Managing On-site Stockpiling and Use of High Volumes of Concrete-based Demolition Material

Joanne Foy, Geoff Jones, Millie Sephton, Rachel Gaitonde (AECOM)

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Preface

This report has been prepared by Unity2, a consortium comprising of NSG Environmental Ltd., AECOM Infrastructure & Environment UK Ltd. and KDC under contract to the Nuclear Decommissioning Authority (NDA). The views expressed and conclusions drawn are those of the authors and do not necessarily represent those of NDA.

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Communications Department
NDA
Herdus House
Westlakes Science and Technology Park
Moor Row
Cumbria
CA24 3HU

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Executive Summary

This project has been undertaken in order to support the nuclear sites within the Nuclear Decommissioning Authority (NDA) estate as they progress through the agreed decommissioning process for their sites. It has been identified that it would be beneficial both environmentally and economically to promote on-site reuse of materials which are out of scope with respect to Radioactive Substances Regulation (RSR) and on-site disposal of materials which are in scope with respect to RSR. It is recognised, however, that with respect to Recycled Concrete Material (RCM), there is potential for high pH leachate generated from the material to adversely impact on the environment counter to the benefits identified. It was also recognised at project inception that mobilisation of metals as a result of the high pH leachate may also be an issue.

The NDA has previously commissioned a report to outline the regulatory aspects of management of RCM during recovery and reuse. Whilst it is known that crushed concrete will generate high pH leachate when in contact with water, it is less well understood what conditions promote this, the extent of the impact in the environment and how long the leachate will continue to be generated for. This report therefore considers the physical and chemical processes that could influence the generation and impact of high pH leachate and how this knowledge can be applied on Site Licence Company (SLC) sites.

The project combines industry (demolition, construction and remediation) and SLC engagement, with literature research and existing knowledge and experience within the project team to consider the following key points:

- Typical scenarios across the NDA estate in the next few years that this research would be applicable to;
- Standard management techniques used in other industries and how these are applicable to the NDA estate;
- Differentiators for the NDA estate in comparison to other industries e.g. timescales available and void size and depth;
- Potential changes that the NDA estate could implement to improve planning, generation, stockpiling and reuse or on-site disposal of RCM; and
- Knowledge gaps that could be reduced through further research and an indication of how this research may be undertaken in real world scenarios (e.g. field rather than lab studies).

The key findings from the project have been presented along with comment on the supporting evidence for each finding and key data gaps. Key findings are summarised as:

- Robust assessment of the potential risks should be undertaken prior to reuse;
- Site conditions may allow for an extensive plume or it may be limited by site conditions. The relevance of the plume extent will depend on the sensitivity of the receptors identified and the pathways to them;
- Saturation of RCM within groundwater will inhibit carbonation and may extend the time during which high pH leachate will be generated;
- Saturation of RCM within water is more likely to create high pH and metal leachate issues;
- Whilst high pH may promote the leaching of some metals, this is not the case for all metals;
- Inclusion of binders other than Ordinary Portland Cement (OPC) may increase metals content and leaching but decrease pH;

- Stockpiling of materials in a controlled manner does not necessarily generate a high pH leachate;
- Carbonation rates are not well understood but are influenced by freeze/thaw cycles, wet-dry cycles, moisture content and air ingress. Partially carbonated RCM may still produce a high pH leachate;
- Standard laboratory tests may give false data with respect to the potential timescales of high pH and metal leachate generation;
- Mixing with acidic soils may inhibit pH;
- Finer grained material is likely to result in higher pH leachate and potentially metal generation due to the higher surface area exposed;
- Compaction may increase the fines content of material. Compaction will reduce the pore space available and therefore may reduce the rate at which high pH leachate is generated;
- If water can be contained and either abstracted or collected, it can be treated using established technologies at the collection point such that it can be disposed of through the site drainage system in compliance with discharge consent limits. Where appropriate this should be automated to reduce labour commitments, increase safety and increase efficiency of the system; and
- There is potential for reuse of coarse RCM as aggregate in new concrete or for reuse of fine RCM in grout.

Key limitations to the project have been:

- A lack of industry engagement which is considered to be indicative of a lack of awareness or concern within the wider industry. This is likely to be due to a combination of a lack of regulatory guidance and the manner in which RCM is stockpiled and used on non-nuclear sites; and
- The dominance of laboratory data over field data within the literature available. There is evidence that standard laboratory tests overestimate metals leached from RCM but also the rate at which high pH leachate will be generated in-situ.

Recommendations to be undertaken when planning for the generation, stockpiling and reuse of RCM focus on the importance of robust assessment of the Conceptual Site Model (CSM). Recommendations to be undertaken during works on site focus on practical measures to be undertaken on site to reduce the potential for high pH and metal leachate to be produced or methods of control and mitigation. Relevant sections of the report should be read for recommendations and key knowledge gaps identified which are summarised as:

- Planning works:
    - Consider site requirements as a whole, in advance of contracting works and use a CSM and Risk Assessment at this stage. It is noted that this CSM and associated Risk Assessment is likely to be qualitative as there is currently a lack of an established model to assess the potential extent of the pH plume and so provide a more quantitative assessment of the significance of potential risks to receptors (Key Knowledge Gap 1); and
    - If testing mixed or previously stockpiled material to assess for metal or pH leachate potential, consider amended standard laboratory tests to obtain more realistic results.

- Producing aggregates for reuse:
  - Segregate materials and keep fines content to a minimum. It is noted that this is recommended on the balance of evidence, some of which is contradictory (Key Knowledge Gap 2); and
  - Control wash waters and dust from production areas.
- Stockpiling:
  - Select appropriate areas based on the CSM;
  - Keep contact time between rainwater and the RCM to a minimum. This needs further work to confirm (Key Knowledge Gap 3);
  - Crush material prior to stockpiling if it may be retained for an extended period. It is noted there is some evidence that carbonated material may still produce high pH leachate if saturated in water, and the timescales for carbonation are not well understood (Key Knowledge Gap 4); and
  - Monitor leachate to improve understanding of the potential for stockpiles to generate high pH leachate (Key Knowledge Gap 5).
- Reuse or disposal in voids:
  - Where voids are above the water table at all times of year, minimise contact time with rainwater by capping, compacting or puncturing the void walls and base; and
  - Avoid use of RCM in voids which are anticipated to be below the groundwater table at any time of year unless there is confidence from assessment of the CSM that leachate produced is unlikely to cause an environmental issue.
- Reuse in landscaping or as general cover:
  - Avoid use of RCM as unmixed general cover over more impermeable materials close to sensitive receptors;
  - Avoid creation of landscaping bunds close to sensitive receptors unless these can be modified to limit the creation of high pH leachate.
- Treatment of high pH water:
  - Use established techniques and provide an automated system where possible to improve efficiency and reduce health and safety hazards.

It is noted that there is currently a range of regulatory regimes used by the SLCs consulted as part of this project. This is considered partly to be a function of geography and the different regimes available, but also the restrictions inherent in some of the current options (e.g. restriction of stockpiling time frames). Therefore it may not be appropriate to fully standardise or define the approach or use of regulatory regimes. It is recommended however that the NDA and relevant SLCs seek to standardise the approach used and include set elements that can be incorporated into the relevant regulatory regime.

A number of research opportunities to reduce the data gaps have been identified including development of pH plume modelling, monitoring programmes and field studies. Some of these could be incorporated into current projects and activities on NDA estate sites.

Nuclear Decommissioning Authority

Keywords

Recycled Concrete Material (RCM), Stockpiling, Reuse, Voids, pH, Leachate.

Glossary

ALIS – AECOM Library and Information Service

C&M – Care and Maintenance

CEMP – Construction Environment Management Plan

CSM – Conceptual Site Model

DoW CoP – Definition of Waste Code of Practice

DRP – Direct Research Portfolio

DSRL – Dounreay Site Restoration Limited

EA – Environment Agency

EIA – Environmental Impact Assessment

GGBS – Ground Granulated Blast Furnace Slag

GRR – Guidance on Requirements for Release from Radioactive Substances

HC – Highland Council

LA – Local Authority

LLW – Low Level Waste

LLWR – Low Level Waste Repository

MMP – Material Management Plan

NA – Natural Aggregate

NDA – Nuclear Decommissioning Authority

NIGLQ – Nuclear Industry Group for Land Quality

NLS – Nuclear Licensed Sites

NNL – National Nuclear Laboratory

NRW – Natural Resources Wales

OPC – Ordinary Portland Cement

PFA – Pulverised Fly Ash

PPC – Pollution Prevention and Control

QP – Qualified Person

R&D – Research and Development

RCM – Recycled Concrete Materials

RSR - Radioactive Substances Regulation

SEPA – Scottish Environmental Protection Agency

SF – Silica Fume

SL – Sellafield Ltd.

SLC – Site Licence Company

WFD – Waste Framework Directive

WML – Waste Management Licence

WRAP – Waste and Resource Action Programme

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1 Introduction

1.1 Background

The Nuclear Decommissioning Authority (NDA) estate includes Site Licence Companies (SLCs) in various stages of decommissioning and demolition, all of which are progressing through an agreed decommissioning process. The SLCs where Recycled Concrete Material (RCM) will be generated, or will already be present are Magnox Ltd. (Magnox), Dounreay Site Restoration Ltd. (DSRL), Sellafield Ltd. (SL) and Low Level Waste Repository (LLWR). This is anticipated to include material which is both in scope and out of scope with respect to Radioactive Substances Regulations (RSR)[1]. The preference would be to reuse out of scope materials at the site of origin to support its remediation phase as this provides both economic and environmental benefits to the SLCs in line with the waste hierarchy. This may include infilling of voids which may be exposed during demolition, shallow site cover to provide a level site or creation of landscaping features required for site remediation. In addition, with the finalised Guidance on Requirements for Release from Radioactive Substances Regulations (GRR) (Reference 1) published jointly by the environment agencies[2], there is potential for on-site disposal of in scope waste with low levels of radioactivity where this can be shown to be the optimised management solution.

Whether classified as in scope or out of scope the RCM will have certain properties. Fresh concrete will give rise to a high pH (strongly alkaline) leachate[3] when in contact with water. This leachate generation reduces over time as the concrete weathers due to carbonation processes at the concrete surface, however, the weathering only occurs on the exposed surfaces. Exposure of new surfaces through demolition, removal of reinforcement or crushing therefore potentially leads to the generation of more of the high pH leachate from older concrete where previously exposed surfaces have weathered over time. It is also possible that the leachate generated from the RCM will contain metals or that the high pH will release metals in surrounding soils. A more detailed explanation of the chemical processes involved is included in Section 5.2.1 of this report. This leachate, if not correctly managed, could lead to environmental or compliance issues (e.g. non-compliance with discharge consents) that require remediation to correct and therefore could counter the economic and environmental benefits of its reuse or on-site disposal. It is noted that pH is measured on a log scale and therefore 1m^3 of pH 13 water has the potential to raise the pH of over 100,000 m^3 of water from pH 7 to pH 8.

The NDA previously commissioned a report to outline the regulatory aspects of management of RCM during recovery and reuse (Reference 2). Whilst it is known that crushed concrete will generate high pH leachate when in contact with water, it is less well understood what conditions promote this, the extent of the impact in the environment and how long the leachate will continue to be generated for. The NDA therefore wishes to build upon the existing report to consider the physical and chemical processes that could influence the generation and impact of high pH leachate. Further, the NDA wishes to understand how this knowledge can be used by the SLCs to understand under what circumstances reuse or on-site disposal of RCM is appropriate, where it is appropriate, and how it should be managed, stockpiled and used to minimise environmental impacts. Where possible, the NDA wishes to use standard practices and knowledge gained from outside of the nuclear industry where reuse of RCM is more common.

In some cases (Sellafield and Magnox in particular), the amount of RCM reused or stockpiled for later reuse could be increased through a better understanding of these issues and greater confidence in how they can be effectively managed. This will become increasingly pertinent as decommissioning progresses and larger volumes of RCM are generated. There is therefore a strong business case for research that supports the SLCs in appropriate management and reuse of RCM.

It is noted that, unless the material can be stored under a Waste Management Licence (WML), Environmental Permit or Planning Permission (not always desirable or possible) the current regulatory

[1] Definition of Out of Scope is provided as follows in the referenced guidance document: "Out of scope" equates to "not radioactive" for the purposes of the legislation i.e. Radioactive Substances Act 1993 (RSA93) applicable in Northern Ireland and the sections of the Environmental Permitting (England and Wales) Regulations 2016 (EPR16) relevant to radioactive materials. Scope of and Exemptions from the Radioactive Substances Legislation in England, Wales and Northern Ireland. Guidance Document. August 2018. Department for Business, Energy & Industrial Strategy, Department for Environment, Food and Rural Affairs, Welsh Government and Department for Agriculture, Environment and Rural Affairs (Northern Ireland). AECOM note that the EPR16 regulations have been amended by the Environmental Permitting (England and Wales) (Amendment) Regulations 2018. It is also noted that the guidance document does not cover Scotland which is covered by the Environmental Authorisations (Scotland) Regulations 2018 which came into force in September 2018.

[2] Scottish Environment Protection Agency (SEPA), Environment Agency (EA) and Natural Resources Wales (NRW).

[3] A liquid which has passed through a porous solid and extracted soluble substances from the material in the process.

regime is considered somewhat restrictive with respect to the NDA estate as it limits on site stockpiling of RCM to a 12 month period. This report does not seek to address this restriction, rather the aim is to provide the NDA and SLCs with practical solutions to reduce generation or mitigate the impacts of high pH and metal leachate in circumstances where it can be stockpiled or reused within the current regulatory regimes.

This report considers only the non-radiological properties outlined above (high pH and metal leachate generation) and does not distinguish further between on-site disposal of in scope, or reuse of out of scope materials.

1.2 Strategic Alignment and Business Case

This report builds upon the previous assessment of the potential for recovery and reuse of construction and demolition materials referred to in Section 1.1. It relates to the NDAs Direct Research Portfolio (DRP) Research and Development (R&D) topic areas of Site Decommissioning and Remediation and, Land Quality Management both of which fall under Lot B, as set out in the NDA R&D 5-year plan (Reference 3). It addresses barriers to reuse and on-site disposal of RCM. As detailed in Section 2 of this report, barriers at present include concerns over the practicality of control and management of high pH leachate from RCM stockpiling and reuse.

1.3 Project Objectives

The project objectives are to provide information on the following key points:

- Typical scenarios across the NDA estate in the next few years that this research would be applicable to;
- Standard management techniques used in other industries and how these are applicable to the NDA estate;
- Differentiators for the NDA estate in comparison to other industries e.g. timescales available and void size and depth;
- Potential changes that the NDA estate could implement to improve planning, generation, stockpiling and reuse of RCM; and
- Knowledge gaps that could be reduced through further research and an indication of how this research may be undertaken in real world scenarios (e.g. field rather than lab studies).

1.4 Anticipated Applicability of the Research

This research is anticipated to be relevant to the four SLCs above with respect to:

- On-site disposal of RCM under the GRR regulatory guidance;
- Reuse of RCM in creation of disposal facilities at LLWR; and
- Reuse of RCM in infilling of voids, site cover or creation of landscaping features in preparation for sites progressing to agreed End States.

The reuse on site of such material is considered likely to minimise the requirement for import of material to fulfil site requirements for infilling voids and landscaping and removal and disposal of material from site. This provides economic, environmental and logistical benefits (e.g. retention of disposal capacity elsewhere). In addition, on-site disposal under GRR is considered preferable to off-site disposal. Whilst it may be possible to sell RCM as an aggregate for use in other industries, where material is needed on site, the benefit would be off-set by the cost of import of other material.

A summary of the regulatory regimes relevant to reuse of RCM is included in Appendix A.

2 Scope of Project

2.1 Outline Scope

The scope of the project was as follows:

- Engagement with SLCs to understand:
  - Current reuse of RCM and barriers to that reuse;
  - Anticipated future reuse of RCM; and
  - Instances where RCM has been used and has either caused issues that have required remediation or where it has been used successfully and how that use was managed.
- Engagement with the demolition industry to understand:
  - Whether the potential for impacts from generation of high pH leachate from stockpiling or reuse of RCM is routinely considered;
  - Where it is considered, what standard practices are used to manage or mitigate it; and
  - Instances of where RCM has been used and has either caused issues that have required remediation or where it has been used successfully and how that use was managed.
- Literature research covering the reuse and management of RCM and in particular the potential differences in pH and metals leachate caused by different processing, stockpiling and reuse techniques; and
- Presentation of the outcome of this work to the NDA and Nuclear Industry Group for Land Quality (NIGLQ).

The following items are not included in the scope of this project:

- Reuse of RCM as a construction aggregate for new concrete. Whilst this is a possible use of the RCM, it is noted the potential is limited on decommissioning nuclear sites. In addition, as the freshly exposed surfaces of the RCM would be incorporated into the new concrete, there would be limited potential for high pH leachate generation and therefore application of this research would not be required; and
- Consideration of the potential radiological properties of the RCM (where in scope material is being disposed of).

2.2 Key Areas for Considerations

The key areas considered in this report are as follows:

- Standard management techniques used in other industries and how these are applicable to the NDA estate;
- Differentiators for the NDA estate in comparison to other industries e.g. timescales available and void size and depth;
- Potential changes that the NDA estate could implement to improve planning, generation, stockpiling and reuse of RCM; and
- Knowledge gaps that could be reduced through further research and an indication of how this research may be undertaken in real world scenarios (e.g. field rather than lab studies).

3 SLC Engagement: Current Concrete Reuse

3.1 Engagement Methodology

Engagement with the SLCs was initiated through distribution of an invite to participate to the following SLCs using contact details as provided by the NDA:

- Magnox Ltd.;
- Dounreay Site Restoration Ltd.;
- Sellafield Ltd.; and
- Low Level Waste Repository Ltd.

The following subject areas were listed for discussion/consideration:

- How crushed concrete has previously been used (or how it is envisaged it will be used) on site e.g. in voids, stockpiling for future use or landscaping;
- Current control measures used to mitigate potential effects of high pH leachate (both process/assessment controls and practical mitigation measures);
- Monitoring completed for high pH after concrete reuse and what the monitoring indicted; impact or that mitigation measures had been successful; and
- Sites where high pH leachate has caused issues (environmental or compliance) and whether these could be included as case studies in the report.

Following this, a series of phone calls and e-mail exchanges were made to gather the information summarised in the remainder of Section 3.

3.2 Response Summary

3.2.1 Responses

Contacts at all four SLCs responded and this allowed the current use of crushed concrete (if any) on the SLC sites to be fully understood. Furthermore, a number of potential case studies were identified through discussions as identified below.

3.2.2 Key Themes

The following key themes were identified through the communication with the SLCs:

- All SLCs were aware of the potential for reuse of crushed concrete to cause compliance or environmental issues at their sites;
- Engagement by the regulators differs between regions/SLCs; and
- All SLCs are undertaking or are planning for assessments prior to reuse of crushed concrete. In addition, SLCs are working towards or have undertaken assessments of void spaces including size, depth and when they will require infilling.

3.3 Current Use of Concrete Identified: Reuse Scenarios

The following sub-sections describe the reuse of crushed concrete which is anticipated by the SLCs contacted in this engagement task.

3.3.1 Magnox Ltd.

Reuse is currently being undertaken or is planned, in preparation for Magnox sites moving to the Care and Maintenance phase (C&M). Reuse at present is primarily to infill voids exposed during planned demolition activities with voids ranging from, relatively small/shallow voids such as drainage pits, to Cooling Water Pump House basements and Turbine Hall basements. It is recognised by Magnox that the appropriateness of reuse of crushed concrete is dependent on the size and depth of the void in relation to the site setting (drainage, groundwater, surface waters etc.). It is also anticipated that at some sites (e.g. Trawsfynydd), landscaping/screening bunds will be required and surplus demolition materials may be used to create these features.

3.3.2 DSRL

Reuse of crushed concrete to date has been very limited and constrained to infilling of small voids. During works to allow radiological testing, one previously infilled void was found to have accumulated high pH water over time. The RCM from this void was removed and the water pumped out and disposed of appropriately. Following the testing the void walls and base were breached to reduce the potential for water to accumulate and backfilled with natural material. The presence of the high pH water within the void was not considered, by site personnel to have impacted groundwater. Data provided by site personnel for the area included some high pH readings in groundwater (BH2, up to pH 10.93 in field readings), however this was up- gradient with respect to inferred groundwater flow of the void and high readings were recorded after the date of removal of the RCM.

The DSRL planning document, Phase 3 Environmental Statement (Reference 4) identifies the following:

- The number and location of voids anticipated to require infilling;
- The anticipated volume of crushed concrete that will be available for reuse (46,000 m^3);
- That a number of voids extend to below the water table;
- That local site specific risk assessment and agreement with Scottish Environmental Protection Agency (SEPA) will be required regarding how and where crushed concrete can be reused; and
- That the preliminary view is that it can be used at ground surface level, above the water table either as a development platform or for void infilling and also within the old Low Level Waste (LLW) pits once these are excavated and the waste removed. The basis for this assessment is that the pits are hydraulically down-gradient of the main site and close to the sea with high pH leachate anticipated to migrate to and dissipate within the seawater. This use alone is anticipated to potentially account for approximately 75 percent of the material available.

It is noted that this document supports a current planning application which has been granted in principle by the Highland Council (HC) planning committee but with conditions not yet agreed. It is understood however that SEPA support the preliminary view outlined above for reuse of crushed concrete only above the water table. The only exception to this is anticipated to be the LLW pits. It is noted however, that approval for use of crushed concrete in voids will also be required from HC and is not dependent on SEPA agreement only. The regulatory approval process for this is currently in development between DSRL, SEPA and HC.

3.3.3 Sellafield Ltd.

Similar to DSRL, reuse of crushed concrete at SL has, to date, been limited to infilling of small voids. It is reported that voids have not been punctured to allow water to drain, however infiltration has been restricted by covering the voids or subsequent development within a short timeframe. Where such voids have been filled, the concrete produced on site from demolition has been removed from site by a contractor and processed off site under the Waste and Resource Action Programme (WRAP) protocol, with the required volume then returned to site for reuse. Processing on site is impractical due to space restrictions. Surplus concrete has been retained by the contractor off site and Sellafield is billed for this service.

It is noted that the potential use of crushed concrete through the WRAP protocol has been written into the SL Management Systems. This has not been implemented to date as no suitable use has been identified yet. One potential reuse project was considered however it was identified that the drainage network in the area was not fully understood and there was concern that it could result in uncontrolled migration of leachate to surface water receptors. This was not considered to be acceptable and an alternative infill material sourced.

Sellafield report that planned projects in the next couple of years will give rise to large amounts of concrete and it would be preferable to use this on site if possible. One identified project could generate c. 20,000m^3 of material.

3.3.4 LLWR

To date, LLWR has not reused crushed concrete, however they have stockpiled material in anticipation of use within trench cap reprofiling as discussed further in Section 3.4. It is noted that this use will be under a under an engineered cap which should limit but not entirely eliminate infiltration of rainwater. It will also be contained by engineered sides and bases of the repository trench. Preparation for reuse has considered pH leachate and its effects, including on the potential leaching of metals. These assessments are included in the literature research section of this report.

3.4 Requirement for Long Term Stockpiling

Long term stockpiling in this instance is considered to be for greater than 12 months. This is on the basis that the CL:AIRE Definition of Waste Code of Practice (DoW CoP) allows the temporary storage of materials for a maximum of twelve months, but that when the stockpiles are to be present for a longer period, a time limit should be agreed between the appropriate environmental regulator and the person responsible for the Material Management Plan (MMP), and a management plan established.

Long term stockpiling is anticipated to be required with DSRL already undertaking this through storage of material within a designated facility (D6500). This facility was created approximately 15 years ago and has been operated by DSRL under a WML since its creation. Leachate is controlled and tested with appropriate records kept in line with the WML requirements. It is understood that a range of materials are stored in this facility including natural materials and demolition aggregates...

SL also operates a long term storage facility of natural materials in two areas of site (Area D1 and Area H) as landscape bunds created in accordance with a planning permission. It is anticipated that at a later date in the decommissioning process the material in the bunds will be utilised elsewhere on site. It is noted however that concrete has not been used in these bunds to date due to concerns over high pH leachate generation. It is noted that could it be shown to be appropriate, the planning permission is reported not to preclude use of such materials. Transfer of material into these bunds is controlled through application of the DoW CoP. It is reported that stockpiling elsewhere on site would be unlikely due to restrictions on available space.

Magnox has identified that long term stockpiling would be helpful, but recognise the restrictions presented by the DoW CoP and waste legislation. It is understood that discussions are on-going with the regulator and this is discussed in Section 3.5.

LLWR is also currently stockpiling crushed concrete (crushed to 0 to 75mm) with approximately 1,700 tonnes of crushed concrete stored alongside 220,000 tonnes of soil[4]. The crushed concrete was derived from demolition of on-site buildings undertaken within the last nine months with crushing completed in May 2018. It is anticipated that the stockpiles will be retained for a minimum of two years, but this may extend further, depending on site requirements. Ponding of water in the stockpile area is not anticipated, and the area has a local drainage system that discharges to the main site drainage system prior to discharge to a stream. There are no compliance points along the discharge route, however it is noted that LLWR anticipate a large dilution factor of leachate within the drainage. To date, no analysis or testing of leachate has been undertaken, but this is being considered and would be possible utilising access points within the drainage system.

3.5 Regulatory Regimes and view on Reuse

As detailed in Appendix A, a number of regulatory regimes are currently available for use by SLCs to allow storage and reuse of crushed concrete materials.

- Planning regime: This is utilised by SL, where there is a known medium-term requirement for screening bunds that will no longer be required later in the remediation process. It effectively allows temporary stockpiling of materials under controlled conditions as a secondary aim to the main purpose of providing screening. It is noted that there are limitations to this approach, that may make it unsuitable for use by other SLCs/in other circumstances:
    - It requires certainty of use for the material that can be justified through the planning regime;

[4] Reported as 120,000 m^3, converted to tonnes using an assumed conversion factor of 1.8 tonnes to 1 m^3.

- It does not negate the requirement for assessment for suitability of use; at Sellafield reuse is controlled through the DoW CoP as part of the planning condition requirements; and
- It does not guarantee that crushed concrete can be used; to date Sellafield has not transferred crushed concrete to these areas due to concerns over leachate generation and the control of that leachate.

- CL:AIRE DoW CoP: this has been successfully used by Magnox in recent years and continues to be applied with individual demolition and infilling projects assessed and taken through the Qualified Person (QP) declaration process separately. It may be possible to create site wide MMP, however voids to be infilled would still need to be assessed either individually or as groups according to source (relationship to groundwater), pathways (drainage connections remaining in place), and receptor terms. This approach also has limitations for Magnox and other SLCs as follows:
    - It is not in use in Scotland, therefore cannot be employed by DSRL or Magnox Scottish sites (Chapelcross and Hunterston A);
    - Reuse (excluding stockpiling) of material is required with 12 months, unless regulator agreement can be reached for longer term stockpiling. Without evidence of this agreement, the QP declaration cannot be made. It is also noted that the certainty of use must be demonstrated; therefore the SLC must have an understanding of the void spaces that will become available and that can accommodate the volume of material that will be generated. This may require more advanced planning for End States than has currently been undertaken or is possible, for example where decisions are yet to be made about use of voids for on-site disposal of in-scope materials; and
    - It cannot be applied retrospectively to material already stockpiled on site even where suitability for reuse can be demonstrated.
- WRAP Quality Protocol: this is currently used by Sellafield through a third party contractor and is at a cost to Sellafield. It has also been integrated by Magnox into demolition projects (e.g. at Trawsfynydd). Potential issues with its use include:
    - The protocol must be strictly adhered to and shown to be so; missing records can prevent material generated through it been signed off. The aggregate must conform to a standard for use, be produced under factory Production Control, not require further processing and conform to Construction Products Regulations;
    - The aggregate produced must be destined for a designated market and cannot be stored indefinitely with little prospect of reuse as this is considered as showing an intention to discard it;
    - It may not be appropriate to crush the concrete to the specification required by WRAP for a particular void or other reuse due to the influence of grain size on leachate generation; and
    - It is not in use in Scotland, therefore cannot be employed by DSRL or Magnox Scottish sites (Chapelcross and Hunterston A).
- Waste Management Licence Regime: This is currently used by DSRL, however may not be attractive to other SLCs due to the requirements that can be imposed on such licences with respect to the facilities required (e.g. drainage) to be constructed, data collection and reporting, and control of materials and leachate. Some SLCs consider this type of regime to be restrictive and inflexible given their evolving End State planning.

The regulators are aware of a number of stockpiles on sites (including but not limited to crushed concrete) that are not being controlled through these, or other applicable legislative regimes. In most cases, the SLCs are working with the regulators to resolve issues posed by these historical stockpiles.

3.6 Current Standard Practices and Control Measures Identified

As can be seen above, there is not currently a standard practice for stockpiling or reuse of RCM across the SLCs. There is however commonality in the use of assessments prior to reuse and an understanding of the potential impacts from high pH leachate migration.

With respect to reuse of RCM in voids, standardisation of approach is not applicable due to the effect of variation in the void depth, size, location, interaction with groundwater, drainage pathways etc. Consideration of these factors to create a bespoke solution to management of high pH leachate is the recommended approach. This is being undertaken already by a number of SLCs.

4 Construction/Demolition Industry Current Practices

4.1 Engagement Methodology

4.1.1 Engagement Through Survey Completion

Engagement was primarily through distribution of a SurveyMonkey survey. This survey was live from the 8th June to 3rd August 2018.

Distribution of the survey was primarily undertaken by KDC to 31 companies.

The companies were selected to provide a cross section of company sizes, sectors and geographic locations. KDC made initial contact by telephone to establish who was most appropriate to send the link to, and followed up by sending the link promptly. With the exception of three companies (in italics above), all agreed to take part in the survey and were provided with the link. Survey responses were monitored and when it was noted that the response rate was low, all contacts were followed up to ensure they had the link and encourage participation. In addition, at this stage AECOM and NSG distributed the survey to selected contacts, primarily within these companies and within the remediation industry to garner additional responses. It is noted that to incentivise participants to complete the survey, a prize draw was established as well as an indication that if possible, the outcome of the research would be shared.

4.1.2 Other Engagement Methodologies

Additional industry engagement was conducted with a remediation and ground engineering company (at the suggestion of the NDA), who work within the nuclear sector. Discussion points from this are included in Section 4.3.4.

AECOM also discussed this project with the local AECOM Transport and Environmental Impact Assessment (EIA) team to understand their awareness of issues regarding high pH leachate when planning reuse of RCM for road and other developments.

4.2 Response Summary

The response to the survey was found to be poor; however, this was not unexpected as the response rate was in line with similar projects undertaken by AECOM. The responses were as follows:

- 8 people started the survey but did not complete it;
- 5 people completed the survey. Responses were received from:
  - Two remediation contractors;
  - One environmental consultant; and
  - Two demolition contractors.

4.2.1 Key Responses and Themes

It is possible that the poor response is a reflection on the lack of awareness within the industry on this subject rather than a reflection on the engagement methodology or number of companies contacted. It is also possible that the timescale constraints on this task were unhelpful in obtaining responses.

The key theme, from both the response rate and from the responses obtained, is an indication of a lack of awareness, at present, of the potential for high pH leachate. It is noted however that the indications are that awareness and consideration of these issues is growing. There is more recognition of issues relating to high pH leachate within the remediation industry than the demolition industry. Once people become aware of the issue, through direct or indirect contact with a site where the effects need to be addressed, it is considered on a more frequent basis.

The AECOM transport team noted that the potential for RCM to generate a high pH leachate is not normally considered, but had recently been raised as a concern on one project. One reason for this lack of consideration may be that RCM is classified as “inert” under waste legislation and the WRAP Quality

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Protocol[5]. Such inert wastes are described in the Landfill Directive as wastes which “do not undergo any significant physical, chemical or biological transformations. Inert waste will not dissolve, burn or otherwise physically or chemically react, biodegrade or adversely affect other matter with which it comes into contact in a way likely to give rise to environmental pollution or harm to human health. The total leachability and pollutant content of the waste and the ecotoxicity of the leachate must be insignificant, and in particular not endanger the quality of surface water and/or groundwater”.

It is also noted that Appendix D of the WRAP Quality Protocol describes Good Practice for the transportation, storage and use of recycled aggregates. It does not include measures to control or limit leachate/run off, focussing primarily on dust generation and migration.

The AECOM EIA team indicated that they were aware of the potential for high pH leachate to be an issue from concrete in general and from crushed concrete in particular. Measures to address high pH leachate had been included in a Construction Environment Management Plan (CEMP) produced for a recent development project. It is noted that in this case the source of the pH was anticipated to be runoff from areas for the storage and batching of cement rather than use of RCM.

4.3 Current Reuse of Concrete Identified

4.3.1 Reuse Scenarios

All five respondents indicated they had experience of using RCM as unbound backfill material in one or more of the following scenarios as indicated:

- Sub base for road (1 respondent - a demolition company);
- Above ground landscaping (2 respondents);
- Infilling small below ground voids (all respondents);
- Infilling substantial below ground voids (3 respondents); and
- Infilling below the water table (3 respondents).

All but one of the demolition company respondents indicated they were aware of the potential for RCM to create a high pH leachate in contact with water. Whilst this is only one response and may not be representative of the wider industry, it is notable that the demolition company have experience of using RCM for road bases and small void infilling yet are not aware of the potential for pH to be generated.

4.3.2 Requirement for Long Term Stockpiling

As above, long term stockpiling is considered to be greater than 12 months. From discussions with people who responded to the survey and with AECOM Transport and EIA teams it is considered that long term stockpiling is not common in remediation or development projects. Where new aggregates are brought to site for use (including RCM sourced from off-site), these would be brought at the appropriate time for reuse. On-site sourced materials would be stockpiled pending reuse but it would be considered unusual for this to be for more than 12 months.

4.3.3 Regulatory Regimes and View on Reuse

Of the four respondents who indicated they were aware of potential issues with high pH, all four also indicated they had undertaken assessments to consider the risks from that potential, although only two responded that this had been driven by regulatory controls or involvement. The regulatory controls/involvement was indicated to be:

- EU Waste Framework Directive, EU Technical Standards and Regulations Directive; and
- Environment Agency.

The fact that four people responded that they had done assessments, but only two indicated regulator involvement and those two quoted different drivers for involvement is again indicative of the range of options available for reuse and management of RCM.

[5] Included in Appendix C of the WRAP Protocol as a material that is considered to be inert and acceptable for the production of recycled aggregate as either concrete (waste code 17 01 01) or mixtures of concrete, bricks, tiles and ceramics other than those mentioned in 17 01 06 (waste code 17 01 07).

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4.3.4 Standard Practices and Control Measures: Stockpiling and Reuse

Of the five respondents, only one indicated they had standard practices for the management of stockpiles of RCM with regards to the potential for management of pH leachate. The lack of standard practices may be due to a lack of consideration of the issue, and lack of industry guidance, however it is noted that the Conceptual Site Model (CSM) has a strong influence on whether there is an issue or not (as illustrated by the various case studies). It may therefore be that set practices are not appropriate, rather standard practices should involve assessment and selection of appropriate control measures, from a list of potential options.

Of the five respondents, only one indicated they had had to undertake control measures when placing backfill to reduce/prevent elevated pH or metal leachate generation or migration to sensitive receptors. They also indicated they had undertaken groundwater or surface water monitoring to assess for the impact of pH.

Discussions with one remediation company indicated no standard practices as their work often involves stabilisation of concrete which prevents high pH leachate being generated. The following items were however discussed as potential solutions.

- For shallow or sealed voids where contact between groundwater and crushed concrete is not a consideration, they would suggest removing the fines from the crushed material and using them to create a cap, which would be more cost effective than using fresh material to create the cap. Previous works have indicated such caps have good geotechnical properties;
- For voids where contact with groundwater is a consideration, they would suggest stabilisation through crushing to a small grain size (e.g. 50mm) with compaction used to minimise water ingress through the material. It is noted this strategy would need to be balanced with the potential for such small crushing and further the compaction to create a high fines content which could generate a high pH leachate if the compaction did not successfully prevent water infiltration to the mass of concrete; and
- Alternatively, given the quality of concrete likely used in construction if there is no contamination to consider or if there is a surplus of material, they would expect it would be possible to create a good quality aggregate under the WRAP protocol that could be sold or removed from site at low cost. It is noted that at present, SL are paying for a contractor to remove excess concrete and process it under WRAP. The costs of this may outweigh the benefits of being able to sell the material once processed.

4.4 Additional Experience

One remediation company indicated that they had experience of research into the effects of weathering, however with further clarification this research was based on soil washing and consideration of the relationship between pH and leachable anthracene. Whilst data has been provided, to the extent possible within their confidentiality policies, it is difficult to draw conclusions relevant to this current research. AECOM will continue to liaise with them to establish whether the data can be used, however at present, it is not considered to warrant a case study.

AECOM and KDC have experience of using RCM or mitigating the effects of use at a number of sites including:

- A site where AECOM undertook demolition and remediation works including reuse of crushed concrete to backfill remedial excavation;
- A site where AECOM currently undertakes monitoring[6] following issues identified from use of crushed concrete as in backfill material in largely contained below ground voids:
    - o During periods of high rainfall, high pH readings are reported from the drainage system and this is considered to be due to overtopping from the below ground voids where the concrete is in continual contact with water. In investigating the source of the high pH,

[6] It is noted that this is the site referred to in Celtic Technologies survey response where they mentioned a site they were aware of with high pH issued caused by use of RCM.

AECOM found that rainwater and groundwater sourced from the site did not produce immediate high pH leachate, but did over time. Use of deionised water in similar tests produces the high pH leachate immediately;

- The first key learning from this example is that saturation of crushed concrete will produce a high pH leachate from groundwater or rainwater infiltration. This process may take time and therefore reducing the contact time between the RCM and water may be effective in limiting the production of high pH leachate; and
- The second key learning from this example is that laboratory testing using standard methodologies which use deionised water may give false results as to the time required to produce a high pH leachate in comparison to the material in-situ. Note: as high pH leachate will be eventually produced from rainwater and groundwater, the actual pH reading is not considered to be falsely high, just the rate at which that is reached.

- A former synthetic resin manufacturing facility where AECOM was aware of high pH perched groundwater discharging to and impacting on shallow surface waters at the site boundary. In this instance a layer of demolition rubble (RCM) had been laid on the surface of the underlying natural superficial clays. Perched water accumulated within the granular RCM, supported by the clays and migrated directly to the surface waters. Following discovery of the issue, the RCM was removed from areas of the site adjacent to the surface water, mixed with site derived clay soils and re-laid. This resolved the issue; however it is not clear whether the effect was due to decreased permeability of this layer or soil buffering of pH by the clay constituent of the mix. It is considered likely that it was a combination of both;
- A power station site where KDC previously used crushed concrete to infill cooling tower basins under an MMP. The assessment undertaken in support of the MMP indicated the material was suitable for use in that particular scenario; and
- Two sites where KDC implemented acid dosing systems (one manual, one automated) to reduce the pH of abstracted groundwater to allow discharge through the site drainage system in compliance with the discharge consent.

4.4.1 Differentiators from Other Industries

Through engagement with the SLCs and industry contacts and from previous experience within the project team the following key differentiators have been identified:

- Void size and depth. In many instances of concrete reuse, the material is reused at a very shallow depth within the non-nuclear sector e.g. in road construction. Where voids are infilled on demolition sites, these are not usually as large or as deep as some voids on Nuclear Licensed Sites (NLS);
- Proximity to sensitive ecological receptors. The majority of the NLS are at coastal locations, often in remote areas. They are therefore often close to or within land or sea areas with statutory designations based on the local ecological habitats and species. Pathways to the receptors may be short or may be via preferential routes such as discharge from voids via drainage to surface waters. Consideration of these sensitive receptors is therefore required and must take into account the potential lack of natural dissipation/attenuation of the leachate. Conversely, the proximity of many sites to the coast limits the potential for groundwater to be a plausible resource and therefore limits the consideration required of impact on such resources;
- Timeliness of reuse (e.g. duration of stockpile retention). During the industry engagement, it was noted by one participant from a remediation contracting company that on most construction sites, crushed concrete reuse is undertaken immediately following its generation. It was noted that, for them, stockpiling for as long as nine months was highly unusual. This could be one of the main reasons for a lack of consideration of the effects of high pH run off from stockpiles in the wider construction industry. Reuse within the nuclear decommissioning industry may not be for many years, possibly decades after the RCM is generated from demolition projects and therefore management of stockpiles is of greater importance;

- Regulatory oversight. The NDA estate is highly regulated with frequent liaison by the various regulators. SLCs are used to following strict, highly defined, tightly controlled regulations. Uncertainty can lead to concerns and lack of confidence in applying regulations and an unwillingness to operate in those circumstances. Uncertainty in this case comes from the choice of regulatory regime to follow and the technical difficulties in understanding under what circumstances leachate will be generated, how long for following reuse or stockpiling, migration and natural dissipation and attenuation of the high pH etc. In some cases, the risks or assessment requirements of reuse of RCM are considered to be too great and reuse is avoided in favour of off-site disposal of the material; and
- Certainty of use. The extended timelines for reuse of RCM on SLC sites increases the potential for changes in End State planning, site procedures and priorities and regulatory regimes in the time from generation of the RCM to either use or site release from regulation. The potential for such changes increase the risks perceived by SLCs with respect to tying into requirements of WML etc.

5 Literature Review

5.1 Literature Review Methodology

In order to obtain information relevant to the scope of the report, key word searches were initially conducted in Google Scholar using the following search terms:

- Crushed concrete high pH leachate;
- Carbonation of stockpiled concrete;
- Carbonation of crushed concrete; and
- Alkaline leachate concrete crush.

An additional search was subsequently carried out using AECOM Library and Information Services (ALIS) using the keywords below:

- Reclaimed concrete aggregate;
- Reclaimed concrete materials;
- Concrete pH;
- Alkaline leachate, concrete carbonation;
- Concrete and Groundwater;
- Concrete Leachate; and
- Carbonation timescales.

This identified a number of potentially useful sources. Sources accessed and reviewed are included in Appendix B; each was assigned a reference (A through to BY) with this reference used in the text below. Full access to a number of papers was purchased (Sources I, AJ, AM-AP) with other sources being accessible without additional payment.

Additional targeted Google Scholar searches were carried out to obtain additional sources (Sources AQ – BV) after identifying areas of the ALIS search where additional information would be useful.

Two reports from LLWR (Sources AY and AZ) were also reviewed along with a report supplied by the NDA (Source BW) and one supplied by Magnox (Source BX).

All sources reviewed are detailed in Appendix B, however only those marked with blue in the reference column have been used in the text of this report. The remaining sources were not considered relevant to include either due to their subject matter or methods used. They are included for completeness in the Appendix. The Appendix also indicates where only the abstract of a paper was reviewed.

5.2 Key Themes

5.2.1 Chemistry of concrete and the carbonation process

5.2.1.1 Concrete

Concrete is composed of a binder (typically 25-40%) and a fine to coarse grained inert aggregate (typically 60-75%), which is held together by the binder (Source BM). Typically the binder is cementitious, usually OPC, though other binders can also be used. Admixtures may also be used as replacement for cementitious binders, affecting concrete properties (Section 5.2.1.3). The aggregate used in the production of concrete is ideally well-graded, with a range of grain sizes, and should be durable with low reactivity, such as crushed rock or gravel (Source BN). The use of different components of concrete can result in different leachate pH values, for example, concrete admixtures can improve properties, though may result in a higher pH leachate. It is noted that the admixtures used in that construction of the NDA estate is not known. Source D states that calcium oxide (CaO) and total Ca are the most important components of RCM that contribute to the alkalinity of the aqueous solutions. These are not normally known for concrete mixes historically used, and cannot be changed through management techniques, and so this assessment focusses on other factors (e.g. crushing, grading) that may influence the pH and can be controlled. For completeness an overview of some consideration of the effect of binders is included in Section 5.2.7.

5.2.2 Ordinary Portland Cement

OPC is an active hydraulic cement that is typically used as the binder in concrete; it reacts with water in order to set without the need for an activation agent such as lime (Source BT). It is composed predominantly of calcium silicates, which react with water to form fine-grained calcium hydroxide (Portlandite). Other components include calcium aluminates and alkalis (Source AC).

OPC is produced by heating a ground calcareous material, usually limestone, with other constituents such as clays or shales, which are typically 55-60% silica, 15-25% aluminium oxide and 5-10% iron oxide. Waste materials can be used as fuel for the process, or incorporated as part of the material – e.g. calcium oxide provided from blast furnace slag (Source BU). During the process, calcium carbonate in the limestone is broken down (calcinated), and calcium silicates (alite and belite) are produced. The end product is produced by pulverising clinker with added gypsum, with the key constituents being calcium silicates and aluminium- and iron-containing phases, along with minor amounts of sulphate and magnesium oxide (Sources AC, BN).

When OPC is mixed with water to form a cement paste, hydration reactions occur, leading to setting and hardening of the cement. This process occurs in a number of stages. Firstly, setting occurs within a few hours, with little development of compressive strength. Hardening is the process by which compressive strength develops, and occurs much more slowly. Curing is storage of the concrete mixture such that hydration can occur (Source BU). The process of hydration is complex, but in general involves the reaction of calcium silicates to form calcium hydroxide (Portlandite) and calcium-silicate hydrate gel, which fills pore spaces between aggregate grains, binding them together. The process is influenced by cement composition, grain size and grading, the water/cement ratio used, the temperature and the admixtures used. The water/cement ratio used affects the strength of the concrete, with a lower ratio resulting in higher strength, though the material may be harder to work with. Typically, when producing the paste, a w/c ratio of 0.5-0.6 is used (Source BT).

5.2.2.1 Admixtures

In some cases, admixtures including Ground Granulated Blast furnace Slag (GGBS) and Pulverised Fly Ash (PFA) are used as additives or as substitutes for OPC to improve concrete properties and reduce the demand of the cement production process for raw materials. The additives typically have pozzolanic properties, meaning that they react with calcium hydroxide, in the presence of water, forming cementitious materials (Source BT). A summary of the effects of different admixtures is presented in Table 1 below.

Table 1. Effects of concrete admixtures

Admixture	Details	Effects on concrete properties	Key Papers (reference as per Appendix B)
PFA	Can be silico-aluminous or silico-calcareous Obtained from dust from flue gas produced by coal combustion.	Retardation of setting time. Improvement in long term properties e.g. workability and reduced permeability. 30% inclusion increased compressive strength by ~10%. Increase in strength observed when it replaces either cement or aggregate, with strength gain roughly proportional to the concrete's active silica content.	BO, BP, BQ, BT
GGBS	Formed during iron/steel manufacture, and consists mainly of calcium oxides and silica with some magnesium and aluminium oxide.	Retardation of setting time. Benefits include: lower permeability and higher strength at later ages, decreased chloride ion penetration, increased resistance to sulphate attack	BP, BR

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Admixture	Details	Effects on concrete properties	Key Papers (reference as per Appendix B)
		and alkali silica reaction. Increased carbonation rates, surface scaling and frost attack. Lower initial early strength than normal cement.	
Silica Fume (SF) / micro silica	Fine particulate solid produced through silicon oxide loss during the production of silicon or silicon alloys.	Retardation of setting time. Improvement of short-term and long-term properties. Strength gain due to pozzolanic reactions and fine particle size. 10% inclusion increased compressive strength by ~10%. Reduces permeability by 71% after one day and 87% after 1 year. Increased potential for shrinkage cracking.	BO, BP, BT

5.2.2.2 Concrete Leachate

The leachate produced from fresh concrete and RCM is highly alkaline. Experimental leaching tests of concrete and RCM described in literature produced high leachate pH values between pH 9 – 12, due to weathering of calcium hydroxide within the concrete material – Appendix B, sources E & F as described in Section 5.2.1.5.

Leaching of concrete in the field is likely to produce a high pH leachate plume (Source AT). Little information is currently available regarding the extent of these plumes, though one Swedish study (Source BV) indicated that, although pH plume extent from a sub-sea geological repository for low and medium level short-lived waste had not been investigated, it was thought that a high pH plume from cement fill would be neutralised by dilution within in a short distance of the site. The extent will be dependent on the chemical and physical conditions in the surrounding area.

5.2.2.3 Carbonation

Over time, concrete surfaces in contact with the atmosphere will slowly carbonate, taking up atmospheric carbon dioxide (CO_2) during the process. During the process of carbonation, atmospheric CO_2 dissolves in water to create carbonic acid and enters pore space within the concrete. The dissolution process releases carbonate ions, which react with calcium ions to produce calcite ($CaCO_3$).

This process consumes calcium hydroxide (Portlandite) and calcium silicate hydrates in the cement paste (Sources AC, AJ). The process occurs most rapidly at moderate humidity and is limited in low humidity due to a lack of water to dissolve the CO_2 and create carbonic acid and at high humidity (saturation) due to water filled pores preventing infiltration of carbonic acid. As the process requires CO_2 dissolved in water to enter pore space within the concrete, it is initiated at the surface and gradually penetrates the concrete surface with time. It is noted however that the process is limited and does not penetrate the full depth of concrete. Freshly exposed surfaces of old concrete (i.e. crushed material from demolition of old buildings and structures) therefore behaves as fresh concrete would and generates the high pH leachate. pH plumes are not considered to be an issue from mass concrete due to the relatively low surface area exposed. The difference with RCM is the amount of surface area available and therefore the much greater capacity for changes in pH in comparison to mass concrete.

A method described in Source G allows the calculation of the CO_2 binding capacity for a concrete material, from which it is possible to then calculate the amount of CO_2 uptake over a certain period of time.

5.2.3 Potential for Release of Metals within Leachate

5.2.3.1 Influence of pH

A number of literature papers examined the potential for pH to influence the leaching of metals from crushed concrete. The findings are summarised in the table below with cross referencing to the papers listed in Appendix B.

Table 2. Evidence of pH influence on metal leaching

Compound	Evidence of pH Influence	Key Papers (reference as per Appendix B)
Aluminium (Al)	A decrease in pH from 12 – 11 decreased leaching. High leaching at alkaline pH values (in exceedance of groundwater risk levels considered).	AM, AP
Arsenic (As)	Leached at high pH in field and lab tests. Weak soil sorption and high mobility at high pH. Significant amounts of As were not detected in laboratory testing of alkaline (pH 10 – 12) eluates from recycled concrete aggregates obtained under field conditions.	A, B, Z
Barium (Ba)	Highest leaching between pH 4.5 – 5.3; leaching declines as pH increases from these values.	AO
Cadmium (Cd)	Highest leaching between pH 4.8 – 5.2; leaching declines as pH increases and decreases from these values, according to laboratory leach tests. A decrease in pH from 12 – 11 did not show significant variation in leaching; decreasing pH below 8.5 has a more significant impact on increasing Cd leaching in laboratory leach tests. Significant amounts of Cd were not detected in laboratory testing of alkaline (pH 10 – 12) eluates from recycled concrete aggregates obtained under field conditions.	B, AM, AO
Calcium (Ca)	Highest leaching at high (alkaline) pH observed in field leaching tests and pH-dependent laboratory leach tests. High leaching with a very slight decline from pH 0 to 12; significant decline at pH > 12 observed in laboratory tests. Decreasing pH from 12 – 11 decreased leaching in laboratory leach tests, and decreasing pH from 11.25 to 9.94 in laboratory tests (where the concrete was aged to mimic field aging) decreased leaching.	B, D, I, AM
Copper (Cu)	Highest leaching indicated at low pH (<4), according to laboratory leach tests. A decrease in pH from 12 – 11 did not show significant variation in leaching; decreasing pH below 8.5 has a more significant impact on increasing Cu leaching in laboratory leach tests. Significant amounts of Cu were detected in laboratory testing of alkaline (pH 10 – 12) eluates from recycled concrete aggregates obtained under field conditions.	B, AM, AO
Chromium (Cr)	Leaches more in the pH 10-13 region. Weak soil sorption and high mobility at high pH. Lowest leaching at pH 5 – 6.5 (weak acid); highest leaching at high and low pH. Leaching from fine particles higher at pH 2 only, according to laboratory tests where the effects of pH and grain size were considered. Significant amounts of Cr were detected in laboratory testing of alkaline (pH 10 – 12) eluates from recycled concrete aggregates obtained under field conditions.	B, Q, Z, AM

Compound	Evidence of pH Influence	Key Papers (reference as per Appendix B)
Iron (Fe)	Highest leaching indicated at low pH in pH-dependent laboratory leach tests.	D
Lead (Pb)	Highest leaching at low pH (<4), according to laboratory leach tests. A decrease in pH from 12 – 11 did not show significant variation in leaching; decreasing pH below 8.5 has a more significant impact on increasing Pb leaching in laboratory leach tests. Significant amounts of Pb were not detected in laboratory testing of alkaline (pH 10 – 12) eluates from recycled concrete aggregates obtained under field conditions.	B, AM, AO
Magnesium (Mg)	At high pH, changes in pH have little effect on amount of leaching	B
Manganese (Mn)	A decrease in pH from 12 – 11 did not show significant variation in leaching; decreasing pH below 8.5 has a more significant impact on increasing Mn leaching in laboratory leach tests.	AM
Molybdenum (Mo)	Leaches more in the pH 10-13 region. Weak soil sorption and high mobility at high pH. High leaching at alkaline pH values (in exceedance of groundwater risk levels considered) observed in laboratory leach tests.	Z, AP
Mercury (Hg)	Mercury leaching from recycled concrete aggregates from the demolition of a 50-year-old building exceeded permissible limits in laboratory leach tests. Significant amounts of Hg were detected in laboratory testing of alkaline (pH 10 – 12) eluates from recycled concrete aggregates obtained under field conditions.	B, AG
Nickel (Ni)	Leaching declines as pH increases, according to laboratory leaching tests. A decrease in pH from 12 – 11 did not show significant variation in leaching; decreasing pH below 8.5 has a more significant impact on increasing Ni leaching in laboratory leach tests. Significant amounts of Ni were not detected in laboratory testing of alkaline (pH 10 – 12) eluates from recycled concrete aggregates obtained under field conditions.	B, AM, AO
Selenium (Se)	Amount of leaching fluctuates with pH change but leaching overall decreases slightly as pH increases, according to laboratory leach tests. Leached at high pH in field and lab tests. Weak soil sorption and high mobility at high pH.	A, Z, AO
Silicon (Si)	A decrease in pH from 12 – 11 increased leaching in laboratory leach tests. A decrease from 11.25 to 9.94 in laboratory tests (where the concrete was aged to mimic field aging) had no effect on leaching.	I, AM
Sulphur (S)	A decrease in pH from 12 – 11 increased leaching in one study in laboratory leach tests. A decrease from 11.25 to 9.94 decreased leaching in in laboratory tests (where the concrete was aged to mimic field aging).	I, AM
Technetium (Tc)	At high pH and reducing conditions, Tc sorbs to cement.	AY
Uranium (U)	Uranium is highly insoluble at high pH and reducing conditions. At neutral pH, solubility increases by several orders of magnitude, increasing leaching.	AY

Compound	Evidence of pH Influence	Key Papers (reference as per Appendix B)
Vanadium (V)	Leaching increases with pH. Weak soil sorption and high mobility at high pH.	U, Z
Zinc (Zn)	Highest leaching indicated at low pH in laboratory tests. A decrease in pH from 12 – 11 did not show significant variation in leaching; decreasing pH below 8.5 has a more significant impact on increasing Zn leaching in laboratory leach tests. Significant amounts of Zn were not detected in laboratory testing of alkaline (pH 10 – 12) eluates from recycled concrete aggregates obtained under field conditions.	B, AM

The following table summarises the above results.

Table 3. Summary of pH influence on metal leaching

Metals where raised pH may promote leaching	Metals where raised pH may retard leaching	Metals where the influence of raised pH is not clear
Aluminium	Barium	Arsenic
Calcium	Cadmium	Magnesium
Chromium	Copper	Silicon
Mercury	Iron	Sulphur
Molybdenum	Lead	
Selenium	Manganese	
Vanadium	Nickel	
	Technetium	
	Uranium	
	Zinc	

It is noted that one source (Y) indicated that cementitious materials are used in engineered groundwater remediation barriers to increase the pH and reduce the solubility of some compounds and promote sorption onto the matrix. In this study, the potential contaminants under consideration were non-nuclear in origin (e.g. organic acids), though it was noted that cement reduces actinide leaching in the containment of radioactive materials. Cementitious materials have been used to immobilise radioactive wastes via sorption (Source AT), and are used at the UK LLWR as grout, maintaining high pH (~11) reducing conditions in vaults, buffering organic acid production and CO_2. Neutral pH and reducing conditions are maintained in the waste disposal trenches (LLWR Source AY). Leaching of radiological contaminants is low, however leachate from the site sometimes exceeds local baselines for a number of metals, most significantly Cu, Fe and Ni. Groundwater and surface water also exhibit exceedances for a number of metals (Source AZ). It is noted from the summary above that the leaching of Cu, Fe and Ni would not be expected to be as a result of raised pH.

5.2.3.2 Influence of Water Type

Source AA (abstract reviewed only) considered the effects of different water types on metal leaching from concrete. Laboratory tank leaching tests were conducted using deionised water, four different groundwater types and two synthetic water types. Their findings indicated that deionised water produced significantly overrated metal leaching, in comparison to the other water types. It was also found that metal leaching was dependent on water hardness, Ca concentration and hydrocarbonate availability.

Another source, BB (abstract reviewed only), conducted leaching tests over a number of years for cementitious wasteforms containing radiological contaminants. It was found that the annual caesium-137 leach rate in deionised water was 35 times greater than the values observed in the initial year of field testing.

Although not the subject under investigation in the study reported in Source A, neutral pH was observed in leachate from material that had been stockpiled for over one year but when the same material was subject to laboratory testing, a high pH was observed. It was suggested this may be due to carbonation of percolating water and/or preferential flow due to weathering and that more investigation was needed. Based on the other results discussed in this section, it may also be that the laboratory tests were giving false high results due to the use of synthetic rainwater.

As noted above, AECOM investigations at one site also showed that the type of water used in laboratory leaching tests is critical in understanding the rate of leaching/how soon high pH leachate will be generated.

5.2.4 Effects of Crushing / Grading

A number of sources were considered to determine the effects of crushing and/or grading RCM on the leachate produced, both with respect to pH and metals leachates.

Higher amounts of metals, including Al, Ca, Cu, Fe, Mg and Zn, silicon and sulphate were leached from finer-grained RCM, as a larger surface area was available from which metals could be leached (Sources D, Q).

In Source D, one of the two materials tested did not show a difference in pH based on the nine particle size fractions tested (up to a maximum of 10mm), however in the other material tested particle size appeared to influence the pH with a reduction in pH with an increase in particle size. It is noted that only particles up to 10mm were tested and the lowest pH recorded was still approximately pH 11. The authors stated that the composition of the concrete was a larger influence on pH than particle size.

In Source Q, the RCM was graded to three fractions (fine, sand and gravel). All samples were then reduced to less than 2mm size prior to testing. AECOM considers that the process of reducing the grain size would have altered the results by generating fresh concrete surfaces in some of the sand and all of the gravel fractions. The authors of the research paper note that the gravel fraction had a higher material pH than the sand or fine particles and attribute this to weathering of the fine and sand material. This implies that crushing to a smaller grain size promotes the rate of carbonation; however these results may be influenced by the laboratory crushing step in the testing.

Trace elements were also found to be detectable in leachates from fine-grained material (Source AM). In this study, non-standard leach tests were undertaken on different fractions without supplementary crushing. In all cases the pH was elevated, however this may be as the samples were sourced from recently generated RCM.

Source Q observed increased leaching of Cr and Zn from fine particles than coarser particles, however they noted that for Cr, this was only the case at pH <2, which is unlikely to be present in the field.

A major application of RCM is as road base, with this material having been used successfully in a number of cases in unbound form (Sources A, D). A French study (Source AM) found that the maximum grain size used during crushing of RCM influenced the amount of fine grains produced, and that therefore a maximum grain size as high as possible should be used to minimise the proportion of fines present, and therefore reduce the leaching of trace elements.

In the 2015 Arcadis laboratory based study (Source BX), it was observed that varying the ratio of crushed concrete fines (i.e. the clay and silt size fraction) influenced the rate of leaching through advective / diffusive processes. It was recognised that although the higher surface area of the fines would theoretically increase the dissolution rate from the solid surfaces, the inclusion of increased fines reduced the void space (porosity) and permeability of the crushed concrete backfill which in turn reduced the rate of leaching. This was determined using a monolithic tank test whereby leaching of inorganic components from moulded and monolithic materials was determined under aerobic conditions. The samples (reduced fines / standard fines / increased fines) were leached over the course of 64 days (divided into 8 stages) at a controlled temperature of 20°C +/- 2°C. The sample reported to have leached the most calcium carbonate and bicarbonate was the sample with the reduced fines and the sample that leached the least was the one with increased fines. During stages 1 and 2 (up to 1 day) the standard fines and increased fines samples leached at a similar rate. However during the subsequent stage (Stage 3) the rate of leaching from the standard fines sample increased significantly compared to the reduced fines sample. For the remaining stages (Stages 4 to 8) the two samples leached at a similar rate. The reduced fines leached at a higher rate than the other two samples from Stage 1 onwards. However a significant increase in leaching rate compared to the other two samples is noted from Stage 3 onwards. Notwithstanding the above all three test samples reached or approached pH 12 within tens of days from commencement of the test. It is noted that the tests did not simulate or provide indication of the long-term effects of processes that could be expected to operate in a mass of crushed concrete backfill, such as cementation of pore spaces (affecting hydraulic properties) and carbonation of pore surfaces by atmospheric CO_2 dissolved in groundwater.

5.2.5 Effects of Compaction

One source, AN, found that compaction of RCM increased metal leaching during testing. This was attributed to the compaction process increasing the proportion of fine particles in the aggregate (from 3.6% to 7.5% and 1.7% to 8.5% in the two samples compacted), thus increasing the available surface area. It is noted that this was a laboratory study and the compaction method may not replicate real world practices. Conversely, the Arcadis report suggests that compaction should reduce the pore space and therefore the contact with water and potentially slow the release of OH^- ions from cement which produces high pH leachate. Arcadis go on to state that high pH was eventually reached in all cases, but at that the increased compaction delayed the effect.

Source AO indicates that a greater contact time increases the release of metals in laboratory leaching tests. Where infilling in voids is being undertaken above the water table with rainfall being the only source of water, it may be preferable to not compact the RCM (if geotechnical requirements allow) to allow the rainwater to drain more freely. In addition, Source AN above indicated that compaction increases the fine particle content of the material which may lead to more leaching, however the compaction used in the laboratory may not be comparable to actual compaction practices undertaken on construction projects. Where infilling in voids below the water table is being undertaken, a high degree of compaction may be preferable to reduce flow of water through the RCM.

5.2.6 Potential for Reuse within New Structural Concrete or Grout

This research focusses on the reuse of RCM in its unbound form and potential methods of reducing the generation of high pH leachate. Binding of the RCM into new concrete would minimise the potential for high pH leachate to be generated by reducing surface area in contact with water. Should NDA sites identify opportunities to reuse the concrete in this way it may represent a more environmentally sensitive use of the RCM available on site. The potential for this reuse scenario to be plausible is therefore discussed below.

The properties of RCM are different from those of Natural Aggregate (NA), with RCM having a lower density, decreased specific gravity, increased crushability, increased ability to absorb water, greater quantity of organic impurities and possibly harmful substances, and in general, a greater proportion of fine particles (Source AW). This study found that the performance of concrete made with RCM is mainly satisfactory with the exceptions being the modulus of elasticity and shrinkage deformation (assuming the RCM used is of good quality). It was therefore not recommended to use such concrete for structures for which large deformations would be expected. In addition, it was not recommended for use where the structure could be exposed to aggressive environmental conditions without further testing. It indicated that coarse RCM should be used when substituting for NA.

Structural issues can result from the reuse of crushed concrete, as expansion of concrete material can occur when the concrete itself or the surrounding conditions are rich in sulphate, via a process of internal or external sulphate attack. External attack is more common, and occurs when sulphate solution penetrates the concrete, precipitating gypsum and ettringite and causing expansion (Source BE). Alternatively, internal concrete attack occurs when significant sulphate ions are present in the concrete, resulting from high gypsum content in the concrete. Interaction with calcium-aluminate hydrates results in ettringite formation, causing expansion and cracking (Source BF). It was observed in Source BC that excessive heave and expansion are a problem when the crushed concrete contains significant sulphate content, in this case 9% sulphur trioxide (SO_3), resulting from the addition of gypsum to the concrete. However, it was noted that commercially produced concrete had a much lower sulphate content of

0.38% SO_3. When commercially produced concrete was exposed to a 5% sulphate solution, significant expansion was also observed, though this was considered to be an atypically high sulphate concentration, when compared to most field conditions. Another form of sulphate attack occurs when concrete contains significant available carbonates, at high moisture contents and low temperature (Source BH). Reaction of calcium-silicate hydrates with sulphates and carbonates turns the concrete into a ‘mush’ (Source BG).

Expansion can also result from the reaction of reactive silica in the concrete or aggregate with alkalis in the presence of water, producing an expansive gel (Sources BD, BL). It was also noted that dissolution of soda-lime glass in concrete can also result in the precipitation of expansive gel, under moist conditions at pH > 12 (Source BD).

A study considering replacement of NA with RCM in the production of new structural concrete in Egypt (Source AU) found that the physical properties of an aggregate 100% RCM were significantly reduced compared to one 100% NA, however a blend comprising 25% RCM and 75% NA could be used in new structural concrete with no significant changes in properties. A study outlined in Source AV indicated that RCM can also be used as granular infill in segmental concrete units in place of coarse NA with minimal change in aggregate frictional properties. This was found to be irrespective of the grade of the RCM.

A report by the National Nuclear Laboratory (NNL) and NDA (Source BW) conducted small- and large-scale tests to assess the possibility of fine RCM reuse in grout for radioactive wastes. Small-scale tests indicated that fine (<2.36mm) RCM was suitable for use in the production of high fluidity grouts, with acceptable strength and heat generation. The optimum grout blends used a 2.5:1 to 3:1 RCM:binder ratio, with a binder incorporating GGBS and Portland cement. However, results for large-scale tests did not produce grouts with acceptable properties, attributed to be due to the increase shear applied during the large-scale tests. Further work assessing grouts produced in large-scale tests was recommended.

Whilst on some NDA estate sites it may therefore be possible to reduce the fines content of RCM in infill material by screening it out and using in new concrete, this needs further investigation. Its application would also be limited by logistical and scheduling issues as screened, fine RCM for future reuse in concrete would need to be kept dry to avoid creating high pH leachate (more likely to be produced from the finer material than a mixed stockpile – see Section 5.2.3).

5.2.7 Promotion of Weathering

5.2.7.1 Timescales

Leachate pH decreases over time as RCM is weathered, as a result of the carbonation process (Section 5.2.1.5). A review of several papers was conducted to investigate the timescales over which a reduction in leachate pH was observed experimentally. The results of this review are summarised in Table 4.

Table 4. Timescales for reduction of leachate pH

Papers (as per Appendix B)	Experimental timescale for leachate pH reduction
D	After 28 days curing (placement of sieved material in bowls or bags with deionised water at 9.5% moisture content in a moisture-controlled humidity chamber), leachate pH reduced by up to 10%, however was still above pH 10. Leaching of Cu, Ca, Cr and Fe also decreased. Freeze/thaw cycles were also shown to reduce pH leaching slightly.
A	In field tests: - RCM previously stockpiled for 1 year produced a neutral leachate after 7 months. - At a different site, fresh RCM produced highly alkaline leachate over the same period, whereas RCM stockpiled for >5 years showed initially neutral leachate pH which increased to highly alkaline; leachate pH from stockpiled RCM increased over the first two pore volumes of flow to above pH 12. It is noted that further data are not available therefore it is unknown if they remained high. In laboratory tests, highly alkaline leachates were observed for all materials throughout testing.
I	Over a 1-year aging period (in lab conditions), leachate pH decreased from a maximum of 11.25 to 9.94, and Ca, Al and Fe content also decreased. Concrete carbonate content increased, and

Papers (as per Appendix B)	Experimental timescale for leachate pH reduction
	this increase was believed to be the cause of pH decrease. Laboratory aging tests were conducted on fresh RCM using synthetic rainwater, with ion concentrations and pH developed to match field conditions. The RCM material was wetted on a weekly basis, replicating the average monthly field rainfall for the period. Field (northern Virginia, USA) temperature and humidity conditions were also replicated.
K	Over 14 months, leachate pH decreased for uncovered and asphalt-covered RCM. The RCM was sourced from a demolished roadway and crushed to 20-120mm prior to testing shortly after demolition. The decrease was larger for uncovered RCM than for covered. It is noted that testing was done in the field on a section of road, rather than as a stockpile of RCM. The testing included the depth of carbonation which was given as 3-10mm in the upper layer of the field (assumed to mean that carbonation on individual pieces in the upper sections of the fill had reached this depth).
O	In field tests, leachate pH from fresh RCM remained highly alkaline over the first 3 pore volumes of flow, whereas leachate from stockpiled RCM (5-10 years) showed an initially neutral pH, which increased to highly alkaline and then decreased slightly to 10.6. This was interpreted to be dissolving of the carbonate that had built up over the previous stockpiling. In field tests, the concrete material was leached by rainwater, although the water type used in laboratory tests was not given. Note, this is the same data as source A.
J	After 20 – 50 years, 75% of calcium oxide in RCM had been carbonated.
BY	Reports a rapid decrease in pH value within run off from stockpiles over a few weeks.

It has been noted in two studies (Sources A, Q) that observed leachate pH over time is different in field and laboratory tests. This may be due to the different conditions experienced by the RCM, such as exposure to atmospheric CO_2, freeze-thaw and wet-dry cycles enhancing weathering. A crack in the asphalt overlying one of the test sites may have also created a preferential pathway to allow more rapid weathering to occur.

The initially lower pH observed from stockpiled RCM (Source A) may be due to the presence of existing carbonation products coating the grains. A separate source discussing the same data (Source O) attributed this to the carbonate being dissolved soon after the leaching test began. This may mean that stockpiling prior to infilling with the aim of allowing the RCM to weather/carbonate may not be a successful strategy if the carbonation can be reversed.

The amount of carbonation that is possible is dependent on a number of factors, all of which can be highly variable. Source G reported that influential factors included stockpiling time, material surface area and stockpile moisture content. The process of stockpiling affects surface area, as material is generally crushed prior to stockpiling, increasing surface area and allowing a greater amount of carbonation to occur, lowering the leachate pH (Source H). It was also stated that stockpiled RCM would weather faster than buried concrete due to both exposure to air and the dryer environment.

The rate at which RCM weathering can occur may be accelerated by exposing the material to air. It was observed in Source A that cracked asphalt overlying an RCM road base allowed neutral leachate pH values to be observed during testing earlier than they might otherwise have been. Freeze-thaw weathering has also been observed to reduce leachate pH (Source D).

5.2.8 Effects of Inclusion of Other Binders

It was explained in Source D that the initial concrete and cement production processes often use fly ash and steel slag, meaning that such materials are often present in RCM, and provide an additional source of metals which may be leached. Source O observed greater concentrations of As, Ba, Co, Cr, Cu and Ni in RCM than in natural aggregate due to the presence of these additives.

A strongly alkaline (up to pH 13) leachate is produced from steel slag (Source AH), with associated metals including Fe, Mn, Cr, Mo and V. The leachate produced from coal fly ash can be highly variable in its pH, from strongly acidic to strongly alkaline, although alkaline leachates are considered to be more common (Source AR). Like RCM, metal leaching is dependent on pH. It is possible that inclusion of steel slag and / or fly ash may slightly reduce concrete leachate pH.

Metal leaching from a steel slag was investigated (Source AQ), finding that leaching of Ca, Mg and other metals was below 0.5% for each.

Leaching of As, Ca, Cr, Cu, Fe, K, Mg, Na, Pb and Zn from fly ash was investigated in Source T over a 180-day period. In general, metal leaching was much lower at higher pH, apart from arsenic. It was also found that blending the ash with lime reduced metal leaching.

It has also been shown (Sources BI-BK) that the inclusion of admixtures such as nano silica, micro silica, fly ash and ground granulated blast furnace slag increases concrete resistance to sulphate attack and reduces the resulting expansion, with nano silica and slag being particularly effective.

5.2.9 Effects of Inclusion of Acidic Soils

Blending the RCM with soil may be a potential method to lower leachate pH. A study outlined in both Source F and Source AP found that mixing 200ml of leachate with 100g of alkaline soil produced only ~1 unit reduction in soil pH. A study described in Source AP investigated the extent to which soil is capable of neutralising leachate pH. Overall, it was found that leachate pH decreased as the proportion of soil relative to RCM increased. In addition column tests were used, with soil samples initially saturated with nanopure water following which an upwards flow of RCM leachate was induced at a steady rate through use of a pump. The resultant leachate was collected at various ratios ranging from 0.2 to 0.45 liquid to solid ratio. The cumulative liquid to solid ratio of the samples collected was 10:1 liquid (litres) to solid (kg) ratio. Initially the acidic soil produced leachate pH values as low as 4 however this reduction was only effective with a low liquid to solid ratio. Once a cumulative liquid to solid ratio of 4:1 had been reached the resultant leachate had a pH similar to the input RCM leachate. When less acidic soils were used, the pH in the resultant leachate rose from neutral to highly alkaline within the same 4:1 liquid to solid ratio. This indicated limited capacity for pH to be buffered in soils. It should also be considered that, as reactions occur the buffering capacity of the soils would be expended. Assuming a 1 m^3 of soil is 1,800 kg, the 4:1 liquid (litres) to solid (kg) ratio above would mean 7.2 m^3 of leachate is required to replicate this ratio. Over a 1 m^2 area therefore, 7.2 m of rainfall producing a highly alkaline leachate would be required to use the soils buffering capacity to the depth of 1 m. This implies buffering may be possible in the medium term (up to 10 years).

The study considered migration of high pH leachate through the unsaturated zone to groundwater, therefore in addition to the soils tests above, a desktop study was undertaken on the capacity of carbon dioxide in the pore spaces in the unsaturated zone to reduce the pH. No appreciable drop in pH was predicted from the calculations, however it was noted that it did not include for carbon dioxide production from degradation of organic materials. Further, calculations were then undertaken to assess the potential for reaction and dilution within groundwater to reduce the pH. These were based on conditions typically found in groundwater local to the study area (Florida, USA) and therefore may differ from those within the UK. It is noted that at high dilution factors (e.g. dilution factor of 100) significant drops in pH from 12 to below 9 were predicted.

5.2.10 Emerging Technologies

RCM will weather and carbonate over time, and it may be possible to accelerate the process by actively carbonating the material. The resulting products would produce a lower pH leachate once in contact with water and potentially reduced leaching concentrations of a number of metals. Source Z suggests that promoting such processes in a range of alkaline wastes could allow sequestration of atmospheric CO_2, offsetting the CO_2 released during production, however at the scale of reuse for the NDA estate sites, this is not considered to be a significant opportunity. Source Z also includes discussion on the potential for metal (e.g. Co, Li, Se and V) recovery from alkaline leachates however, again at the scale of reuse at the NDA estate sites this is unlikely to present a realistic opportunity. The authors of the paper also noted the potential of this process is limited, due to the difficulty of developing low energy, low cost methods of extracting these metals.

Another management strategy that shows potential for management of high pH leachate is the use of wetlands to bioremediate contamination passively, although further evaluation of the mechanisms and overall effectiveness is required (Source Z). This would have limited use where RCM is used below ground as it requires the run off to be directed through the wetland at surface.

It may also be possible to reduce the amount of concrete slab excavated at demolition. Use of a blend of compost and recycled aggregate (unspecified as to whether it was RCM or not) over in-situ concrete slab allowed cultivation of a diverse wildflower population at a former industrial site in Cumbria. This was considered to be preferable to removing the concrete slab and using soil to allow planting of grass or trees. Overall it was considered a successful method of reducing the cost of site remediation (Source BA). The information does not include whether pH leachate from the aggregate/compost mix was measured.

5.2.11 Summary of Literature Review

Overall, the literature review indicates a large amount of studies and information available, some of it contradictory. It is noted however that much is based on laboratory experiments that may not replicate real world conditions either through use of deionised water, scale of experimentation or inability to replicate real world conditions (e.g. degree of compaction) in the laboratory. In addition, a lot of the information available is based on studies that were not designed to assess or replicate the conditions under which NDA estate sites would reuse RCM. For example, much is based on RCM use in roads which is at a shallower depth and more likely to be covered than anticipated for NDA estate site reuse. In addition, the focus of studies is commonly on metal leaching rather than reduction or management of high pH leachate. A number of preliminary conclusions and recommendations can be drawn from the information presented as discussed in Section 6.

6 Overview of Findings

6.1 Applicability of Findings to NDA Estate Sites

As discussed above, the literature research is often from studies not designed to assess situations that are anticipated to be relevant to the NDA estate sites. Additionally, the majority of the research is based on laboratory trials rather than field trials. It is possible, however to make a number of preliminary recommendations by considering these results alongside the anticipated reuse scenarios and real-world examples provided from the engagement element of the project.

The evidence from the industry engagement is indicative of a general lack of awareness of potential issues within the demolition and construction industries. This is not true for the whole of the demolition and construction industry and in general, awareness within remediation contractors seems to be greater. Overall, this lack of awareness has resulted in a lack of standard procedures for assessing and controlling high pH leachate.

It is noted that within the NDA estate sites, awareness is higher and all sites have undertaken assessments of potential issues. It is noted that the lack of consideration of pH from RCM within guidance (i.e. not mentioned in the WRAP protocol) and complexity of regulatory regimes for control and reuse of waste is not helpful. This has resulted in each of the SLCs using different regulatory regimes for their current stockpiling and reuse arrangements.

6.2 Key Findings

The key findings are detailed in Table 5 below.

Table 5. Preliminary Key Findings

Key Finding Subject	Key Finding	Literature Evidence	SLC Evidence	Industry Evidence	Data gaps
Assessment prior to reuse	Assessment of the potential risks associated with concrete reuse must be made in advance of the reuse to enable that use under legislation (most require the materials to be shown to be suitable for reuse), to satisfy regulators, to reduce the potential for future reactive mitigation measures and to reduce the potential for issues to prevent the site entering the Care and Maintenance phase. This assessment should include a good understanding of the CSM.	No information.	Assessment and implementation of mitigation measures in advance of RCM reuse can be relatively cost efficient in comparison to reactive mitigation which can be more expensive and would constitute unplanned spend (it is noted there is a difference in scale of reuse of RCM between these sites). Reviewing the CSM at Trawsfynydd allowed identification of a direct pathway from the RCM infill in the Turbine Hall basement to a compliance point receptor. Removal of this pathway was key to reducing the pH at that compliance point. Reviewing the CSM at Chapelcross allowed identification of a direct pathway through drainage to a surface water receptor. Modification of the drainage systems in the area allowed the potential for high pH leachate to enter that surface water to be minimised.	In one instance, the use of RCM following assessment showed that there was no viable linkage to a sensitive receptor.	-
Plume extent and receptor sensitivity	Depending on the site conditions plumes may be limited, however this may not be the case. In addition, the relevance of the plume extent will be dependent on the receptors identified within the CSM and the pathways to them.	Laboratory testing indicated that soils could be used to buffer pH plumes but that this would be expected to have a limited capacity. Extrapolation of the results indicates this may provide a solution in the medium terms. Desk based study (modelling) within that assessment indicated that buffering and dilution within groundwater could be expected to reduce the pH.	One company plan to use RCM below the water table in pits close to the northern site boundary at the coast. The regulator has provisionally agreed to this on the basis that the plume extent will be limited by, and be of low importance due to the proximity to the sea.	In this instance, CSM indicated a lack of pathways for migration and a lack of sensitive receptor. The field data indicated the plume extent was limited, potentially by permeable ground conditions and buffering within soils and groundwater.	Little evidence was available of where the extent of a pH groundwater plume has been assessed. Each case will be highly dependent on the CSM. A good understanding of the CSM should be demonstrated before deciding whether and how to use RCM. The exact site conditions needed to naturally limit a plume are not well understood, but could be further assessed through modelling.
RCM saturation in water – carbonation	Saturation within water (e.g. groundwater) will inhibit carbonation and may extend the time during which high pH leachate will be generated.	Literature sources indicate the mechanism by which carbonation is inhibited in saturated conditions.	High pH leachate is still present from the RCM, more than 10 years since placement. The RCM is saturated in water within below ground concrete structures.	This example indicated high pH leachate is still being detected more than 10 years since placement below the water table.	-
RCM saturation in water – rate of leachate generation	Saturation within water is more likely to create pH and metal leaching issues.	Literature sources indicate higher pH and metal leaching in saturated conditions.	One company stockpile RCM in a controlled environment with no high pH readings in drainage and groundwater monitoring well samples.	The assessment of leaching mechanisms on a site where high pH leachate has been produced in situ: high pH leachate was not immediately produced from contact between the RCM and rainwater or groundwater from the site	-
Metal leaching	Whilst high pH may promote the leaching of some metals, this is not the case for all metals.	Literature research, mostly using standard laboratory tests, indicates enhanced leaching of seven metals, and reduced leaching of nine metals.	Some metal leachates are detected in site data however the literature research does not indicate that the pH is a prime factor in this.	None identified.	The influence of pH on some key toxic metals (e.g. mercury) is not clear. Much of the data is based on laboratory testing that may not

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Key Finding Subject	Key Finding	Literature Evidence	SLC Evidence	Industry Evidence	Data gaps
					reflect conditions and reactions in-situ.
Concrete binders	Inclusion of binders other than OPC may increase metals content and leaching but decrease pH.	Literature sources detail the effect of use of binders such as fly ash and steel slag.	None identified.	None identified.	Composition of concrete used in construction of NDA estate sites not known.
Stockpiling	Stockpiling of materials in a controlled manner does not necessarily generate a high pH leachate.	None identified.	One company stockpile RCM in a controlled environment with no high pH readings in drainage and groundwater monitoring well samples.	None identified.	Leachate from stockpiles is not generally monitored due to a lack of awareness and the relatively short turnaround reuse time at most sites. Data is therefore limited.
Enhanced carbonation of RCM in air	Carbonation rates are not well understood but are influenced by freeze/thaw cycles, wet-dry cycles, moisture content and air ingress.	Literature sources identified all of the mentioned factors on carbonation rates and resultant pH leachate. Air ingress is the factor most likely to be able to be controlled on-site through stockpile management.	None identified.	None identified.	As stated, carbonation rates in RCM are not well understood and will be variable based on site conditions.
	Partially carbonated RCM may still produce a high pH leachate.	One source tested material that had been stockpiled for a number of years and found that pH was elevated in the leachate produced in field trials.	None identified	None identified.	It was not clear whether the material had been treated or crushed prior to reuse.
Assessment of leaching potential	Standard laboratory tests may give false data with respect to the potential timescales of high pH and metal leachate generation.	Literature sources indicate differing results in field and laboratory testing.	None identified.	The assessment of leaching mechanisms on a site where high pH leachate has been produced in situ: use of deionised water did not replicate results from use of rainwater or groundwater collected on the site.	Some literature sources do not specify the type of water used in testing. Most literature sources use standard laboratory testing (e.g. deionised water).
Inclusion of acidic soils	Mixing with acidic soils may inhibit pH.	One literature source indicated that acidic soils do have the potential to inhibit pH of leachate but that this was limited at high liquid to solid ratios.	None identified.	Experience at one site found mixing RCM with clays was effective in mitigating high pH leachate migration to an adjacent shallow stream. This may have been due to a combination of the buffering capacity of the clay and the lower permeability inhibiting water movement.	Capacity for this mechanism to have an impact in-situ is not well understood.
Crushing/Grading	Finer grained material is likely to result in higher pH leachate and potentially metal generation due to the higher surface area exposed. It is noted that selection of crushing specification will influence the proportion of fine grained material.	Literature sources indicated higher metal leaching and higher pH from finer grained materials.	None identified.	None identified.	This effect may be off-set by increased carbonation on these surfaces, however the timescale for this is not well understood. It may also be off-set by a reduction in porosity however again, this is not well understood.
Compaction	Compaction may increase the fines content of material.	One literature source included a measured increase in fines content following compaction for laboratory testing.	None identified	None identified	It is not clear if the compaction used in the laboratory testing is similar to actual levels of compaction in construction or demolition projects.
	Compaction will reduce the pore space available and therefore may reduce the rate at which high pH leachate is generated.	Arcadis report undertaken on behalf of Magnox indicates higher fines content delays generation of high pH leachate, however it is noted that highly alkaline leachate was still generated.	None identified.	One respondent identified stabilisation through compaction as a method of reducing permeability.	It is not clear how effective this technique would be in practice i.e. whether sufficient compaction could be achieved to limit water movement to the degree necessary to limit high pH leachate generation. It may be most effective combined with an engineered

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Key Finding Subject	Key Finding	Literature Evidence	SLC Evidence	Industry Evidence	Data gaps
					capping layer to reduce infiltration.
Treatment of high pH water	If water can be contained and either abstracted or collected, it can be treated relatively easily at the collection point such that it can be disposed of through the site drainage system in compliance with discharge consent limits. Where appropriate this should be automated to reduce labour commitments, increase safety and increase efficiency of the system.	None identified.	On-going treatment of high pH water at Chapelcross using established technology to reduce suspended solids (siltbuster) and pH (CO_2 injection).	In one instance, it was demonstrated that treatment of water using established technology to reduce pH (acid injection) with differing degrees of automation.	-
Reuse in structural concrete or grout	There is potential for reuse of coarse RCM as aggregate in new concrete or for reuse of fine RCM in grout.	Literature sources indicate that satisfactory structural properties of concrete can be obtained whilst using a proportion of RCM instead of natural aggregate. A report by the National Nuclear Laboratory and NDA indicated that at small scale testing, fine RCM could be used in production of high fluidity grouts.	None identified.	None identified.	Some limitations were noted for structural concrete. One company's research identified that it was difficult to scale the testing up to give satisfactory results. Reuse would also be limited by logistical and planning considerations.

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6.2.1 Summary of Key Findings

As noted in Section 1, the reuse (out of scope materials) or disposal (in scope materials) of site derived material on-site is considered beneficial through reduction of the amount of material needed to be imported or exported from site. As discussed, whilst it may be possible to sell RCM as an aggregate for use in other industries, where material is needed on site, the benefit would be insufficient to cover the cost of import of other material.

The key findings above indicate that use of RCM is possible on NLS; however, it should be assessed to allow SLCs to avoid uncontrolled release of high pH leachate to the environment. The following sections detail preliminary conclusions and recommendations as to how best to plan for and manage the reuse of RCM.

6.3 Conclusions and Recommendations

6.3.1 Planning Works

Key conclusions and recommendations are made as follows:

- Consider the requirements of the site as a whole and identify opportunities to use RCM within new concrete. Where applicable, the planning process for the Site End State could be used to facilitate this;
- Plan in advance of contract tender for demolition works to allow appropriate specifications (e.g. crush grading or segregation of materials) and mitigation measures (e.g. breaching of voids or covering of materials) to be incorporated as planned activities and planned spend;
- Identify possible locations for stockpiling and reuse through comparison of available areas and voids with respect to proximity to receptors and known pathways to those receptors;
- Confirm suitability of those locations for reuse/disposal through creation of a CSM which considers appropriate pathways (including direct links through drainage), and receptors (including compliance points). It should also consider receptor sensitivity. The source term (volume and type of material should be established. It is noted that this CSM and associated Risk Assessment is likely to be qualitative as there is currently a lack of an established model to assess the potential extent of the pH plume and so provide a more quantitative assessment of the significance of potential risks to receptors (Key Knowledge Gap 1);
- Use the CSM to design mitigation measures prior to the works; and
- If testing mixed or previously stockpiled material to assess for metal or pH leachate potential, consider amended standard laboratory tests, for example to:
    - Exclude crushing during sample preparation as this will expose new surfaces which may create high pH leachate faster than previously exposed surfaces;
    - Use rain or groundwater instead of de-ionised water as use of de-ionised may provide unrealistic data; and
    - If known or can be estimated reducing leaching time to match realistic on-site contact times as extended contact times can provide unrealistic data.

6.3.2 Production of Aggregates for Reuse

Key conclusions and recommendations are made as follows:

- Segregate brick and concrete demolition materials in order to allow flexibility in use of materials as brick does not create a high pH leachate. Brick could then be used either in more sensitive voids/areas or as a low permeability cap as required by the mitigation measures designed; and
- Keep fines content to a minimum through specification of crushing grading. It is noted that there may be geotechnical consideration to take into account in this specification also. It is also noted that there is some contradictory evidence on whether reducing fines provides a benefit. On

balance, in most situations, it is considered that it is likely to be a benefit however this is an area for further investigation (Key Knowledge Gap 2).

- Control wash waters and dust from production areas as finer particles are more likely to produce a high pH leachate and migration of these particles to receptors may cause a temporary issue during works.

6.3.3 Stockpiling

Key conclusions and recommendations are made as follows:

- Where possible, select areas that are not in proximity to or have direct pathways to sensitive receptors;
- Aim to keep contact times between rainwater and the RCM to a minimum. It is noted that one example suggests high pH leachate runoff is not inevitable and other evidence suggests contact times are key to minimising high pH leachate production. This needs further investigation or confirmation (Key Knowledge Gap 3) but contact times could be reduced by:
    - Selecting areas where surface ponding of water is unlikely;
    - Keeping fines to a minimum; or
    - Placing stockpiles on a free draining surface.
- Where stockpiling is anticipated for an extended period, crush material prior to stockpiling to a grade anticipated to be suitable for future reuse without additional processing. This should allow the carbonation process to begin and mitigate future risks when used at a later date. It is noted that the timescale for carbonation to be effective is not well understood and some evidence indicates that carbonated material can still produce a high pH leachate when that material is later saturated in water (Key Knowledge Gap 4); and
- Monitor leachate to improve understanding of the potential for stockpiled materials to generate high pH leachate (Key Knowledge Gap 5). This may also help future use of RCM in landscape areas.

6.3.4 Reuse or Disposal in Voids

Key conclusions and recommendations are made as follows:

- Where voids are anticipated to be above the groundwater table and surface water ponding at all times of year, ensure contact time with rainwater is minimised by:
    - Effective capping of the void to prevent rainwater infiltration;
    - Effective puncturing of the void to prevent ponding in the base of the void. This may need to be done in combination with capping drains that might provide direct pathways to sensitive receptors; or
    - Compaction to reduce the potential for infiltration. It may be more effective to provide a low permeability cap rather than compact the full depth of material. Compaction is also anticipated to require consideration with respect to geotechnical properties and reuse of the area.
- Avoid use of RCM in voids which are anticipated to be below the groundwater table at any time of year unless there is confidence from assessment of the CSM that leachate produced is unlikely to cause an environmental issue. It is noted that the evidence for use of weathered/previously stockpiled RCM is mixed and at present it is not possible to state that such material would not create a high pH leachate when saturated in water. It is therefore recommended that this is avoided unless additional research confirms that weathered materials do not pose a risk.

6.3.5 Reuse in Landscaping or as General Cover

Key conclusions and recommendations are made as follows:

- Avoid use of RCM as unmixed general cover over more impermeable materials close to sensitive receptors. It may be effective to mix the RCM with acidic, low permeability soils to allow use closer to sensitive receptors; and
- Avoid creation of landscaping bunds close to sensitive receptors. It is noted that use of lower permeability soils to enclose RCM may be an effective mitigation measure where landscape bunds are required closer to sensitive receptors. If appropriate for the planting required, use of acidic soils mixed with the concrete may also be effective mitigation for high pH leachate.

6.3.6 Treatment of High pH Water

It is noted that this is not a preferred option, but is included to provide information on how to address or handle high pH water where it is found to be present and causing an issue. In particular information on methods of water treatment. It is recommended that where possible, the system is automated to improve efficiency and reduce health and safety hazards particularly where strong acids are used.

7 Knowledge Gaps

The table below details the key knowledge gaps identified and possible future research that could reduce these.

Table 6. Knowledge Gap Summary

Knowledge Gap	Summary	Potential Future Research Opportunities
1	Ability to undertake Quantitative Risk Assessment.	Development of a model.
2	Effect of grading (in particular fines inclusion).	Establish programme of monitoring.
3	Effectiveness of reducing contact time in minimising high pH leachate generation.	Field trials using freshly crushed concrete in contact with rain and groundwater over different periods of time.
4	Timescale required for effective carbonation in stockpiling to reduce future high pH leachate generation.	Field trials. These should include assessment of whether carbonated concrete generates pH if saturated.
5	Confirmation of the impact that RCM stockpiles have on the environment	Establish programme of monitoring of leachate from stockpiles on NLS.

8 Conclusions

In general, it is considered that this project has fulfilled its objectives through collation and assessment of a broad range of evidence from literature research, the SLCs, the experience of Unity2 team and consultation with industry. It is noted that learning from other industries is less relevant than anticipated at project inception. This is likely to be due to a number of factors that have led to a general lack of awareness or concern with respect to issues from high pH leachate generated from RCM. This is not true of the whole of the demolition and construction industry. These factors include regulatory guidance, and the manner in which such materials are normally used. Our conclusion is that awareness is increasing, and will continue to do so, including with the regulators. This lack of awareness does not reflect the potential size or cost of issues relating to high pH leachate. The scale of RCM generation and voids to be filled differentiates the NDA estate sites from much of the construction industry, which typically uses RCM as a backfill beneath roads or to fill small voids; this increases the importance for the issues presented by use of this material on the NDA estate to be better understood.

It is noted that there is currently a range of regulatory regimes used by the SLCs consulted as part of this project. This is considered partly to be a function of geography and the different regimes available, but also the restrictions inherent in some of the current options (e.g. restriction of stockpiling time frames). Therefore it may not be appropriate to fully standardise or define the approach or use of regulatory regimes. It is recommended however that the NDA and relevant SLCs seek to standardise the approach used and include set elements that can be incorporated into the relevant regulatory regime. It is suggested that the approach be based on the recommendations included in Section 6.3.1 and as a minimum, include assessment of the CSM and confirmation that use or disposal of RCM is appropriate to that setting. Further, it is recommended that the approach is agreed with the environmental regulators such that departures from the current restrictions (e.g. extended stockpiling of RCM where use is certain) can be agreed and controlled appropriately to provide confidence that the departures do not cause environmental issues.

The literature research provided some useful information, albeit that much of it was based on laboratory trials rather than field works. Additionally the focus of a number of the assessments was the potential for increased mobility of metals, rather than the increased pH, and not designed specifically to address some of the key uncertainties associated with the assessment and management of RCM on the NDA estate. As such, a number of key knowledge gaps associated with the recommendations have also been highlighted with opportunities to reduce these through research included. It is noted that current activities on SLC sites could be used to reduce the knowledge gaps and it is recommended that in the first instance opportunities to collect extra data should be identified. Current site activities, such as on-going demolition projects also present opportunities to conduct field trials in parallel to those projects or to provide material for off-site field trials.

The combination of engagement with industry, past experience within the project team and literature research has led to a number of key findings and subsequently recommendations for management and use of RCM on SLC sites. Some key findings from the project have not resulted in recommendations, for example the influence of pH on metals and the influence of different binders within the concrete. These are important factors for consideration within this project but have not given rise to clear actions to be undertaken on site.

Nuclear Decommissioning Authority

References

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Appendix A: Summary of Regulatory Regimes Relevant to Reuse of RCM

The use of RCM as an aggregate can be potentially permitted using a variety of regulatory directives, protocols, code of practices or waste exemptions. These are summarised below.

The Waste Framework Directive (EU WFD 2008/98/EC) (WFD) defines waste as "any substance or object that the holder wishes to discard or is required to discard". Within this definition waste includes:

- Any substance which constitutes scrap materials or an effluent or other unwanted surplus substance arising from the application of any process;
- Any substance or article which requires to be disposed of as being broken, worn out, contaminated or otherwise spoilt; and
- Any substance or article which, in the course of carrying on any undertaking, is discharged, discarded or otherwise dealt with as if it were waste is presumed to be waste unless the contrary is proved.

When a material becomes a waste, the waste producer is responsible for correctly classifying the waste. The correct classification of each waste arising on the site will be necessary to determine the potential options for on-site use, or off site treatment or disposal. Material classified as hazardous is unlikely to be permitted for on-site reuse and therefore appropriate off-site management route will need to be sought. Materials classed as non-hazardous or which meets the legal definition of 'inert waste' as defined in WFD may reused on site with or without treatment using a number of regulatory frameworks/approaches as outlined below.

CL: AIRE Definition of Waste: Development Industry Code of Practice (England and Wales)

The CL:AIRE DoW CoP (Reference 5) allows materials from decommissioning to be recovered for reuse on the site of origin providing the risks to human health and the environment from the material are not unacceptable. It is applicable in England and Wales only. CL:AIRE allows the temporary storage of materials for a maximum of twelve months.

The following summarise the background and main principles for use of the industry guidance document: CL:AIRE (2011) The Definition of Waste: Development Industry Code of Practice version 2.

The purpose of DoW CoP is stated as:

- To set out good practice for the development industry to use when:
  - Assessing on a site specific basis whether the excavated materials are classified as waste or not; and
  - Determining on a site specific basis when treated excavated waste can cease to be waste for a particular use.
- It describes an auditable system to demonstrate the DoW CoP has been adhered to.

Good practice is described in the DoW CoP as:

- Ensuring an adequate MMP is in place;
- Ensuring that the MMP is based on appropriate risk assessment and that objectives of preventing harm to human health and pollution of the environment will be met if the materials are used in the proposed manner; and
- Ensuring that materials are actually treated and used as set out in the MMP and that this is subsequently demonstrated in a verification report.

Where it turns out that materials were not used in accordance with the MMP, the regulator may conclude that the materials have been discarded and therefore are a waste. The DoW CoP relates to the following excavated materials:

- Soil, both top soil and sub-soil, parent material and underlying geology;
- Soil and mineral based dredgings;

- Ground-based infrastructure that is capable of reuse within earthworks projects, e.g. road base, concrete floors;
- Made Ground;
- Source segregated material arising from demolition activities, such as crushed brick and concrete, to be reused on the site of production within the earthworks projects as sub-base or drainage materials; and
- Stockpiled excavated materials that include the above.

The DoW CoP covers both contaminated and uncontaminated materials, from anthropogenic and natural sources, excavated:

- For use on the site of excavation, with or without treatment as part of the site development;
- For use directly without treatment at another site subject to the material meeting specific requirements;
- For the use in the development of land other than the site from which the material was excavated following treatment at an authorised Hub site; and
- Combination of the above.

There are four factors which are relevant in determining whether excavated materials used on sites undergoing development is a waste or not. These factors are as follows:

- Protection of human health and protection of the environment.' Measures to protect the environment and prevent harm to human health have to be assessed and found to be adequate given the proposed use of the materials. Creating an unacceptable risk of pollution of the environment or harm to human health indicates that the material is a waste;
- 'Suitability for use, without further treatment.' The chemical and geotechnical properties of the material(s) has to be suitable and meet its relevant specification for use, otherwise it would be considered as waste;
- 'Certainty of use.' The materials must have certainty of use not probability of use; and
- 'Quantity of material.' Materials can only be used in the quantities needed for that use. Any surplus material is considered a waste.

These four factors are considered to determine the nature of the material(s) as waste or not. The MMP is intended to provide the following:

- Details of the parties that will be involved with the implementation of the MMP;
- A description of the materials in terms of potential use and relative quantities of each category;
- The specification for use of materials against which proposed materials will be assessed, underpinned by an appropriate risk assessment related to the place where they are to be used;
- Details of where and, if appropriate, how these materials will be stored;
- Details of the intended final destination and use of these materials;
- Details of how these materials are to be tracked;
- Contingency arrangements that must be put in place prior to movement of these materials; and
- Verification plan.

A QP is required to review the evidence in relation to the proposed use of materials on the site. If the QP is satisfied with the MMP and supporting documentation they will sign a Declaration and submit it to the regulator.

WRAP Quality Protocols (England and Wales)

The WFD also permits certain specified waste to cease to be a waste when it has undergone a defined recovery operation and complies with specific criteria developed in line with particular legal conditions:

- The substance or object is commonly used for specific purposes;
- There is an existing market or demand for the substance or object;
- The use is lawful in that the substance or object fulfils the technical requirements for the specific purpose and meets applicable legislation and standards for those products; and,
- The use will not lead to overall adverse environmental or human health impacts.

WRAP quality protocols provide the framework, in line with the defined WFD requirements, whereby materials can be produced in accordance with a specification which demonstrates that 'end of waste' criteria have been met, and the material is thereafter effectively classed as a product, and in essence ceases to be classified as a waste. It is applicable in England and Wales only.

The applicable Quality Protocol is for the Production of Aggregate from Inert Waste (Reference 6) which will permit inert wastes as outlined above that can't be used without treatment under CL:AIRE to meet an 'end of waste' designation and facilitate reuse on site without the need for an environmental permit. It should be noted that any treatment needed on site will likely need some form of regulatory permit.

Promotion of Material Reuse (Scotland)

SEPA has published a guidance document Recycled Aggregates from Inert Waste (Reference 7) which is very similar to the WRAP Quality Protocol and which clarifies the point at which recycled aggregates manufactured from inert waste, in SEPA's view, cease to be waste and waste management controls are no longer required (i.e. end-of-waste). Annex 1 of this document lists the same waste codes as the QP with respect to construction and demolition waste and as such applies to RCM.

Resource Efficient Scotland (a Scottish Government programme) provides guidance on maximising reuse of materials on site (Reference 8). It specifies that if materials are not being reused for their original purpose then it is classified as a waste management activity and compliance with waste legislation is required. It lists uses as fill, sub-base material or driveway/car parking substructure as potential reuse opportunities for brick, concrete and masonry from demolition.

Recovery with Permit/Regulatory Requirements

The following is a summary based on the Environmental Permitting Guidance Core Guidance for the Environmental Permitting (England and Wales) Regulations 2010 (rev. March 2013).

The Regulations specify which facilities require an environmental permit and provide that some facilities can be exempt from those requirements providing general rules are laid down for each type of exempt activity, and the operation is registered with the relevant registration authority. Exemptions provide a less stringent regulation for small scale, low risk, waste operations and aim to encourage waste recycling and recovery. The facilities that require a permit are described collectively as 'regulated facilities'. There are seven different kinds of regulated facility and each is known as a 'class' of regulated facility.

In Scotland the Waste Management Licensing (Scotland) Regulations 2011 apply. The regulations specify which facilities require a Waste Management License and the information to be provided. They also specify which activities may be exempt from the regulations, again generally for small scale, low risk operations.

Exemptions

A waste exemption is a waste operation that is exempt from needing an environmental permit, or in Scotland a Waste Management License– each exemption has specific limits and conditions that need to be met. Exemptions are usually time-limited, need to be registered with the regulator and are generally for smaller scale activities and smaller volumes of waste. The relevant exemptions are:

- England and Wales: U1 Use of Waste in Construction – this exemption enables non-hazardous wastes that fulfil recovery criteria and which can be used without treatment to be used for small-scale construction instead of using virgin raw materials. The construction activity to which this applies is 'carrying out building or engineering work which includes repair, alteration, maintenance or improvement of an existing work and preparatory or landscaping works'. The exemption is limited to 5,000 tonnes of construction/demolition waste or 1,000 tonnes of soils with a maximum storage period of 12 months in any 3 year period;

- England and Wales: T7 Treatment of Waste Bricks, Tiles and Concrete by Crushing, Grinding or Reducing Size – this exemption permits the temporary small scale treatment of non-hazardous construction and demolition waste to produce a soil or aggregate a the place of construction or demolition. The exemption allows treatment up to 20 tonnes/per hour, with a maximum storage of 200 tonnes at any one time. Total allowed throughput would be agreed as part of the application process. This exemption is regulated by the Local Authority (LA) and applications should go the LA for the site rather than the Environment Agency (EA) or Natural Resources Wales (NRW);
- Scotland: Paragraph 9 – the reclamation or improvement of land – this exemption permits the storage for up to 6 months of materials for subsequent treatment of land with specified wastes. These wastes include crushed concrete. There are limits on how the waste can be used and it must be shown to be suitable for use. The waste can only be used to a depth of 2m. It must be registered with SEPA and a fee is required. Registration expires after 12 months but can be renewed;
- Scotland: Paragraph 19 – waste for construction and other "relevant work" – this exemption permits the storage of up to 50,000 tonnes of crushed concrete for up to 6 months. The waste must be used for construction and does not include land reclamation. It must be registered with SEPA and a fee is required. Registration expires after 12 months but can be renewed; and
- Scotland: Paragraph 24 – size reduction of bricks, tiles or concrete – this exemption permits the crushing and storage of such material up to a total of 20,000 tonnes. It must be registered with SEPA but no fee is required. It is not time limited, however SEPA can withdraw the registration if it is found to be not managed properly, if it no longer fulfils the requirements of the exemption or if the activities cause pollution or harm to health.

It should be noted that exemption T7 will require an operator with a Mobile Plant and associated permit. It should be noted that where an environmental permit (recovery or standard rules) is required, if the application does not successfully demonstrate that the activity covered is accepted as recovery by the regulator, then the regulator will deem it to be a disposal operation, and as such a disposal licence (landfill) will be required. Crushing of concrete on a Scottish site requires a Pollution Prevention and Control (PPC) Part B permit from SEPA.

Appendix B: Literature References