LLW Repository Ltd

LLWR Environmental Safety Case Project

Progress on Research and Development to July 2009

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EXECUTIVE SUMMARY

The Environment Agency (the Agency) is the UK regulatory authority responsible for authorising the disposal of radioactive waste at the Low-Level Waste Repository (LLWR) in West Cumbria. The Agency issued a new Authorisation (BZ2508/BZ2508) for the LLWR on 1 May 2006, which includes a list of improvement and additional information requirements (Schedule 9) that must be fulfilled by the operator, and are currently being addressed.

Item 4 of Schedule 9 requires the LLWR SLC to undertake a programme of research and development (R & D) to support specific improvements in the safety of the site. In response to this, a programme of R & D was submitted to the Agency in July 2006. Annual reviews were carried out in 2007 and 2008. This document reports progress in the year to July 2009. The main components of the LLWR's R & D programme, directed at supporting the 2011 Environmental Safety Case (2011 ESC) and developing our overall understanding of the environmental impact of the LLWR, are summarised in the following paragraphs.

A substantial programme of work is underway to address uncertainties in the inventory and build overall confidence in the inventory used as a basis for the assessment. This includes interviews with previous operational staff and investigations of key radionuclides and waste streams. An overall objective is to obtain a better understanding of the wasteform associations of key radionuclides and to characterise the uncertainty in key components of the inventory.

In the near field area, work is being undertaken to:

- revise the model of coupled transport and chemical reaction in the LLWR, previously developed using the GRM software;
- develop a better understanding of the effect of heterogeneities in the near field relating to pH conditioning and carbonation;
- use Scanning Electron Microscopy to determine the form of uranium in Springfields fluoride wasteform, with which a major proportion of the Trenches uranium inventory is associated;
- determine the sorption of U(IV) and U(VI) to a range of near-field substrates;
- restart monitoring of the Long-term Vault and Trench Experiments (LTVE and LTTE);
- develop an updated conceptual model for the near field.

A range of activities has been pursued to develop understanding of the geology and hydrogeology of the area around the facility. Advantage has been taken of the Vault 9 excavations to examine the geology exposed in the excavation walls and via trial pits. This has been the basis of an updated geological interpretation. An important observation has been the continuity of an individual clay layer that has been traced across the exposure, but which would not have been recognised based on borehole logs.

It was recognised that there is a paucity of geological and hydrogeological data in the region between the site and the coast, owing to the small number of boreholes in that area. Drilling of a suite of seven boreholes is therefore underway between the facility and the coast. These will provide important geological and hydrogeological information.

We have undertaken a review and reanalysis of previous slug test data for the site, noting that the hydro-test data for the LLWR site give a number of unexpected results compared to results for similar lithologies from other sites. A number of previous tests were found to be unreliable and a further programme of slug tests is therefore being undertaken using more rigorous approaches to testing and interpretation.

The water balance is an important constraint on the calibration of groundwater flow models. New estimates of stream baseflows have been obtained using a digital filter technique. Recharge is considered to be higher than previously thought, which would be consistent with a lower vertical hydraulic conductivity in the LP2/3 layer than in the most recent Site-scale Groundwater Flow Model.

A range of work is ongoing to improve the hydrogeological conceptual model of the site and the link with the geology. This work will be brought together in a revised hydrogeological conceptual model report that will be an important reference to the 2011 ESC.

It is recognised that the Quaternary sediments in the vicinity of the LLWR are highly heterogeneous, giving rise to spatial variations in the hydrogeological properties. A possible approach has been developed to represent such heterogeneity in numerical models, taking account of the geological understanding of the Quaternary.

A programme of work is just beginning to develop an updated model of groundwater flow, suitable as a basis for the 2011 ESC. This will cover a domain somewhat larger than that the existing Site-scale model.

A programme of monitoring is currently being implemented to provide a baseline for future coastal surveys to determine the rate and characteristics of coastal erosion. A workshop was held in January 2009 to consider what further characterisation work and modelling might be undertaken in relation to coastal processes. Based on this workshop, the following activities are being taken forward:

- systematic collation of all of the data gathered during previous work;
- geophysical characterisation of Quaternary sediments along the coastal strip and between the facility and the sea;
- geological characterisation of the barrier spit and other coastal features, linked to an estimate of sediment budgets;
- modelling to address aspects of the evolution of the Ravenglass Estuary, longshore processes and coastal erosion;
- production of an updated conceptual model;
- review of the scenarios for climate change and coastal erosion as an appropriate basis for the 2011 ESC.

TABLE OF CONTENTS

1. INTRODUCTION

This report provides a summary of the research and development (R & D) undertaken over the past year by the Low Level Waste Repository Ltd. (LLWR) in the areas of repository post-closure and operational environmental safety.

It also summarises the process used to define the programme of research and development (see section 2). The report has been produced to satisfy Requirement 4 of Schedule 9 of the LLWR's Authorisation to dispose of radioactive waste (Environment Agency, 2006). Requirement 4 sets out the need to '… *establish and carry out a programme of research and development in support of Items 1, 2 and 3…'* and to provide a programme and reports to the Environment Agency.

Items 1, 2 and 3 of Schedule 9 are respectively:

Item 1:

> *'The Operator shall provide the Agency with a full report of a comprehensive review of whether the current disposal practices for waste generated on the site continue to represent the best practicable environmental option, together with a programme for carrying out any necessary changes identified by the review.'*

Item 2:

> *'The Operator shall provide the Agency with a full report of a comprehensive review of national and international developments in best practice for minimising the impacts from all waste disposals on the site. This shall include a comprehensive review of options for reducing the peak risks from deposit of solid waste on the site, where those risks arise from potential site termination events (e.g. coastal erosion and glaciation) and potential future human action.'*

Item 3:

> *'The Operator shall provide the Agency with a full report of a comprehensive review of the means used to assess the activity of radionuclides in disposals and to determine compliance with this Authorisation including consideration of national and international developments in best practice.'*

A systematic process was pursued to develop an initial programme of R & D to address the requirements of Item 4. This included an analysis of gaps in understanding (Grimwood and Paulley, 2006). The review concluded that no R & D was required in support of Items 1 and 3 of Schedule 9, as the relevant methodologies and approaches are relatively well established. For Schedule 9, Item 2, however, a number of R & D projects were taken forward. The initial R & D programme comprised eight areas:

- climate change and site evolution;
- engineering material studies;
- evolution of vault waste form;
- trench waste colloid and organic complexation;
- near-field sorption of radionuclides;
- effects of seawater incursion into the near-field;
- hydrogeological tracer tests; and
- geosphere sorption.

In addition to these initial areas, five areas for further review were identified. It was anticipated that these reviews would be likely to recommend further R & D. These areas were:

- non-radioactive contaminant transport factors;
- use of alternative safety indicators;
- characterisation of the present day biosphere;
- upscaling of meteorological data to determine future climate and landscape change behaviour;
- biosphere data for impacts assessments.

An interim review of the initial R & D programme was carried out in February 2007 (Grimwood, 2007). This review took account of:

- work undertaken over the previous six months;
- input from a full review of the Agency's Issue Assessment Forms (IAFs) (Grimwood, 2006);
- feedback from the Agency on the initial R & D programme.

Further updates on the R & D programme were provided in May 2007 (Wareing, 2007) and July 2008 (Baker, 2008).

In May 2008, the LLWR submitted documentation against Item 2 of Schedule 9 (see above). Given the completion of work against Item 2, no further supporting R & D is required. However, the technical issues that have been addressed in the R & D programme continue to be important in developing and supporting the LLWR's Environmental Safety Case (ESC). The ESC is required under Item 6 of Schedule 9 and will be submitted by May 2011. Accordingly, this document discusses R & D in support of the 2011 ESC.

In annual R & D reports previous to July 2008, we have reported R & D that fell within a particular budget area, but excluded work that could be argued to be R & D, but which was funded within other budget areas. In this Section and in future reports, a broader definition of R & D is adopted. We cover all technical work that is undertaken in support of the programme of environmental assessments except:

- the development of assessment methodologies and tools for safety assessment and actually carrying out the safety assessments;
- work in non-technical areas, for example the maintenance of databases and the management of Issue Assessment Forms;
- any work associated with monitoring;
- programmes of work associated with optimisation and the assessment of waste management innovations;
- safety Case development work.

In section 2, the process by which the programme has been developed is summarised. A key consideration is whether studies are addressing some issue or uncertainty that has the potential to have a significant affect on calculated environmental impacts or are able to build further confidence in current estimates of those impacts. Work that does not fulfil these requirements will normally have been screened out. In section 3, the content of the R & D programme is described. As the work is reported against different categories than used in the 2007 report, a link is provided in Table 1.1 to the earlier categories.

Table 1.1 Status of R & D against Research Areas identified in the 2007 R & D Report.

Technical Area	Current Status
Climate change and site evolution	A series of climate change and coastal evolution scenarios have been developed as part of earlier work. A programme of work is being taken forward on monitoring and coastal erosion and evolution and is discussed in subsection 3.2.8.
Engineering material performance	Progress has been made by means of an Engineering Performance Assessment. Further work is scheduled. However, we have not categorised this work as R & D.
Evolution of LLWR wasteforms	A general review has been completed. The focus will be on developing a better understanding of the form of uranium in Springfields disposals (see subsection 3.1.3). Monitoring of the Long-term Vault and Trench Experiments has also bee reviewed (see subsection 3.1.5).
Colloids	A review has been carried out of current status. We consider that focus is appropriate on possible source-term enhancements as this would be the major influence on calculated impacts. A review was undertaken of current data, leading to the conclusion that no further work was required (see subsection 3.1.6).
Near-field sorption	A general review has been completed. We have commissioned an experimental programme to measure sorption of U(IV) and U(VI) to a range of near-field substrates (see subsection 3.1.4)
Tracer tests	We have considered the possibility of undertaking long-term tracer tests at the site, although these would not be completed in time to deliver input to the 2011 ESC. Such tests pose a number of difficulties. We have decided at present to focus on a general review of long-term monitoring requirements in order to reach a decision concerning future programme (see subsection 3.2.7).
Geosphere sorption	Measurements of the sorption of uranium to Quaternary sediments have been undertaken. Further work in this area is not planned because geosphere sorption is not now considered to be a significant control on calculated impacts.
Alternative safety indicators	Work has been undertaken on the use of natural analogue data and on comparisons of repository-derived with natural concentrations and fluxes. These approaches will be considered further and taken forward as part of our work on safety case development, rather than as R & D.
Biosphere data	A biosphere database has been generated, suitable for use in future assessments. We plan a general review of biosphere data and models, although this is not categorised as R & D.
Characterisation of the present day biosphere	We consider that significant further work in this area is not required as an input to the 2011 ESC, noting that the current biosphere is likely to be significantly different from the future biosphere at the time that key radiological impacts arise. We envisage some focused work to review existing information on local biosphere conditions relevant to assessment (e.g. land use, soil types, agriculture, local wells).
Upscaling of meteorological data	A study has concluded that it is feasible to use an upscaling approach to consider climate change at the LLWR. No further work is planned.

Table 1.1 (Continued)

Technical Area	Current Status
Non-radioactive contaminant transport factors	We consider that the main issues relate to the development of a better understanding of the inventory (see subsection 3.1.1). Review of the data collected by the monitoring programme may also be appropriate. At this stage, we have decided not to undertake work to characterise the chemical behaviour of specific contaminants (see subsection 3.1.6).

2. DEVELOPMENT OF THE R & D PROGRAMME

In identifying areas of work, our objective is to focus on those issues and uncertainties that might have some impact on the management or environmental performance of the site. Thus, we would not usually plan to undertake work to address an uncertainty that we do not believe impacts on performance. This requires consideration of the results of recent assessments, most recently the update undertaken as part of our response to the Environment Agency's Requirement 2. Overall, this requires an iterative approach in which the results of successive safety assessments are used as an input to subsequent R & D.

In developing the plan for future R & D, the following inputs have been considered:

Results from the work undertaken in support of the submission of Requirement 2
Our submission in support of Requirement 2 (Baker, 2008) identified a number of issues that require further work and which have been captured in the forward plan.

IAFs and Environment Agency comments
We have reviewed the issues raised in the Environment Agency's IAFs (Grimwood, 2006; Lean, 2007) and set out in the Environment Agency's review of the 2002 PCSC (Environment Agency, 2005). We have also considered other Environment Agency comments, including those received informally in relation to the Requirement 2 submission.

Recommendations arising from Previous R & D
A number of activities in the previous R & D programme resulted in recommendations for further work.

Due diligence
As part of the due diligence review undertaken by UK Waste Management Ltd., a technical review was undertaken of the post-closure safety case work. As a result, a number of issues and risks were identified and are addressed in our programme of work.

Workshops
As an input to the development of the ESC Lifetime Plan, a series of workshops were held to discuss appropriate technical approaches in some key areas. These workshops covered:

- geology and hydrogeology;
- assessments and safety case development;
- biosphere and human intrusion;
- assessment of non-radiological impacts;
- near field and gas;
- inventory;
- optimisation;
- Operational Environmental Safety Case.

Some of the workshops were attended only by LLWR staff. In other cases, staff from contractors and/or from Serco Ltd. (Serco are a member of the UKNWM Ltd. consortium and played a leading role in the due diligence review) attended. The purpose was not to agree or define the future work programme, but to seek opinions and ideas on the technical programme. Each workshop was documented using a flip chart approach – the output was then available for consideration in the development or review of the Lifetime Plan.

Peer review recommendations and comments
During peer review of the deliverables associated with Requirement 2 and subsequent work, a number of comments were received that need to be considered in defining future work (Bennett et al., 2008).

The above inputs were used by the ESC Project Team to define the programme of work set out in the current Lifetime Plan (LTP) for the LLWR's ESC Project. The programme was reviewed for gaps and coherence before submission to and agreement by the NDA. The programme is now refined and kept under technical review through a range of technical meetings, involving LLWR staff and subcontractors. Modifications to the LTP are subject to change control.

3. R & D TO SUPPORT THE 2011 ESC

3.1. Near Field

3.1.1. Inventory

As a basis for the Requirement 2 submission, two reports were prepared on the inventory and its spatial heterogeneity (Lennon et al, 2008; Wareing et al., 2008). Since that time, the LLWR has carried out a programme of work to build confidence in the inventory and to characterise uncertainties in the inventories of key radionuclides.

Interviews have been held with former operational staff at the LLWR and other sites to determine disposal practices and the potential for any disposals that might not be consistent with the Conditions for Acceptance. These interviews were filmed, and are shortly to be comprehensively analysed. The output will be used as an input to characterising uncertainties in key aspects of the inventory. Consideration will also be given to further work that might be necessary to resolve any issues arising.

A programme of work has been pursued focusing on key radionuclides and waste streams. The key radionuclides were identified in the basis of contributions to the radiological impacts, estimated in the work undertaken to support the Requirement 2 submission (Sumerling, 2008): ^{14}C, ^{234}U and ^{238}U, ^{36}Cl, ^{99}Tc, ^{226}Ra and ^{129}I. The objective is to understand more about the wasteform associations of different radionuclides as a basis for the development of source-term models and to characterise the uncertainty in key components of the inventory. In this work, a distinction is made between the uncertainties associated with the estimates of the radionuclide contents of waste and any uncertainties about which waste streams will be consigned to the LLWR or how they will be treated before they are consigned.

The review was undertaken on the basis of:

- information in the national inventory;
- review of Waste Stream Characterisation Documents held by the LLWR and information in the Waste Stream Tracking Database;
- further information on key waste streams from waste consignors.

The focus was on key waste streams that contribute more than 1% of the inventory of any key radionuclide. For each key waste stream and key radionuclide, information was compiled on:

- the origins and form of the radionuclide;
- the physical and chemical processes (e.g. corrosion) that might lead to release to groundwater;
- the method by which the activity has been estimated;
- the uncertainties in the inventory.

Two draft reports have been produced as an output from this work programme (Wareing 2009a; Wareing, 2009b). Analysis of the 2007 UK National Inventory has shown increases in future forecast activity compared to those presented in the 2004 UK National Inventory for ^{234}U, ^{99}Tc, ^{226}Ra and ^{129}I designated for LLWR disposal, whilst forecast activities for ^{238}U and ^{36}Cl were found to have decreased by around 50%. According to the data in the national inventory, the inventory of ^{14}C for disposal has decreased to about 1.7 TBq (from 7 TBq in 2004) and probably only some tens of GBq are associated with cellulosic materials. Detailed studies of a number of specific waste streams suggested some overestimation of potential disposals. A key issue was the discovery of significant errors in the inventory of Sellafield LLW in the 2007 national inventory. These errors are being resolved.

Future work will involve derivation of an updated LLWR disposal inventory, based on the 2007 national inventory. A small number of inventories may be developed to take account of alternative consignment and treatment scenarios. As part of the future programme, we will be undertaking further work on specific waste streams that are significant contributors to the inventories of key radionuclides. Formal data elicitation is planned for some components of the inventory in order to obtain probability density functions.

The inventory of non-radioactive materials will be reviewed to determine if improvements can be made. There may be recommendations for the data required in future national inventories or there may be short-term actions that could be taken to improve understanding of certain components of the inventory.

3.1.2. Near Field Understanding

A substantial programme of work on the near field was completed prior to the submission of the LLWR's response to Requirement 2 (summarised in Randall (2008)). The current focus is on developing assessment models, an area of work not described in this document. However, supporting work has been or will be undertaken to:

- revise the model of coupled transport and chemical reaction in the LLWR, developed previously using the GRM software;
- develop a better understanding of the effect of heterogeneities in the near field relating to pH conditioning and carbonation;
- develop an updated conceptual model for the near field.

These are discussed in turn.

In the 2002 PCSC a coupled model of transport and chemical reaction was developed using the GRM software. The model developed for the LLWR was known as DRINK and was used directly within the assessment calculations (BNFL, 2002). Our strategy for the 2011 ESC is not to use the GRM model directly within the assessment calculations, but rather to use it as a supporting tool, for example to estimate pH and Eh variations with time and to estimate the generation rates of different gases. A programme of work is underway to revise the GRM model. This includes developing a revised grid to represent the current design and reviewing and adding to the available thermodynamic data.

There are uncertainties concerning the pH of the Vaults and the effects of heterogeneity. Work was therefore been undertaken:

- to determine the pH buffering capacity of LLWR Vault 8 grout in which pozzolanic reactions have occurred due to the relatively high proportion of PFA in the cement blend;
- to investigate the extent to which pH buffering and carbonation may occur if flow is heterogeneously distributed, within voids such as fractures or cracks in the LLWR wasteform grout.

Approaches included batch equilibrium and coupled transport and chemical reaction modelling (Wilson and Metcalfe, 2009). Results suggested that grout may have long-term porewater pH values up to ~11. However, the pH could decrease towards values of ~9.5 depending on the kinetics of pozzolanic reactions and the leaching of CSH gel. A reasonable assumption would be that higher pH conditions would be expected to evolve in parts of Vault 8 that are further from CO_2 generating cellulosic wastes. If fissures develop transecting waste pucks containing cellulosic material, there may be localised regions within the Vault where acidic conditions develop, at least while cellulose degradation occurs at a rate comparable with that measured in the Long Term Trench Experiments (LTTE).

Further work has been commissioned to develop an understanding of the potential variability of chemical conditions, taking account of the variability in waste types and grout distribution in different containers. This will make use of simple mass balance and equilibrium chemical approaches. The output will be some descriptions of the evolution of chemical conditions within containers containing different wastes and with different grout contents. Following completion of this work, we will consider what further work, if any, is required to support the 2011 ESC. In some areas, it may be necessary to acknowledge some uncertainty in local chemical conditions and to take account of this in assessment modelling.

An updated conceptual model will be developed for the near field of the LLWR. This will be presented as a word picture of the evolution of the facility over the period of interest. Where appropriate the model will be supported by calculations relating to the chemical and physical evolution of the system and/or the effects of heterogeneity. The conceptual model will be reported in a document that will be an important reference for the 2011 ESC.

3.1.3. Physical Form of Uranium

In the recent assessment carried out in support of the Requirement 2 submission (Baker, 2008), an effective solubility limit was used to represent the effects of rate-limited dissolution of the Springfields fluoride wasteform with which much of the Trench uranium inventory is associated. It is envisaged that uranium is present as discrete inclusions within the fluoride wasteform (Small et al., 2008). We have just commissioned a programme of work to determine the form of uranium. This will include a scanning electron microscopy study to identify the form of uranium within the wasteform and simple experiments to determine the rate of dissolution and uranium release from the wasteform. This work will confirm whether or not the current model of uranium leaching from the fluoride wasteform is appropriate.

3.1.4. Sorption

We have recently commissioned work to address the sorption of uranium(IV) and uranium (VI) to a range of near-field substrates: soil, cement, concrete and corrosion. A number of experiments are about to start, addressing:

- conditions appropriate to uranium (IV) and uranium (VI);
- sorption to soil, concrete, grout and corrosion products;
- for cement and concrete, sorption at a single appropriate pH and, for soil and corrosion products, under appropriate neutral and high pHs.

The results will substantiate the treatment of uranium series radionuclides in near-field assessment modelling. Uranium was selected because uranium series radionuclides are key contributors to radiological impact for releases in groundwater.

3.1.5. LTVE and LTTE

Long-term experiments appropriate to Vault and Trench conditions had been underway, but maintenance and monitoring had lapsed for a number of years. The experiments were designed to increase understanding of near field evolution and support appropriate treatments in assessment models. The Long-term Vault and Trench Experiments (LTVE and LTTE) have been examined and it was decided that continued monitoring is feasible. Accordingly, maintenance activities have been carried out and data are being collected again from these experiments. Data will be interpreted and used as appropriate to support the treatment of the near field in safety assessment calculations. If the experiments proceed according to plan, it is envisaged that destructive analysis of one or more of the experiments will eventually be undertaken.

3.1.6. Other Work Areas

We have given consideration to a number of other work areas, but have decided not to initiate any major studies.

We have reviewed the previous work undertaken on colloids to determine whether appropriate techniques and approaches have been used (Swanton, 2008). It was concluded that sampling of colloids in trench leachate subsequent to 2000 is based on an acceptable methodology. Low concentrations of colloids have been found in trench leachate and there is little evidence for significant association of radionuclides and colloids. On this basis, it was considered that further work on trench colloids was not required. Consideration was given to the feasibility of obtaining samples for colloid characterisation from the Long Term Vault Experiments, as this might provide some insight into colloid populations that might be associated with vault leachate, but this was found not to be practicable. Further work has not therefore been commissioned. Overall, it is considered that colloidal effects are likely to be only a small perturbation on estimated releases; relevant arguments will be set out in the 2011 ESC.

We have considered the need for work in support of the development of an assessment of non-radiological impacts. In our view, the main issues relate to the development of a better understanding of the inventory. Review of the data collected by the monitoring programme would also be appropriate and is planned. At this stage, we have decided not to undertake work to characterise the chemical behaviour of specific contaminants. The key issue is the chemical behaviour of such contaminants in the near field. However, with an emphasis on the calibration of models using observed leachate

concentrations, such data are less important and at this stage of the programme, further work is required to determine the contaminants of most interest.

3.2. Site Understanding

3.2.1. Geological Investigations

Opportunities have arisen, associated with the construction of Vault 9 to obtain further geological data (see Smith et al., 2009). Interpretation of the exposures in Vault 9, when examined alongside an updated interpretation of the sequences that outcrop on the nearby Drigg Beach, provides a valuable analogue to the unexposed sequences underlying the site. Geological information from exposures within the Vault 9 excavation has been integrated with interpretations from a number of trial pits dug into the floor of the excavation between November 2008 and July 2009, and borehole logs from boreholes penetrating sequences between the east side of the Vault 9 excavation and the west side of Trench 3, in order to build up a three-dimensional (3D) view of the geology of the excavation area. This 3D view illustrates a number of points including the extent and distribution of clay rich and sand/gravel rich units, and the geometry of such units, which provide an indication of the likely geological structure over the whole of the LLWR site. It has been possible to trace individual clay units over order a hundred metres. A correlation has been proposed between the Vault 9 exposures and those seen in the coastal sequences. It has been possible to trace individual clay units over distances of order a hundred metres. Such continuity may be significant and had not previously been inferred from the evidence supplied from borehole logs.

3.2.2. New boreholes

It was recognised that there is a paucity of geological and hydrogeological data in the region between the site and the coast, owing to the small number of boreholes in that area. Drilling of a suite of 7 boreholes is therefore underway between the facility and the coast. These penetrate to 50m or more below ground level. These boreholes will provide the following:

(i) Information on geological features and their continuity between the facility and coastal exposures;

(ii) Information to constrain models of groundwater flow and contaminant transport between the LLWR and the coast;

(iii) Reliable data on hydraulic conductivities and water fluxes in the shallow and deep Drift units between the LLWR and the coast;

(iv) Information on the hydrogeological characteristics of the Ormskirk Sandstone beneath the LLWR and between the LLWR and the coast;

(v) Information on the spatial distribution of potentially significant hydrogeological features (e.g., glaciotectonic features);

(vi) Information on the location of the saline interface to the west of the LLWR;

(vii) Data on the distribution of radioactive and nonradioactive contaminants in soil and water.

Data from these boreholes will provide a significant enhancement to our understanding of the geology and the hydrogeology and will provide a firmer basis to treatments in the 2011 ESC.

3.2.3. Pump tests

We have undertaken a review of previous slug test data for the site, noting that the hydro-test data for the LLWR site give a number of unexpected results relative to similar lithologies from other sites. Forty seven slug tests, recently conducted on new boreholes drilled at the LLWR, were reinterpreted and it was found that a number of tests are problematic (Black et al., 2009). Approximately two thirds of the tests analysed were considered to be dubious or unreliable. When the problematic tests are excluded, the resultant data correlate well with the expected results based on similar lithologies from other sites, albeit bounded by the maximum and minimum hydraulic conductivities that can be measured using the test procedure. The re-interpreted slug test results strongly suggest that the bulk horizontal hydraulic conductivity used for the shallow superficials in the groundwater flow model is an overestimate. In turn, this implies that there is a misinterpretation in the site water balance, which provides boundary conditions and calibration criteria for the current groundwater flow model, because the high bulk

horizontal hydraulic conductivity used in the groundwater flow model is required for the model to reproduce the baseflow component of the site water balance. On the basis of this review, it has been decided to undertake a further programme of slug tests using a more rigorous approach. This programme will be commissioned shortly.

3.2.4. Water Balance

The water balance is an important constraint on the calibration of groundwater flow models. New estimates of stream baseflows have been obtained using a digital filter technique (Henderson, 2008a). The estimated baseflow values are higher than those estimated using a stream routing model and are regarded as more realistic. New recharge estimates are also higher and are consistent with a higher vertical hydraulic conductivity within the LP2/3 layer than assigned to this layer in the Site-scale Groundwater Flow Model. This is an important step forward in updating and building confidence in the calibrated model of the site.

3.2.5. Conceptual Model Development

A range of work is ongoing to improve the hydrogeological conceptual model of the site and the link with the geology. This work will be brought together in a revised hydrogeological conceptual model report that will be an important reference to the 2011 ESC.

We have undertaken a review of the main hydrogeological uncertainties in order to consider whether there are any viable alternative hydrogeological models (Serco, 2009a). Such uncertainties include:

- the link between the geology and the hydrogeology and the extent to which the Drift can be treated as a series of laterally continuous layers;
- the need for a better understanding of geological heterogeneity within each hydrogeological unit in order to better understand hydrogeological heterogeneity. On the basis of available information, it is likely that hydrogeological variability within lithofacies packages is greater than that between lithofacies packages;
- the lack of a good geological explanation for the much higher permeability anisotropy in the LP2/3 unit;
- resolution of issues with the water balance;
- the significance of channel features.

A key issue is the extent to which the geological model can be used to further develop the hydrogeological model. This will only become clear when the extent to which local hydraulic conductivity is related to local lithology has been clearly demonstrated. A study has therefore been completed to address this point and a report is being finalised (Serco, 2009b). It was found that there were good correlations between laboratory measurements and lithology. However, there were poor correlations between downhole measurements attributed to a particular lithology. This most likely arises because a supposed measurement for 'Clay' is not really a measurement for 'Clay', but a measurement for a more transmissive nearby horizon that is connected to a test interval by the borehole, or by the gravel pack around the piezometers.

A further key issue is the need to consider the implications of heterogeneity and the need for specific representation of the heterogeneity in models. A possible approach has been developed (Serco, 2009c), consistent with the geological understanding of the Quaternary deposits – in particular that there appear to be lithological correlations over distances of over tens of metres. It is envisaged that each lithofacies package is represented in terms of rectangular parcels with dimensions comparable to the length scale of the correlations in lithology. Upscaling calculations would be undertaken to determine the distributions of the effective permeability of a block of a lithofacies package with dimensions comparable to the dimensions of part of the LLWR. Then a small number (possibly a few tens) of realizations would be generated in which the hydraulic conductivity of each grid block is randomly sampled from these distributions. Flow and transport calculations could be undertaken for each realization. This approach would demonstrate explicitly that heterogeneity on different length scales had been taken into account. The approach will be considered further, and implemented as appropriate, as part of our current programme of modelling.

3.2.6. Development of Numerical Models

A programme of work has been commissioned and is just beginning to develop an updated model of groundwater flow, suitable as a basis for the 2011 ESC. This will cover a domain somewhat larger than that of the existing Site-Scale model (Arthur et al., 2008). The model will be developed within the CONNECTFLOW software.

Key aspects of the model will be:

- a detailed representation of the engineered system;
- calibration against observed heads, recharge;
- consistency of the model with observed transient responses of the system;
- groundwater flow and radionuclide transport simulations;
- the ability to undertake transient calculations if required;

As required, the model will be used as a basis for a model with explicit representation of spatial variability in hydrogeological properties (see above). Consideration will also be given to the need to represent alternative hydrogeological conceptual models.

As part of the supporting material for the 2011 ESC, a revised hydrogeological conceptual model will be documented, building on that documented by Henderson (2008b).

3.2.7. Long-term Monitoring

We had made provision for carrying out tracer tests in the vicinity of the LLWR, taking account of the recommendations made by Henderson (2007). However, the potential success of such tests was unclear and they would not deliver data in time for use in the 2011 ESC. It was therefore decided to focus instead on developing a plan for long-term monitoring at the site, leaving open the possibility of such tracer tests.

3.2.8. Coastal Erosion

A programme of monitoring is currently being implemented to provide a baseline for future surveys. A substantial programme of work has been pursued since 2002 (see Halcrow, 2008). This has resulted in a conceptual model for the site and the development of a simple quantitative model for the progress of erosion.

During the last year a further suite of coastal monitoring data has been collected (Halcrow, 2009). This involved a survey undertaken during March 2009 by the Environment Agency and consisted of 0.5 m resolution LiDAR and 12.5 cm resolution digital photography collected simultaneously. A multibeam echosounder bathymetry survey was also undertaken. This survey provides a good baseline for comparison with future monitoring data.

A key question is the extent to which this conceptual model and the quantitative model can be improved upon. We held a workshop in January 2009 to consider what further characterisation work and modelling might be undertaken. This workshop included LLWR staff and established experts from commercial and academic backgrounds. As a result of the workshop, the following programme of work was defined and is being commissioned (noting that it is possible that not all of the modelling work will be taken forward in the short term):

- systematic collation of all of the data gathered during previous work;
- geophysical characterisation of Quaternary sediments along the coastal strip and between the facility and the sea;
- geological characterisation of the barrier spit and other coastal features, linked to an estimate of sediment budgets;
- modelling to address evolution of the Ravenglass estuary, longshore processes and coastal erosion;
- production of an updated conceptual model;

- review of the scenarios for climate change and coastal erosion (see Thorne and Kane, 2007) and documentation of an appropriate basis in this area for the 2011 ESC.

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