert**
Region:			
Category:	Free use	Use on landfill	Landfilling
Materials:	Waste	Waste	Inert waste
Test:	CEN/TS 14405	CEN/TS 14405	EN 12457-2 CEN/TS 14405
L/S (l/kg):	10	10	10
Unit:	mg/kg	mg/kg	mg/kg
Bromide			
Chloride	130	11000	800
Fluoride			10
Sulphate	200	8500	1000
NH4-N			
Nitrate			
Nitrite-N			
Cyanide			
Na			
As	0.09	0.4	0.5
Ba			20
Be			
Cd	0.02	0.007	0.04
Co			
Cr tot	1	0.3	0.5
Cr(VI)			
Cu	0.8	0.6	2
Hg	0.01		0.01
Mn			
Mo			0.5
Ni	0.4	0.6	0.4
Pb	0.2	0.3	0.5
Sb			0.06
Se			0.1
Sn			
V			
Zn	4	3	4
TDS			
DOC			500
Phenol indx			1
HC indx			
PAH (EPA)			
COD			
Asbestos			
pH			
EC (mS/m)			
TDS			
Sources:	I	I	J

I Swedish EPA (2010): Återvinning av avfall i anläggningsarbeten Handbok 2010:1. ISBN 978-91-620-0164-3.pdf. Naturvårdsverket, Stockholm, Sweden. Note that these limit values are guidance values and not binding. Limits for total content for PAH are split up according to molecular weight category of the congeners.

J CEC (2003): Council Decision 2003/33/EC of 19 December 2002 establishing criteria and procedures for the acceptance of waste at landfills pursuant to Article 16 and Annex II to Directive 1999/31/EC. Official Journal of the European Communities, 16.1.2003, L11/27-49.

Table 5.3a

Leaching limit values for utilisation of waste-derived aggregates in several EU Member States. Limit values have all been converted to values corresponding to leached amounts at L/S = 10 l/kg and expressed in mg/kg and are therefore all comparable.

Country:	**Austria**	**Austria**	**Austria**	**Belgium**	**Denmark**	**Denmark**	**Denmark**
Region:				Vlandern			
Category:	A+	A	B	Unbound	Cat 1	Cat 2	Cat 3
Materials:	C&D W	C&D W	C&D W	General	Residues	Residues	Residues
Test:	EN 12457-4	EN 12457-4	EN 12457-4	EN/TS 14405	EN 12457-1	EN 12457-1	EN 12457-1
L/S (l/kg):	10	10	10	10	10	10	10
Unit:	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Bromide							
Chloride	800	800	1000		440	440	8800
Fluoride	10	10	15				
Sulphate	1500	2500	5000		1000	1000	16000
NH4-N	1	4	8				
Nitrate							
Nitrite-N	0.5	1	2				
Cyanide							
Na							
As	0.5	0.5	0.5	0.8	0.071	0.071	0.45
Ba	20	20	20		1.8	1.8	24
Be							
Cd	0.04	0.04	0.04	0.03	0.0063	0.0063	0.13
Co							
Cr tot	0.3	0.5	0.5	0.5	0.055	0.055	2.8
Cr(VI)							
Cu	0.5	1	2	0.5	0.20	0.20	9
Hg	0.01	0.01	0.01	0.02	0.00083	0.00083	0.0083
Mn							
Mo							
Ni	0.4	0.4	0.6	0.75	0.043	0.043	0.30
Pb	0.5	0.5	0.5		0.045	0.045	0.45
Sb	0.06	0.06	0.1				
Se	0.1	0.1	0.1		0.037	0.037	0.11
Sn							
V							
Zn	4	4	18	2.8	0.44	0.44	6.6
TDS							
DOC	500	500	500				
Phenol indx	1						
HC indx	1	3	5				
PAH (EPA)	4	12	20				
COD							
Asbestos							
pH	7.5 - 12.5	7.5 - 12.5	7.5 - 12.5				
EC (mS/m)	150 (200)	150 (200)	150 (200)				
TDS	4000	4000	8000				

Note: The Danish limit values has been recalculated from limit values at L/S = 2 l/kg to limit values at L/S = 10 l/kg using equation (3.5) and the kappa-values shown in Table 3 in Annex 4. Due to the very soluble nature of chloride and sulphate this may lead to an overestimation of the limit values at L/S = 10 l/kg. For chloride and sulphate the “temporarily” elevated values (see Table 5.2a) have not be recalculated. Neither have the limit values for Na and Mn (no kappa value available).

Table 5.3b

Leaching limit values for utilisation of waste-derived aggregates in several EU Member States. Limit values have all been converted to values corresponding to leached amounts at L/S = 10 l/kg and expressed in mg/kg and are therefore all comparable.

Country:	**Finland**	**Finland**	**Finland**	**Finland**	**France**	**France**	**France**
Region:							
Category:	Covered	Paved	Covered	Paved	Level 1A 80%	Level 1B 95%	Level 1C 100%
Materials:	C&D W	C&D W	Ashes	Ashes			
Test:	CEN/TS 14405	CEN/TS 14405	CEN/TS 14405	CEN/TS 14405	EN 12457-2 EN 12457-4	EN 12457-2 EN 12457-4	EN 12457-2 EN 12457-4
L/S (l/kg):	10	10	10	10	10	10	10
Unit:	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Bromide							
Chloride	800	800	800	2400	800	1600	2400
Fluoride	10	50	10	50	10	20	30
Sulphate	1000	6000	1000	10000	1000	2000	3000
NH4-N							
Nitrate							
Nitrite-N							
Cyanide							
Na							
As	0.5	0.5	0.5	1.5	0.5	1	1.5
Ba	20	20	20	60	20	40	60
Be							
Cd	0.02	0.02	0.04	0.04	0.04	0.08	0.12
Co							
Cr tot	0.5	0.5	0.5	3.0	0.5	1	1.5
Cr(VI)							
Cu	2.0	2.0	2.0	6.0	2	4	6
Hg	0.01	0.01	0.01	0.01	0.01	0.02	0.03
Mn							
Mo	0.5	0.5	0.5	6.0	0.5	1	1.5
Ni	0.4	0.4	0.4	1.2	0.4	0.8	1.2
Pb	0.5	0.5	0.5	1.5	0.5	1	1.5
Sb	0.06	0.06	0.06	0.18	0.06	0.12	0.18
Se	0.1	0.1	0.1	0.5	0.1	0.2	0.3
Sn							
V	2.0	2.0	2.0	3.0			
Zn	4.0	4.0	4.0	12	4	8	12
TDS					4000	8000	12000
DOC	500	500	500	500			
Phenol indx							
HC indx							
PAH (EPA)							
COD							
Asbestos							
pH							
EC (mS/m)							
TDS							

Table 5.3c

Leaching limit values for utilisation of waste-derived aggregates in several EU Member States. Limit values have all been converted to values corresponding to leached amounts at L/S = 10 l/kg and expressed in mg/kg and are therefore all comparable.

Country:	**France**	**France**	**France**	**France**	**Germany**	**Germany**	**Germany**
Region:							
Category:	Level 1C 100%	Level 1 Exclusion	Level 2A	Level 2B	Z0/Z1.1	Z1.2	Z2
Materials:					Soil	Soil	Soil
Test:	EN 12457-2 EN 12457-4	EN 12457-2 EN 12457-4	EN 12457-2 EN 12457-4	EN 12457-2 EN 12457-4	EN 12457-2	EN 12457-2	EN 12457-2
L/S (l/kg):	10	10	10	10	10	10	10
Unit:	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Bromide							
Chloride	2400	15000	10000	5000	300	500	1000
Fluoride	30	150	60	30			
Sulphate	3000	20000	10000	5000	200	500	2000
NH4-N							
Nitrate							
Nitrite-N							
Cyanide					0.05	0.1	0.2
Na							
As	1.5	2	0.8	0.5	0.14	0.2	0.6
Ba	60	100	56	28			
Be							
Cd	0.12	1	0.32	0.16	0.015	0.03	0.06
Co							
Cr tot	1.5	10	4	2	0.125	0.25	0.6
Cr(VI)							
Cu	6	50	50	50	0.2	0.6	1
Hg	0.03	0.2	0.08	0.04	0.005	0.01	0.02
Mn							
Mo	1.5	10	5.6	2.8			
Ni	1.2	10	1.6	0.8	0.15	0.2	0.7
Pb	1.5	10	0.8	0.5	0.4	0.8	2
Sb	0.18	0.7	0.4	0.2			
Se	0.3	0.5	0.5	0.4			
Sn							
V							
Zn	12	50	50	50	1.5	2	6
TDS	12000	60000					
DOC							
Phenol indx					0.2	0.4	
HC indx							
PAH (EPA)							
COD							
Asbestos							
pH					6.5-9.5	6-12	5.5-12
EC (mS/m)					25	150	200
TDS							

Table 5.3d

Leaching limit values for utilisation of waste-derived aggregates in several EU Member States (the limit values for The Netherlands also cover products). Limit values have all been converted to values corresponding to leached amounts at L/S = 10 l/kg and expressed in mg/kg and are therefore all comparable.

Country:	**Italy**	**Netherlands**	**Netherlands**	**Spain**	**Spain**	**Spain**
Region:				Cantabria	Basque Con	Catalonia
Category:		300 mm/y	6 mm/y			
Materials:	Residues	All materials	All materials	Slags	Slags	Slags
Test:	EN 12457-2	CEN/TS14405	CEN/TS14405	EN 12457-4	EN 12457-4	DIN 38414-S4
L/S (l/kg):	10	10	10	10	10	10
Unit:	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Bromide		20	34			
Chloride	1000	616	8800	800		
Fluoride	15	55	1500	10	18	
Sulphate	2500	1730	20000	1000	377	
NH4-N						
Nitrate	500					
Nitrite-N						
Cyanide	0.5					
Na						
As	0.5	0.9	2	0.5		1
Ba	1	22	100	20	17	
Be	0.1					
Cd		0.04	0.06	0.04	0.009/0.6	1
Co	2.5	0.54	2.4			
Cr tot	0.5	0.63	7	0.5	2.6	5
Cr(VI)						1
Cu	0.5	0.9	10	2		20
Hg	0.01	0.02	0.08	0.01		0.2
Mn						
Mo		1	15	0.5	1.3	
Ni	0.1	0.44	2.1	0.4	0.8	5
Pb	0.05	2.3	8.3	0.5	0.8	5
Sb		0.16	0.7	0.06		
Se	0.1	0.15	3	0.1	0.007/0.2	
Sn		0.4	2.3			
V	2.5	1.8	20		1.3	
Zn	30	4.5	14	4		20
TDS				4000		
DOC				500		
Phenol indx				1		
HC indx						
PAH (EPA)	300					
COD	300					
Asbestos						
pH	5.5-12					
EC (mS/m)						
TDS						

Table 5.3e

Leaching limit values for utilisation of aggregates in several EU Member States as well as the EU WAC for inert waste landfills. Limit values have all been converted to values corresponding to leached amounts at L/S = 10 l/kg and expressed in mg/kg and are therefore all comparable.

Country:	**Sweden**	**Sweden**	**EU LFD Inert**
Region:			
Category:	Free use	Use on landfill	Landfilling
Materials:	Waste	Waste	Inert waste
Test:	CEN/TS 14405	CEN/TS 14405	EN 12457-2 CEN/TS 14405
L/S (l/kg):	10	10	10
Unit:	mg/kg	mg/kg	mg/kg
Bromide			
Chloride	130	11000	800
Fluoride			10
Sulphate	200	8500	1000
NH4-N			
Nitrate			
Nitrite-N			
Cyanide			
Na			
As	0.09	0.4	0.5
Ba			20
Be			
Cd	0.02	0.007	0.04
Co			
Cr tot	1	0.3	0.5
Cr(VI)			
Cu	0.8	0.6	2
Hg	0.01		0.01
Mn			
Mo			0.5
Ni	0.4	0.6	0.4
Pb	0.2	0.3	0.5
Sb			0.06
Se			0.1
Sn			
V			
Zn	4	3	4
TDS			
DOC			500
Phenol indx			1
HC indx			
PAH (EPA)			
COD			
Asbestos			
pH			
EC (mS/m)			
TDS			
Sources:	I	I	J

5.2 EU legislation that may influence the use of waste-derived aggregates and EoW criteria

5.2.1 The Waste Framework Directive (by-products)

The Waste Framework Directive opens the possibility (in Article 5) to reclassify a waste material as a by-product which will exempt it from further waste legislation. The conditions and procedure for the waste versus by-product decision is illustrated in Figure 5.1. If a material is deemed a by-product, it legally becomes a product, and an EoW assessment is no longer relevant. Article 5, 1 (d) does set the condition that "further use is lawful", i.e. the substance or object fulfils all relevant product, environmental and health protection requirements for the specific use and will not lead to overall adverse environmental or human health impacts". This is the same requirement on environmental and health protection as that in Article 6,1 (d) which defines EoW criteria, but it does not call for limit values for pollutants (which might possibly be relevant, if the by-product is used as an aggregate and not covered by other environmental legislation).

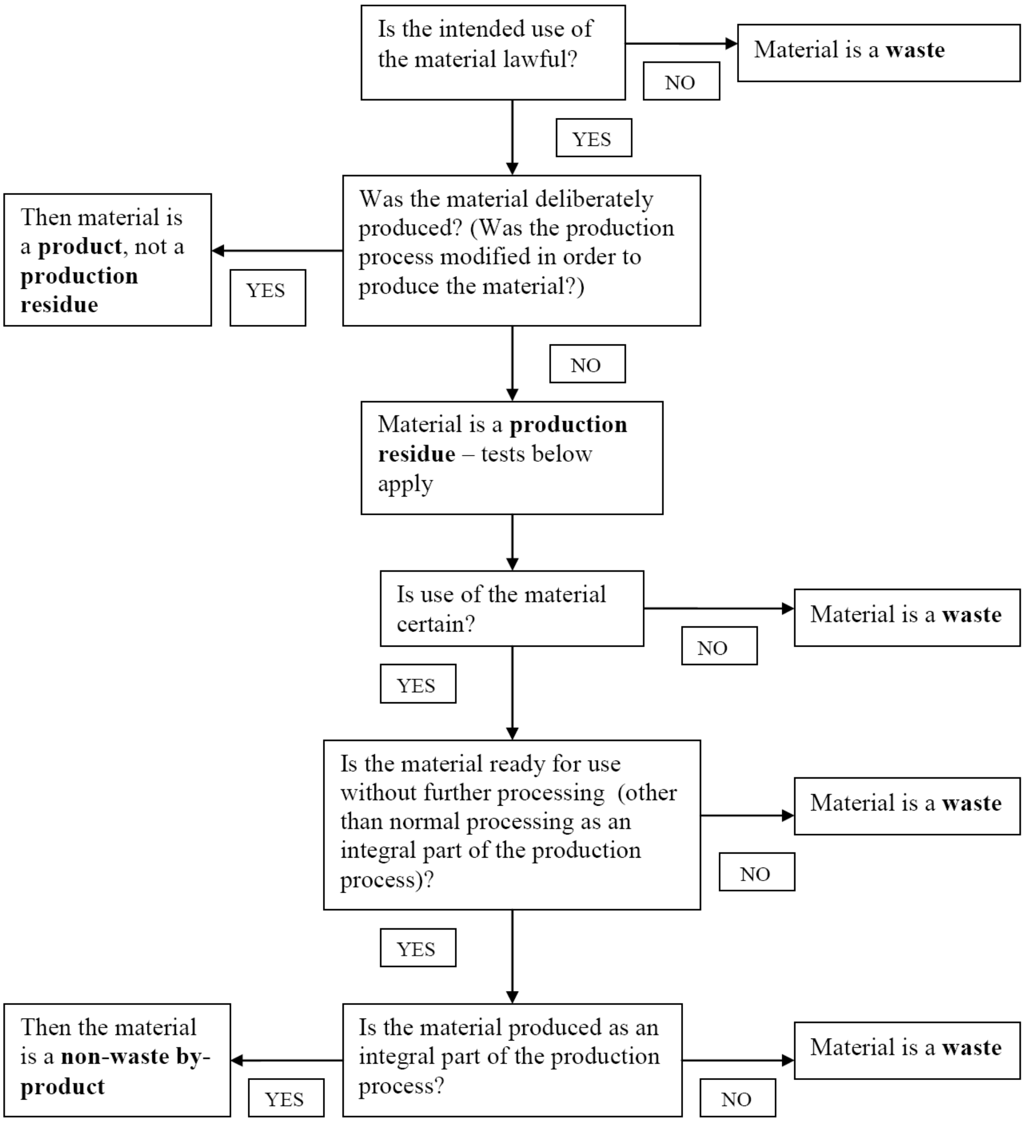

Figure 5.1
Decision tree for waste versus by-product decisions (from COM(2007) 59 Final, 21.02.2007).

The Communication from the Commission to the Council and the European Parliament on the Interpretative Communication on waste and by-products (COM(2007) 59 final of 21.2.2007), states that: "*Blast furnace slag is produced in parallel with hot iron in a blast furnace. The production process of the iron is adapted to ensure that the slag has the requisite technical qualities. a technical choice is made at the start of the production process that determines the type of slag that is produced. Moreover, the use of the slag is certain in a number of clearly defined end uses, and demand is high. Blast furnace slag can be used directly at the end of the production process, without further processing that is not an integral part of this production process (such as crushing to the appropriate particle size). This material can therefore be considered to fall outside of the definition of waste.*"

5.2.2 The REACH Regulation

The REACH regulation ((EC) No 1907/2006 of the European Parliament and the Council) lays down specific duties and obligations on manufacturers, importers and downstream users of substances on their own, in preparations and in articles. The objective is to ensure a high level of protection of human health and the environment as well as the free movement of substances, on their own, in preparations and in articles, while enhancing competitiveness and innovation. Any manufacturer or importer of a substance, either on its own or in one or more preparations in quantities of one tonne or more per year shall submit a registration to the European Chemicals Agency (ECHA). REACH focuses on substances. The main principle of the legislation is that if no data are provided, the product cannot be placed on the market.

Article 2(2) of REACH provides that "waste as defined in Directive 2006/12/EC [now 2008/98/EC] of the European Parliament and of the Council is not a substance, preparation or article within the meaning of Article 3 of this Regulation." Therefore, REACH requirements for substances, mixtures and articles do not apply to waste (at least not in full, see ECHA (2010)). This will, of course, change when a waste becomes a product as a result of an EoW assessment, unless the material can be regarded purely as an article, i.e. an object for which the shape, surface or design is more relevant for its function than its chemical composition, in which case it may be exempted from registration under REACH.

In its guidance document, ECHA (2010) has stated that for the sake of consistency and enforceability, all forms of recovery, including mechanical processing, are considered as a manufacturing process whenever, after having undergone on or several recovery steps, they result in the generation of one or several substances as such or in a mixture or in an article that have ceased to be waste.

In the same guidance document, ECHA presents the following considerations concerning the need to register recovered (waste-derived) aggregate products:

"Recovered aggregates [with EoW status as products] should be understood in the following as covering aggregates resulting from the processing of inorganic material previously used in construction (e.g. concrete, stones), as well as certain aggregates of mineral origin resulting from an industrial process involving thermal or other modification (e.g. unprocessed slag, waste from processing of slag, fly ash).

The question was raised whether such recovered aggregates can be seen as articles or whether they are substances on their own or in a mixture.

Recovered aggregates from construction consist of concrete, natural stones, masonry, ceramics (e.g., roofing tiles) and/or asphalt, either alone or in certain cases mixed. They can have diverse applications, such as in civil engineering works, in roads and as railway ballast. The main function of this application is to provide stability and resistance to degradation/fragmentation. If for this function the shape, surface or design is more important than the chemical composition, the recovered aggregates would be considered as articles. By definition, this would however only be the case if the shape, surface or design of the material has been deliberately determined and given during its production (e.g. in order to meet certain recognised aggregate standards such as EN 12620, EN 13043 or EN 13242). If for this function the shape, surface or design does not determine the function of the material to a greater degree than its chemical composition, then the aggregate would not be in *line with the article definition, and should thus be seen as a substance on its own or in a mixture. Examples of different recovered aggregates are given below:*

Aggregates from construction and demolition waste

Particles from aggregates from construction and demolition waste are produced with specific shape and surface characteristics depending on their application, like e.g. in asphalt pavements. The shape of such a particle is described using the ratio of the longest and smallest dimension of the particle. EN Standards 933-3 and 933-4, for instance, describe methods to determine the shape of such particles. The surface of such a particle is defined by its micro- and macrorugosity (i.e. variations in the height of a surface at different scales), which are measured as described by the EN Standards 1097-8 and 933-5 respectively. Shape and surface of a particle from aggregates from construction and demolition waste determine its function to a greater degree than the chemical composition of the particle. The essential chemical properties are restricted to a maximum of allowed solubility - if the aggregate is soluble it cannot fulfil its function - and are less important than the shape and surface. These particles are therefore considered to be articles according to the article definition under REACH.

Ferrous slags

Most of the slags produced by the iron and steel industry throughout Europe will be registered as UVCB[2] substances and are used in applications such as the production of cements and concrete products. It is the hydraulic properties of the slag that is important to these applications. Thus, the chemical composition of the slag is clearly more important. As a result, ferrous slag is to be considered as a substance. By analogy, slags from other metallurgic processes should be considered as substances as well.

Fly ash

Fly ash is a heterogeneous mixture of constituents consisting of amorphous and crystalline silicon dioxide (SiO_2), aluminium oxide (Al_2O_3), iron oxide, calcium oxide and carbon. It has various uses such as in the production of cement, cement clinker and grout, embankments and structural fill, stabilization of soft soils, road sub-base and as a mineral filler in asphaltic concrete. For its use the chemical composition is more important than the shape, surface or design of particles. Therefore fly ash is considered to be a UVCB substance.

For recovered aggregates that are substances on their own or in a mixture it will be necessary to determine the exact status of the material under REACH and to verify whether the conditions of Article 2(7)(d) apply. If the substance as such or in a mixture is not exempted from registration, late pre-registration - provided that all conditions under Article 28(6) are fulfilled - or decreasing the volume below 1 tonne/year until the substance has been registered (by any actor) are possible alternatives for potential registrants.

In determining the exact status of the recovered aggregates, the following considerations should also be taken into account:

a) *Some of these materials, such as certain slags and residues of various melting or metallurgic processes, will normally be UVCB substances. There may however also be cases where such substances are multi-constituent substances (e.g. when the substance is the result of a chemical reaction during recovery and consists of a limited number of constituents).*

b) *Some recovered aggregates may consist of materials which are exempted from registration, evaluation and downstream user obligations under other REACH provisions, in particular Annex V. Examples include minerals which are not chemically modified (e.g. natural stones) or*

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[2] Substances of Unknown or Variable Composition, Complex reaction or Biological materials, also called UVCB substances cannot be sufficiently identified by their chemical composition, because (ECHA, 2010):

- The number of constituents is relatively large and/or
- The composition is, to a significant part, unknown and/or
- The variability of the composition is relatively large or poorly predictable.

For such substances, further identifiers have to be considered such as sources of origin or type of production processes.

substances occurring in nature which are not chemically modified and do not meet the criteria for classification as dangerous (e.g. wood).

c) *In the case where recovered aggregates consist of one main constituent (possibly with impurities), they will be a mono-constituent substance. In case they consist of several constituents, those constituents may either be seen as separate substances (i.e. then the recovered aggregate will be a mixture) or as constituents of one complex UVCB substance. As outlined in section 2.2.3 [in ECHA (2010)], it is up to the manufacturer of the recovered material to decide whether the recovery operation resulted in a substance (mono-constituent, multi-constituent or UVCB) as such or in a mixture.*

In determining the registration status of the recovered aggregates, information on the origin may be important in order to establish which constituents may be present in the material and whether they should be seen as impurity or separate substance. To identify the substances, that in principle, are subject to registration and analysis of the waste material will only be necessary insofar as constituents may in normal cases occur in quantities above 20%[3] (or are intended to be present in the recovered material - however, in this case the recovery operator should know about their presence).

The manufacturers of recovered aggregates should also have information on the identity and quantities in which hazardous minor constituents or impurities are present in the recovered aggregate to the extent needed as described in the section on impurities (chapter 2.2.3 in the ECHA guidance document)."

From the above it may be concluded that each stream of waste-derived aggregates that obtains EoW status will have to be considered separately concerning obligations in relation to REACH. It appears that for example C&D waste aggregates with EoW status might be classified as articles and possibly at least partly exempted from obligations under REACH. Ferrous slags and ashes are considered UVCB substances. Although ECHA refers to "fly ash" in general terms – it should be noted that fly ash from coal combustion for example is very different from fly ash from waste incineration, both with respect to composition, leaching properties, and potential for useful application.

In 2009 Delgado et al. (2009) pointed out that ashes and slags already are listed in the European Inventory of Existing Chemical Substances (EINECS), and therefore fulfilled the phase-in substances criteria.

The obligations for waste-derived aggregates (in particular C&D waste) with EoW status under REACH have been discussed in more detail in a study funded by the Nordic Council of Ministers (Hjelmar et al., 2014).

5.2.3 The Construction Products Directive/Regulation

The Construction Products Directive (CPD, 89/106/EEC) and the Construction Products Regulation (CPR, 305/2011/EU) which replaced the CPD in 2013, have already been discussed, e.g. in section 3.8.3 and section 7.7. The CPR will become the regulatory and logistic framework of waste-derived aggregates with EoW status. Although the CPR will extend the considerations of environment and health from concerning only the service life in the CPD to the entire lifecycle, the associated product standards will still only prescribe the harmonized test methods to be used in environmental and health assessments – the actual criteria to be met by construction products will still be a matter for the individual Member States. As mentioned elsewhere, only the Netherlands and to some extent also Germany have set leaching limit values for construction products to be used for different applications. If such general criteria are to be imposed at EU level for aggregates, they will have to be incorporated as part of the development of the EoW criteria and conditions.

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[3] In cases where such constituents are regularly close to this limit, it is recommended to take a safe approach and consider the constituent as a separate substance. Where constituents exceed 20% only in rare, individual batches which cannot be realistically expected under normal conditions, those constituents do not have to be considered as separate substances. It is also not necessary to examine each individual batch of waste material for the presence of such constituents.

5.2.4 The Water Framework Directive and the Groundwater Directive

The Water Framework Directive (2000/60/EC) obliges EU Member States to improve the quality of natural water bodies, in particular groundwater. Both this general requirement and the national requirements arising from the implementation of the Water Framework Directive and its daughter directive, the Groundwater Directive (2006/118/EC) in the Member States must be taken into account when setting the primary water quality criteria as e.g. described in Step 2 in section 7.5.2.

6. Consideration of the need for and requirements of pollutant limit values for aggregates

This chapter discusses the needs and requirements for EoW criteria from an environmental protection perspective. The advantages for the industry of obtaining EoW status for certain waste-derived aggregates include e.g. the lifting of requirements related to the handling of waste such as the need to have a permit for temporary storage of waste and the need to have people on staff trained to handle waste. These and other advantages are acknowledged but not discussed any further in this context. In principle, the criteria and limit values will be general and not material-specific.

6.1 Assessment of the need for limit values to protect the environment and human health

The aggregates considered in this context are classified as waste materials and currently regulated under waste legislation as laid out in the Waste Framework Directive. As shown in chapter 5, several EU Member States have regulations on the use of recycled waste-derived aggregates for construction purposes, and several Member States have found it necessary to protect the environment and human health by requiring testing and setting limit values for the leachability and content of several substances considered dangerous or undesired in the environment as a condition for various types of beneficial use. In addition, specific limitations are often placed on the conditions of the use of waste-derived aggregates, e.g. on height, area, cover and location of the application. Some of the Member States without direct legislation on the use of waste-derived aggregates will instead require site-specific risk assessments on a case-by-case basis to permit beneficial use of waste materials.

In chapter 4 it has been shown that for several of the examples of waste-derived aggregates discussed in this study, there may be a risk that they will not even comply with the EU WAC for inert waste landfills. Some of the waste aggregates, e.g. some of the steel slags, are produced under very controlled conditions and aimed for specific uses, but many of the other waste aggregates are produced under less controlled or controllable conditions and may therefore vary considerably with respect to leachability and content of substances and other properties.

Based on substantial experience, several European Member States thus seem to have concluded that testing and associated limit values or risk assessments will be required to provide adequate environmental and human health protection in association with beneficial use of waste-derived aggregates in general. This is very much in line with the requirement in Article 6 (1) of the Waste Framework Directive that the use of aggregates with EoW status must not lead to overall adverse environmental or human health impacts, and that the criteria shall include limit values where necessary and shall take into account any possible adverse environmental effects (see section 1.1).

Limit values are further required to ensure that future European EoW criteria do not conflict with other European and national environmental policy and legislation. There must be a high degree of certainty that waste-derived products that are traded and used for construction purposes or stored or otherwise placed or spread in the landscape do not give rise to an unanticipated increase in the local or general pollution level. The Water Framework Directive (2000/60/EC) and its daughter directive, the Groundwater Directive (2006/118/EC) set rather strict limits on the allowable impact on water bodies in the Member States and directly forbid the discharge of certain substances.

The establishment of limit values (as opposed to a one-time risk assessment of a particular type of waste-derived aggregate, albeit comprehensive) has the advantage that it will be possible at any time to check if a given waste stream with EoW status still is in compliance with e.g. leaching criteria, and it allows for the establishment of routine testing at factory control level. It should be noted that such routine testing of functional requirements is also required for (non-waste) aggregate products under the product standards.

As it has been pointed out e.g. in section 3.1, the total content of a substance in aggregates cannot be used as an indicator of the leachability or release of that substance, and since groundwater and surface water protection against released substances has high priority, leaching tests are required.

Based on the above, it does seem appropriate and necessary to establish limit values for leaching of substances of environmental concern and limit values for the content of substances of human health concern as part of EoW criteria for waste-derived aggregates.

6.2 The purpose and function of EoW limit values

The primary purpose of EoW limit values on the leaching and content of substances are, of course, to ensure that the materials that are tested and comply with the limit values cannot cause “any overall adverse impacts” to the environment or human health when used in accordance with the conditions associated with the EoW status gained. The assessment of the acceptability and the quantification of “overall adverse impacts” on the environment have already been carried out and are expressed in EU and national legislation in terms of surface water and groundwater (and soil) quality criteria for a number of relevant substances (see the discussion on primary quality criteria in section 2.2.5). The remaining work consists of establishing a rational, scenario- and risk-based relationship between the primary water quality criteria (WQC) at the receptor and the results of a leaching test performed on the aggregate in question. This relationship must ensure that when the aggregate complies with the limit values for EoW, then the impact from any application possible under the EoW criteria will not cause the water quality at the point of compliance (POC) at the receptor to exceed the primary WQC for any substance considered. The relationship between the leaching limit values and the primary WQC must be established in such a way that compliance with the limit values actually does ensure compliance with the WQC. In principle, the most restrictive primary WQC in any EU Member State should be applied when setting limit values, since the EoW status of a waste-derived aggregate will be European-wide, or – alternatively - the conditions of use associated with the EoW status must ensure the appropriate protection of all European water bodies. However, if free trade of waste-derived aggregates across borders is not considered important, then the primary WQC and hence the leaching limit values could alternatively be determined on a national basis (within certain limits) and thus be adjusted to national needs for protection of groundwater and surface water. Waste-derived aggregates with EoW status could then be declared as classes in the product standards under CPR in accordance with the compliance with national criteria.

As already pointed out in section 2.2.5, the primary WQC as such are independent of the nature of the potential source of pollution, including the type of waste-derived aggregate in question. The primary WQC should represent the substances against which it is considered necessary to protect the groundwater, soil and surface water, and in principle, the general list of substances for which leaching limit values are to be defined should match the list of primary WQC. Following the initial type assessment (ITA, see section 3.8.3), a (shorter) material-specific list may be drawn up for routine testing. For ITA and the dossier (see section 3.8.3 and Annex 3), a fairly broad range of substances corresponding at least to the primary WQC should, however, be included. If there is knowledge or suspicion of the presence of potentially harmful substances not included in the WQC, then the producer should be obliged to include such substances in the testing programme and the dossier (precautionary principle).

It is important to realise that a leaching limit value is closely associated with the test method to which it refers (see for example section 3.4). This is e.g. why the leaching limit values for landfilling of waste in Council Decision 2003/33/EC expressing the same risk or degree of protection of the environment are different, depending on whether they are measured at L/S = 0.1 l/kg, 2 l/kg or 10 l/kg. A leaching limit value is meaningless without reference to a specific leaching test (or specific test conditions).

Even though the EU inert waste landfill WAC were used in chapter 4 to obtain a first impression of the likelihood that some of the waste aggregates considered would be potential candidates for EoW status, and even though some EU Member States have proposed the use of these WAC as EoW criteria, it is strongly recommended **not** to adopt the EU inert landfill WAC directly as leaching limit values for EoW. It is, however, equally strongly recommended to adopt the **principles** of the methodology used in developing the EU inert landfill WAC, but the scenario(s) to be applied shall be adjusted to the EoW situation and will hence be different from the landfill scenario, and the list of substances considered should in all likelihood be increased (there are international or national WQC for several substances not included in the EU landfill WAC which were established 10 years ago). The Water Framework Directive also requires development of WQC for some substances which are not covered by the EU landfill WAC, such as e.g. ammonia.

For limit values on total content (particularly of organic substances), the relationship with the "primary criteria", set by EU or national legislation e.g. on soil quality, is much simpler, since the limit value for a substance simply is the primary criterion for the substance. The limit values to be adopted should reflect the conditions of use associated with the EoW status of aggregates, e.g. free use or restricted exposure.

6.3 Basic principles of a methodology

A number of basic principles upon which the selection of a methodology for establishing (leaching) limit values for pollutants as part of EoW criteria for waste-derived aggregates should be based in order to ensure that they fulfil the needs listed in section 6.1 and the requirements listed in section 6.2 are proposed in the following:

- The methodology should be risk-based, and follow the source-pathway-receptor chain as described in section 2.2.2.
- The main principles of the methodology should be scientifically based and the process of development of leaching limit values should be transparent. Stakeholders can discuss and provide input to the selection of in-use scenarios, but decisions on environmental protection criteria, including the type and location of the POC, should be taken by regulators in cooperation with environmental experts. The necessary impact modelling that is required for this purpose should be carried out by experts who can understand, interpret and explain the implications of chosen boundary conditions and parameters. The transparency of both this process and the derived limit values is mandatory to obtain acceptance among regulators and stakeholders.
- The methodology should be generally recognised and preferably applied previously for development of leaching limit values both at EU and Member State level.
- The methodology is independent of the type of aggregate it is applied to, and it is valid also for the setting of criteria under waste regulation (or for by-products, for that matter).
- The primary WQC imposed at the point of compliance (POC) are independent of the source and pathway scenarios and also applicable to the setting of criteria for beneficial use under waste regulation.
- The test methods required should be the same as required for any evaluation of the aggregate under waste legislation (beneficial use, landfilling) to avoid the risk of double testing.
- The primary WQC should reflect EU and national Member State requirements on water quality in terms of substances to be regulated and thresholds to be complied with. They should also be consistent with the requirements of the Water Framework Directive and the Groundwater Directive (or other relevant directives).
- If no restrictions or conditions are placed upon the use of a waste-derived aggregate with EoW status, both the source and pathway have to be chosen very conservatively, i.e. they must describe worst case scenarios, because the aggregate can be traded and used freely and may end up anywhere in the environment (see sections 2.2.3 and 2.2.4).
- Aggregates used in bound applications shall be tested under granular conditions (i.e. after crushing), because the release of substances during the intended service life of bound aggregates is not critical in relation to EoW. The critical impacts may occur when the material (unintentionally) crumbles or otherwise disintegrates. This requirement will also prevent the use of materials which may constitute a major management problem at the end of the service life. Aggregates used in

bound applications should be tested as part of the bound product, after appropriate maturing/ageing and subsequent crushing.

- If it is possible to place restrictions or conditions on the use of a waste-derived aggregate with EoW status and require that the material is removed and managed at the end of its service life, these restrictions/conditions can be taken into account in the development of the limit values, and it may be possible to choose source and pathway scenarios that are less conservative and lead to less stringent EoW limit values. Examples of such conditions could be minimum distance to groundwater and surface water bodies, maximum thickness of application, maximum allowed rate of infiltration through top cover, obligation to remove aggregates at the end of the service life, etc.

7. Proposal of a methodology for development of limit values for leaching

In this chapter the elements of a proposed methodology for development of leaching limit values for EoW for waste-derived aggregates are described. The methodology is based on the discussion in sections 6.1 and 6.2 and applies the principles listed in section 6.3. To ensure a useful result and keep some options open, the methodology addresses both unconditional/free use of waste-derived aggregates with EoW status and the situation where certain conditions are placed upon the use of such aggregates. As an example, a full calculation of leaching limit values for selected substances has been carried out for the case of use of aggregates with EoW status without any restrictions. The methodology for calculation of leaching limit values in the case where restrictions are imposed on the use of aggregates with EoW status is described and discussed.

7.1 A transparent and traceable process

The main principles of the proposed source-pathway-receptor chain approach are scientifically based and the principles of the methodology have been acknowledged and applied in EU legislation (Council Decision 2003/33/EC on criteria and procedures for acceptance of waste at landfills and the implementation of ER3 in the Construction Products Directive, 89/106/EEC) and in legislation at Member State level (e.g. the Dutch Soil Quality Decree, see Annex 7) and the Danish Statutory Order on reuse of residual waste and soil in building and construction works (see Annex 5). The source-pathway-receptor principle has also been applied in the new waste (and product) utilisation regulation in Germany and partly in the waste utilisation guidance in France. The national EoW criteria for certain aggregates in the UK are also based on risk assessments using the source-pathway-receptor chain for the in-use phase of the materials.

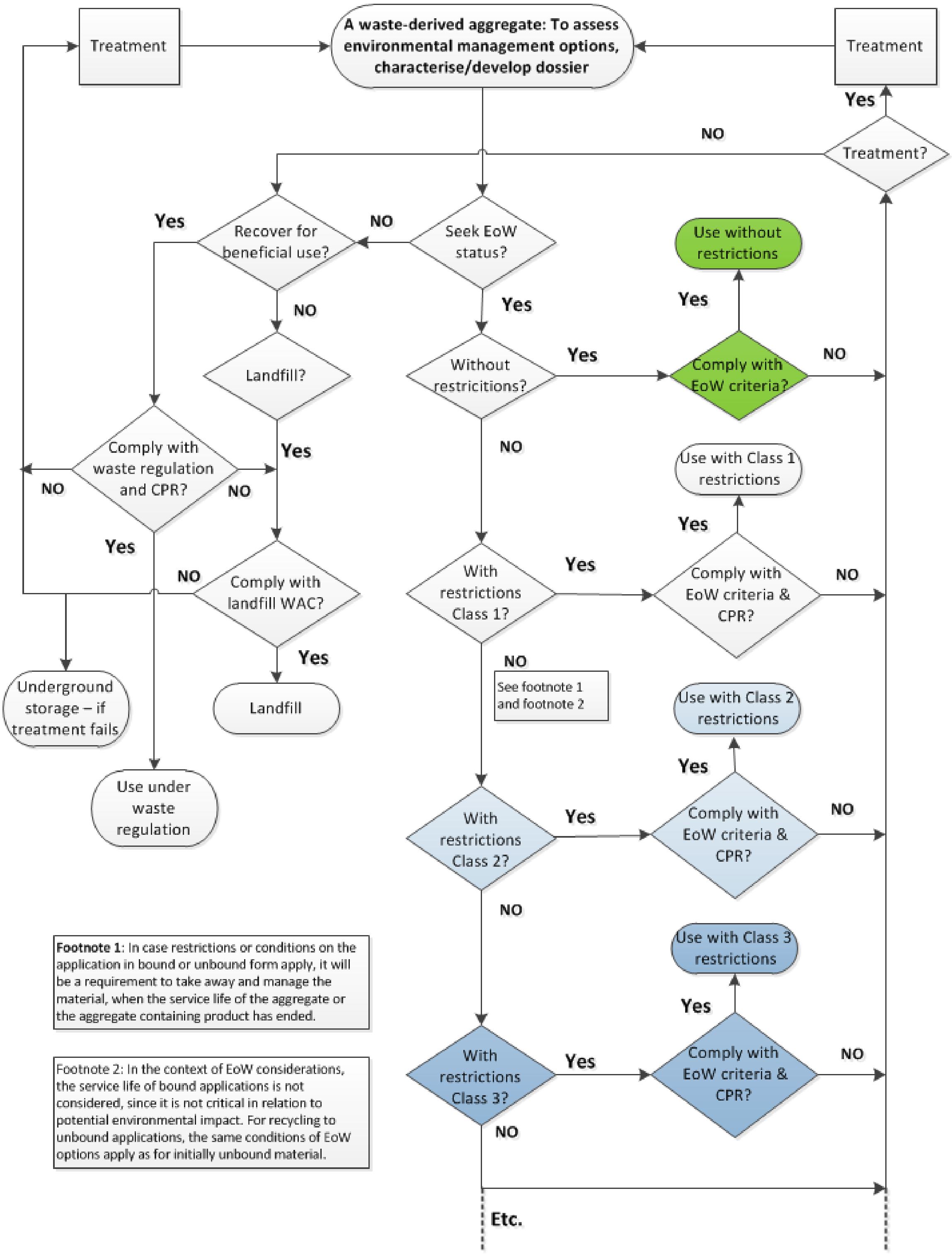
If and when it is decided to actually apply the methodology and develop European EoW criteria for waste-derived aggregates, it is important to keep the process transparent and traceable. To achieve this, frequent stakeholder consultation should be performed and all important decisions (and the detailed justification of the decisions) should be documented and published. As discussed in section 6.3, it is important to distinguish between different types of stakeholders and their particular role and responsibility. While the EoW criteria are meant to benefit the industry, it should not be forgotten that the purpose of developing leaching limit value values and the associated framework is to protect against “adverse environmental or human health impacts”. The use of cautious, but realistic conditions and considerations can ensure that this goal is achieved without placing excessive requirements on the producers of waste-derived aggregates to be tested for EoW quality.

As a minimum, the following types of stakeholders should be involved in the process:

- Legislators/regulators (Commission, Member States)
- Experts on leaching, modelling, environmental impact and risk assessment, criteria-development
- Representatives of CEN/TC 351, CEN/TC 154, CEN/TC 227 and CEN/TC 292
- Producers and manufacturers of waste-derived aggregates
- Users of aggregates

7.2 Overview of choices and steps in the EoW assessment procedure based on leaching limit values

Figure 7.1 shows an overview of the assessment framework in which the proposed methodology will result. The figure also illustrates the fact that the same testing and characterisation results that are obtained up front and used for EoW assessment of a waste-derived aggregate can also be used to assess the management options under waste legislation if the results do not comply with the EoW limit values. It is noted that the methodology provides a choice between unrestricted use and restricted use of waste-derived aggregates with EoW status. In addition, the figure shows the close relationship between EoW legislation and CPR.



Footnote 1: In case restrictions or conditions on the application in bound or unbound form apply, it will be a requirement to take away and manage the material, when the service life of the aggregate or the aggregate containing product has ended.

Footnote 2: In the context of EoW considerations, the service life of bound applications is not considered, since it is not critical in relation to potential environmental impact. For recycling to unbound applications, the same conditions of EoW options apply as for initially unbound material.

Figure 7.1

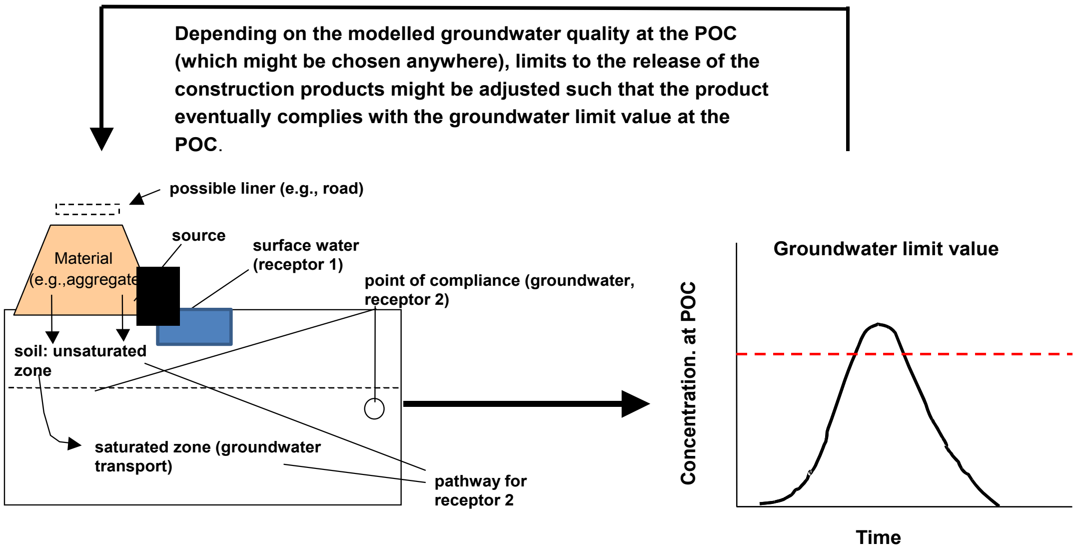
Overview of the management and application options for waste-derived aggregates under EoW and waste legislation (use for construction purposes, landfilling) within the proposed methodology. The same test and characterisation results should be used for evaluation in relation to all the different *management options. The different classes of restrictions under EoW correspond to different use conditions and different EoW criteria.*

7.3 Conditions/no conditions imposed on the use

If no restrictions or conditions are placed on the use of waste-derived aggregates with EoW status, then the **source** term must account for the "worst case" release that may potentially take place. This would include testing of size reduced material both under initial conditions (first porewater composition) and under long term exposure conditions to determine the potential maximum release of substances. If, on the other hand, some restrictions and control were placed on the application of aggregates with EoW status, the scenario conditions used to assess the leaching results could possibly be less severe without compromising the safety of the environment and human health.

The description of the **pathway** and the modelling of the transport of the substances released from the source to the receptor also depend on the conditions under which the aggregates may or can be used when they become products. If no restrictions or conditions are imposed on the use of aggregate products with EoW status, the potentially critical pathway can be very short or non-existent, i.e. the aggregate may be placed in direct contact with the **receptor**, which, e.g., can be groundwater or surface water. In that case, the release of substances from the source may have to directly fulfil the primary criteria at the receptor, i.e. the initial porewater in the aggregate would then directly have to meet, e.g., groundwater quality criteria. Again, if some restrictions and controls are placed on the conditions under which waste-derived aggregates with EoW status can be applied, it may be safe to consider taking into account the dilution and/or retardation of substances along the pathway, which could result in less stringent criteria. If, for example, direct contact with the receptor is prevented by such conditions on the use, the attenuating effect of the pathway may be taken into account, as was done in the methodologies used in the setting of LFD WAC for inert waste and in the setting of the criteria in the Dutch SQD.

Thus, two approaches may be appropriate: One approach representing free, unrestricted use of aggregate with EoW status and hence based on the most critical source and pathway conditions, and a second approach representing the situation where some restrictions are placed on the use of the aggregates, allowing less severe source and pathway conditions. The two situations are illustrated in Figure 7.2 and each of the possibilities is discussed in the following sections.



Depending on the modelled groundwater quality at the POC (which might be chosen anywhere), limits to the release of the construction products might be adjusted such that the product eventually complies with the groundwater limit value at the POC.

Figure 7.2
Illustration of the two situations for development of regulatory criteria – direct contact between the source and the receptor (receptor 1) and a situation where the mitigating effect of the pathway can be taken into account because of regulatory conditions/controls on the use of the aggregate (receptor 2).

The latter situation corresponds to the principles applied in the setting of the LFD WAC and the leaching criteria in the Dutch SQD: forward modelling and reverse adjustment of acceptance values based on quality criteria at the point of compliance (POC).

7.4 EoW criteria without restrictions or conditions on the use

7.4.1 The source term

If it is not possible to place any restrictions on the uses of waste-derived aggregates which have obtained EoW status, the environmental and health criteria to be fulfilled must take this into account, i.e. must be based on relatively conservative (if not worst case) application scenarios. Delgado et al. (2009) mainly refer to the service life and intended use applications of the EoW products in their considerations, and the same is true for the EoW scenarios upon which the UK system is based (see chapter 5). However, in order to take "any (potential) adverse environmental effects" into account, the entire life cycle of the product, including the End-of-Life (EoL) situation, should be taken into consideration. This approach will probably differ most from the in-use situation for aggregates used in bound applications. The release of substances from bound materials during the service life, when they are fully or nearly intact, will probably be small (and hence not restrictive with respect to potential environmental impact) compared to the potential release of substances when the products disintegrate/crumble sometime in the future. When that happens, the products may be anywhere in the environment if the use is uncontrolled and unrestricted. This means that the critical release of substances from bound use of waste-derived aggregates to be compared to appropriate limit values should be determined on size reduced material under conditions that represent an initial release and a long term exposure scenario.

In many cases the concentrations of the substances of interest that occur in the porewater in an application with a granular or size reduced aggregate will represent the highest and hence the critical values to be used in the source term as described in section 2.2.3. Since there are no restrictions, it should be assumed that the application (or heap) could be relatively high (5 to 10 m or more) and that the rate of infiltration of precipitation into the application (or heap) and hence the rate of production of leachate could be substantial (e.g. 300 to 350 mm/year or more). As mentioned, for most substances the highest concentrations are seen in the initial porewater (i.e. at low L/S), but some substances, particularly those that are solubility controlled, may show increasing concentrations when the L/S ratio increases over a certain range, e.g. due to removal of other substances or due to changes (decreases) in pH as a result of carbonation. Many relevant waste-derived aggregates will have a relatively high starting pH (typically 10 – 12.5) that may be reduced over time to more neutral values by natural carbonation), see chapter 4 and Separate Appendix Part 1. The testing should reflect the effects of the possible change of pH over time.

7.4.2 The pathway

In this case of unrestricted use the pathway is simple: Due to the lack of restrictions, it is necessary to assume that the material can be placed in direct contact with the receptor, which can be groundwater or surface water, so there is no pathway along which attenuation of released substances can take place. The source is discharged directly into the receptor. Calculations during development of the limit values for the Dutch SQD have shown that, for the Dutch WQC, the groundwater pathway is generally more restrictive than the surface water pathway, when dilution in a (water body specific) mixing zone is considered (Verschoor et al., 2006).

7.4.3 The receptor

The receptor will be groundwater or surface water. It is proposed to use either national values or European values as the primary water quality criteria (WQC). In this calculation example, the lowest values found in the first four columns of Table 2.2, i.e. drinking water and groundwater criteria as well as Danish surface water quality criteria (fresh water), have been chosen to take into account the worst possible situation. The calculations in section 7.10.4 are fairly simple, so other water quality criteria can easily be substituted and used instead. It is the responsibility of the appropriate environmental authorities to determine the primary water quality criteria, taking into account existing legislation at EU and national level. For the sake of this example, the limit values have been calculated only for the primary WQC corresponding to the substances for which the EU WAC for inert waste landfills were set. If and when EoW criteria for aggregates are developed, it will be necessary to consider a broader range of substances for which primary WQC should be selected and limit values calculated, not the least based on requirements of the Water Framework Directive and its implementation.

7.4.4 Calculation of leaching criteria

The "translation" of leaching criteria from one L/S value to another has been explained in section 3.4. The starting point is that the concentration of the substances in the porewater in the aggregate application should not exceed the chosen primary water quality criteria. If this concentration is C, it is equivalent to a leached amount of E = C x 0.2 mg/kg at L/S = 0.2 l/kg, which is the estimated L/S value corresponding to the pore water condition, i.e., the pore volume for a material with a dry bulk density of 2 kg/l and a porosity of 40 % (see Annex 1). Using equation (3.5) in section 3.5 and the kappa values shown in Table 7.1, the leached amounts of the substances at L/S = 2 l/kg and L/S = 10 l/kg corresponding to the values determined for L/S = 0.2 l/kg are calculated. The limit values can be compared to results of the percolation leaching test CEN/TS 14405 (accumulated leached amounts) at the corresponding L/S = 0.2 l/kg, L/S = 2 l/kg and L/S = 10 l/kg. They can also be compared to the results of the batch leaching tests EN 12457-1 (L/S = 2 l/kg), EN 12457-2 (L/S = 10 l/kg) and EN 12457-3 (L/S = 2 and 10 l/kg). And at L/S = 10 l/kg they can be compared to the results of the pH dependence tests CEN/TS 14997 and CEN/TS 14429 at L/S = 10 l/kg carried out at relevant pH values. The leaching tests are described in section 3.7.2. Compliance with the limit values at the higher L/S ratios of 2 and 10 l/kg ensures that the WQC will also be met at the End-of-Life/crumbled/carbonated state of the aggregates as discussed above. The water quality criteria and the kappa values used are shown in Table 7.1 together with the calculated limit values at the three values of L/S. The table also shows the EU acceptance criteria for landfills for inert waste for comparison.

Table 7.1

The calculated leaching limit values at L/S = 0.2 l/kg, 2 l/kg and 10 l/kg for EoW for aggregates without restrictions and control of the use. The table also shows the water quality criteria and kappa values used in the calculation of the limit values. The EU WAC at L /S = 10 l/kg for inert waste landfills are shown for comparison. Phenol = phenol index.

Substance	**WQC**	**Kappa**	**Calculated limit values**			**EU Inert landfill WAC**
			L/S = 0.2 kg/l	L/S = 2 l/kg	L/S = 10 l/kg	L/S = 10 l/kg
	mg/l	kg/l	mg/kg	mg/kg	mg/kg	mg/kg
Chloride	150	0.57	30	190	280	800
Fluoride	1.5	0.22	0.3	2.5	6.2	10
Sulphate	250	0.33	50	380	750	1000
As	0.0043	0.03	0.00086	0.0084	0.037	0.5
Ba	0.0093	0.15	0.0019	0.016	0.049	20
Cd	0.00008	0.5	0.000016	0.00011	0.00017	0.04
Cr	0.02	0.18	0.004	0.034	0.094	0.5
Cu	0.012	0.28	0.0024	0.019	0.041	2
Hg	0.001	0.05	0.0002	0.0019	0.0079	0.01
Mo	0.02	0.35	0.004	0.030	0.057	0.5
Ni	0.003	0.29	0.00060	0.0047	0.010	0.4
Pb	0.00034	0.27	0.000068	0.00054	0.0012	0.5
Sb	0.002	0.11	0.0004	0.0036	0.012	0.06
Se	0.01	0.38	0.002	0.015	0.027	0.1
Zn	0.0031	0.28	0.00062	0.0049	0.011	4
DOC	3	0.17	0.6	5.2	15	500
Phenol	0.1	0.3	0.02	0.15	0.33	1

The WQC are the lowest values from the first four columns in Table 2.2
The kappa values used are those used in the calculation of the EU WAC for landfilling of inert waste
The EU Inert landfill WAC are those listed in EU Council Directive 2003/33/EC

It is evident from Table 7.1 that the calculated leaching limit values for EoW without restrictions or conditions are very stringent and they will most likely be extremely difficult to comply with for most waste-derived aggregates. The resulting limit values at L/S = 10 l/kg are up to 400 times lower than the EU WAC for inert waste landfills for some substances.

7.5 EoW criteria with restrictions or conditions on the use

7.5.1 Conditions that can modify EoW limit values

Some of the conditions that could be imposed on the use of a given waste-derived aggregate with EoW status are listed in Table 7.2 which also indicates which parts of the source-pathway-receptor chain will be affected (in terms of modelling conditions) by the measures taken.

The two most basic requirements that will set the scene for the proposed methodology for development of leaching limit values as part of EoW criteria are:

1) The aggregate can only be used for specified purposes, and

2) The aggregate must be taken back by the user/owner at the end of its service life.

The first of these requirements is already implied in indent a) in Article 6 (1) of the WFD, but it should be further specified and refer to one or more specific scenario type(s), e.g. use as sub-base in a road or a filling material in an embankment. This requirement could then lead to more than one set of limit values (corresponding to different application purposes) or, if that is considered impractical, to the adoption of the most restrictive of these for all the relevant purposes.

The second requirement, which is for example already part of the Dutch Soil Quality Decree (SQD), will, together with the first requirement, ensure that the risk assessment only has to be performed for specific, relevant in-use scenarios (as opposed to the very conservative scenario applied in the case of free or unrestricted use), albeit always assuming that the material is granular. However, this requirement would still need consideration of aggregate alterations (e.g. carbonation) that may enhance the leaching of substances during the service life. The practical implementation of this requirement will probably require some careful consideration of measures to ensure that the responsibility remains with someone, if ownership and other conditions change in the course of a long service life.

In the following discussion and presentation of a methodology for development of limit values it is assumed that these two basic requirements are mandatory.

One, several or all of the following requirements (3 to 7 in Table 7.2) are in principle optional and can be chosen to protect the environment and allow for conditions that will lead to less stringent leaching limit values. Specifications of conditions 1 and 3 to 7 will, under all circumstances, be required as input to the impact modelling. A limited set of different levels of limit values could be created by assembling various combinations of requirements that would lead to increasingly stricter limit values corresponding to the levels or classes (Class 1, Class 2, ...etc.) shown in Figure 7.1. Such combinations should correspond to relevant in-use (and lifecycle) scenarios based on the use conditions described in the product standards.

Requirement no. 3, that there must be a minimum distance from the application to the surface of the groundwater will provide protection of the groundwater while allowing the risk-based methodology for assessment of the leaching limit values to take into account the attenuation of released substances in the unsaturated zone. Compared to a situation without such a minimum distance, this will result in higher limit values for most substances.

Requirement no. 4, that there must be a minimum distance from the application to a surface water body (providing the surface water body is the receptor), will protect the surface water body from released substances from the aggregate application while allowing for attenuation in the aquifer, i.e. the pathway between the groundwater directly below the application and a downstream surface water body. All other conditions equal, the resulting leaching limit values will increase with increasing length of pathway, i.e. increasing distance to a surface water receptor.

Table 7.2
Overview of conditions that may be imposed on the use of waste-derived aggregates as part of End-of-Waste criteria. In the proposed methodology conditions 1 and 2 may be mandatory, whereas the conditions 3 to 7 are optional (recommended, but variable). A general ranking of the conditions is not useful since the relevance and effect of the different conditions will vary from on scenario to another.

No	Imposed condition	Source	Pathway	Receptor
1	The material can only be used for specified purposes	Can be influenced	Can be influenced	May determine which receptors are relevant
2	Take back the material after service life	Reduction in the time span to be considered	Not affected	Not affected
3	Minimum distance to groundwater level	Not affected	Attenuation in the unsaturated zone may be taken into account	Depends on POC
4	Minimum distance to surface water	Not affected	Attenuation in the unsaturated zone and the aquifer may be taken into account	Depends on POC
5	Restrictions on height of application	May reduce source term	Not affected	Not affected
6	Restrictions on the length and width of the application	May reduce the source term	Not affected	Not affected
7	Restrictions on allowed rate of infiltration	Reduction of the flux (the load per time unit)	Not affected	Not affected

Requirement no 5, restrictions on the height of the application, will generally modify the source term in the sense that it will decrease faster as a function of time with decreasing application height. In general, a faster decrease in source strength may lead to higher (i.e. less restrictive) leaching limit values.

Requirement no. 6, restrictions on the length and width of the application, will in situations of horizontal flow towards a downstream POC generally limit the source term in a similar manner as for requirement 5 (i.e. faster decline as a function of time) and may hence allow for less restrictive limit values. The length of the application in the direction of the groundwater flow has the strongest influence on the impact at a point of compliance (POC) and the limit values.

Requirement no. 7, restrictions on the allowed rate of infiltration, has a strong influence on the source strength and, consequently, on the resulting leaching limit values. Such restrictions can occur naturally from the nature of the applied material (low permeability or monolithic character), and they can be imposed in terms of a required top cover with a specified maximum permeability or quality (e.g. only use under asphalt cover of a certain quality).

It is important to note that, particularly for requirements 5-7, the magnitude of the potential increase of limit values for specific substances, relative to those for unrestricted use, depends strongly on (regulatory) choices with regard to the location of the POC, the (water) quality criteria, and the time frame considered.

Some of the conditions of use listed in Table 7.2 may possibly be derived and specified from the appropriate harmonized product standards for aggregates.

7.5.2 Stepwise modelling approach

Overview

This section describes a generic stepwise (iterative) modelling approach that can be used to develop leaching limit values for EoW for waste-derived aggregates. The approach is in agreement with the principles described in EN 12920: "Characterisation of waste – Methodology for the determination of the leaching behaviour of waste under specified conditions", and it is also applicable to the setting of criteria for utilisation of the materials under waste legislation. It is based on the same fundamental principles that have been applied in the setting of the EU leaching criteria for acceptance of waste at inert waste landfills (see Annex 4) and in the development of leaching criteria for application of virgin and waste materials under the Dutch Soil Quality Decree (see Annex 5). The steps are:

Step 1: Description of the application type and the imposed conditions

Step 2: Description of the relevant receptor(s) and the primary water quality criteria

Step 3: Description and modelling of the source term

Step 4: Description and modelling of the migration of substances from the source to the point of compliance (pathway)

Step 5: Assessment of the impact at the receptor and reverse modelling or iteration to adjust the source term

Step 6: Transformation of source term criteria to specific limit values

Step 7: Assessment of the resulting limit values and possible repetition of the stepwise procedure

Step 8: Taking other considerations into account to possibly modify the limit values calculated in steps 1 to 7 (particularly if the limit values are relatively high)

The procedure should be performed by experts and be subject to involvement of and discussion with stakeholders as described in section 7.1.

Step 1: Description of the application type and the imposed conditions

The first step should be to determine which types of applications and conditions will be relevant (requirement 1, Table 7.2). This should be done with reference to the aggregate product standards and in close co-operation with application experts from CEN/TC 154 and CEN/TC 227. Realistic specifications and ranges of conditions 5, 6, 7 (Table 7.2) should be generated, also in co-operation with application experts from CEN/TC 154 and CEN/TC 227. Ranges for conditions 3 and 4 in Table 7.2 should be determined in close co-operation with legislators and regulators. The step should result in a limited number of specified application scenarios and ranges of conditions to be used for the source modelling in step 3. If the result of the assessment in step 7 is that the calculated limit values are too low, then the imposed conditions chosen for the scenarios in question could be reconsidered and changed, and the stepwise procedure repeated.

Step 2: Description of the relevant receptor(s) and the primary water quality criteria

In this step, the WQC to be complied with at the point(s) of compliance in groundwater and surface water should be determined. If the EoW criteria are to be generally applicable within the EU, then the WQC should be agreed on by all Member States, and in principle they should represent the lowest criteria found in any Member State. When selecting the WQC for these purposes, due consideration must also be taken to the implementation of the Water Framework Directive and the Groundwater

Directive. It is proposed to produce a long-list of substances for which primary WQC should be determined, based on input from all Member States. When individual materials are to be tested for comparison to the EoW limit values, the programme may be reduced to a short-list of substances relevant for that material, based e.g. on the dossier to be prepared. A further important criterion in this step is the time frame to be considered for the assessment of the potential impact at the POC.

If, as a first attempt and an example, a minimum distance to the groundwater of e.g. 1 m, and a minimum distance to surface water bodies of e.g. 30 m are chosen, then a POC (groundwater QC) in the groundwater at the interphase between the unsaturated and saturated zone could be considered as well as a POC (surface water QC) in the groundwater at the interphase between the groundwater and the surface water. The POC leading to the lowest limit values (after step 6) should then be adopted for that particular scenario.

Step 3: Description and modelling of the source term
Each of the application scenarios chosen in step 1 must be described in detail in terms of height, width, length, hydraulic conductivity, dry bulk density, porosity, and net rate of infiltration through the top cover. A water balance should be set up for the application. Based on equation (3.2) a relationship between the average L/S for the application and time can be established. Since the source will change with time and progression of the leaching processes and the result will be used as input to models describing the transport of the substances through the unsaturated zone and the aquifer, it is useful to express the source analytically as function of time and/or L/S. For the sake of simplicity it is assumed that the release of each substance to be considered can be described as an exponentially decreasing function of time or L/S (although this is not entirely true for all substances). The source term can then be described by equation (3.3) where C_0 is the initial peak concentration of the substance occurring at the bottom of the application or in a percolation test performed on one of the materials to be considered. For each substance a kappa value, which describes the rate of decrease of the concentration in the eluate as a function of L/S, is required. Again for the sake of simplicity, it is assumed that the kappa values are independent of the waste material (and again, this may not be entirely true). Currently, kappa values are available for As, Ba, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se, Sn, V, Zn, cyanide, bromide, chloride, fluoride and sulphate (see Annex 7). Most likely, the long-list of substances with WQC will include substances for which no kappa values yet exists. Such kappa values will then have to be derived from percolation tests on relevant materials. The resulting source term describes the flux (e.g. in mass per unit time) as a function of time of each of the substances of interest released into the unsaturated zone below the application. Since condition 2 in Table 7.2 is mandatory, the material in the application will be removed at the end of the service lift of the aggregate, and flux becomes zero at this point in time.

Step 4: Description and modelling of the pathway
The next step will be to describe and model the transport of the substances along the pathway to the receptor(s) and the point(s) of compliance, first through the unsaturated zone to the surface of the groundwater below the application, and then (if required) through the aquifer to a point of compliance at some distance downstream of the application. For this purpose it is necessary to develop hydrogeological and geochemical scenario description including information on the thickness and hydraulic conductivity of the unsaturated zone, the retention properties of the unsaturated zone (i.e. a measure of the interaction between the substances in the leachate and the soil) and the general rate of (rainwater) infiltration for the area. Additional hydrogeological information in varying degrees of detail will be required, depending on the model chosen. The background concentration of the substances considered in the groundwater should also be determined. The scenario conditions should be selected in such a way that they represent the chosen scenario as realistically as possible. Once the transport models have been selected and run, it is recommended to test the sensitivity of the results towards changes in the various conditions.

The above boundary conditions should be incorporated into appropriately chosen (numeric) transport models. It is often most convenient to use a set-up which combines the unsaturated and saturated zone transport in a single model. It is recommended to use a 3 D model. Most state-of-the-art models are based on the same fundamental groundwater transport equations and may be expected to give the same results for the same input. The models may, however, differ in the way they handle substance transport and account for soil/leachate interaction processes that occur in the unsaturated zone and the aquifer, and the input requirements may differ accordingly. The model(s) chosen should as a minimum be able to incorporate the effect of sorption/ion exchange e.g. either by use of a simple linear partitioning coefficient (Kd), (non-linear) transfer functions (see e.g. Groenenberg et al. (2010)) or by applying geochemical modelling. Even though the source is interrupted at the end of the service life of the application, the transport modelling should continue until the impact at the POCs has peaked.

Step 5: Assessment of the impact at the receptor and reverse modelling/iteration
The result of the pathway modelling is a description of the concentration of each of the substances as a function of time at the POC(s). Due to the dispersion and attenuation effects and the decreasing nature of the source those concentrations will increase with time, show a peak, and then decrease. The peak thus represents the maximum impact on the receptor (the groundwater at the POC below the application or the groundwater at the POC downstream of the application) that will occur over time. Depending on the substance, the thickness and character of the unsaturated zone and the aquifer, the groundwater flow velocity and the distance to the POC(s), the time until the peak occurs may vary between a few years and several thousand years. It could be a matter of debate whether or not an environmental impact that is predicted to occur after several thousand years is meaningful and should be taken into account (given model uncertainties, particularly over such long time frames). Alternatively, a time limit of e.g. 500 or 1000 years could be introduced. If the transport modelling is interrupted after this period, some of the substances may never be observed to reach the peak value. The highest concentration – corresponding to a point on the increasing slope of the concentration vs. time curve at the POC – would be the endpoint where the calculation was stopped. This would lead to leaching limit values for these substances that are higher than they would have been if the modelling had been continued until the peak occurred. For very immobile substances that do not show any significant increase at the POC within the selected time frame, alternative criteria may be based on compliance with soil quality criteria, averaged over a certain soil volume along the pathway (e.g., CV_{soil} as applied in the Dutch SQD and outlined in Annex 7).

When calculating the resulting concentration at the POCs in the groundwater, a decision has to be made of whether to assume total vertical mixing of the plume (averaging the concentration over the entire depth of the aquifer) or whether to use for example the average concentration level over part of aquifer depth.

If a linear Kd relationship has been used to describe the retention of substances in the model, then the relationship between the initial peak concentration at the bottom of the application, C_0, and the peak concentration at the POC in the aquifer, C_P, is also linear for a given substance and application. The ratio between the two, $C_P/C_0 = f_a$, is called the attenuation factor for that particular scenario and substance. If a water quality requirement, WQC, is then imposed on the groundwater at the POC (C_P), this means the corresponding requirement on the source term, C_0, can be calculated as follows:

$$C_0 = (1/f_a) \times (C_P - C_{BG}) + C_{BG} \qquad (7.1)$$

where C_{BG} is the background concentration of the substance in the groundwater upstream of the application.

If geochemical modelling is used to describe the retention of substances along the pathway from the source to the POC (or if a non-linear relationship between the substances in the solid and the aqueous phase is used to describe the retention), then the relationship between C_0 and C_P will be non-linear, and the value of C_0 corresponding to C_P = WQC will have to be found by iterative modelling.

A linear Kd description of the retention was used in the development of the leaching WAC for inert waste landfills (see Annex 4), whereas geochemical modelling was applied in the development of the leaching limit values associated with the Dutch SQD (see Annex 7).

Step 6: Transformation of source term criteria to specific limit values
Once the value of C_0 corresponding to the WQC for a given application scenario and substance has been established – and still assuming that the release of the substance can be described as an exponentially decreasing concentration as a function of time - the result can be expressed in terms of

a limit value, release E_{LV} (mg/kg), for a percolation or batch leaching test performed at a specified (accumulated) L/S value:

$$E_{LV} = (C_0/\kappa) \times (1 - e^{-(L/S)\kappa}) \qquad (7.2)$$

This allows the limit value to be adjusted to the preferred test method or test conditions in terms of L/S (usually 2 l/kg or 10 l/kg or both).

Step 7: Assessment of the results and possible repetition

When the limit values for the entire suite of substances have been established, the compliance of various relevant waste-derived aggregates with these values can be assessed based on existing information (e.g. as included in this report) or based on the performance of new tests. If it is felt that the limit values are too restrictive (too low), the step-wise procedure can be repeated, starting by applying more stringent conditions in step 1. As a rule of thumb, a thicker unsaturated zone, a longer distance to surface water bodies/POC, a more shallow and smaller application, and a lower rate of infiltration will all influence the calculations in the direction of less stringent (higher) limit values, the magnitude of which being dependent also on other criteria such as the quality criteria for water/soil at the POC and the time frame.

Step 8: Taking other considerations into account

Once the risk to groundwater and surface water has been assessed and accounted for in steps 1 through 7, the calculated limit values should be carefully reviewed, and other issues should also be considered. For some substances, e.g. substances displaying low mobility in soil and groundwater, the calculated limit values may be relatively high and give rise to other concerns. Some of the issues to consider in this context could be:

- The reluctance to create a number of potential landfills (a requirement could be that the leaching (or content) limit values should not exceed those for landfilling at inert waste landfills or at non-hazardous waste landfills receiving stable, non-reactive hazardous waste).
- The reluctance to have EoW limit values for C&D waste that are higher than or even equal to national limit values for utilisation of waste materials or soil in construction engineering works (adjustment may be required even though the conditions may be different).
- The risk that a substance that has a high limit value because of a low impact at the POC may influence other substances and for example increase their solubility and leachability. This could e.g. be the case with high concentrations of DOC, chloride and sulphate.
- The risk of causing damage to structures or processes (sulphate in higher concentrations may cause corrosion of concrete, and if biodegradable material is present, it may form toxic and smelly hydrogen sulphide). This may in some cases call for a reduction of calculated limit values for sulphate.
- The risk that alternative exposure pathways may occur and provide particular exposure conditions without the mitigating effects taken into account in the above scenario calculations.

For large construction projects the establishment of maximum permissible additions of selected substances to the soil below the application could be considered (see e.g. the Dutch SQD in Annex 5).

7.6 Proposal of a methodology for development of health-related limit values

While the limit values on leaching are necessary to protect the environment, it will also be necessary to apply limit values on the content of a number of substances to provide protection against human health hazards e.g. from ingestion, inhalation and direct contact with the aggregates. Since no standardised leaching tests are available for organic substances, such limit values will also provide a certain degree of protection against release and migration of organic substance into soil, groundwater and surface water.

If and when EoW criteria for aggregates are developed, it will be necessary to consider the regulations in all Member States as well as a broader range of substances (and not only those shown as examples in Table 2.3), as discussed in section 2.2.6. Since the criteria shall be applicable in all EU Member States, it will probably be necessary to choose the lowest limit values found in the Member States as EoW limit values (unless the use conditions prevent human contact with the material throughout the entire life-cycle). New legislation on utilisation of soil and waste aggregates that include limit values on content of both inorganic and organic substances is underway in some Member States. Specifically for recycled crushed concrete, for example, special attention should be paid to the possible content of PCB. It is necessary to specify precisely the number of congeners to be measured (the seven PCB congeners 28, 52, 101, 118, 138, 153 and 180 are suggested), the factor by which the sum of the seven congeners have to be multiplied to provide an estimate of the total content of PCB (5 is suggested) and the method of analysis (EN 15308 is suggested). It should be quite clear if the limit refers to the sum of congeners or to the estimate of the total content of PCB. In general, it should be ensured that the content of persistent organic pollutants (POP) is sufficiently low (see the POP Regulation), and that the content of any substance does not cause the aggregate to be classified as a hazardous waste. Test methods for determination of total content are discussed in section 3.7.3, and assessment of compliance of measured total contents of aggregates with established limit values should follow the same principles as assessment of compliance of leaching results with limit values.

7.7 Testing and documentation requirements (dossier)

It is suggested that a dossier should be prepared to document compliance with the requirements on leaching and content of substances and any other requirements of the aggregate to be considered for EoW status (see section 3.8.3 and Annex 3). To be approved for EoW status, it should be shown that a number of samples of the aggregate, representing a realistic cross-section of the material in question in the form it will have when it is to be used, comply with the criteria established for leaching as well as for the content of substances. Existing data of good quality should also be included in the dossier. A convention should be established for the statistical requirements for compliance with the limit values (see sections 3.9 and 7.8). If the dossier indicates a reasonable degree of compliance with the limit values at the level of characterisation or initial type testing (ITT), rules for routine testing (compliance testing or factory production control (FPC) in terms of frequency, sampling requirements, test methods and pass/fail conventions should be established. ITT and FPC are procedures established within CE marking under the Construction Products Directive, CPD (89/106/ECC) and its successor the Construction Product Regulation, CPR (Regulation (EU) No 305/2011), see section 3.8.3.

It is proposed that the leaching testing under ITT for the dossier should include a percolation test (CEN/TS 14405 or TS-3), a pH dependence test (CEN/TS 14429 or CEN/TS 14997) and a batch leaching test EN 12457-part 1, 2 or 3 (for future compliance/FPC purposes). The application of the pH dependence leaching test has become particularly important also in relation to the CPR which, in contrast to the CPD it replaces, addresses the entire lifecycle of a product. The analytical programme considered should as a minimum for ITT include all major substances (mainly salts) and all substances for which water quality criteria exists in the EU Member States. Any substance that may be of concern and known to be present in the aggregate, but not included in the above, should also be part of the analytical programme. Dissolved organic carbon (DOC) should be analysed in the eluates (because of its ability to enhance the leaching of metals and POPs). ITT Testing should also include determination of the total content of a number of substances. Minimum requirements for ITT analysis of content should account for at least 95 % of the mass of the material and include TOC, PCB, BTEX, PAH and hydrocarbons and any inorganic substances of concern. The analytical programmes for testing of leaching and content during FPC should be based upon the findings in the ITT and may be substantially reduced as compared to the ITT programme.

In the case of unrestricted use, the criteria in Table 7.1 should be met at L/S = 0.2 l/kg, L/S = 2 l/kg as well as L/S = 10 l/kg by the column/percolation test results and they should also be met by the batch test results and the results of the pH dependence test (at L/S = 10 l/kg) for pH between 7.0 and the materials own pH (often alkaline, as mentioned before). The list of substances shown in Table 7.1 (based on the substances to be tested for landfilling within the EU) should be supplemented to represent all substances for which regulatory water quality criteria exists in the European Member States (see above). In the case of use with restrictions/conditions, a similar table should be set up on the basis of the limit values developed under the procedure described in section 7.5.

If a discrepancy of compliance occurs between the percolation test and the batch test, the results of the percolation test should take precedence, as the latter provides a better representation of percolation-based release. A producer should have the choice to use the percolation test (recovering a single eluate at L/S = 2 l/kg or L/S = 10 l/kg) instead of the batch test for FPC purposes.

The appropriate environmental authorities (the Environmental Protection Agencies in the Member States and/or the EU Commission) should be responsible for approval/refusal of dossiers. The control of the FPC compliance with regulatory requirements could be placed at national level.

If common European limit values for EoW appear to be impractical, it could possibly be considered to divide aggregates with EoW status into classes representing the Member States or regions for which the leaching and content criteria associated with free use or conditional use are fulfilled, e.g. based on the water quality criteria used in the development of limit values. It would be important also to include general requirements of relevant EU directives. This could mean that a given type of waste-derived aggregate (for a given use) could obtain EoW status and become a product in some Member States, whereas it would remain a waste material in other Member States. This would be described in Annex AZ of the product standard as part of the CE marking in accordance with the CPR.

It is, however, recommended to take another related but probably more operational and practical approach in which classes are defined on the basis of the conditions or combination of conditions imposed on the use of the materials (see Table 7.2) and the associated limit values calculated in the stepwise procedure when these conditions and restrictions are taken into account. In this way a number of classes with different requirements on the use (possibly ranging from free use to very restricted use under very stringent conditions) and with different limit values (ranging from very restrictive to less stringent values in accordance with the scenarios dictated by the use conditions) could be described in Annex AZ of the appropriate product standards. Recovered aggregate materials can then be tested and characterized to achieve EoW status and a class denomination, and Member States can decide which classes they will allow to be used on their territory. Routine FPC would of course still be required. This approach is in line with the procedure for EoW assessment outlined in Figure 7.1 where different classes are shown under EoW in different colours. It is Europe-wide and yet allows each Member State full freedom in relation to EoW for aggregates.

7.8 Requirements on input materials and pre-treatment

For some waste-derived aggregates, particularly those resulting from highly variable or one-of input streams, it will be necessary to place strict controls on the quality of the input materials. One example is the production of crushed concrete from C&D waste, where procedures for selective demolition, depollution of buildings and sorting of C&D waste/concrete will be required to ensure a good quality input material. The procedures suggested by the JRC in Delgado et al. (2009), pp. 309 to 312 for C&D waste may be applicable, with the important addition that FPC testing and compliance at a regular basis will be required for crushed concrete products originating from all categories of input materials.

7.9 Compatibility of the proposed methodology

The proposed methodology for development of pollutant limit values for end-of-waste aggregates with restrictions/conditions is basically compatible with the approach to environmental protection and development of risk-based limit values for utilisation of waste and product aggregates taken in several EU Member States, including Belgium, Denmark, France, Germany, The Netherlands and Sweden. The scenario-based risk assessment methodology is also largely in agreement with the risk assessments carried out in the UK as part of the WRAP procedures for EoW assessment. At European level, the basic principles of the methodology are similar to those applied in the setting of EU waste acceptance leaching criteria for landfilling which is incorporated into Council Decision

2003/33/EC, and both the application of leaching tests and the logistics of the proposed procedures correspond to those prescribed by and applied in the Construction Products Directive and its successor, the Construction Products Regulation as well as the associated product standards.

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Annex 1

Estimation of pore water concentrations from leaching data

Porewater concentrations

It is sometimes useful or necessary to be able to estimate the pore water concentrations for an aggregate from the results of a leaching test. In principle, the first fraction of eluate from a well equilibrated column leaching test should have a composition similar to that of the pore water under saturated conditions. If the eluate or leachate composition for an aggregate is described as a function of L/S, either in terms of test results or as an exponentially decreasing source term based on kappa (κ) values – assuming a simple CSTR model of the leaching process as described in section 3.4– then the pore water concentration may be found by interpolation of the results to the L/S value which represents the pore volume of the aggregate in a given application. The relationship between pore volume and L/S will be:

$(L/S)_{PV} = n/d_{DB}$

where $(L/S)_{PV}$ is the L/S value corresponding to the pore volume n, and d_{DB} is the dry bulk density of the aggregate in the application in question. The concentration at $(L/S)_{PV}$ may then be estimated from the leaching curve for a column leaching test.

If the source term is described as a function of κ, and only batch test data are available, then the pore water concentration, C_{PW}, may be described as:

$C_{PW} = C_X \cdot (\exp(-(L/S)_{PV} \cdot \kappa)/(\exp(-X \cdot \kappa))$, or

$C_{PW} = (M_X/X) \cdot (\exp(-(L/S)_{PV} \cdot \kappa)/(\exp(-X \cdot \kappa))$

where C_X is the concentration of a given substance in the eluate from a single batch leaching test (or the first fraction of eluate from a column leaching test) performed at L/S = X, and M_X is the amount of that substance leached at L/S = X.

The closer L/S of the leaching test is to $(L/S)_{PV}$, the more accurate is the estimation likely to be. This means that in general, leaching data from a batch test performed at L/S = 2 l/kg is likely to provide better pore water estimations than data from a batch test performed at L/S = 10 l/kg.

Similarly, κ values based on the initial part of the leaching curve, i.e. determined at low L/S values are likely to provide better pore water concentration estimates than κ values based on the entire L/S range from 0 to 10 l/kg or on the high L/S part of the leaching curve. The best option will be to use the first few fractions from the column leaching test (L/S = 0 – 0.5 l/kg).

When using the CSTR model to describe the source term or to estimate the pore water concentrations for steel slag, the estimate of the κ values used could be improved by determining them specifically for aggregates under consideration. The general values determined by Aalbers et al. (1996) and used in the setting of the EU waste acceptance criteria for landfills (Hjelmar et al., 2005) may not provide a the optimal description of the source term for all aggregates.

Annex 2

Assessment of leaching from coarse granular materials

Assessment of the leaching from coarse granular materials

The problem

Industry often objects to the crushing of coarse granular materials/aggregates prior to the performance of a leaching test. The argument is that the aggregates are used in the coarse form (e.g. with particle sizes from 8 to 32 mm) and crushing them to e.g. 4 mm will give leaching results that are exaggerated and conservative and much higher than those that would result in the field. While this is a very valid objection and pinpoints a real and legitimate problem in the testing and evaluation of these materials **in the intended use phase** (although size reduction actually in some cases may lead to lower release rates), the proposed solutions have generally not been acceptable. It has been suggested to test the aggregates as they are without any reduction of particle size and using the same methods as those used for size reduced materials. This practice disregards the mechanisms that controls the release of contaminants from the materials and provides results that are potentially useless.

Most of the standards developed by CEN to assess the release of inorganic contaminants from granular materials require that the materials are size reduced to at least < 4 mm prior to testing. The reason for this requirement is that the performance of the tests (particularly the batch tests EN 12457 part 1, 2 and 3 and the column leaching test CEN/TS 14405) and the interpretation of the results are based on the assumption that equilibrium or near-equilibrium conditions (local equilibrium in the case of the column test) are attained during the performance of the leaching tests. The limitation on particle size is meant to reduce the diffusion pathway within the particle and hence facilitate the attainment of equilibrium between a given component in the solid phase and in solution. If equilibrium is reached after a certain contact period, further contact beyond that period will not change that state, i.e. the concentration of the components in equilibrium will not change. This provides a certain robustness in the testing, and it means that the results can be generalised and used (often in conjunction with scenario modelling) to describe other systems in equilibrium. The 4 mm requirement has been established on the basis of experience and testing.

If the particle size is large and equilibrium or equilibrium-like conditions are not reached during the contact time (due to diffusion resistance), then the results becomes dependent on the total surface (and hence the specific particle size distribution) of the granular material being tested and the results will be different for different contact times, even for the same batch of material. The results can therefore not be generalised, they apply only to a scenario with the exact same particle size distribution and the exact same contact time with water as the test system. Useful results (in terms of flux through the surface) may sometimes be extracted from such tests if the total surface area of the material tested and the contact time is known, but this information is seldom or never registered.

The above applies particularly to dense materials with low porosity. For more porous materials the particle size plays a lesser role, both in the test and in application scenarios. For the sake of consistency and appropriate handling, such porous materials may as well be size-reduced prior to testing. Several studies have found very little difference in results and little sensitivity to changes in contact time for leaching tests performed on materials with particle sizes up to 32 mm. However, those materials have often been porous or brittle, and a substantial amount of the material have had sufficiently low particle size (or the porosity have ensured sufficient contact with water) for equilibrium to occur for most components anyway.

Because of uncertainties in the combined effects of particle size, carbonation and time dependent release issues, the robustness intercomparison study launched by CEN/TC 351/WG1 intends to provide some clarity in the matter by studying products from the same batch in different size gradations to be supplied by producers.

Options

The so-called compacted granular tank leaching test may provide a solution for coarse granular materials with low porosity for which crushing to < 4 mm is undesirable. The test is based on some minor modifications to the Dutch standard compacted granular tank leaching test (NEN 7347)[4], in which the granular material is compacted into a beaker of approximately 8 cm diameter (variable). The surface of the waste material is subsequently covered by small glass beads to avoid removal of particles. The beaker is then placed in a larger vessel, which is filled with the leachant, so that the beaker is fully covered with leachant (demineralised water), see the figure. The water is then exchanged at predetermined intervals in the same way as with the monolithic tank test, and the results are managed similarly, relating the release rate to the surface area of the material in the inner beaker and to time (diffusion controlled release).

The modifications to accommodate coarse granular materials may e.g. consist in enlarging the system (there is already some built-in flexibility in this respect in the existing standard) and in removing the glass beads, since there will be no risk of suspension of small particles. In the calculation of the flux, the surface area of the inner beaker will be used. This is on the conservative side since the real surface will be very irregular and somewhat larger, but it will provide a much more “fair” and representative description of the leaching from coarse granular materials/aggregates with low porosity than those obtained from size reduced materials, and the method respects the actual release mechanisms of the system. The results will be expressed in terms of flux, i.e. mass/surface area/time, e.g. mg/m^2/day as a function of time and may be used as input to scenario-based impact assessments.

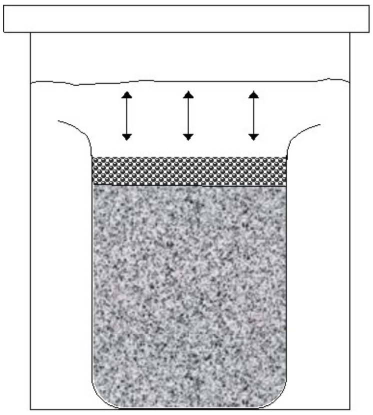

Figure
Illustration of compacted granular tank leaching test for coarse granular materials

In addition to the above, an alternative option has been suggested that covers the non-waste issue on a broader scale by assessing possible release under fully carbonated and oxidised conditions as that will possibly be an end point for these materials, when they are used freely in different scenarios and may be reused at a later stage in other as yet unknown applications. This implies assessing potential release under a range of L/S values (percolation test), pH values (pH dependence test) and redox conditions. Defining the pH domain as a window of a variety of possible use scenarios and comparing release with regulatory targets provides a means of identifying truly non–critical materials from materials that at least require some additional level of control in subsequent use stages. The tools to follow such an approach are available now.

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[4] The CGLT now constitutes a specific option in the technical specification CEN/TC351/TS-2 which has been developed by CEN/TC 351. The test currently undergoes robustness validation.

Example of practical/simplified use of results from the CGLT

For coarse granular material with a low internal porosity and a low permeability, water will flow around rather than through the material. Therefore the compacted granular leach test may apply. Guidance on conditions as to when to use one or the other test has been in discussion in working groups under CEN/TC292 and in CEN/TC351. A simple way to use the results of the CGLT is described below:

1. Obtain results from at CGLT in terms of flux, F, (e.g. $mg/m^2/day$) and accumulated leached amounts AC, (e.g. mg/m^2) of a given substance as a function of time for the parameters of interest from the coarse aggregate of interest. Plot accumulated leached amounts as a function of time, t, on a log-log scale.

2. Obtain an estimate of the total particle surface area, A, of the aggregate per unit bulk volume, V, under in-use conditions (e.g. m^2/m^3).

3. Describe the application scenario for the coarse aggregate material, particularly in terms of water flow and water contact. If there are wet/dry situations, estimate e.g. on an annual basis how many days - on the average - the aggregate is wet (DW) and dry (DD), respectively. In the Dutch Building materials Decree on average it was raining 14 % of the time (Aalbers et al, 1996). In Denmark, the number of days with more than 0.1 mm precipitation constituted approximately 50% of one year. The annual flow of water, Q, (m^3/year) through the application should be estimated. A typical net infiltration for uncovered applications is around 300 mm/year (0.3 m^3/year). For covered applications, this may reduce to around 50 mm/year (strongly dependent on local conditions)

4. To estimate the release from the application during the first year, extrapolate the test results to one effective year. Effective time, t_{eff}, is the time during which the material is wet. It is calculated as follows:

   $t_{eff} = t \times (DW/(DW+DD))$,

   where t is the actual time (one year).

   To find the accumulated amount per unit surface leached after the first year, AC_{1year} , find by extrapolation the accumulated leached amounts after t_{eff} corresponding to t = 1 year. If the slope of the accumulated amounts vs. time in the log-log plot decreases with time, use only the latter part of the curve for the extrapolation. The following equation can be used for the extrapolation:

   $\log(AC_{1year}) = \log(t_{eff\ 1\ year}) \times (\log(AC_2) - \log(AC_1))/(\log(t_{eff2}) - \log(t_{eff1}))$

   $AC_{1year} = 10^{(logAC1year)}$

   where the subscripts 1 and 2 refer to different sets of results (log(t), log(AC)) on the curve (subscript 2 will often be the last set of data). To obtain the amount released from the entire application, AC_{1year} must be multiplied by the surface area, A.

5. To estimate the accumulated release per unit area from the application during the first x years, the following equation applies:

   $\log(AC_{x\ years}) = \log(t_{eff\ x\ years}) \times (\log(AC_2) - \log(AC_1))/(\log(t_{eff2}) - \log(t_{eff1}))$

   …and so on. This could then, for example, be converted to the average annual release during the period from year 1 to year x by multiplying by A and dividing by (x-1).

6. It is always wise to check the mass balance to make sure that the estimated release of a substance does not exceed the total amount (may e.g. be known from determination of the total content) or the total available amount (may e.g. be known from pH-dependence leaching test at low pH) of the substance in question.

7. Since temperature has a significant effect on release, the average release must be corrected for the ambient conditions in the field. For the Netherlands, the average annual temperature is around 10 °C , which in comparison with the normal lab conditions of around 22 - 23 °C implies a factor of about 1.7 lower release (done by dividing the measured fluxes by 1.7).

A more elaborate discussion of the interpretation and application of the results may be found in the Dutch standard tank test NEN 7375.

For a material that consists of partly fine and partly coarse material this option may not prove to be adequate and a mix between percolation based and diffusion controlled release must be aimed for. In that case, it is important to have a better insight in the contributions of fine and coarse material to the overall release as a function of time. This aspects is covered in the ongoing robustness validation study of CEN/TC 351/WG1.

Annex 3

Draft example outline of possible dossier format

Draft example outline of dossier format for EoW compliance for a specific type or class of aggregate (working document)

1 The product

1.1 Detailed description of the product. (Reference to the harmonized product standard(s). Specification of the product (sub) family and product conditions/ranges as specified in the standard)

1.2 Detailed description of the composition of the product (including allowed materials/constituents, elements, components, ancillaries).

1.3 Detailed description of the technical and environmental relevant parameters, controlling release mechanisms, scenarios of use and other parameters that may influence the final performance of the product,

1.4 Permissible or likely variations in the product during the manufacture, taking into account the (allowed variation in) raw materials/constituents and the allowed variation in way of production itself.

1.5 Intended use of the product.

1.6 End use(s) conditions of the product.

2 The Classification

2.1 Essential characteristic/materials/substances in which the product performance is considered to be stable in relation to the envisaged end use(s).

2.2 The performance class(es) claimed.

2.3 Reference to the harmonized product standard(s). Specification of the (sub) product in the standard, the relevant conditions in the standard and relevant additional conditions in case the existing standard is not yet strict enough for the proposed application.

2.4 Reference to the European supporting standard(s) and European standard(s) (where relevant).

2.5 Parameters affecting the performance of the essential characteristic claimed.

3 Historical data

3.1 Copy of test reports containing the results of European test methods carried out before the WFT application is introduced and regarding the same essential characteristic for which the performance classification is claimed.

3.2 Copy of (recent) test reports/historical data containing the results of national test methods (if relevant).

3.3 Proof of presence of the product on national lists, where this exists.

4 Results from executed test programmes

4.1 List of the tests proposed for testing the performance related to the essential characteristic (including the number of tests envisaged, the number of samples to be tested and the reference to the European standard describing the test).

4.2 Procedure and responsibilities for selecting test samples.

4.3 Mounting and fixing conditions under which the proposed test will be carried out.

5 Testing requirements for the classification

6 Test evidence submitted

6.1 …………….

6.2 …………….

7 Potential influence of variation in product parameters on the performance test

8 CONCLUSIONS

8.1 Statement of product and class sought

8.2 Proposed table for inclusion in Commission Decision

Table – Technical classes of …………..…….. performance for …………..…….

Product	Product detail	Technical class (1)

(1) Technical class as provided in clause ……… of the harmonized product standard

The following documents provide complementary information:
Commission working document DS036: "Accepted Without testing/without further testing (WT/WFT) - Procedural aspects".

CEN Technical Report 15858: "Construction products; Assessment of the release of regulated dangerous substances from construction products based on the WT/WFT/FT procedures"

CPD Guidance Paper E: Levels and Classes in the Construction Products Directive

CPD Guidance Paper G: THE EUROPEAN CLASSIFICATION SYSTEM FOR THE REACTION TO FIRE PERFORMANCE OF CONSTRUCTION PRODUCTS

CPD Guidance Paper H: A harmonized approach relating to dangerous substances under the CPD

Annex 4

The methodology used to set the LFD WAC for inert waste

The methodology used to set the LFD WAC for inert waste

Introduction

The methodology used to develop the acceptance criteria in the Council Decision 2003/33/EC has been described in detail by Hjelmar et al. (2001 and 2005), DHI and ECN (2003) and Hjelmar (2003). The methodology is briefly summarised in this section, and some comments on the changes introduced when the methodology was applied under Danish conditions are also provided. The basic principle is that a series of simplified scenario-based model calculations is used to establish a direct relationship between the leaching behaviour of mainly inorganic contaminants released from landfilled granular waste, expressed in terms of the results of a leaching test, and the risk these contaminants pose to the quality of downstream groundwater.

The approach may best be described in terms of a series of consecutive steps. First a decision is made concerning the primary target or point of compliance (POC), e.g. the quality of groundwater at one or more points downstream of the landfill. Quality criteria are then selected for the groundwater, and the physical characteristics of the landfill and environment scenarios are selected and described. The environment scenario includes the net rate of infiltration and a hydrogeological description of the unsaturated and saturated (aquifer) zones upstream, below and downstream of the landfill. The source of the various contaminants is subsequently described in terms of the flux of contaminants as a function of time (or the liquid to solid ratio, L/S) based on leaching data and the hydraulic scenario defined. The leaching is approximated mathematically as an exponentially decreasing function of L/S, using a component-specific constant, kappa (κ) – see section 3.4 in the main report. Then the migration of the contaminants from the base of the landfill through the unsaturated zone into the groundwater and through the aquifer to the POC is modelled including only reversible, sorption-based contaminant/subsoil interaction processes and using proven and accomplished flow and transport models. Selected K_d-values are used for each contaminant to calculate and incorporate the retardation factors (assuming linear sorption isotherms). Based on these "forward" calculations so-called "attenuation factors" (the ratio between peak concentration as modelled at the groundwater POC and the source peak concentration at the base of the landfill) are determined for each contaminant. The principle of the three coupled source and transport models is illustrated in Figure 1.

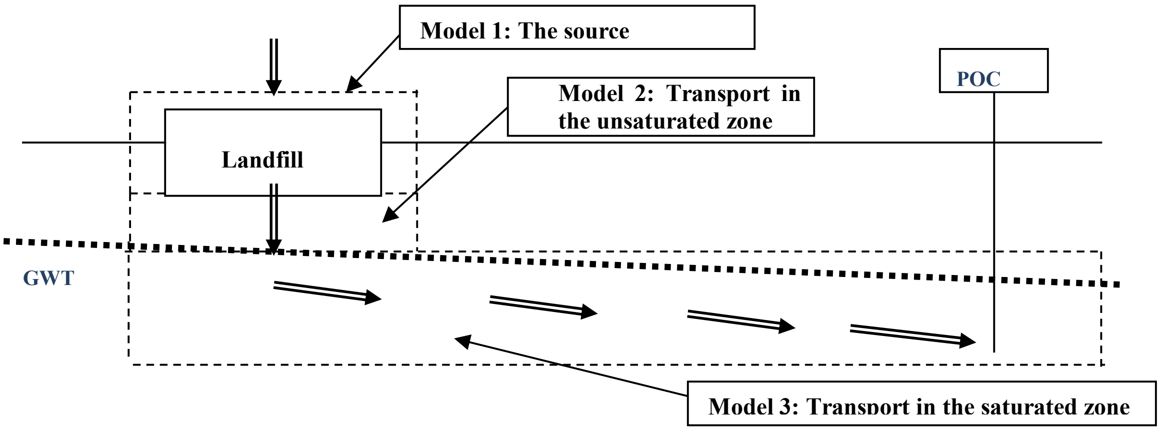

Figure 1
Cross-section showing the principle of three coupled source and transport models used for the forward impact calculation at a landfill scenario.

The attenuation factors are then used for a “backwards” calculation of the permissible values of the source term corresponding to the selected groundwater quality criteria for each contaminant at a particular POC. In the TAC calculations the background concentration of the contaminants in the upstream groundwater was not taken into account. The Danish calculations will include consideration of such background concentrations. The final step consists of transforming the resulting source term criteria to a limit value for a specific test.

It should be noted that the procedure involves simplifications and generalisations of complex and diverse physical-chemical processes. This may be justified by the need to have an operational and relatively simple system, which can be used for the development of general criteria. If needed, it is always possible to apply other or more sophisticated models and to adapt them to other general or site-specific conditions without changing the principle of the calculations.

Scenario and calculation/modelling conditions

Selection of targets for protection and contaminants to be included

The EU WAC calculations carried out by the Model Group under the Technical Adaptation Sub-committee on landfilling (the TAC calculations) only considered downstream groundwater quality, and the POCs were located 20 m and 200 m downstream of the edge of the landfill, respectively. In practice, only the POC located 20 m downstream of the landfill was used for the setting of criteria.

It would seem appropriate to base the criteria aiming at the protection of groundwater on groundwater quality criteria. The latter are generally stricter than drinking water criteria since they take potential effects on the entire ecological system into consideration. Drinking water criteria only consider risks to humans consuming the water and, in addition, make allowance for substantial uptakes of e.g. Cu and Zn from water pipes. The problem was that in 2000 – 2002, when the EU WAC were developed, there are international criteria or guidelines (EU/WHO) for drinking water quality, no such international criteria existed for groundwater quality. In fact, national groundwater quality criteria existed only in very few of the Member States. It was therefore proposed to use criteria based on international drinking water criteria and possibly later lower some of those parameters, which were very high compared to normal groundwater values. The EU Drinking Water Directive (CEC, 1998) and WHO drinking water criteria (WHO, 1996) in combination provided limit values for the following components in drinking water: As, Al, B, Ba, Cd, Cr(total), Cu, Hg, Mn, Mo, Ni, Pb, Sb, Se, Zn, Br^-, Cl^-, CN^-, F^-, NH_4^+, NO_3^-, NO_2^- and SO_4^{2-}. The calculations were carried out for all these parameters except B, Mn, NH_4^+, NO_3^- and NO_2^-.

In the Council Decision, leaching-based criteria were subsequently set for As, Ba, Cd, Cr, Cu, Hg. Mo, Ni, Pb, Sb, Se, Zn, chloride, fluoride, sulphate, DOC, phenol index, and TDS (as an alternative to chloride and sulphate) for waste to be accepted at landfills for inert waste. For landfills for non-hazardous waste receiving stable, non-reactive hazardous waste (from here on referred to as non-hazardous waste landfills) and landfills for hazardous waste, leaching based criteria were set for the same components as for inert waste landfills with the exception of the phenol index. In Denmark, leaching criteria are set for the same substances.

Description of scenarios

The inert waste landfill scenario used in the TAC calculations is shown in Table 1. A general rate of infiltration of precipitation of 300 mm/year were assumed (in DK 350 mm/year was assumed). An active landfill operation period of 30 years is anticipated, but a release of 300 mm of leachate/year into the unsaturated zone is assumed throughout the existence of the landfill. The resulting relationship between the liquid to solid ratio (L/S) describing the average progress of leaching of the landfill and time is shown in Table 2 for the first 100 years.

Table 1
Description of inert waste landfill scenario conditions and assumptions used in the calculation in the EU WAC calculations.

Parameter	Unit	EU Inert waste landfill
Height of the landfill	m	20
Length of the landfill	m	150
Width of the landfill	m	150
Surface area	m^2	22500
Volume	m^3	450000
Porosity of the waste	-	0.3
Dry bulk density of the waste	t/m^3	1.5
Dry weight of the waste	t	675000
Permeability of the waste	m/s	1×10^{-5}
Hydraulic conductivity of top cover	mm/år	> 300
Type of bottom liner	-	none

Table 2
Accumulated L/S as a function of time for the landfill scenarios for the first 100 years.

Time elapsed (years)	**Accumulated L/S (l/kg)**
	TAC scenario for inert waste landfill
1	0.01
10	0.10
30	0.30
60	0.60
80	0.80
100	1.00

3.3 The composition of the leachate as a function of L/S

A rather crude and simplified description of the release of contaminants as a function of L/S or time is used in the TAC calculations. Waste/waste interactions are neglected and the landfill is regarded as one large column or lysimeter, and it is assumed that the leaching of the contaminants under consideration can be described as an exponentially decreasing function of L/S or time, originally based on a simple continuously stirred tank reactor model (see e.g. Hjelmar et al., 2001). The concentration C of a contaminant in the leachate (or eluate, from a laboratory leaching test) may then be estimated as follows:

$C = C_0 \times e^{-(L/S)\,\kappa}$ where

C_0 is the initial peak concentration of the contaminant in the leachate (mg/l),
L/S is the accumulated liquid to solid ratio corresponding to the concentration C (l/kg).

κ is a kinetic constant describing the rate of decrease of the concentration as a function of L/S for a given material and a given component (kg/l). κ may be estimated from laboratory leaching data and is for this purpose considered independent of the material/waste in question (this is not actually true as κ may vary both with material and L/S, and the description of the source term may be improved by using material-specific κ values over limited L/S ranges).

By integrating the above expression, the amount of contaminant, E (in mg/kg), released over the period of time it takes for L/S to increase from 0 l/kg to the value corresponding to C, can be calculated:

$$E = (C_0/\kappa)(1 - e^{-(L/S)\kappa})$$

Only a limited number of determinations of κ are available, and the values used for the inorganic contaminants in the TAC calculations were produced by Albers et al. (1996) based on column leaching tests performed on construction materials. Additional data on phenol and DOC were estimated by ECN (DHI and ECN, 2003). The values are listed in Table 3. A lower κ corresponds to a slower decrease in leachate concentration, and this generally leads to a higher downstream peak groundwater concentration).

Table 3

List of the κ values for inorganic components and phenol and DOC used in the TAC calculations.

Parameter	Average values and 95 % confidence intervals for κ (kg/l)	Number of determinations	Data source
As	0.03 ± 0.05	44	Aalbers et al. (1996)
Ba	0.15 ± 0.04	55	Aalbers et al. (1996)
Cd	0.50 ± 0.10	37	Aalbers et al. (1996)
Cr	0.18 ± 0.03	82	Aalbers et al. (1996)
Cu	0.28 ± 0.03	90	Aalbers et al. (1996)
Hg	0.05 ± 0.03	5	Aalbers et al. (1996)
Mo	0.35 ± 0.04	76	Aalbers et al. (1996)
Ni	0.29 0.05	37	Aalbers et al. (1996)
Pb	0.27 0.06	52	Aalbers et al. (1996)
Sb	0.11 ± 0.07	33	Aalbers et al. (1996)
Se	0.38 ± 0.18	10	Aalbers et al. (1996)
Zn	0.28 ± 0.05	41	Aalbers et al. (1996)
Chloride	0.57 ± 0.07	45	Aalbers et al. (1996)
Fluoride	0.22 ± 0.14	6	Aalbers et al. (1996)
Sulphate	0.33 ±0.05	49	Aalbers et al. (1996)
Phenol	0.3		ECN (DHI &ECN, 2003)
DOC	0.17		ECN (DHI &ECN, 2003)

Figure 3.4 in section 3.4 in the main report has already shown the influence of κ on the rate of release of contaminants: For low values of κ the changes in C/C_0 over a considerable L/S (or time) range remains relatively small, whereas the changes are much more significant for larger values of κ. It should be noted the description of the release as exponentially decreasing function of κ and L/S or time is an oversimplification that helps in the setting of criteria, but does not fit all substances.

Transport and groundwater quality parameters

Table 4 shows the values of K_d used to describe the contaminant/subsoil interaction in the transport modelling both in the TAC calculations and in the Danish calculations. The same K_d values were used to describe the conditions in both the unsaturated and the saturated zones.

In the Danish calculations, the background concentrations of the contaminants in the upstream groundwater are taken into account in the determination of the dilution. The background concentrations used are also shown in Table 4. The table also shows the groundwater quality criteria set at the POC in both cases. Substantial reductions are seen in the Danish values as compared to the TAC values for Hg, Mo and phenol. Smaller reductions are seen for As, Cd, Cr, Ni, Pb, Sb and chloride, whereas an increase is seen for Cu.

Table 4
Subsoil K_d values (both for the unsaturated and saturated zones), groundwater background concentrations and GW criteria used in the TAC calculations (DHI and ECN, 2003) and for the Danish calculations.

Component	K_d (l/kg)		GW background concentration (µg/l)	GW quality criteria at POC (µg/l)	
	DK	TAC	DK only	DK	TAC
As	20	50	0.8	8	10
Ba	14	2	62	700	700
Cd	20	20	0.008	2	4
Cr	23	100	0.09	20	50
Cu	100	14	0.3	100	50
Hg	20	1	0.0011	1	1
Mo	15	10	0.7	20	70
Ni	20	50	0.5	10	20
Pb	100	50	0.05	5	10
Sb	7	5	0.08	2	5
Se	5	5	0.10	10	10
Zn	20	30	3.0	100	100
Chloride	0	0	25000	150000	250000
Fluoride	2	2	500	1500	1500
Sulphate	0	0	50000	250000	250000
Phenol	5	40	0	Undetermined	100
DOC	0	0	Undetermined	3000	10000

Transport modelling in the unsaturated and saturated zones
The input to the transport model for the unsaturated zone in terms the flux of each contaminant as a function of time is calculated by combining the information on the flow of leachate out of the landfill with the information on the composition of the leachate as a function of L/S. For a given scenario, the relationship between L/S and time is easily calculated (e.g. Hjelmar, 1990):

$t = (L/S) \times d \times H/I$

where
t = the time since the landfill started producing leachate (years)
L = the total volume of leachate produced at time t (= t x 6750 m^3/year)
S = the total dry mass of waste deposited at the landfill (450,000 m^3 x 1500 kg/m^3 = 675,000 tonnes)
d = the average dry bulk density of the deposited waste (1500 kg/m^3)
H = the average height of the landfill (20 m)
I = the net rate of infiltration of precipitation (300 mm/year)

A numerical 3 D flow and transport code, MIKE-SHE, in which the modelling of the transport through the unsaturated and the saturated zones is integrated, is applied in the Danish contaminant transport calculations (DHI, 2003). The corresponding TAC calculations were performed using CXTFIT/ECOSAT and HYDRUS 2D for the unsaturated zone and MODFLOW and MT3D for the saturated zone (DHI and ECN, 2003). More sophisticated models are used now.

The thickness of the unsaturated zone under the landfill was assumed to be 5 m in the TAC calculations and 2 m (clay) in the Danish calculations. The parameter values used in the model calculations of the transport in the saturated zone both in the Danish and the TAC calculations are shown in Table 5.

The relatively large differences between the DK and TAC dispersivities may be explained by the fact that in the TAC calculations, high dispersivities were used in the model to ensure the occurrence of total vertical mixing in the aquifer, which was one of the pre-conditions. Total vertical mixing was not assumed in the Danish calculations.

Table 5

Parameter values used in the model calculations of transport in the saturated zone in the Danish calculations and in the calculations performed by the TAC (DHI and ECN, 2003).

Parameter	Unit	Used in DK	Used by TAC
Width of catchment	m	300	500
Length of catchment	m	250	600
Distance from water divide to beginning of landfill	m	50	100
Distance to POC	m	100 (and 30)	20 and 200
Net rate of infiltration	mm/year	350	300
Thickness of unsaturated zone	m	2 (clay)	5
Thickness of aquifer	m	6	Approx. 6
Upper boundary	-	Closed	Closed
Fixed hydraulic head at downstream boundary	m	Approx. 5.75	Approx. 4.1
Horizontal hydraulic conductivity Kx = Ky	m/s	10^{-4}	1.4×10^{-4}
Vertical hydraulic conductivity Kz	m/s	10^{-5}	1.4×10^{-4}
Effective porosity	-	0.3	0.3
Longitudinal dispersivity	m	0.45	20
Transversal dispersivity	m	0.001	4
Vertical dispersivity	m	0.0005	2
Cell size	m	2	10
Number of calculation layers	-	8	6

Determination of attenuation factors and limit values

Once the attenuation factor (i.e. the ratio between the peak concentration at the POC and the peak concentration at the bottom of the landfill) has been determined for a given contaminant and a given landfill scenario, it can be used to determine the maximum allowable concentration at the base of the landfill. In the TAC calculations, the maximum allowable concentration was found by dividing the groundwater quality criteria (Table 4) by the attenuation factor. In the Danish calculations, where background concentrations are accounted for, the upstream background concentration (Table 4) is subtracted from the groundwater quality criteria before it is divided by the attenuation factor (and the background concentration is added again).

The last step in the procedure is to calculate the actual limit value corresponding to a percolation-related leaching test such as the column test CEN TS 14405 or the corresponding compliance batch leaching test EN 12457 (part 1-4). To find the leaching limit value in terms of released amount (mg/kg) of a given component, the maximum allowable concentration found above is entered into equation (6.2) as C_0. Using the appropriate values for L/S and κ (see Table 3), the limit value E corresponding to the L/S value used can be calculated. Denmark has chosen to refer the limit values to L/S = 2 l/kg and to use the batch leaching test EN 12457-1 for compliance purposes. Most other Member States have chosen the criteria set at L/S = 10 l/kg for regulatory purposes. In principle, the limit values at L/S = 2 l/kg or L/S = 10 l/kg express the same degree of protection of the groundwater at the POC when they are calculated from each other using equation 3.5 in section 3.4 in the main report and κ.

The regulatory limit values

Once the limit values were calculated using the scenario modelling, the results were subjected some consequence analyses using databases on waste leaching properties to assess the consequences in terms of percentages of waste passing or not passing criteria if the WAC were changed in one direction or the other compared to the risk-based calculated values. This supported the final political discussion in the TAC during which the values that are now in Council Decision 2003/33/EC were determined. For the WAC for acceptance at landfills for inert waste, some values were increased, some were decreased and some were kept largely unchanged as compared to the modelling results.

Annex 5

Regulation of the use of waste-derived aggregates in several EU Member States

Existing pollution control legislation on the use of aggregates

Austria

In Austria, waste management is regulated by the Waste Management Act[5] and accompanying ordinances. End of waste criteria have been defined for compost but not for any other waste materials.

Of interest in this context is a voluntary agreement between plant operators, the Austrian Association for Building Material Recycling, the Federal Environment Agency and the Federal Ministry of Agriculture, Forestry, Environment and Water Management on environmental and health quality requirements to be fulfilled by C&D waste to be recycled for use in construction works (Böhmer et al., 2008). These quality requirements are shown in the table below. The limit values in the table refer to the batch leaching test EN 12457-4.

Additional limit values obligatory if contamination is possible (Austria) [6].

Parameters[A]	Unit	Grade A+	Grade A	Grade B
Eluate at L/S = 10 l/kg				
Antimony	mg/kg DM	0.06	0.06	0.1
Arsenic	mg/kg DM	0.5	0.5	0.5
Barium	mg/kg DM	20	20	20
Lead	mg/kg DM	0.5	0.5	0.5
Cadmium	mg/kg DM	0.04	0.04	0.04
Molybdenum	mg/kg DM	0.5	0.5	0.5
Nickel	mg/kg DM	0.4	0.4	0.6
Mercury	mg/kg DM	0.01	0.01	0.01
Selenium	mg/kg DM	0.1	0.1	0.1
Zinc	mg/kg DM	4	4	18
Chloride	mg/kg DM	800	800	1,000
Fluoride	mg/kg DM	10	10	15
Phenol index	mg/kg DM	1	1	1
DOC[B]	mg/kg DM	500	500	500
TDS[C]	mg/kg DM	4,000	4,000	8000
Total content				
Arsenic	mg/kg DM	20	30	30
Lead	mg/kg DM	30	100	100
Cadmium	mg/kg DM	0.5	1.1	1.1
Chromium tot.	mg/kg DM	40	90	90
Copper	mg/kg DM	30	90	90
Nickel	mg/kg DM	30	55	55
Mercury	mg/kg DM	0.2	0.7	0.7
Zinc	mg/kg DM	100	450	450

[A] *Significant hydrocarbon content is only permitted on condition that this originates from primary construction materials and from oil contamination.*

[B] *Can be investigated if own pH value or alternatively where L/S = 10 l/kg and pH value 7.5 to 8.0.*

[C] *The values for totally dissolved solids (TDS) can be used instead of sulphate and chloride. However, sulphate must be determined in any case.*

The different grades of C&D quality refer to the allowed fields of application, see the table below.

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[5] Austrian Federal Government (2002): Waste Management Act 2002 as amended (Abfallwirtscaftsgesetz 2002, Federal Legal Gazette I No 102/2002 as amended).

[6] Federal Ministry of Agriculture and Forestry, Environmental and Water Management (2006):

Fields of application according to environmental engineering aspects - minimum requirements (Austria)[7]*.*

Form of application	Hydrogeologically less delicate area	Hydrogeologically delicate area
In bound form or unbound with covering layer[8]	Quality class B	Quality class A
Unbound without covering layer	Quality class A	Quality class A+
In bound form, used as aggregate	Quality class B	Quality class B

Belgium

Belgium is split in three major regions: Flanders, Brussels, and Wallonia. In each of these regions, different law, targets and approaches are used, although it could be said that they all focus on prevention of waste generation and increasing of material recycling.

Flanders region

In Flanders the Public Waste Agency of the Flemish region (OVAM) is responsible for the achievement of waste management objectives by means of waste projects. In general Flanders sticks to the European waste hierarchy and lays its focus of waste management activities on waste prevention followed by re-use and recycling. The objectives for C&D waste are developed in the 4th Regional Waste Prevention and Management Plan, which targets at recycling of 90% of C&D by 2020. Currently, over 85% of recovery is achieved for C&D waste.

The management of C&D waste is legally regulated by VLAREMA, 17 February 2012 (Article 2.3.2): Decree of the Flemish Government adopting the Flemish Material Cycles and Waste (Sustainable Management) Regulation.

VLAREMA has replaced the former VLAREA legislation and no longer refers to secondary raw materials but merely makes the distinction between waste materials and resources ("grondstoffen"). It specifically refers to a possible ending of the waste phase.

Distinctions on the requirements for testing and declaration of material properties are made for different waste aggregate categories.

Article 2.3.2 stipulates:

Taking account of the relevant requirements in force for works or construction materials, fulfilment of at least the following criteria in terms of composition is needed in order for materials as referred to in Annex 2.2, Section 2, to be considered resources intended for use as construction materials:

1. they do not exceed the maximum total concentrations in organic compounds as referred to in Annex 2.3.2.A;
2. the maximum total concentrations in metals as referred to in Annex 2.3.2.A are to be considered target values. For metals for which the total concentrations are below the target values for soil quality as referred to in Annex III of the Vlarebo, the leachability need not be determined;
3. the maximum leachability values of metals for use in or as a non-shaped construction material, as referred to in Annex 2.3.2.B, are not exceeded. The maximum leachability applies to a standard application where the height of application of the non-shaped construction

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[7] Austrian Construction Materials Recycling Association (2007): Guideline for recycled building materials, 7th edition.

[8] Specific requirements for covering layer.

material, as measured perpendicularly to the earth's surface, is 0.7 m, its density is 1 550 kg/m3, and its effective infiltration into the structure is 300 mm/yr. In case of different leachability values, different densities and different proposed heights of application, the calculated emission limit value for the soil shall meet the requirements of Annex 2.3.2.C;

4. the leachability values for metals intended to be used in or as shaped construction materials should result in calculated emission limits corresponding to the values as referred to in Annex 2.3.2.C;
5. the calculated total proportion of asbestos fibres shall not exceed 100 mg/kg of dry matter.

OVAM (the Public Waste Agency of the Flemish region) shall lay down a general control system for recycled granulates. This control system shall comprise at least a unified regulation, subject to approval by the Minister, which sets forth the requirements and procedure for inspections of recycled granulates.
Recycled granulates used as resources shall comply with the provisions of the unified regulation.
The parameter lists from the Annexes as referred to in Article 2.3.2.1 may be reduced to a single list as referred to in the unified regulation.

A proposed resource that fails to comply with the imperative compositional requirements for the relevant application as referred to in Article 2.3.2.1, may still be allowed for certain specific applications. The natural person or legal entity wishing to confirm the end-of-waste phase for the material shall submit a resource certificate application to OVAM.

A material used in a specific application in accordance with the first paragraph may only be disposed of or recycled in an identical specific application which ensures at least the same level of protection of public health and the environment as the original application.

A proposed resource for which it cannot yet be demonstrated at the time of application that it fulfils the imperative compositional requirements for the application as referred to in Article 2.3.2.1 because its specific application is not yet operational, may nevertheless be permitted as a resource, provided that the application comes from the initial resource producer. Laboratory analyses must demonstrate that the compositional requirements for the relevant application as referred to in Article 2.3.2.1 can still be fulfilled. The initial resource producer wishing to confirm the end-of-waste phase for the material shall submit a resource certificate application to OVAM.

Conditions for use in or as a building material – aromatic hydrocarbons

PARAMETERS	**TOTAL CONCENTRATION (A) (mg/kg dry substance)**
Benzene	0.5
Ethyl benzene	5
Styrene	1.5
Toluene	15
Xylene	15
Benzo(a)anthracene	35
Benzo(a)pyren	8.5
Benzo(ghi)perylene	35
Benzo(b)fluoranthene	55
Benzo(k)fluoranthene	55
Chrysene	400
Phenanthrene	30
Fluoranthene	40
Indeno(1,2,3cd)pyrene	35
Naphthalene	20

(A) ...determination of the concentration of organic pollutants according to the method included in part 3 of the Compendium for Sampling and Analysis

Conditions for use in or as a building material.

PARAMETERS (concentration applies for the metal and its compounds expressed in metal)	TOTAL CONCENTRATION (A) (mg/kg dry substance)
Arsenic (As)	250
Cadmium (Cd)	10
Chromium (Cr)	1250
Copper (Cu)	375
Mercury (Hg)	5
Lead (Pb)	1250
Nickel (Ni)	250
Zinc (Zn)	1250

(A) *the determination of the metal concentration is to be performed according to WFC method 2/II/A.3., included in the Compendium for Sampling and Analysis.*

Table 72: Conditions for use in or as a building material - Other organic substances.

PARAMETERS	TOTAL CONCENTRATION (A) (mg/kg dry substance)
Extractable organohalogen compounds (EOX)	10
Hexane	1
Heptanes	25
Mineral oil	1000
Octane	90
Polychlorinated biphenyls (PCB)	0.5

(A) .determination of the concentration of organic pollutants according to the method included in part of the Compendium for Sampling and Analysis.

Brussels region

In general Brussels Capital Reagion (BCR) sticks to the European waste hierarchy and lays its focus of waste management activities on waste prevention followed by re-use and recycling. The management of C&D waste is legally regulated by *Arrêté du Gouvernement de la Région de Bruxelles-Capitale relatif au recyclage obligatoire de certains déchets de construction ou de démolition 16/03/95* (MB.06/05/1995).

The BCR's objectives for C&D waste are developed in the 4th Regional Plan of Waste Prevention and Management. The general idea is to achieve a high recycling rate and to minimise the impacts of this type of waste during the entire period of life of the building (from its construction to its demolition including its occupation). Currently, a recycling rate of 80% is achieved for C&D.

Walloon region

The Walloon waste management plan defines targets for the prevention, composting, recycling and landfilling of industrial and municipal waste, respectively and specifies instruments which should support the achievement of these targets. No targets are specified for C&D waste and alike but landfilling of C&D waste is banned as of 2004. Landfilling of waste incineration slag has been banned in 2004, slag from metal industry in 2007, dust from iron/steel production in 2008, foundry sands in 2009 and finally all bulky waste is banned from landfilling in 2010.

Czech Republic

The management of C&D waste is legally regulated by Act No. 185/2001 Coll. (Waste Act) and the Waste Management Plan of the Czech Republic for 2003-2013. The re-use of C&D waste is regulated by Order No. 294/2005, which defines leachability classes and limit concentrations for waste to be landfilled. There are 3 leachability classes (I, IIa, IIb, III) determined on the base of eluates from EN

12457-4 test (see table below). Order No. 61/2010 on reuse of inert waste in surface constructions is also applied for use of C&D waste.

***Table:** Leachability classes determined according to Order No. 294/2005*

mg/l	I	IIa	IIb	III
DOC	50	80	80	100
Phenol index	0,1			
Cl	80	1500	1500	2500
F	1	30	15	50
SO4	100	3000	2000	5000
Ba	2	30	10	30
Cd	0,004	0,5	0,1	0,5
Cr	0,05	7	1	7
Cu	0,2	10	5	10
Hg	0,001	0,2	0,02	0,2
Ni	0,04	4	1	4
Pb	0,05	5	1	5
Sb	0,006	0,5	0,07	0,5
Se	0,01	0,7	0,05	0,7
Zn	0,4	20	5	20
Mo	0,05	3	1	3
TDS	400	8000	6000	10000
pH		≥ 6	≥ 6	

Currently, there is no legislation implemented with special focus on *end-of-waste* criteria for aggregates or C&D for that matter. Center for Waste Management (CeHo, VUV Praha) is proposing an evaluation scheme (see figure below) which was derived from the Austrian guidelines for recycling of materials from constructions. List of controlled elements was also derived from the Austrian guidelines and includes determination of elements both in solid phase (As, Cd, Cr, Cu, Hg, Ni, Pb, V, Zn, PAH, PCB, hydrocarbons C10-C40) and in eluate (As, Ba, Cd, Cr, Cu, Hg, Ni, Pb, Zn, pH).

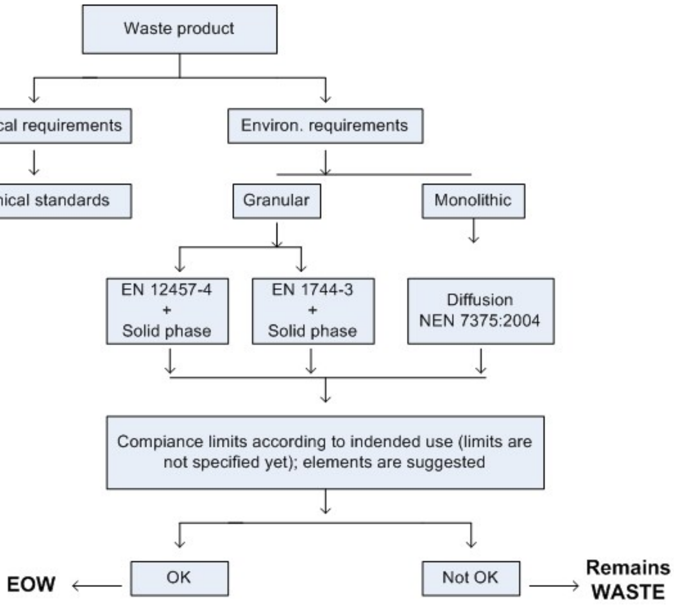

***Figure:** Proposed EOW scheme in Czech Republic (source: CeHo)*

Slags from ferrous metal production. Except for general rules in Act 185/2001 Coll., on waste and its Decrees, no specific national regulation on slags from the ferrous metal production regarding their management has been established yet (Böhmer et al., 2008).

Ashes from coal combustion. Except for general rules in Act 185/2001 Coll., on waste and its Decrees, no specific national regulation on ashes from coal combustion processes regarding their usage has been established yet (Böhmer et al., 2008).

Denmark

Statutory Order no. 1662 of 21 December 2010 on recycling of residual products and soil in building and construction works and on recycling of sorted, unpolluted C&D waste (replacing and updating a series of Statutory Orders on recycling of residual products and soil with similar contents first implemented in 2000 and parts of Statutory Order no. 20/2010) sets criteria and conditions for the recycling of certain residual waste materials and slightly polluted soil that contains neither organic contaminants nor other inorganic contaminants than those for which the Statutory Order sets criteria. It also describes the conditions for recycling of sorted, unpolluted C&D waste (as distinguished from residual products).

Residual products (at the moment only including municipal solid waste incinerator (MSWI) bottom ash, coal fly ash and coal bottom ash) and **slightly polluted soil** to be recycled must fulfill quantitative criteria regarding the content and leachability of specified inorganic substances. In addition, the content of total organic carbon (TOC) in MSWI bottom ash must not exceed 3 % (w/w). Since soil contaminated with organic substances (as well as soil polluted with other inorganic substances than those mentioned in Table 3.2) are excluded from recycling and since and most polluted soils are contaminated with organic substances, the Statutory Order has had very limited practical application to soil so far.

Statutory Order no. 1662/2010 distinguishes between three different categories of residual materials and soil, based on the results of a determination of the content of some trace elements (after partial digestion with 7 M nitric acid) and on the results of a leaching test. The prescribed leaching test is, EN 12457-1, a batch leaching test performed at L/S = 2 l/kg with a contact time of 24 hours. The combined criteria for content and leached amounts which define the three categories are shown in the table below.

In order to enhance the recycling of MSWI bottom ash, the limit values for chloride, sulphate and sodium for category 2 have been “temporarily” elevated to 3000 mg/kg, 4000 mg/kg and 2000 mg/kg, respectively, for more than 10 years. It is specified for each type of residue for which of the substances in Table 4.2 limit values are relevant.

Residues (and soil) falling in Category 1 may be used for certain specified purposes, i.e. construction of roads, paths, squares/parking lots, noise reduction walls, ramps, dikes, dams, railway embankments, pipe/cable trenches, landscaping, marine constructions, refilling floors and foundations. Category 2 and Category 3 residues/soil may be recycled under increasingly more stringent conditions concerning type of application, thickness and top cover. No later than 4 weeks prior to the intended start of the recycling project the user must submit a notification to the municipality detailing the location of the project, the start and end dates of the project, the amount, type and category of residue or soil to be used, the dimensions of the project (including drawings), an areal situation plan showing the involved land register numbers, the location relative to drinking water borings and extraction wells, rivers, lakes and the sea, and information on whether or not direct discharges or indirect discharges via drainage systems to rivers, lakes or the sea will occur. The municipal authorities may, if there is a risk that the project will cause environmental pollution, within 4 weeks after receiving the notification, determine that the project shall be delayed until the impact on the environment has been studied or assessed. The municipal authorities will ban the project if it does not comply with regulatory requirements.

The limit values on content are based on toxicological considerations whereas the limit values on leaching are based on a risk assessment scenario (modelling the impact of a constant source on a groundwater extraction well placed 30 m downstream of the application and not taking sorption into consideration). It was assumed that testing for compliance with the limit values at L/S = 2 l/kg would to a certain degree resemble the initial porewater concentrations and thus be on the conservative side.

In the Statutory Order, C&D waste is defined as waste listed under EWL code 17. Uncontaminated C&D waste is defined as C&D waste for which it can be assumed with a high degree of certainty that the waste does not contain contaminating materials or substances to such an extent or of such a type and concentration, that the recycling of the waste can have a harmful effect on the environment or human health. The waste must thus not contain contaminating substances, including substances which can cause contaminating seepage or percolation to soil or groundwater, including e.g. impregnated wood, PCB containing sealants, tar, soot, remains of paint and lacquer.

Uncontaminated C&D waste originating from industry and trade and belonging to fractions 1 to 7 on the list in Statutory Order no. 20/2010 on sorting and recycling of C&D waste (i.e. natural stone, unglazed tile and masonry, concrete, mixes of these, iron and metal, gypsum, and stone wool) may without permission and without testing be prepared for reuse for the same or similar purposes as those the waste materials were previously used for, including reuse of bricks, tiles or gypsum plates in house building. Uncontaminated C&D waste may be stored on-site for up to 1 year without permission. Uncontaminated C&D waste of fractions 5 to 7 (iron and metal, gypsum and stone wool) may without permission and after treatment be recycled at a company or a plant that receives waste to be recycled. Uncontaminated C&D waste of fractions 1 to 4 may without permission and after treatment be recycled as a replacement of virgin raw materials. Other types of recycling of C&D waste than those just mentioned can only take place in accordance with other regulation in the Environmental Protection Act.

***Table:** Limit values for content and leached amounts in Statutory Order 1662/2010.*

Substance	Category 1	Category 2	Category 3
	Solid content in mg/kg dry matter		
As	≤ 20	> 20	> 20
Cd	≤0.5	> 0.5	> 0.5
Cr (total)	≤ 500	> 500	> 500
Cr (VI)	≤ 20	> 20	> 20
Cu	≤ 500	> 500	> 500
Hg	≤ 1	> 1	> 1
Ni	≤ 30	> 30	> 30
Pb	≤ 40	> 40	> 40
Zn	≤ 500	> 500	> 500
	Leached amounts at L/S = 2 l/kg in mg/kg		
As	≤ 0.016	≤ 0.016	0.016 – 0.10
Ba	≤ 0.60	≤ 0.60	0.60 – 8.0
Cd	≤ 0.004	≤ 0.004	0.004 – 0.080
Cr (total)	≤ 0.020	≤ 0.020	0.020 – 1.0
Cu	≤ 0.090	≤ 0.090	0.090 – 4.0
Hg	≤ 0.0002	≤ 0.0002	0.0002 – 0.002
Mn	≤ 0.30	≤ 0.30	0.30 – 2.0
Ni	≤ 0.020	≤0.020	0.020 – 0.14
Pb	≤ 0.020	≤ 0.020	0.02 – 0.20
Se	≤ 0.020	≤ 0.020	0.020 – 0.060
Zn	≤ 0.20	≤ 0.20	0.20 – 3.0
Chloride	≤ 300	≤ 300	300 – 6000
Sulphate	≤ 500	≤ 500	500 – 8000
Sodium	≤ 200	≤ 200	200 - 3000

As mentioned above, no environmental testing requirements have been imposed on C&D waste to be recycled so far, but the Danish EPA expects to explore the possibilities of bringing the conditions for recycling of C&D waste in line with the conditions for recycling of other waste aggregates and soil by setting testing requirements and corresponding limit values for C&D waste to be recycled in 2011 or 2012.

Finland

Approximately 25 million tonnes of mineral C&D waste are produced annually in Finland, and a substantial amount of this is recycled for construction purposes. The Finnish decree on reuse of some waste materials in earth construction (Government Decree 591/2006, amended by 403/2009 and 1825/2009) regulates the recycling of crushed concrete as well as fly ashes and bottom ash from combustion of coal, peat and wood-based materials. The Decree sets limit values for content of PCB, PAH, hydrocarbons and some trace elements and for leaching of several inorganic substances (almost corresponding to the substances to be tested for acceptance at European landfills). The required test methods are CEN/TS 14405 (basic characterisation) and EN 12457-3 (compliance). The applications in which the crushed concrete is used must be covered or paved. Finland has identified the following harmful substances in mineral demolition waste: Organically bound Cd, metallic Cd, metallic Hg, metallic Pb, organic Pb, PCB compounds, CFC compounds oil and PAH, Cr and Mo, Cu and phenolic compounds. The origin of these substances has also been assessed.

The Finnish decree (Government Decree 591/2006) on reuse of some waste materials in earth construction set the requirements shown in the table below for concrete chippings (EWC codes 10 13 14, 17 01 01, 17 01 07 and 19 12 12). Concrete chippings refer to waste made of dismantled concrete structures or concrete waste from new buildings and the concrete industry by crushing the material into grains with a maximum diameter of 150 mm (content of bricks max. 30 %). The second table shows the corresponding limit values for utilisation of residues from coal combustion (EWC codes 10 01 02, 10 01 03, 10 01 17, 10 01 01, 10 01 07, 10 01 15 and 10 01 24).

The determination of harmful substances included in the waste and leaching from the waste to be utilised shall be conducted, in the first instance, by using standardised and, secondarily, other methods found adequate in terms of sensitivity of detection, accuracy and repeatability.

Table: Limit values for content and release of crushed concrete for utilisation.

Harmful substance	**Limit value, mg/kg of dry matter Basic characterisations** [1]			**Limit value, mg/kg of dry matter Quality control investigations**[1]		
	Content	Leaching (L/S = 10l/kg) Covered structure	Leaching (L/S = 10l/kg) Paved structure	Content	Leaching (L/S = 10l/kg) Covered structure	Leaching (L/S = 10l/kg) Paved structure
PCB[2]	1.0			1.0		
PAH[3]	20					
Hydrocarbons[4]	500					
DOC[5]		500	500			
Antimony (Sb)		0.06	0.06			
Arsenic (As)	50	0.5	0.5	50		
Barium (Ba)		20	20			
Cadmium (Cd)	10	0.02	0.02	10	0.02	0.02
Chrome (Cr)	400	0.5	0.5	400	0.5	0.5
Copper (Cu)	400	2.0	2.0	400	2.0	2.0
Mercury (Hg)		0.01	0.01			
Lead (Pb)	300	0.5	0.5	300	0.5	0.5
Molybdenum (Mo)		0.5	0.5			
Nickel (Ni)		0.4	0.4			
Vanadium (V)		2.0	2.0			
Zinc (Zn)	700	4.0	4.0	700		
Selenium (Se)		0.1	0.1			
Fluoride (F^-)		10	50			
Sulphate (SO_4^{2-})		1,000	6,000		1,000	6,000
Chloride (Cl^-)		800	800			

[1] Determination of metal content: acid digestion and microwave assisted digestion in compliance with standard SFS-EN 13656 or digestion with aqua regia in compliance with standard SFS-EN 13657. For determining the leaching of harmful substances, the up-flow percolation test shall be used in compliance with draft standard CEN/TS 14405. For quality control purposes, the two-stage batch test in compliance with standard SFS-EN 12457-3 can also be used.

[2] Polychlorinated biphenyls, total quantity of congenerics 28, 52, 101, 118, 138, 153 and 180. For the determination of polychlorinated biphenyls (PCB), the method to be used shall comply with draft standard EN 15308

[3] Polycyclic aromatic hydrocarbons, total amount of compounds (anthracene, acenaphthene, acenaphthylene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, dibenzo(a,h)anthracene, phenanthrene, fluoranthene, fluorene, indeno(1,2,3-c,d)pyrene, naphthalene, pyrene, chrysene).

[4] hydrocarbon fractions C10-C40. Test method: EN 14039

[5] Dissolved organic carbon.

The development of the leaching criteria is not based on direct scenario-based risk assessments; they are rather adopted from other legislation and adjusted to the purpose.

Table: Limit values for utilisation of ashes from coal combustion.

Harmful sub-stance	**Limit value, mg/kg of dry matter Basic characterisations**			**Limit value, mg/kg of dry matter Quality control investigations[1]**		
	Content	Leaching (L/S = 10l/kg) Covered structure	Leaching (L/S = 10l/kg) Paved structure	Content	Leaching (L/S = 10l/kg) Covered structure	Leaching (L/S = 10l/kg) Paved structure
PCB[2]	1.0					
PAH[3]	20/404					
Hydrocarbons[4]		500	500			
DOC[5]		0.06	0.18			
Antimony (Sb)	50	0.5	1.5	50		
Arsenic (As)	3,000	20	60	3,000		
Barium (Ba)	15	0.04	0.04	15		
Cadmium (Cd)	400	0.5	3.0	400	0.5	3.0
Chrome (Cr)	400	2.0	6.0	400		
Copper (Cu)		0.01	0.01			
Mercury (Hg)	300	0.5	1.5	300	0.5	1.5
Lead (Pb)	50	0.5	6.0	50	0.5	6.0
Molybdenum (Mo)		0.4	1.2			
Nickel (Ni)	400	2.0	3.0	400	2.0	3.0
Vanadium (V)	2,000	4.0	12	2,000		
Zinc (Zn)		0.1	0.5		0.1	0.5
Selenium (Se)		10	50		10	50
Fluoride (F^-)		1,000	10,000		1,000	10,000
Sulphate (SO_4^{2-})		800	2,400		800	2,400

[1] Determination of metal content: acid digestion and microwave assisted digestion in compliance with standard SFS-EN 13656 or digestion with aqua regia in compliance with standard SFS-EN 13657. For determining the leaching of harmful substances, the up-flow percolation test shall be used in compliance with draft standard CEN/TS 14405. For quality control purposes, the two-stage batch test in compliance with standard SFS-EN 12457-3 can also be used.

[2] Polychlorinated biphenyls, total quantity of congenerics 28, 52, 101, 118, 138, 153 and 180. For the determination of polychlorinated biphenyls (PCB), the method to be used shall comply with draft standard EN 15308

[3] Polycyclic aromatic hydrocarbons, total amount of compounds (anthracene, acenaphthene, acenaphthylene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, dibenzo(a,h)anthracene, phenanthrene, fluoranthene, fluorene, indeno(1,2,3-c,d)pyrene, naphthalene, pyrene, chrysene).

[4] hydrocarbon fractions C10-C40. Test method: EN 14039

[5] Dissolved organic carbon.

France

In March 2011, the French organisation Sétra has published a new methodology guideline on the Acceptability of alternative materials for road construction – Environmental assessments, resulting from cooperation between ADEME, MEDDTL, Sétra, CETE, BRGM, INERIS, INSAVALOR and IFSTTAR (Sétra, 2011). The objectives of the guideline are (Chateau, 2011):

- To improve confidence in the use of alternative materials on environmental characteristics
- To propose set of criteria applicable whatever the alternative material
- To propose a tiered approach, both in terms of limit values and of test methods.

The tiered approach: The guide proposes limit values for basic characterisation. Compliance criteria shall be derived from the results obtained at the basic characterisation level. This approach has already been applied in Belgium (Flanders) for soil waste material (Quaghebeur et al. 2006, Nielsen et al., 2006). Except for first level for which compliance criteria are equal to characterisation criteria. For the basic characterisation the tiered approach is as follows:

First level: Use leaching test and compare to inert WAC in inert landfill. The results shall comply with the level 1 criteria (80%, 95 and 100% of the material stream shall comply respectively with 1 time, 2 times and 3 times the inert WAC – Level 1A, 1B and 1C in Table 5.3c and table 3 in Annex 3 of the French guide). Non-compliance with the criteria set in Annex 3, Tables 4 and 5 of the guide leads to the impossibility to use the material in road construction. For the intermediate cases, the second level shall be applied. The criteria are based on leaching tests for inorganic parameters and on total content for organic parameters. TDS or the set chloride/sulphate/fluoride is to be analysed. See table below.

Table: Level 1 criteria for leaching (Table 3 in Annex 3 of the Sétra guidance).

Parameter	**Quantity leached at L/S = 10 l/kg (NF EN 12457-2 or NF EN 12457-4)**		
	Limit values to be met by at least 80 % of the samples	**Limit values to be met by at least 95 % of the samples**	**Limit values to be met by 100 % of the samples**
	mg/kg dry matter	mg/kg dry matter	mg/kg dry matter
As	0.5	1	1.5
Ba	20	40	60
Cd	0.04	0.08	0.12
Cr total	0.5	1	1.5
Cu	2	4	6
Hg	0.01	0.02	0.03
Mo	0.5	1	1.5
Ni	0.4	0.8	1.2
Pb	0.5	1	1.5
Sb	0.06	0.12	0.18
Se	0.1	0.2	0.3
Zn	4	8	12
Fluorides	10	20	30
Chlorides*	800	1600	2400
Sulphates*	1000	2000	3000
TDS*	4000	8000	12000

*Concerning the chlorides, sulphates and total dissolved solids (TDS), the limit values for chlorides and sulphates can be considered met if the limit values for TDS are met.

Table: Absolute compliance required on content (Table 4 in Annex 3 of the Sétra guidance)

Parameter	**Limit values to be met by at least 80 % of the samples**	**Limit values to be met by 100 % of the samples**
	mg/kg dry matter	mg/kg dry matter
TOC (total organic carbon)	30000	60000
BTEX (benzene, toluene, ethylbenzene and xylenes)	6	
PCB (polychlorinated biphenyls, 7 congers: no 28, 52, 101, 118, 138, 153 and 180)	1	
THC (total hydrocarbons, C10-C40)*	500	
PAH (polycyclic aromatic hydrocarbons*	50	
Dioxines and furans**	10 ng I-TEQ$_{oms, 2005}$/kg dry matter	

*For use under roads (base or foundation course) or for surface layers (wearing layers or interlayers) the limit values associated with TOC, THC and PAH may be adapted, particularly to take into account hydrocarbon binders (TOC and THC) or the technology implemented (PAH). All modifications of limit values must be validated by the ministry in charge of the development of sustainable development, particularly within the framework of the development of guidance for utilisation.

**Only for alternative materials and road development partly or totally based on the use of waste from a thermal process.

Table: Absolute compliance required on leaching (Table 5 in Annex 3 of the Sétra guidance)

Parameter	**Quantity leached at L/S = 10 l/kg (NF EN 12457-2 or NF EN 12457-4)**
	mg/kg dry matter
As	2
Ba	100
Cd	1
Cr total	10
Cu	50
Hg	0.2
Mo	10
Ni	10
Pb	10
Sb	0.7
Se	0.5
Zn	50
Fluorides	150
Chlorides*	15000
Sulphates*	20000
TDS*	60000

*Concerning the chlorides, sulphates and total dissolved solids (TDS), the limit values for chlorides and sulphates can be considered met if the limit values for TDS are met.

Second level: Use percolation test and compare to the specific criteria developed for the use of granular material in road construction. Two types of uses have been distinguished: pavement (level 2A of Table 5.2c in Annex 3 of the guide) and shoulders/surrounding works that shall be covered by capping material (level 2B of Table 5.2c in Annex 3 of the guide). See table below.

Table: Level 2 criteria for leaching corresponding to two types of road construction scenarios (Table 6 in Annex 3 of the Sétra guidance).

Parameter	Scenario: "Sublayer or paved shoulder"*	Scenario: "Embankment technique or covered slopes"**
	Accumulated leached quantity at L/S = 10 l/kg (NF CEN/TS 14405)	**Accumulated leached quantity at L/S = 10 l/kg (NF CEN/TS 14405)**
	mg/kg dry matter	mg/kg dry matter
As	0.8	0.5
Ba	56	28
Cd	0.32	0.16
Cr total	4	2
Cu	50	50
Hg	0.08	0.04
Mo	5.6	2.8
Ni	1.6	0.8
Pb	0.8	0.5
Sb	0.4	0.2
Se	0.5	0.4
Zn	50	50
Fluorides	60	30
Chlorides	10000	5000
Sulphates	10000	5000

*Covered by an alleged impermeable surface layer (asphalt, cover, coated surface, concrete, roads with sealed joints) and with a minimum slope of 1%.

**Covered by at least 30 cm of natural materials (including arable soil), with a minimum slope of 5% on top of this cover to limit the infiltration of water.

Third level: If the two previous levels have not been complied with, a possibility is offered to the material producer to perform a specific risk assessment study, based, taking into account the same principle that were used to develop the specific criteria presented above. The specific road construction criteria have been presented by Bellenfant and Guyonnet (2009). Their determination is based on the calculation of attenuation factors for specific road scenario in terms of construction and exposure conditions, following the same basic principles that were used in the calculation of the EU WAC for landfilling (and as proposed in this report for calculation of limit values for EoW criteria).

Germany

Tables 5.2c and 5.3c show the old German leaching limit values for application according to the Länderarbeitsgemeinschaft Abfall (LAGA, 2004) which appear still to be used by some of the Federal States. The LAGA defines three classes of use of soil and inorganic aggregates, Z0 (unrestricted use), Z1 (use with some restrictions) and Z2 (restricted use with defined technical protection measures) with increasingly higher limit values for leaching and content of primarily inorganic substances. The limit values have not been based on risk assessment but have been determined by convention. Germany is, however, preparing new legislation on the use of secondary construction materials based on leaching and risk assessment. The leaching limit values are material-specific and refer to specific application and receptor scenarios. However, basically, the principles of methodology applied are compatible with the methodology proposed in this study for the development of leaching limit values for EoW for waste-derived aggregates. Due to the large number of materials and scenarios, the proposed new German limit values are not listed in Tables 5.2 and 5.3 in the main report.

The following description of the methodology applied in the development of the new German criteria for utilisation of waste aggregates in construction work has been copied from Susset and Maier (2011):

Parallel to the legislative procedure of the German Federal Ministry of Environment (German Federal Decree for the Use of Mineral Recycling Materials and Amendment of German Federal Soil Protection

Decree) and with respect to the results of the German joint research project “Sickerwasserprognose” of the Federal Ministry of Research and Technology (BMBF) a strong demand exists for the improvement of existing methods und regulation systems and for the establishment of new regulatory concepts. For that purpose the LANUV NRW evaluated the results of the BMBF-joint research project “Sickerwasserprognose” with respect to practical proposals for regulations. These were further developed within this follow- up project of the Centre for Applied Geosciences of University of Tubingen (ZAG).

Based on the results of studies in Germany which focused on contaminant leaching from various materials and reactive solute transport in the unsaturated soil zone to identify the key factors for groundwater risk assessment, Susset and Leuchs (2008) developed new and improved existing methods for the new regulatory concept in the upcoming “Decree for the Requirements of the Use of Alternative Mineral Building Materials in Technical Constructions and for the Amendment of the Federal Soil Protection and Contaminated Sites Ordinance" of the German Federal Ministry of Environment, which was publishes as a first draft in the end of the year 2007. The new concept aims at a holistic and scientifically sound assessment of the use of mineral recycling materials (e.g. mineral waste, soil materials, slag and ashes, recycling products, etc.) in technical constructions (e.g. road dams) and permanent applications (e.g. backfilling and landscaping) which is based on a mechanistic understanding of leaching and transport processes. Fundamental for risk assessment are leaching standards for the mineral recycling materials.

For each application of mineral recycling materials specific maximum concentrations of a substance in *LS* (liquid- to solid ratio) 2-eluates, which are suitable to describe the seepage water at the bottom of an application, were calculated. Technical boundary conditions and policy conventions derived from the “German precautionary groundwater and soil protection policy” were accounted for in order to prevent adverse effects on the environmental media soil and groundwater. This includes the rapid concentration decline of highly soluble substances (e.g. chloride and sulphate), retardation or attenuation of solutes, accumulation of contaminants in sub-soils and the hydraulic properties of recycling materials used for specific applications. To decide whether the use of a mineral recycling material is possible in a specific application, the leaching qualities were evaluated based on column percolation tests with various samples to derive material values to classify material quality and compared with application-specific maximum concentrations.

In the upcoming federal decree this concept is realized using detailed tables, which classify the quality of mineral recycling materials and demonstrate potential applications. A quality assurance system will be mandatory which defines specific testing programs (material properties and limit concentrations to be tested, number and schedule of testing) for the different mineral recycling materials using standardized methods (column percolation test).

Within the follow-up project, which is reported here, several technical construction scenarios for railway tracks were modelled and street dam scenarios were re-modelled based on improved harmonized input parameters derived in close collaboration with the Federal Ministry of Transport Building and Urban Development and the Federal Highway Research Institute. The media related application values were calculated or adjusted for these constructions and adapted to new filter capacity criteria of soils, background values as target values in the seepage water and adjusted sorption isotherms for herbicides and recalculated distribution coefficients of vanadium based on an established linearization method of sorption isotherms. The work was done in close collaboration with the related Working Groups of the Federal States and the Federal Institute for Geosciences and Resources and the Federal Environmental Agency. More than 700 new datasets of *LS* 2-eluates of column test and partly batch tests were evaluated to derive and adapt the material values for the different mineral recycling materials and to derive recycling quotas for impact assessment with regard to the environmental requirements of the upcoming German Recycling Degree. All these further developments are implemented in the upcoming Draft of the Recycling Degree in 2011.

Italy

According to Decree 22/97[9] the waste management system is based on: a) prevention of waste generation (to be developed in national and local waste plans); b) material and energy recovery from waste. The decree established that permits for incineration plants should be granted only if the plant had an energy recovery system and that waste disposal must be reduced as much as possible. The issuing of decree 22/97 gave input to many actions for waste prevention and recycling in Italy (Böhmer et al., 2008).

At local level several agreements have been signed in the field of agricultural waste and C&D waste.

The Ministerial Decree of 5th of February 1998[10] stipulates the recovery of non-hazardous waste. Construction and demolition waste, ashes and slags are covered by the decree. The table below shows leaching limits defined for the recovery of waste.

The specified leaching test method is the single step batch leaching test EN 12457-2 performed at L/S = 10 l/kg on material < 4 mm (with or without size reduction).

There is no information on whether or not the limit values have been set by convention or are based on risk assessments.

Table: Leaching limits obtained for different recovery activities in Italy (leaching test EN 12457-2).

Substance/parameter	Unit of measurement	Limit value
Nitrates NO_3	mg/l	50
Fluoride F	mg/l	1.5
Sulphate SO_4	mg/l	250
Chlorides Cl	mg/l	100
Cyanides CN	µg/l	50
Barium Ba	mg/l	1
Copper Cu	mg/l	0.05
Zinc Zn	mg/l	3
Beryllium Be	µg/l	10
Cobalt Co	µg/l	250
Nickel Ni	µg/l	10
Vanadium V	µg/l	250
Arsenic As	µg/l	50
Cadmium Cd	µg/l	5
Chromium total Cr	µg/l	50
Lead Pb	µg/l	50
Selenium Se	µg/l	10
Mercury Hg	µg/l	1
Asbestos	mg/l	30
COD	mg/l	30
pH	-	5.5 - 12.0

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[9] Ministry of Environment (1997)

[10] Ministry of Environment (1998)

The Netherlands

In the Netherlands, the utilisation of materials for construction is regulated with respect to environmental and health protection without distinction between waste materials and products. The environmental protection criteria have been developed on the basis of scenario-based risk assessments, first under the Dutch Building Materials Decree (BMD, 1995 to 2008) and now under the Dutch Soil Quality Decree (SQD) which replaced the BMD in 2008. The methodologies used to develop the leaching limit values applied in the BMD and the SQD are described in the following.

The Dutch Building Materials Decree (1995-2008)

From 1995-2008, the potential impact of construction materials on the environment was regulated by the Dutch Building Materials Decree (BMD), the predecessor of the current Soil Quality Decree (SQD). The BMD specifies the environmental quality criteria for the application of stony materials (including excavated soil) in construction, and does not distinguish between primary, secondary and waste materials. The basis of this regulation is described by Eikelboom et al. (2001). The principles regarding the regulation of leaching from construction materials in the current SQD find their basis in the BMD. Internationally, the BMD is frequently seen as a guiding example for a regulatory framework for controlling leaching from construction materials, and it is still frequently cited both in this report and elsewhere. For these reasons, this section outlines the principles of the BMD.

Definitions

The BMD is limited to stony materials that are utilised in works outside. According to the definition in the BMD, stony materials consist of a minimum of 10% silicon, calcium or aluminium. Examples of such materials are concrete, asphalt, asphalt aggregate, clay, sand/sieve sand, roof tiles, tiles, concrete and mixed aggregate bricks, tarry asphalt aggregate, earth and dredging sludge, fill sand, bituminous roof coverings, and bottom ash from waste incineration plants. Wood and straw are not stony and not covered by the Decree, and neither are plastics and metals. Although sheet glass and metallic aluminium are covered by the above definition of “stony”, these materials are excluded from the scope of the BMD. An important feature of the BMD is that it does not distinguish between the use of primary and secondary building materials. Newly manufactured products or newly extracted raw materials are considered to be primary materials, while secondary materials originate from demolished constructions or from industry. The same rules apply to primary and secondary building materials and, hence, all stony materials (new and used) are required to meet the same conditions.

A work according to the definition in the BMD is an earthwork, road building work, hydraulic engineering work or construction work. Examples of works include dykes, additions to or raising of the soil level, viaducts, harbour basin fills, riparian works, fills, aqueducts, houses, bridges, sound barriers, offices, quays, and roads. The Decree applies to building materials that may come into contact with rainwater, groundwater or surface water. Building materials used in outside walls, roofs, foundations and road embankments are covered by the Decree, building materials used in inside walls are not.

Categories

The guiding principle of the BMD is that pollution of the soil, groundwater and surface water should remain within precisely defined bounds. It is necessary to avoid more than a given (marginal) amount of a harmful substance getting into the environment per unit of time (measured in years) as a result of the use of a building material containing that harmful substance. Usually, the building material will contain or release so little of a harmful substance that tests will show that pollution of the environment will in all likelihood remain within the bounds set. In some cases additional protective measures will be required to prevent excessive pollution. In that case, use of the building material will only be permitted if these measures are taken to protect the soil. When the concentration or leaching of harmful substances is above the defined bounds, the material is totally banned from utilization in (construction) works.

Complying with the above principle, the Building Materials Decree draws a distinction between a number of categories of building materials. The principle grouping is into category 1 and category 2 building materials. Besides this main grouping, three other special categories of building materials are defined in the BMD, i.e. earth, bottom ash from waste incineration plants and tar-rich asphalt aggregate. The distinction between the categories of building materials is made on the basis of their composition and leaching behaviour. The leaching behaviour is translated into what is known as an “immission value” (see below). Composition and immission values are established through testing and the category is determined on the basis of the values established by means of the tests.

Category 1 building materials are materials of which the composition and immission values for the various substances do not exceed those stipulated in the BMD when the materials are used in a work. Use of these building materials is permitted without measures, or additional measures, being required to protect the environment. Category 2 building materials are building materials of which the composition values do not exceed those stipulated in the Building Materials Decree, while their immission values would if additional isolation measures were not taken. Materials that do not fall into category 1 or category 2 may not be used as a building material. Figure 1 shows the grouping for category 1 and category 2 building materials.

An extra category has been created in the Building Materials Decree for earth, i.e. clean earth, for which a composition value (Sg1) has been defined. Earth that remains below this value is considered “clean earth”. Composition value 2 (Sg2) gives the value above which earth may no longer be used as a building material (see Figure 2).

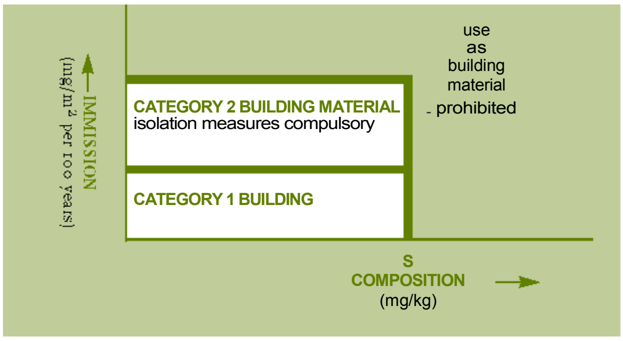

Figure 1.
Categorisation of building materials.

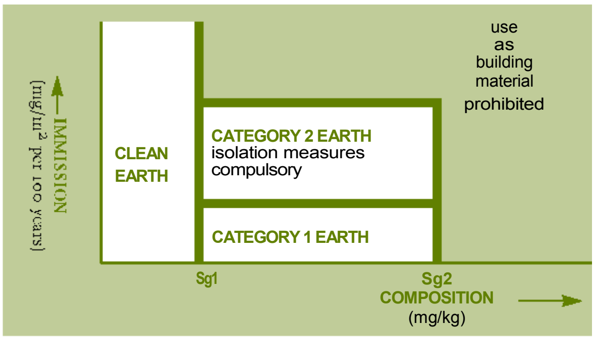

Figure 2.
Categorisation of earth.

Besides the main grouping into categories for building materials and earth, there are two more (temporary) special categories. These have been introduced temporarily to allow the regular reuse of bottom ash from waste incineration plants and of tarry asphalt aggregate to continue. These special categories have been created to ensure that some of the bottom ash from waste incineration plants and tarry asphalt aggregate satisfies the requirements of the Building Materials Decree. Special regulations for protecting the soil apply to the special categories.

Isolation measures

Measures to protect the soil (isolation) must be taken for category 2 building materials and the special categories, e.g. use at least 0.5 m above the highest mean groundwater level (to prevent contact with groundwater), and provisions to isolate the materials from contact with rainwater. The owner of a work containing these building materials is responsible for the inspection and maintenance of these isolation facilities, to ensure they continue to function properly. The ministerial decision to the Building Materials Decree contains details of the requirements for soil-protection facilities.

Emission and immission values

The immission value depends on two factors: the leaching behaviour of a material and its proposed use. The difference between leaching and immission is explained in Figure 3. The leaching (emission) is a fixed value; the immission depends each time on the circumstances, e.g. the temperature, degree of contact with water, presence of isolation measures and the height (thickness of the layer) at which the building material is used. The immission value expresses how much of a substance will in practice actually end up in the soil.

The immission value is established in two stages. First, the leaching from a building material (emission value) is measured in a laboratory using standard leaching tests (see below). The emission values obtained in the laboratory are then converted with the aid of formulae into expected immission values in practice. These relationships are further detailed in the description of the new Soil Quality Decree below.

Immission values have only been established for inorganic substances. No suitable leaching tests are available as yet for organic substances such as polycyclic aromatic hydrocarbons (PAHs), mineral oils, pesticides and PCBs. Until such tests are developed, composition values are all-decisive for organic compounds and there are no critical immission values.

The regulations governing exemption from the composition and immission values of the building materials decree were published in the Netherlands Government Gazette, No. 126, of 6 July 1999. The values given in these regulations replace the values stipulated in Appendix 1 and Appendix 2 of the Decree (as published in the Bulletin of Acts, Orders and Decrees No. 567 of 23 November 1995), retroactive to 1 July 1999.

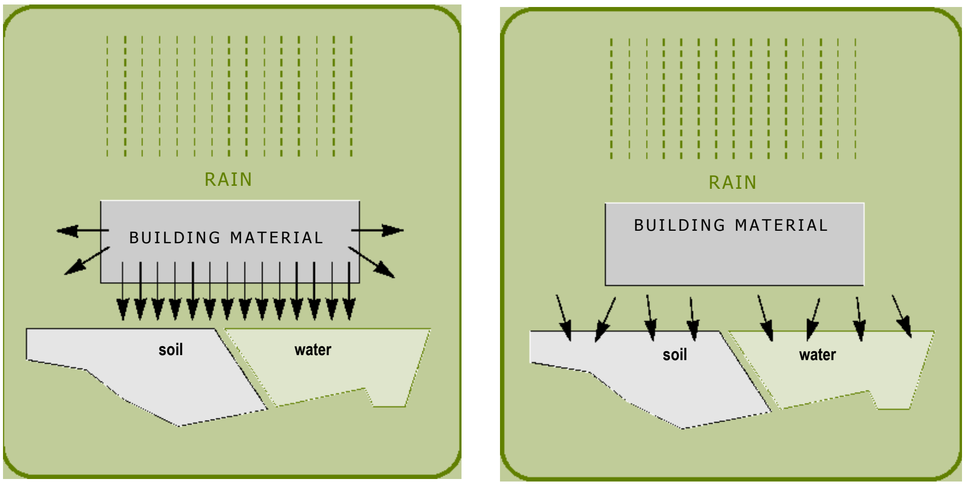

Figure 3.
Leaching: contact with rain or groundwater causes substances to be released from a building material (left); Immission: as a result of leaching, substances released from a building material get into the soil or water (right)

Utilisation of building materials in surface water

The Building Materials Decree also covers the use of building materials in surface water, to protect the aquatic sediment. For this purpose the Building Materials Decree is also based on the Pollution of Surface Waters Act (WVO). The term “surface water” also covers the floodplains. Examples of the use of building materials in surface water include bridges, quays and dykes. There are a number of differences in respect to the use of building materials on land, with regard to procedural requirements (including the reporting of the use of the building materials) that the owner or principal of a work has to comply with.

Proving the quality of building materials

The owner or principal of the construction or other work must provide sufficient proof of the environmental quality of each building material used (duty to provide information). This is necessary to be able to prove into which category the building material falls. Owners and principals will therefore require foreign manufacturers to prove the quality of their building materials. Details on what information is considered sufficient proof of environmental quality are outlined by Eikelboom et al. (2001).

Test protocols

The Ministerial Decision on the Building Materials Decree describes how the various tests are to be carried out. Protocols have been drawn up for specific tests. The test protocols of the Building Materials Decree contain detailed instructions for all actions required to test a building material. The ministerial decision includes user protocols for clean earth and building materials, enforcement protocols for clean earth and enforcement protocols for contaminated earth and building materials. The competent authority can use the enforcement protocols to prove with a large degree of reliability that the composition and immission values of the Building Materials Decree have been exceeded. For the testing of the leaching of substances, the BMD prescribes for granular materials the percolation test NEN 7343 (similar to CEN/TS 14405 for waste, ISO/TS 21268-3 for soil and CEN/TC351/TS-3 for construction products; see Table 3.3 in the report). The diffusion test NEN 7345 is prescribed for monolithic materials (similar to CEN/TS 15863 for waste and CEN/TC351/TS-2 for construction products; see Table 3.3 in the main report).

Approach used for the derivation of emission (leaching) limits for granular construction products in the Dutch Soil Quality Decree

Introduction

From 1995-2008, the Dutch Building Materials Decree (BMD) has regulated the potential impact of construction materials on the environment. The decree specifies the environmental quality criteria for the application of stony materials (including excavated soil) in construction, and does not distinguish between primary, secondary and waste materials. The basis of this regulation is described by Eikelboom et al. (2001). After 10 years of experience with the BMD, a revision of the Decree was found necessary, a.o. for reasons of costs and transparency following the publication of several amendments with exemptions.

The aim of the revision, currently the Soil Quality Decree that came into force in July 2008, was to develop a simplified and more transparent regulation containing a consistent set of emission limit values, which warrant the protection of soil and groundwater quality with minimal restrictions for the re-use of (secondary) materials. The standard compliance test for the granular materials is the percolation test NEN 7343 (NEN, 1995), which is similar to CEN/TS 14405, the limit values being based on the cumulative amount leached at a liquid/solid ratio of 10 L/kg. The vast amount of quality control data that was obtained with this test in the previous years was used to assess, for individual construction materials, the potential economic consequences of the newly calculated emission limit values. For some substances, such policy-based considerations have led to formally published emission limits that deviate from the values that comply with the selected environmental quality criteria (see below).

The full approach used for the derivation of the emission (leaching) limits for granular construction products in the Dutch Soil Quality Decree (SQD) is described in detail by Verschoor et al. (2006, in Dutch) and in English, in more condensed form, by Verschoor et al. (2008). An outline of the approach is given below.

General approach

The emission limit values have been calculated in six steps that are outlined in Figure 1:

1. A generic (i.e. not material-specific) source term was derived from the average release pattern for each of the inorganic substances, based on a large database of quality control data for construction products obtained with the percolation test NEN 7343 (de Wijs and Cleven, 2008).
2. Geochemical modelling was used to compute substance concentrations variable with time and depth of the soil profile. A model setup in the modelling platform ORCHESTRA (Dijkstra et al., 2009) was selected to form the basis of the finally published emission limits (see below)

3. The resulting concentrations in the soil and groundwater at the point of compliance (POC) were compared with the selected compliance values (quality criteria).
4. The source term was adjusted such that computed soil and groundwater concentrations exactly equal the compliance values in the soil and groundwater at the POC. The adjusted source term represents a critical release. Two different source terms are obtained; one derived from groundwater compliance values and one from soil compliance values.
5. The adjusted source terms were transformed to emission limit values.
6. The most stringent emission limit value (based on either soil or groundwater quality criteria) was selected as being protective for both the soil and (ground)water environment.

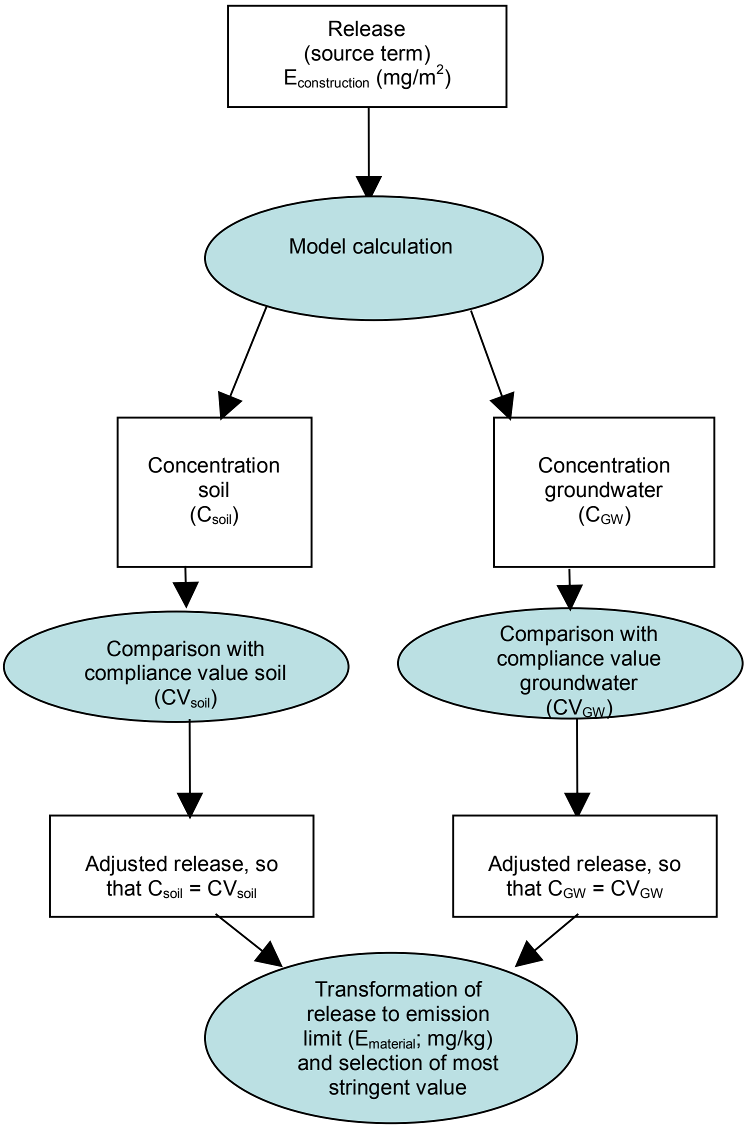

Figure 1
Outline of the calculation of emission limits for granular construction products in the Dutch Soil Quality Decree. See Equation (1) for relation between release (mg/m^2) and emission limit (mg/kg). Modified from Verschoor et al. (2008).

Environmental quality criteria

In the derivation of emission limits for inorganic substances, their Maximum Permissible Concentrations (MPC) have been used as the environmental quality criteria (compliance values). At the MPC level, ecosystems are not significantly affected by chemical exposure. For inorganic substances occurring at natural background concentrations, the MPC is transformed to a corresponding maximum permissible addition (MPA), using MPC = MPA + background (see Verschoor et al., 2008, and references therein). The MPA values for the regulated inorganic substances are listed in Table 1. No MPA values are available for Cl, Br, F and SO4 in soil. As a consequence, emission limit values for these substances are solely based on their effect on groundwater

Table 1

Maximum permissible addition (MPA) values used in the derivation of emission limits for granular construction products in the Dutch Soil Quality Decree

Component		**MPA_{soil} (mg/kg)**	**$MPA_{groundwater}$ (µg/l)**
Antimony	Sb	0.53	6.2
Arsenic	As	0.9	24
Barium	Ba	180	29
Cadmium	Cd	0.79	0.34
Chromium	Cr	0.38	8.7
Cobalt	Co	2.4	2.6
Copper	Cu	3.4	1.1
Mercury	Hg	1.9	0.23
Lead	Pb	55	11
Molybdenum	Mo	39	29
Nickel	Ni	0.26	1.9
Selenium	Se	0.11	5.3
Tin	Sn	34	20
Vanadium	V	1.1	3.5
Zinc	Zn	16	7.3
Bromide	Br	*n.a*	8000
Chloride	Cl	*n.a.*	200000
Fluoride	F	*n.a.*	1500
Sulphate	SO4	*n.a.*	100000

n.a. = not available

Source term

The release pattern of substances from the granular materials in constructions was approximated by equation 1:

$$I_{soil} = E_{construction} = \frac{E_{material} \cdot d_b \cdot h \cdot \left(1 - e^{-\kappa \cdot \frac{N_i \cdot Y}{d_b \cdot h}}\right)}{\left(1 - e^{-\kappa \cdot 10}\right)} \quad \text{(mg.m}^{-2}\text{ in Y years)}$$

in which:

I_{soil} = source term (mg/m2 per Y years);
$E_{construction}$ = emission from a construction (mg/m^2 per Y years);
$E_{material}$ = measured emission of material in a column test at L/S =10 (mg/kg);
d_b = bulk density of a material (default 1550 kg/m^3);
h = height of material in a construction (m);

k = kappa, rate constant for release;
N_i = effective infiltration of rain (mm/years);
Y = time (years)

The constants (kappa values) that have been used for the release rate of the individual components in the source term are listed in Table 2.

Table 2
Kappa values used for the source term used in the derivation of emission limits for granular construction products in the Dutch Soil Quality Decree.

Substance		**kappa (kg/l)**
Antimony	Sb	0.04
Arsenic	As	0.01
Barium	Ba	0.17
Cadmium	Cd	0.32
Chromium	Cr	0.25
Cobalt	Co	0.13
Copper	Cu	0.27
Mercury	Hg	0.14
Lead	Pb	0.18
Molybdenum	Mo	0.38
Nickel	Ni	0.26
Selenium	Se	0.16
Tin	Sn	0.1
Vanadium	V	0.04
Zinc	Zn	0.28
Cyanide		0.225
Bromide	Br	0.508
Chloride	Cl	0.65
Fluoride	F	0.26
Sulphate	SO4	0.33

Modelling scenario and boundary conditions
For the granular materials a scenario was selected with a construction height of 0.5 m, with and without isolating measures, for which separate emission limits have been calculated and published in the SQD. For isolated constructions an infiltration of 6 mm/year was assumed and for open constructions an infiltration of 300 mm/year. Average kappa values, i.e. rate constants for the release of the substances as obtained from column experiments, have been derived from a large database with quality control data from all different types of granular construction materials.

The simulation time was set at 100 years. The soil profile consisted of 1 m unsaturated soil and 1 m saturated soil. The average groundwater level is 1 m below soil surface (bss), being an average for the Dutch situation. Modelled (daily) groundwater concentrations were calculated to average annual concentrations over the upper 1 m layer of the groundwater. The maximum annual concentration within a period of 100 years was used as the groundwater endpoint for derivation of the emission limit value. The same approach was followed for the concentrations in the unsaturated soil. The annual average concentration over 1 m soil after 100 years was used as the soil endpoint for the derivation of the emission limit values. In order to represent a wide range of conditions in The Netherlands, average sand, clay and peat soil have been selected from a large database with 465 real Dutch soil profiles. Results for the most sensitive system (in most cases, but not always, the sandy soil) were used for the final emission limits.

The geochemical model parameters are outlined in Verschoor et al. (2008) and presented in detail in Dijkstra et al. (2009).

Emission limits

The final emission limits that have been published in the Dutch regulation (Regeling bodemkwaliteit; Staatscourant 20/12/2007, 247, p 67) as part of the Soil Quality Decree are shown in Table 3. The assessment of the economic feasibility appeared to be a major and in many cases a decisive factor in the (policy-based) selection of the final published emission limit values. The table does also show the (ORCHESTRA-based) values that are fully compliant with the maximum permissible addition (MPA) values in soil and groundwater as shown in Table 1. In cases where the regulatory values are higher than those calculated on the basis of compliance with the environmental quality (MPA) criteria, the level of protection is lower than the 90% of situations assumed from the choice of the (most sensitive) soil types. In cases where regulatory values in the previous Buildings Materials Decree (1999) where lower and not hindering economic feasibility (e.g. for Cd, Pb, Hg), these more stringent values have been adopted in the Soil Quality Decree.

Table 3

Emission limits ($E_{material}$) in mg/kg, from the Dutch regulation (Regeling bodemkwaliteit; Staatscourant 20/12/2007, 247, p 67) as part of the Soil Quality Decree. Limit values are specified for granular construction materials in "open" applications (infiltration rate of 300 mm/year) and in applications with isolating measures (infiltration rate of 6 mm/year). The shaded column shows the (ORCHESTRA – based) limit values that are fully compliant with the maximum permissible addition (MPA) values shown in Table 1 (i.e. without policy-based adjustments).

Component		MPA-compliant $E_{material}$, granular, open (mg/kg)	$E_{material}$, granular, open (mg/kg)	$E_{material}$, granular, isolated (mg/kg)
Antimony	Sb	0.03	0.16	0.7
Arsenic	As	0.45	0.9	2
Barium	Ba	1.6	22	100
Cadmium	Cd	0.28	0.04	0.06
Chromium	Cr	0.63	0.63	7
Cobalt	Co	0.54	0.54	2.4
Copper	Cu	3.4	0.9	10
Mercury	Hg	0.79	0.02	0.08
Lead	Pb	77	2.3	8.3
Molybdenum	Mo	64	1	15
Nickel	Ni	0.44	0.44	2.1
Selenium	Se	0.15	0.15	3
Tin	Sn	39	0.4	2.3
Vanadium	V	0.76	1.8	20
Zinc	Zn	5.5	4.5	14
Bromide	Br	0.004	20	34
Chloride	Cl	24	616	8800
Fluoride	F	484	55	1500
Sulphate	SO4	9.4	1730	20000

Spain

In Spain, there is no general legislation on pollutant limit values for aggregates as a construction product further to the EU regulation on construction products. Aggregates as a product can be put on the market only after they show the required EC label.

Decree 956/2008, relative to the Instruction for the reception of cements in Spain (RC-08), defines the chemical requirements that these waste-derived aggregates must meet to be recycled as a valid clinker in cements (RC/08: http://www.boe.es/diario_boe/txt.php?id=BOE-A-2008-10442&lang=en). Instruction RC-08 also provides the standardized procedures for performing chemical analyses on these aggregates as components of cements. For example, this Instruction requires the Standard UNE-EN 451-1/2006 for testing the chemical composition of coal fly ashes. The values obtained in these analyses must not exceed the limit values giving in the Standard UNE-EN 450-1/2006 (Table below). Furthermore, Standard UNE-EN 197-1/2000 requires a content of amorphous SiO_2 in silica fume not less than 85% if it is used in cements.

TABLE Chemical limit values for acceptance of cements (RC-08)

Chemical parameter:	**Limit value (mass %)**
Chloride	0.10
CaO free	2.6
CaO reactive	11.0
SiO_2 reactive	22
H_2S	3.5
$SiO_2 + Al_2O_3 + Fe_2O_3$	65
Alkali total content	5.5
MgO	4.5
Soluble phosphate	110

Spanish Royal Decree 1247/2008, relative to the Instruction of structural concrete (EHE-08), allows the manufacture of concrete using cements that incorporate waste-derived aggregates as specified in RC-08. The EHE-08 also allows the use of air-cooled blast furnace slags, removed soils and wastes from demolition of cement/concrete structures as arids, as long as they meet the mixing conditions required in Annex 13 and the required properties of this instruction. (EHE/08: http://www.fomento.gob.es/MFOM/LANG_CASTELLANO/ORGANOS_COLEGIADOS/CPH/instrucciones/EHE_es/default.htm?lang=en)

Water protection is also guarantied through extensive water legislation existing in Spain:

- Legislative Royal Decree 1/2001. Water Law.
- Royal Decree 140/2003. Quality of water for human consumption.
- Royal Decree 1341/2007. Quality of bathing waters.
- Ministerial Order of December 16, 1988. Protection of fish life.
- Royal Decree 1620-2007. Reuse of treated waters.
- Royal Decree 509-1996. Treatment of urban waste waters.
- Royal Decree 995/2000. Water quality objectives for certain substances.
- Ministerial Order MAM/85/2008. Technical criteria for determining the environmental impact of contaminated waters.

There are no general requirements regarding use, including possible conditions/restrictions, at national level. Yet, there are some regulations concerning technical and functional (but not environmental) specifications for certain types of activities where material can be recycled in situ, e.g. in demolition and recycling of road pavements. See for instance:

- Recycled asphalt pavements (http://www.cedexmateriales.vsf.es/view/ficha.aspx?idresiduo=43&idmenu=44)
- Recycled concrete pavements (http://www.cedexmateriales.vsf.es/view/ficha.aspx?idresiduo=28&idmenu=29)

Several regions in Spain (Comunidades Autónomas) have enacted regional regulations on the recovery and use in the respective region of slags from steel production in electric arc furnaces:

- Comunidad Autónoma del País Vasco: Decreto 34/2003 (http://www.euskadi.net/bopv2/datos/2003/02/0301186a.pdf)
- Comunidad Autónoma de Cantabria: Decreto 104/2006 (http://boc.cantabria.es/boces/verAnuncioAction.do?idAnuBlob=105783)
- Cataluña: Decreto 32/2009

In regional legislation on slags, leaching-related criteria have been set for inorganic substances. Only in the legislation in Cantabria, limits for leaching of DOC and phenol index are also established.

Regional regulations on slags establish allowed uses of the recovered material and technical conditions or limitations for those uses (e.g. maximum layer widths where slags are used, impermeable layers on top or beneath them, distance to groundwater, etc). For examples on regional regulations citing conditions/restrictions on the use of certain waste-derived aggregates (slags), see:

- Article 5 and Annex III in Decree 34/2003 of the Basque Country
- Article 7 and Annex I in Decree 104/2006 of Cantabria
- Article 7, Article 8 and Annex II in Decree 32/2009 of Cataluña

According to the information on the studies which served as a base for the regulation adopted in the Basque Country on slags, uses and limitations established in this regulation derive from an evaluation model, which mainly consist of a scenario-based risk/impact assessment.

The regulation on slags in the Basque Country follows the model of the Building Material Decree of The Netherlands, which is based on the source-pathway-receptor principle. Limits are based on the composition of a reference soil, allowing an increase of 1% on the background level in 100 years. Surface and groundwater protection is taken into account through technical conditions or the above cited limitations.

Sweden

At present, there are no reliable statistics on the amount of recycled aggregates, including C&D waste in Sweden, but it appears to be of the order of 1 to 3 million tonnes per year. The amount of crushed concrete recycled appears to be approximately 1 million tonnes per year. About 90 % is used in unbound applications. The use of waste for construction purposes is an environmentally hazardous activity under the Ordinance on Environmentally Hazardous Activities and Public Health (SFS 1998:899). Depending on the risk, the activity must be notified to the municipal council or licensed by the county administrative board. The Swedish EPA provides guidance to supervisory authorities on waste recycling in construction works and may in some cases take part in the permitting process. The Swedish EPA has published guidance in a handbook for utilisation of waste in construction works (. The handbook gives guidance on utilisation of waste as construction material in a safe manner for environment and human health. Legislation that applies for utilisation of waste as construction material and the relation to the national environmental objectives is described. The handbook provides guidance for the supervision authorities when handling notifications and applications for waste utilisation and it describes necessary information for the assessment. The handbook also provides guidance on what can be considered as a pollution risk that is less than minor when it comes to waste recycling in construction works. Pollution levels for "less than minor risk" are presented in the handbook - when there are no restrictions for use and that no notification to the municipal board is necessary. Levels are also presented for utilisation when the waste is used in the top cover of a landfill. Levels are presented for content as well as leaching properties for 13 substances that are often the most critical ones in waste. Guideline for "less than minor risk" values are strict (based on natural background values for some phase-out substances) so that the use does not result in new contaminated sites or that contaminants are leaching where it cannot be controlled in the future Swedish EPA has accounted for these guideline values as an input to “end of waste” criteria in the Austrian Aggregates Case Study. These guideline values do not apply to bound materials e g asphalt pavements.

The table below shows the limit values for total content for free use and use as landfill cover, respectively. The next table shows the calculated leaching limit values for free use, based on drinking water criteria and surface water criteria, respectively, using a risk- and scenario-based methodology based on the same fundamental principles as the methodology used to calculate the EU WAC for landfilling (and as proposed in this study for development of leaching limit values for EoW for aggregates). The values actually chosen as limit values are shown in Tables 5.2 and 5.3 in the main report.

Table: Limit values for total content of inorganic substances.

Substance	**Limit value for free use (mg/kg**	**Limit value for use as landfill cover (mg/kg)**
As	10	10
Cd	0.7	1.5
Cr total	40	80
Cu	40	80
Hg	0.3	1.8
Ni	35	70
Pb	60	200
Zn	120	250

Table: Leaching limit values calculated for free use (CEN/TS 14405).

Substance	**Leaching limit value based on ingestion of drinking water (mg/kg)**		**Leaching limit value based on effects on surface water bodies (mg/kg)**	
	L/S = 0,1 l/kg	L/S = 10 l/kg	L/S = 0,1 l/kg	L/S = 10 l/kg
As	0.011	0.10	0.039	0.34
Cd	0.020	0.04	0.01	0.02
Cr total	0.33	1.52	0.24	1.11
Cu	0.33	1.11	0.24	0.81
Hg	0.002	0.02	0.001	0.011
Ni	0.11	0.35	0.66	2.17
Pb	0.051	0.18	0.31	1.1
Zn	1.16	3.9	1.71	5.72
Chloride	75	130	1650	2890
Sulphate	69	200	760	2230

The figure below shows some of the considerations behind the development of the Swedish guidance criteria for beneficial use of waste aggregates.

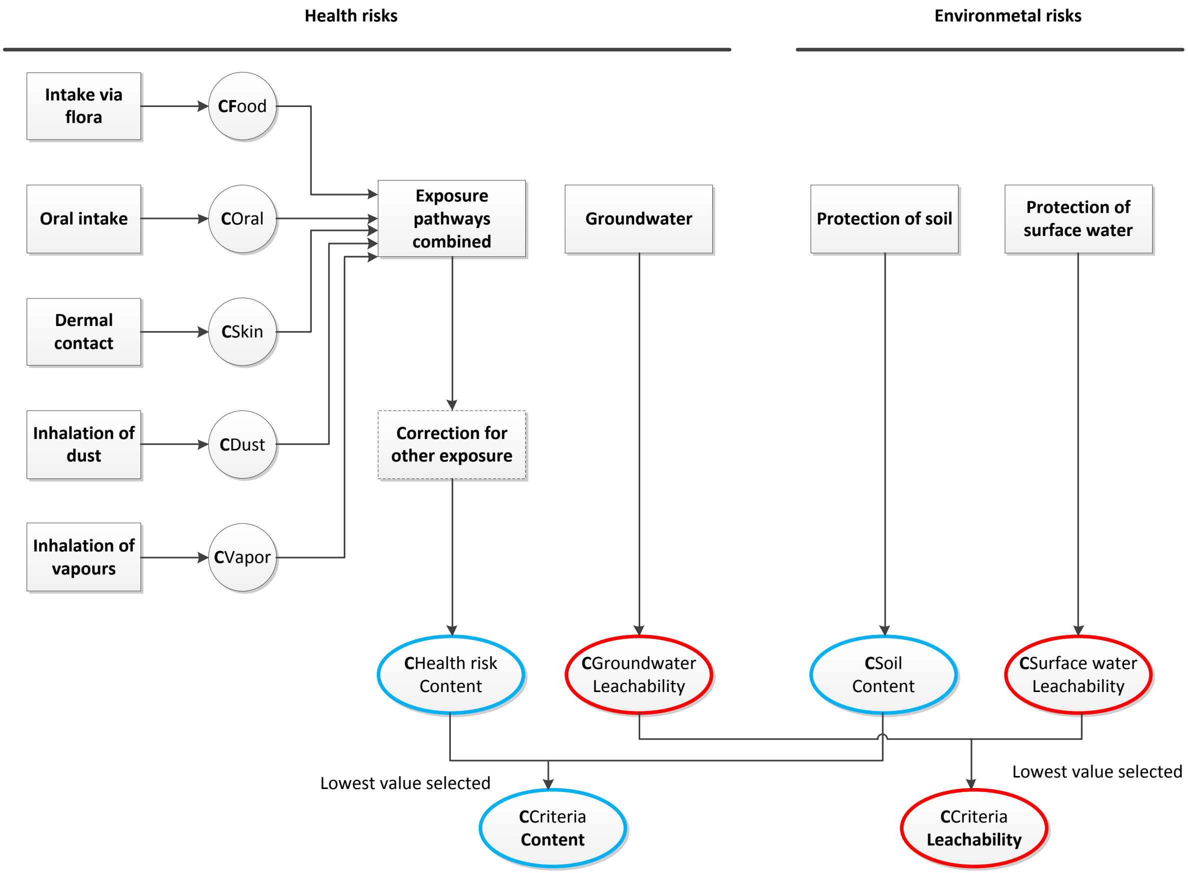

Figure: Illustration of the strategy behind the development of Swedish criteria for beneficial use of waste materials (after Swedish EPA (2010)).

United Kingdom

The United Kingdom is the only EU Member State that is currently defining national EoW criteria for waste-derived aggregates with reference to the Waste Framework Directive. Under the UK Environmental Protection (Duty of Care) Regulations[11], decisions as to whether residues are not waste any more are made by the Environment Agency on a case-by-case basis (Böhmer et al., 2008). To provide more certainty, to stop materials being landfilled unnecessarily and to increase the use of waste as a resource, the Waste Protocols Project[12] has been set up and is conducted mainly by the EA and the Waste and Resources Action Programme (WRAP). Material streams usable for aggregate supply considered in the project are: blast furnace slag, steel slag, uncontaminated topsoil, contaminated soils (washed/stabilised), pulverised fuel ash, wood (not packaging), plastics not packaging.

The project aims at:

- The production of Quality Protocols defining the point at which waste may become a non-waste product or material that can be either reused by business or industry, or supplied into other markets, enabling recovered products to be used without the need for waste regulation controls;
- The production of statements, in accordance with the Environment Agency's low risk regulatory policy, indicating that the use of the waste is considered to be such low risk that it would not

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[11] Department for Communities and Local Government (1991): The Environmental Protection (Duty of Care) Regulations.

[12] The environment agency: http://www.environment-agency.gov.uk

normally be in the public interest to take enforcement action for failure to obtain a waste management licence;

- The production of statements that confirm to the business community what legal obligations they must comply with to use the treated waste material.

The quality protocol specifies which waste materials qualify for the EoW status and which (functional) tests have to be performed to ensure the compliance with functional criteria. No environmental testing is required. Prior to the release of the test protocol, a survey have been performed on the content and release of a number of different samples of the waste material in question to provide an overview of the general leaching behaviour (and composition) of the material. In addition, environmental impact assessments have been carried out on several service life use scenarios using the leaching characterisation data as input to the assessment model which includes several source scenarios, pathways and receptors. The number of substances considered may vary from one material to another. For coal fly ash, for instance, it includes chloride, fluoride, sulphate, Si, Ca, Mg, Na, K, Al, As, B, Ba, Cd, Co, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Sb, Se, Sn, V, Zn, DOC and ammonia. For leaching, the local groundwater or surface water quality criteria (often dictated by the Water Framework Directive and its daughter directives) generally apply as primary quality criteria. The results of the impact assessments and degree of compliance with the criteria are reviewed by a panel that determines if EoW status is awarded.

Beneficial use of waste aggregates under waste legislation may require testing and impact/risk assessment on a case by case basis.

European Commission
EUR 26769 – Joint Research Centre – Institute for Prospective Technological Studies

Title: **Study on methodological aspects regarding limit values for pollutants in aggregates in the context of the possible development of end-of-waste criteria under the EU Waste Framework Directive**

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Abstract

This report provides a methodology proposal for establishing limit values for pollutants in waste-derived aggregates with a view of using such aggregates in a wide variety of construction projects, as part of possible end-of-waste criteria for aggregates in accordance with Article 6 of the Waste Framework Directive (2008/98/EC). More specifically, the study centres on aggregate substances that are subject to leaching and/or release through wear. The report focuses on identifying and assessing the pollution risks of using aggregates derived from waste, on reviewing how the use of aggregates is regulated today in the EU with respect to avoiding pollution, on assessing the need for including limit values for pollutants in end-of-waste criteria, on assessing the suitability of different types of pollutant limit values, on identifying and assessing the different methodological approaches for deriving pollutant limit values and on identifying the most suitable testing approaches and methods, including simplified modes of compliance.

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