Sellafield Ltd

Sellafield

Groundwater Monitoring Annual Data Review 2016

LQTD000758

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Glossary of Terms

<LOD	Less than Limit of Detection. An analytical result reported as less than the detection limit for the analytical method.
3σ	Mean plus three times the standard deviation of the previous 12 analytical results. Used as an internal trigger for investigation.
4σ	Mean plus four times the standard deviation of the previous 12 analytical results. Used as an external trigger for investigation.
Aeolian sediments	Soils/rock formed from the deposition of windblown materials
Alpha-emitters	Radionuclides that decay by emitting an alpha particle. An alpha particle consists of two protons and two neutrons. The primary alpha-emitters include uranium, plutonium, radium-226, neptunium-237 and americium-241.
Aquifer	A body of permeable rock which can transmit and allow abstraction of groundwater.
Becquerel	The SI unit of radioactivity.
Beta-emitters	Radionuclides that decay by emitting an electron or a positron. The primary beta emitters include strontium-90, potassium-40, cobalt-60, ruthenium-106, antimony-125 and caesium-137.
Borehole	A hole that is drilled into the ground, generally used to locate water or oil and to characterise ground conditions
Buried Channel	A palaeochannel within the sandstone which has been infilled with sands and gravels at the end of the glacial period.
Conductivity	Conductivity is the ability of a substance to conduct an electrical current. In our groundwater sampling and analysis we use the measurement of conductivity as a sampling quality parameter and to verify the laboratory analysis.
Data Quality Objectives	The DQO process was developed by the United States (U.S.) Environmental Protection Agency (EPA) as a series of logical steps that guide the implementation of the process required to acquire environmental data. In this instance it is used to develop a fit-for-purpose groundwater monitoring network and associated groundwater sample analysis plan that meets a set of agreed monitoring objectives.
Drift	Soil deposits left after the retreat of glaciers and ice-sheets.
Effective porosity	The fraction of the total volume of rock in which fluid flow is effectively taking place (this excludes dead-end pores or non-connected cavities).
Environment Agency	The leading public body for protecting and improving the environment in England and Wales.
Environmental Quality Standard	A concentration, generally defined by regulation, of a pollutant hazardous or non-hazardous chemicals in an environmental sample(s), that if exceeded could result in harm to human health or the environment.
Fluvial sediments	soils formed by the deposition of material from rivers
Geomorphological	Relating to the topographic features (landforms) of the Earth (or environment).
Groundwater	Groundwater is the term for water that completely fills cracks and voids within rock or soil below the ground surface and which, in principle, can be extracted from a well or discharged to a spring.
Groundwater Monitoring Well	A borehole into which a piezometer and headworks have been installed. The purpose of which is to provide controlled access to groundwater in order to obtain quality samples and hydrogeological data.
Half-life	The time for the radioactivity of an isotope to decrease by radioactive decay to one half of its original value. Half-lives range from fractions of a second to millions of years.
Made Ground	Soils formed by filling in an artificial or natural pit with hard rubble such as broken brick, concrete and/or dirt.
NIREX	A UK government-controlled agency established in 1980 to oversee the storage of radioactive waste.
Piezometer	Individual boreholes that contain multi-level installations are made up of a number of individual access pipes that incorporate a screen interval that monitors a selected depth. These individual access pipes are referred to as piezometers. In the Sellafield site numbering system the deepest piezometer in an individual borehole is labelled as “p1”. Successively shallower piezometers are labelled as “p2”, “p3”, and “p4” (as appropriate) with the highest number representing the shallowest piezometer interval in that individual borehole.
Quaternary	The geological era covering the last 2 million years. In the context of this report, it particularly concerns the most recent series of glacial advances.
Radioactivity	Spontaneous disintegration of atomic nuclei. Radioactive substances or the radiation they emit. Rate of radioactive decay. Measured in Becquerels (Bq).
Radionuclide	A radioactive isotope of a chemical element.
Recharge	Generally where rainwater moves downward from the surface towards the water table. Recharge may be influenced by the nature of surface cover, *i.e*. at Sellafield site recharge in some areas may be low due to hard standing, roads *etc*.

Glossary of Terms (cont.)

Runoff	Where water flows overland (sometimes known as streamflow). This generally occurs when the ground is saturated and no more water can infiltrate into the soil/made ground.
Saturated Zone	The subsurface zone below the water table, *i.e.* where relatively all pore spaces are filled with fluid (water).
Separation Area	Radiologically classified area of Sellafield site.
Source term	The amount and makeup of radioactive or hazardous material released to the environment as a result of a leak or accident.
Standard deviation	The standard deviation measures the spread of the data about the mean value.
Triassic period	A geological period of time spanning 50.9 million years and running from 252.17 million years ago to 201.3 million years ago.
Vadose Zone	The subsurface zone above the water table, *i.e.* where pore spaces are not wholly filled with fluid (water).
Weak beta-emitters	A term used to describe tritium, carbon-14, chlorine-36, technetium-99, plutonium-241 and iodine-129 which decay with the release of a low energy beta particle.
Weathering	The process of wearing away/changing the appearance/breakdown of rock by physical, chemical and biological processes. It does not involve the removal of rock material.

Abbreviations and Acronyms

BAT	Best Available Technique
BPM	Best Practicable Means
Bq	Becquerel
Bql^{-1}	Becquerel per litre
Bqm^{-3}	Becquerel per cubic metre (1 Bql^{-1} = 1 000 Bqm^{-3})
CEAR	Compilation of Environment Agency Requirements
DQO	Data Quality Objectives
EMA	Environmental Monitoring and Assessment
EP	Environmental Permit
EPR-PPC	Environmental Permit Regulations – Pollution Prevention Control
EPR-RSR	Environmental Permit Regulations – Radioactive Substances Regulation
EQS	Environmental Quality Standard
ESC	Environmental Screening Criteria
GC-FID	Gas Chromatography Flame Ionisation Detector
GC-MS	Gas Chromatography Mass Spectrometry
HDPE	High-Density Polyethylene
IC	Ion Chromatography
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
ICP-OES	Inductively Coupled Plasma Optical Emission Spectrometry
LEPS	Low Energy Photon Spectroscopy
LOD	Limit of Detection
m	Metres
m AOD	Metres Above Ordnance Datum
m BGL	Metres Below Ground Level
ma-1	Metres per year
MDA	Minimum Detectable Amounts
meq	Milliequivalents
mgl-1	Milligram per litre
µgl-1	Microgram per litre
NDA	Nuclear Decommissioning Authority
PPC	Pollution Prevention and Control
SCL&GMP	Sellafield Contaminated Land & Groundwater Management Project
SLSP	Sellafield Limited Supporting Procedure
SVOC	Semi-Volatile Organic Compound
TDS	Total Dissolved Solids
TPH	Total Petroleum Hydrocarbons
UKAS	United Kingdom Accreditation Service
VOC	Volatile Organic Compound
WHO	World Health Organisation

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Section 1: Introduction

Introduction

This review is provided for both internal and external stakeholders and meets statutory requirements to document the current understanding and condition of groundwater contamination.

This review describes the status of the Sellafield Ltd groundwater monitoring programme carried out in the calendar year 2016. The purpose of the review is to evaluate analytical data for groundwater and identify any significant year on year changes in quality, both underlying and in the vicinity of Sellafield site. In addition it provides an overview of regulatory requirements regarding the site groundwater monitoring programme with respect to radiological and non-radiological aspects of the Environmental Permits.

During the industrial history of Sellafield site there has been radioactive contamination of soils and groundwater. Sellafield Ltd is committed to a programme of contaminated land and groundwater management to ensure protection of the Sellafield site work force, the public, and the environment. The Land Quality team leads the management of contaminated land and groundwater on Sellafield site. The team was previously located within the Decommissioning Directorate, as of 2016 it moved to the Operations Division forming part of the Remediation value stream.

1.1 Objectives

Groundwater monitoring is a key element of the Land Quality Management Strategy and includes:

- ownership and maintenance of a network of groundwater monitoring wells,
- development, planning and implementation of groundwater monitoring plans and analysis of groundwater underlying Sellafield site and surrounding areas,
- assessment of new and historical data to characterise the distribution and movement of contaminants,
- reporting of the understanding of groundwater quality at both a site scale and for localised areas of site,
- ensuring groundwater monitoring quality, through monitoring well installation, sampling and analysis methods.

Groundwater is the term for water that completely fills cracks and voids within rock or soil below the ground surface and which, in principle, can be extracted from a well or discharged to a spring.

1.2 Setting

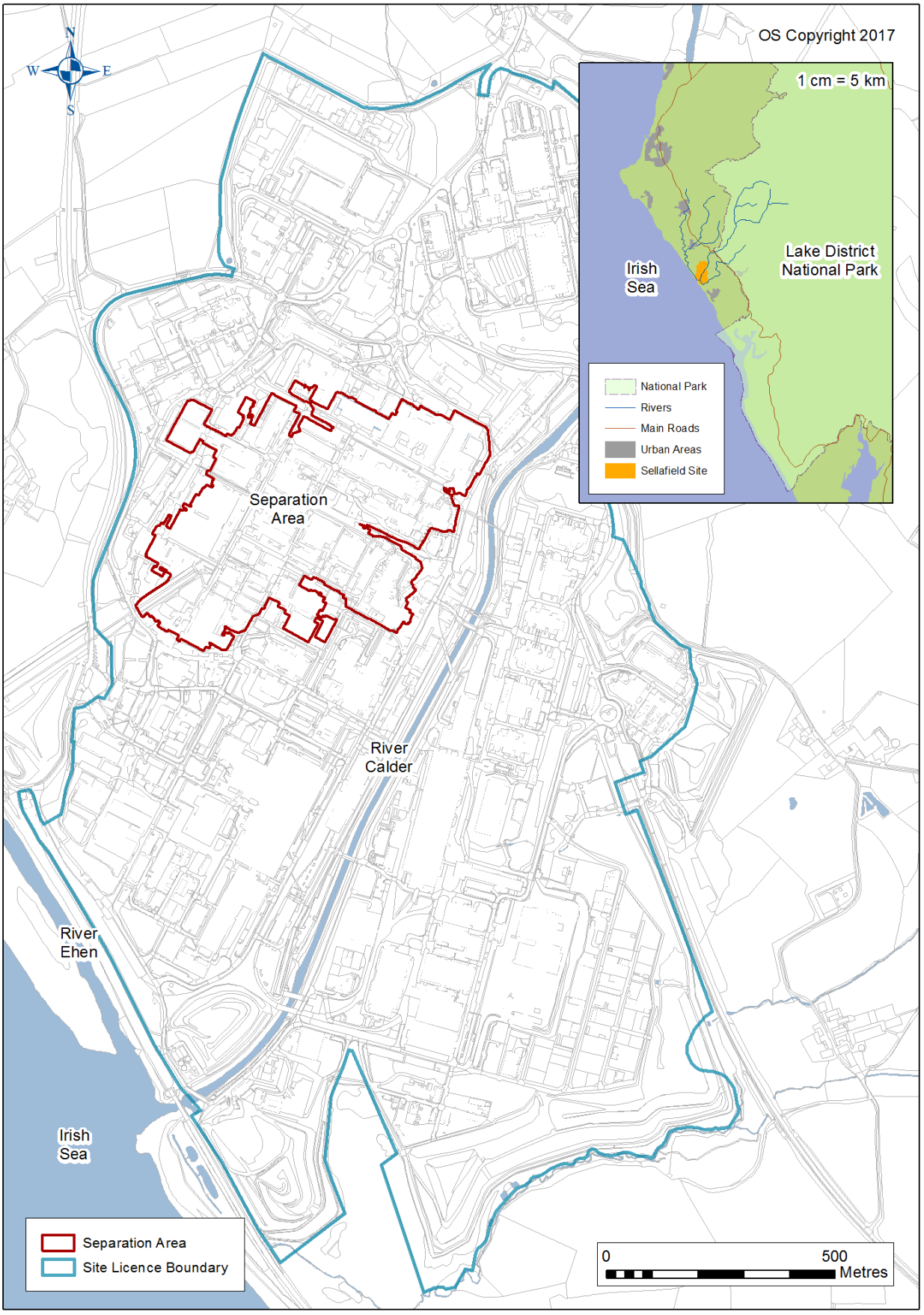
Sellafield site is located on the northwest coast of England in the county of Cumbria. It lies between the town of Egremont to the north and the village of Seascale to the south. To the east are the Cumbrian Fells and Lake District National Park, and to the west the Irish Sea. The surrounding land is predominantly agricultural with a number of farms and villages.

The ground surface of the site generally slopes towards the coast. In the northeast area of the site the maximum elevation is approximately 50 m above ordnance datum (m AOD). Across much of central site the ground surface lies between 15 m AOD and 25 m AOD, reducing to approximately 5 m AOD at the south western boundary, adjacent to the coast.

There are two major surface water features present: the Rivers Calder and Ehen. The River Calder flows towards site from the north and upon reaching the boundary it flows in a direct line from north northeast to south southwest. This is a result of engineering in the 1970s that straightened the river within the site boundary. The River Ehen flows between the site and the coast in a south easterly direction. The two rivers join to the southwest of site where they discharge to the Irish Sea, Figure 1.1. A number of other smaller natural watercourses flow through the area, some of which have been incorporated into the surface water drainage system over time.

Sellafield site itself is comprised of two main areas. Separation Area is roughly central to site and contains many of the legacy operational buildings. Within the site licence boundary but external to Separation Area is the rest of site, this includes more modern operational buildings as well as the Calder Hall site.

Figure 1.1
Sellafield Site



1.3 Geological and Hydrogeological Setting

1.3.1 Geology

Sellafield site is underlain by the Sherwood Sandstone Group, from the Triassic age. The Sherwood Sandstone comprises two main formations: the Wilmslow formation and the overlying Helsby formation (Sellafield Member). These formations are reddish-brown in colour. They are predominantly of aeolian (windblown) origin and loosely bonded, as such the upper surface of the formations show signs of substantial weathering. The effects of weathering decrease with depth. Specific features, such as clay or mudstone bands, bedding planes, fractures and fissures, become increasingly evident with depth. As described in Section 1.2 Setting the site has a general slope towards the coast and the underlying sandstone formations do not lie in flat planes but dip towards the south-west at an angle of approximately 23°.

The geology beneath site is Triassic sandstone bedrock covered with more recent glacial deposits of sand, gravel, clay and silts.

The uppermost soils across most of site are generally classified as made ground, this layer varies in thickness from 10 cm to in excess of 5 m. In built up areas of site it is common to encounter tarmac and concrete within this zone, additionally bricks, timber and concrete fragments may be found in reworked soils or in areas that have been backfilled.

Underneath the made ground the natural soil is formed of glacial deposits. These deposits are collectively referred to as drift. Drift is comprised of a mixture of sands and gravels, with bands of clays and silts at various thickness and persistence over depth. The drift extends to a maximum thickness of approximately 60 m beneath Separation Area within the line of a buried channel. Where possible, drift deposits have been classified into two sections: upper drift and lower drift, using bands of clays and silts identified in geological borehole logs. Should a geological borehole log contains a clay band of over 1 m in thickness, then the drift in that log may be divided into upper and lower either side of this band by a geologist. There are cases where there is no clear delineation, and no distinction between upper and lower is made. This information is useful in describing some of the specific characteristics of groundwater monitoring wells, particularly screen strata which define where the screen depth lies in relation to upper drift, lower drift or sandstone.

At the regional scale, the general geological picture is that the eastern boundary of the Irish Sea Basin is characterised by a series of large, steeply dipping, generally north-south trending normal faults, including the Lake District Fault Zone. At the local scale, there is the north-east trending High Sellafield Fault Zone, this crosses the coastal plain very close to the western site boundary and there are also a series of east to west faults across site.

1.3.2 Hydrogeology

The source of regional and local groundwater is mainly rainfall and surface water from rivers, streams, lakes and tarns, which enter into the ground. This water consolidates into laterally continuous aquifers within porous geological material subsurface. Within an aquifer there are areas known as the saturated zone and the vadose zone. The saturated zone is below the water table and the porous material is filled with water. The vadose zone contains partially saturated soils that sit between the water table and surface. The process where surface water enters into the subsurface aquifers is called recharge. The upper surface of an aquifer approximately follows the land contours, with the direction of groundwater flow passing from recharge areas at higher elevations toward discharge areas at lower elevations.

In the Sellafield area there is the upper aquifer in the drift and the main aquifer in the sandstone. In general the groundwater flows from the Cumbrian fells towards the coast in a south westerly direction (Nirex, 1997). The groundwater mostly discharges into the Irish Sea and immediate coastal zone, and to a lesser extent into some surface waters.

Groundwater flows from the Cumbrian fells towards the coast. Typical groundwater travel times are considered to be between 10 and 20 years from the northern site boundary to the coast, chemical interactions may increase or inhibit these travel times for contaminants.

The mixing of water in the upper aquifer, and its interaction with the main aquifer is complex. This is primarily due to the drift having a more variable permeability. The drift does not generally confine the sandstone aquifer, therefore the groundwater table can vary in elevation.

The sandstone is characterised by fractures and it exhibits heterogeneous properties which arise, in part, from the layered nature of the material. This heterogeneity has been observed at both regional and local scales. Together with this the flow of groundwater in the sandstone is roughly horizontal over a regional scale, although local upward gradients have been observed.

Figure 1.2 shows groundwater elevations taken from monitoring wells across the site in January 2016. Depth to water at each monitoring well was measured from a defined dip reference point and converted to groundwater elevation in m AOD. The figure shows that groundwater elevation was recorded between –3.0 m AOD (adjacent to the coast) and 21.0 m AOD (to the north of site) across the site and is higher in northeast and central Separation Area and lower towards the coast. In the groundwater monitoring programme we measure the depth to groundwater to understand its movement in the ground and influence on the migration of contaminants.

Figure 1.2
Groundwater Elevations January 2016

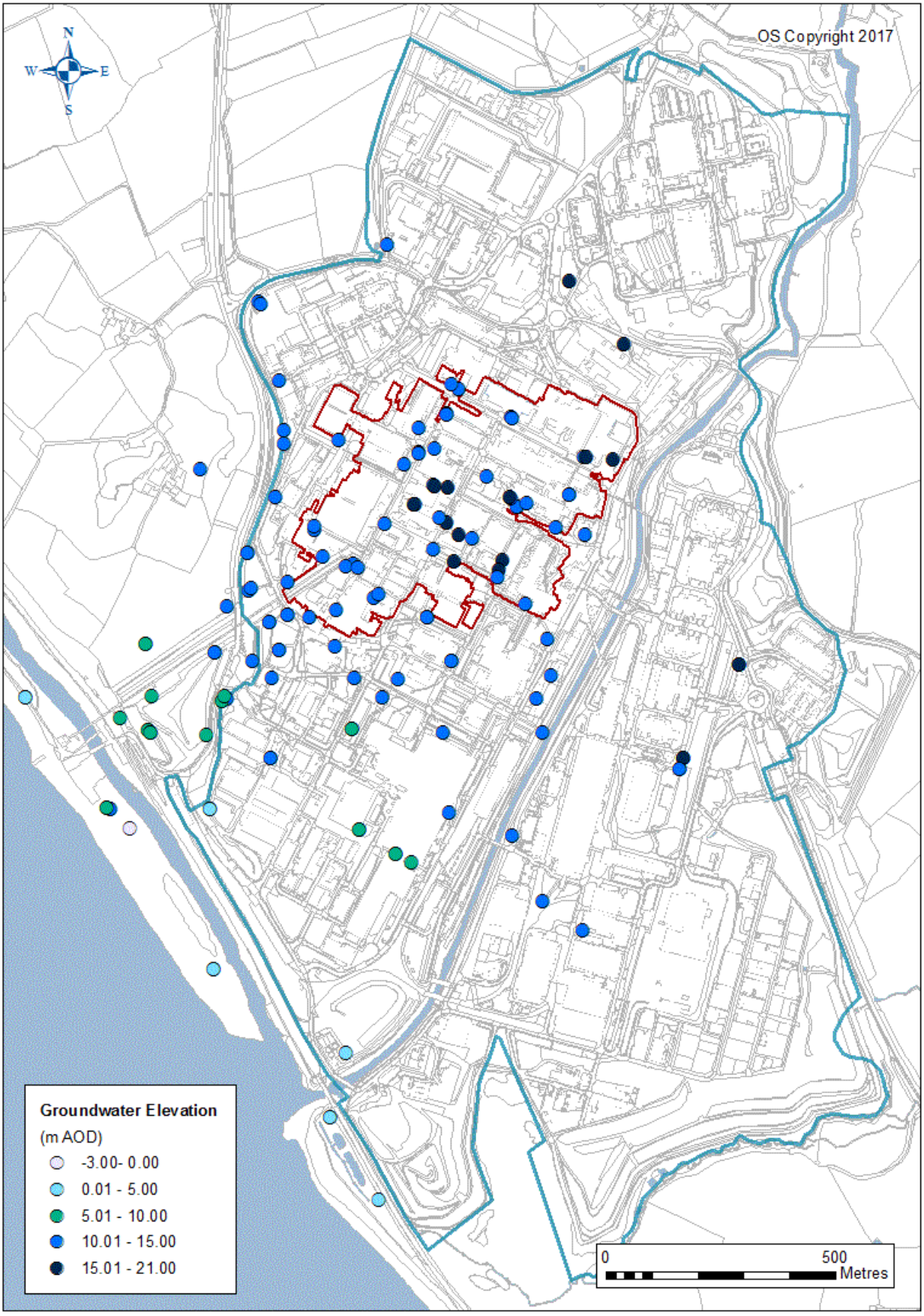
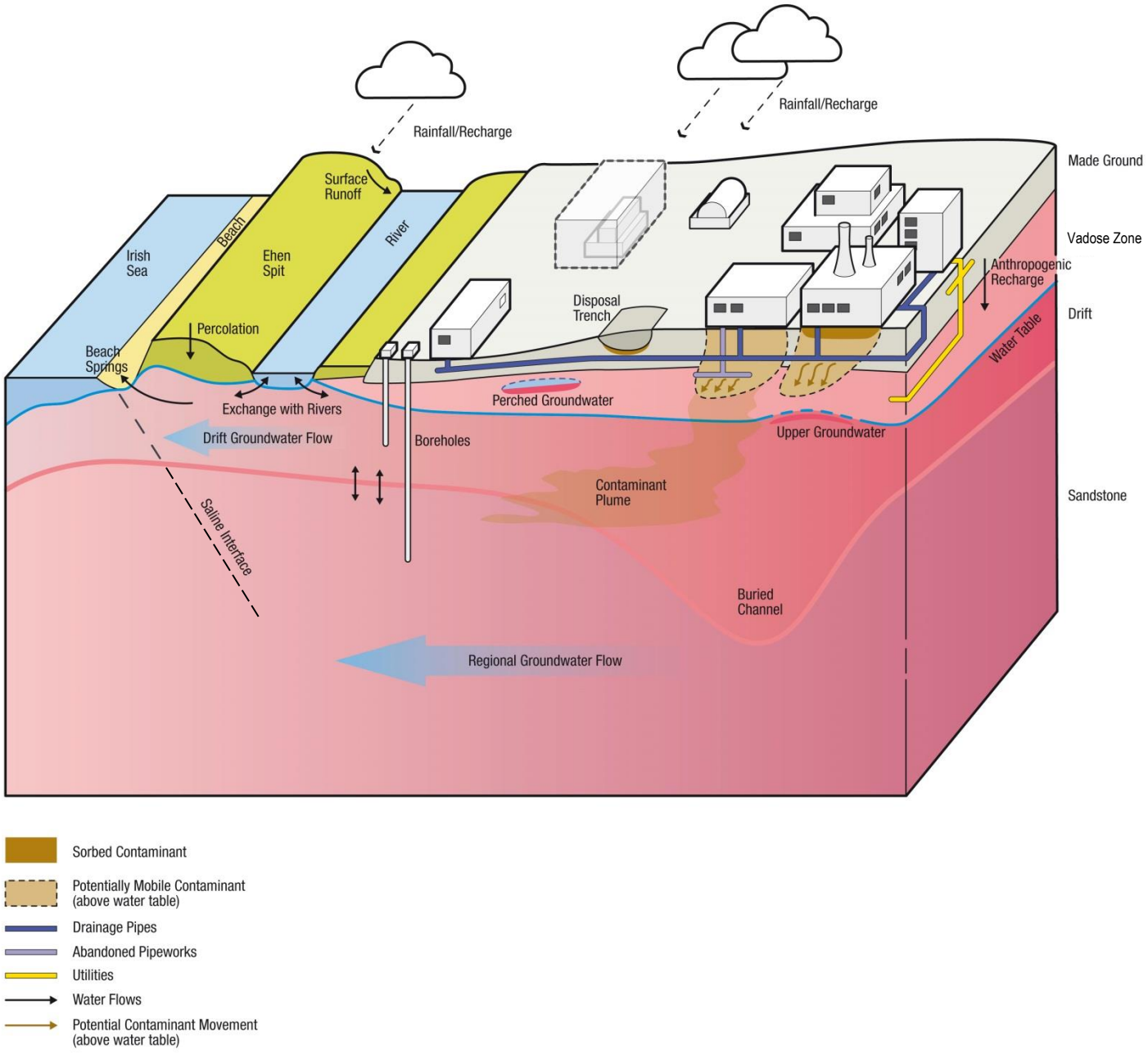


Figure 1.3 shows a schematic representation that broadly describes the geology and hydrogeology, a more detailed description of the elements of the geological and hydrogeological relationships is available in Cruickshank (2011).

Figure 1.3
Schematic Representation of Sellafield Site Geology and Hydrogeology



1.4 Regulatory Background

The Environment Agency is responsible for regulating major industry and water and the management of contaminated land in England and Wales. With regards to the nuclear industry, the Environment Agency has a responsibility for the regulation of radioactive waste discharges and disposals. The Office for Nuclear Regulation is responsible for nuclear safety legislation and sets out, in the conditions attached to a site licence, the requirements to manage the risks on a nuclear site. It also has the power to enforce conventional safety under the Health and Safety at Work Act (1974).

The Office for Nuclear Regulation and the Environment Agency jointly regulate contaminated land and groundwater on the Sellafield site *via* a written Memorandum of Understanding. The Sellafield Environmental Monitoring Programme is a requirement of the Environmental Permit (EP), KP3690SX, which addresses the disposal and monitoring of discharges of radioactive material to the environment. Further to this is an EP EPR-PPC (BM4317X), which is related to the use and disposal of non-radioactive materials, placing additional requirements on the Environmental Monitoring Programme. Under this permit the groundwater monitoring programme includes non-radioactive chemicals of concern.

As part of the Compilation of Regulatory Requirements (CEAR) and the EP, the Environment Agency requires an annual review of the groundwater monitoring programme. This report, produced in September each year, meets this requirement and includes:

- an evaluation of monitoring results from the previous year (and where applicable up to four years previous) using statistical techniques as appropriate,
- an assessment of the reasons why:
  - results are late,
  - samples have not been obtained,
  - analysis has not been undertaken,
  - relevant detection limits have not been achieved.

In addition, this report also fulfils the Office for Nuclear Regulation requirement of an assessment of the level of understanding of groundwater contamination on site and whether current methods of groundwater management comply with site licence conditions.

1.5 Groundwater Monitoring

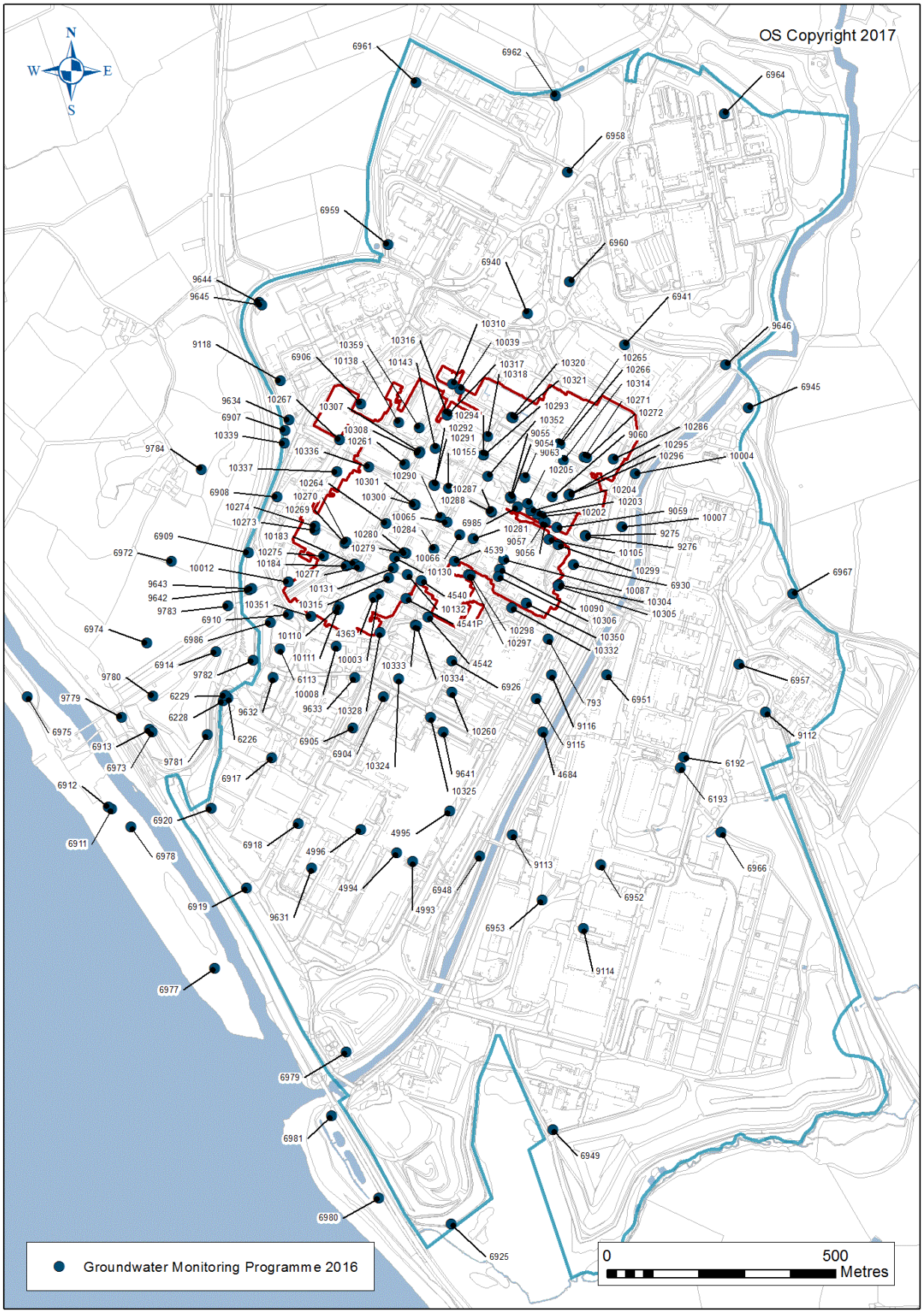
The groundwater monitoring programme characterises, assesses and monitors groundwater quality underlying the site through groundwater sample acquisition and analysis. The groundwater monitoring programme also provides an additional means of reassurance monitoring to support plant leak detection. Analysis of sample data provides an understanding of the nature (contaminant type and concentration) and extent (vertical and lateral distribution) of groundwater contamination and how this changes with time. These datasets are also used to inform near term and long term decision making on how the Land Quality team recommend managing ground and groundwater contamination.

The strategy, which informs the groundwater monitoring programme of sampling, is reviewed every five years, the last review was completed in 2015 and was applied to the 2016 monitoring programme.

The 2015 review continued to use the principles of the Data Quality Objectives (DQO) method. This method helps to define clear guidance on the data review processes, in addition to the physical assessment of monitoring well installations and the analytical requirements for an optimised groundwater sampling and analysis programme. The process considered the objectives and the purpose of the groundwater monitoring programme outlined in Section 1.1 of this report, and reviewed the current method of sample acquisition to ensure best practice was being employed. The outcome of the most recent strategy review resulted in minor changes to account for new wells or deteriorating conditions of older wells that have had to be replaced.

Figure 1.4 shows the location of the groundwater monitoring wells that were included in the 2016 programme and Appendix A provides a summary table documenting individual well characteristics. Appendix B provides a summary of the groundwater monitoring programme specifications for groundwater sample analytical suites and sampling frequency, along with the specifications for non-radiological groundwater monitoring.

Figure 1.4
Groundwater Monitoring Network



1.5.1 Groundwater Monitoring Methods

The sampling strategy is based on objectives of the groundwater monitoring programme, EP requirements, and local operations. This will continue until the design of the programme is reconsidered based on groundwater data collected over time and the needs of Sellafield Ltd. A revised programme was introduced in April 2016 that expanded the non-radiological analytical suite to include major ions at additional locations. The sampling frequency for each determinand at individual locations is outlined in Appendix B.

From 1st January 2011, with the implementation of the 2011 groundwater monitoring programme, the EPR-RSR and EPR-PPC monitoring locations were incorporated into the overall sampling network and programme. While retaining the ability to monitor specific facilities, this change provided more comprehensive environmental monitoring of the site as a whole.

In order to detect any release of contaminants of concern from areas with the potential for pollution and to monitor groundwater quality, determinands were selected specific to each well location. A list of determinands was generated from consideration of the behaviour of each chemical in the environment and the composition of the initial breakdown products. For reference, this list is included in Appendix B.

The analysis of the samples is carried out by Cavendish Nuclear Ltd who is UKAS accredited to undertake most of the analytical suites used in groundwater monitoring at Sellafield site. The suites they do not have accreditation for – primarily organic chemical analyses – are sub-contracted to Concept Life Sciences (CLS), formerly Scientific Analysis Laboratories (SAL), who do hold the necessary UKAS accreditation. For information, the list of methods and limits of detection for each analysis is included in Appendix B.

In order to ensure that only data of appropriate quality were used, all results were reviewed following the methods described in Appendix C. Sample results were assessed and statistical tests were applied to determine whether there were any changes in activity concentration over time. Details of the calculations applied and the investigation stages for those results which exceed these criteria are presented in Appendix D.

1.6 Report Content

Further to Section 1 this report includes:

Section 2 – a review of groundwater monitoring analysis results for radionuclides in 2016, and documents the present condition of groundwater radionuclide contamination underlying Sellafield site.

Section 3 – a review of groundwater monitoring analysis results for non-radiological contaminants in 2016, and documents the present condition of groundwater non-radionuclide contamination underlying Sellafield site. The section also focuses on areas where exceedances have been recorded.

Section 4 – summarises if we have fulfilled our obligation against the CEAR – and EP groundwater monitoring programmes.

Section 5 – a compilation of references.

Appendix A – Sellafield Site Groundwater Monitoring Network Summary Information
Appendix B – Groundwater Monitoring Programme and (EPR-RSR & EPR-PPC) Summary Information
Appendix C – Groundwater Data Screening
Appendix D – Exceedance Information
Appendix E – Compliance Review Information

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Section 2: Annual Groundwater Monitoring Review

Radionuclides

2 Annual Groundwater Monitoring Review – Radionuclides

Groundwater data from the period 1st January 2016 to 31st December 2016 was reviewed to examine current conditions and to determine any year-on-year changes in radionuclide concentrations. The greatest radionuclide concentrations recorded are from samples collected from Separation Area monitoring wells, close to plants and buildings with known historical leaks to ground.

The groundwater monitoring network at Sellafield site allows characterisation activities and monitoring of groundwater quality underlying the site. This is achieved through groundwater sample acquisition and analysis.

Monitoring of groundwater for radioactive contaminants is undertaken as part of the CEAR requirements (Environment Agency, 2016) and Techniques Document SLSP 1.07.46. The Techniques Document identifies individual sampling points (including single installation and multi-level wells), sampling method, sampling frequency and analytical suites for sample analyses. Further information on the groundwater monitoring programme is presented in Appendix B.
The groundwater monitoring network for 2016 includes 181 sample points. 674 individual groundwater samples were successfully collected within the review period. Each groundwater sample was analysed for up to 26 radiological determinands depending on the location and monitoring requirements at each sample point.

In some locations the monitoring well incorporates more than one piezometer (sample point). These are screened within different horizons in the sub-surface, p1 is deeper than p2. The maps in Section 2.1 show average concentrations of all data collected at that location, ignoring any depth variation.

The following section provides a review of the radionuclide distribution in groundwater underlying the Sellafield site.

Groundwater Seepage Monitoring

Sampling of groundwater seepages is undertaken on the Ehen Spit as part of the CEAR requirements. This data is reported in the Monitoring Our Environment Annual Report published in November each year, available at: http://www.gov.uk/government/publications?departments%5B%5D=sellafield-ltd.

2.1 Overview Summary of Results

2.1.1 Variations in Groundwater Radionuclide Concentrations across Site

In order to assess general variations in groundwater radionuclide concentrations across site, datasets have been considered at a monitoring well scale only, ignoring any depth variations.

Descriptions of groundwater radionuclide concentrations are grouped based on the decay characteristics for each measured radionuclide. These groups are:

Alpha-emitters	uranium-234, uranium-238, plutonium-239, plutonium-240, and americium-241
Beta-emitters	strontium-90, caesium-137, plutonium-241, potassium-40, tritium, carbon-14, chlorine-36, technetium-99 and iodine-129

Groundwater sample results have been compared against the World Health Organisation (WHO) drinking water guideline levels to provide a context for the radionuclide concentrations measured within groundwater. Average results above the WHO drinking water guidelines are indicated by a larger marker on each figure, where applicable. WHO drinking water guidelines are used because they define values for a comprehensive list of radionuclides and they are considered to be the most conservative, however it should be noted that these guidelines are not used as compliance targets. A full list of the WHO drinking water guideline levels for radionuclides is presented in Appendix B.

WHO Drinking water guidelines for principal radionuclides:
Total alpha – 0.5 Bql^{-1}(screening analysis)
Total beta – 1.0 Bql^{-1} (screening analysis)
Tritium – 10 000 Bql^{-1}
Technetium-99 – 100 Bql^{-1}
Strontium-90 – 10 Bql^{-1}

There are three wells located along the northern perimeter of Sellafield site, 6961p1, 6962p1 and 6964p1, shown in Figure 1.4, these measure the regional groundwater condition entering the site. Data from 2016 for these wells are presented in Table 2.1. Results from monitoring wells situated across the Sellafield site are compared against those from these northern wells to provide an indication of how the groundwater condition changes as it flows through Sellafield site.

Table 2.1
Average and Maximum Results for Monitoring Wells Situated on the Northern Perimeter of Sellafield Site

	6961p1		6962p1		6964p1	
	Average Bql^{-1}	Maximum Bql^{-1}	Average Bql^{-1}	Maximum Bql^{-1}	Average Bql^{-1}	Maximum Bql^{-1}
Total Alpha	<LOD	0.035	< LOD	0.0233	< LOD	0.0159
Total Beta	<LOD	< LOD	< LOD	< LOD	<LOD	< LOD
Tritium	<LOD	< LOD	<LOD	8.95	<LOD	< LOD
Technetium-99	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD

Alpha-emitting Radionuclides

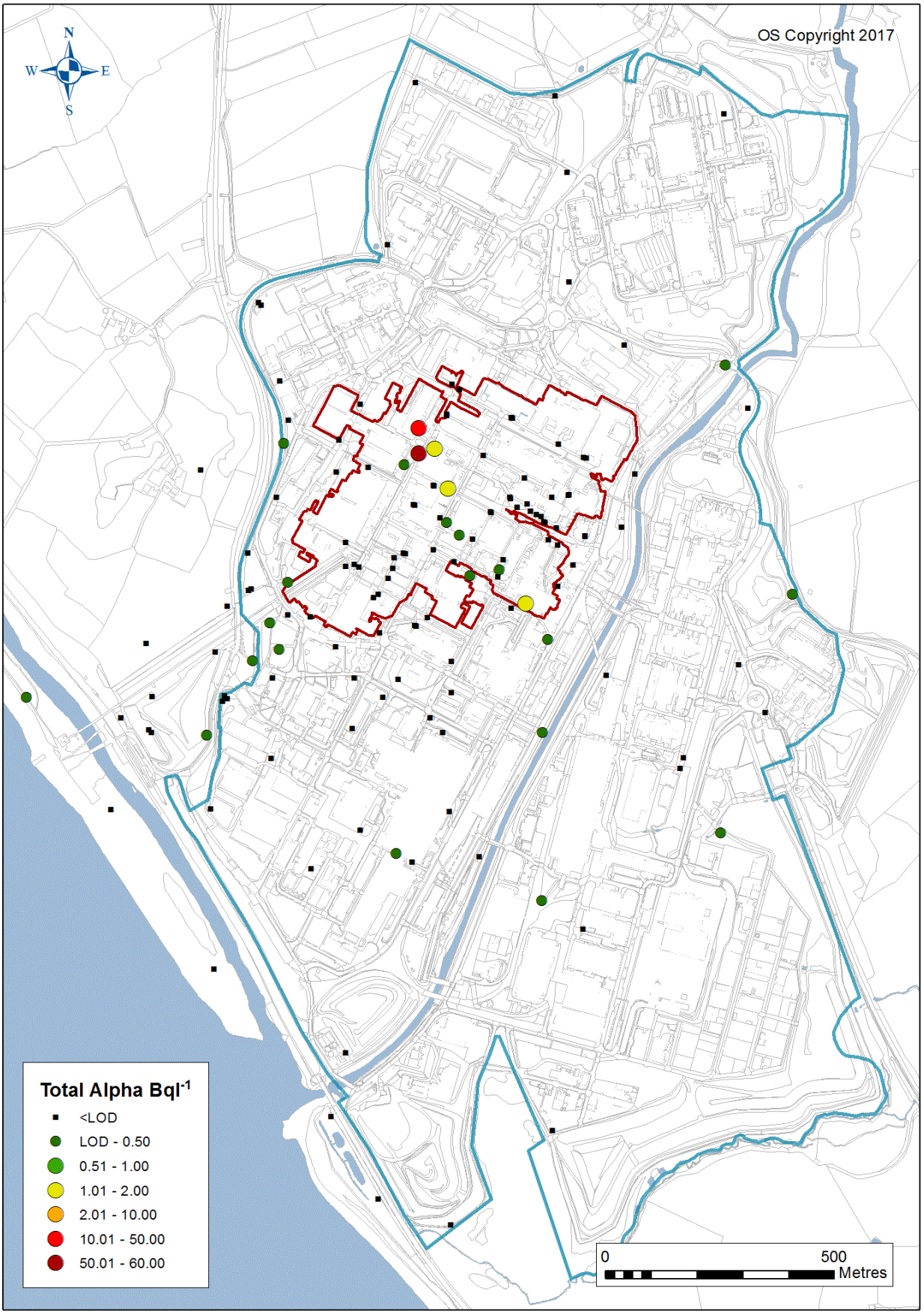
Total alpha screening results are presented in Figure 2.1. The results show that measured total alpha concentrations in the majority of groundwater samples were below the analytical detection limit of 0.03 Bql^{-1}, in line with results from the northern perimeter wells.

The WHO drinking water guideline level for total alpha of 0.5 Bql^{-1} was exceeded in groundwater samples collected from five monitoring wells. All five wells were located within Separation Area, with a highest annual average of 58.15 Bql^{-1} and maximum result of 71.11 Bql^{-1}. These values are lower than the total alpha activity concentrations recorded in 2015 from the same well. The activity concentrations measured from other wells within this area remain in agreement with the results from 2015 and some are lower. These wells are adjacent to buildings associated with nuclear fuel reprocessing activities, some of which have had historical incidents of radioactive liquor leakages and/or spills.

A total alpha measurement has been added to the analysis suite for the well located to the south-east of Separation Area. This well is showing results marginally above the WHO drinking water guideline with an annual average of 1.46 Bql^{-1}. The majority of the groundwater samples down hydraulic gradient from Separation Area have total alpha concentrations less than or equal to the analytical LOD. There are a few that are just above the LOD (0.031 Bql^{-1} to 0.048 Bql^{-1}), including the two new wells installed to the south-west of Separation Area, these were included on the sampling programme in 2016 and account for some of the detections.

The distribution of elevated total alpha shows that it is concentrated around known areas of concern within Separation Area. This is consistent with the observed distributions of contaminants in soils. Total alpha concentrations measured in groundwater from historical wells and the newer wells in comparable locations are very similar. This indicates a common source term associated with a potential localised leak or spill. Groundwater in this area has consistently exhibited the highest total alpha activity since sampling began in 1986.

Figure 2.1:
Average Total Alpha Concentrations

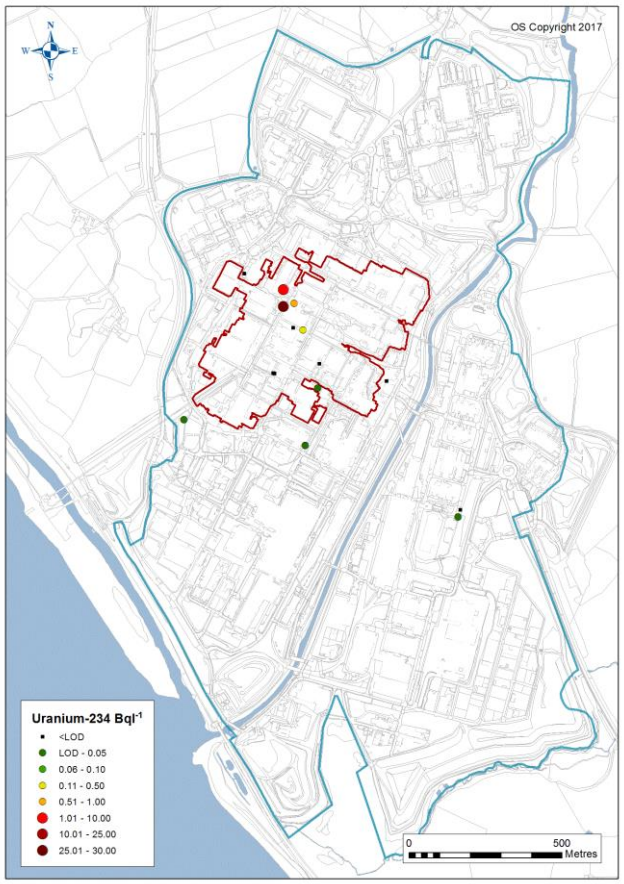


Analyses for other individual alpha-emitting radionuclides that contribute to the total alpha activity have been measured at selected locations. Results indicate that uranium isotopes (specifically uranium-234 and uranium-238) dominated the total alpha activity measured, Figures 2.2 A and 2.2 B. Two monitoring wells had uranium-234 isotope average concentrations greater than the WHO drinking water guideline of 1 Bql^{-1}. One of these wells also exceeded the WHO drinking water guideline of 10 Bql^{-1} for uranium-238. These values are lower than the results from 2015 where there were three monitoring wells that had uranium-234 isotope average concentrations greater than the WHO drinking water guideline. One of these wells also exceeded the WHO drinking water guideline for uranium-238 in 2015.

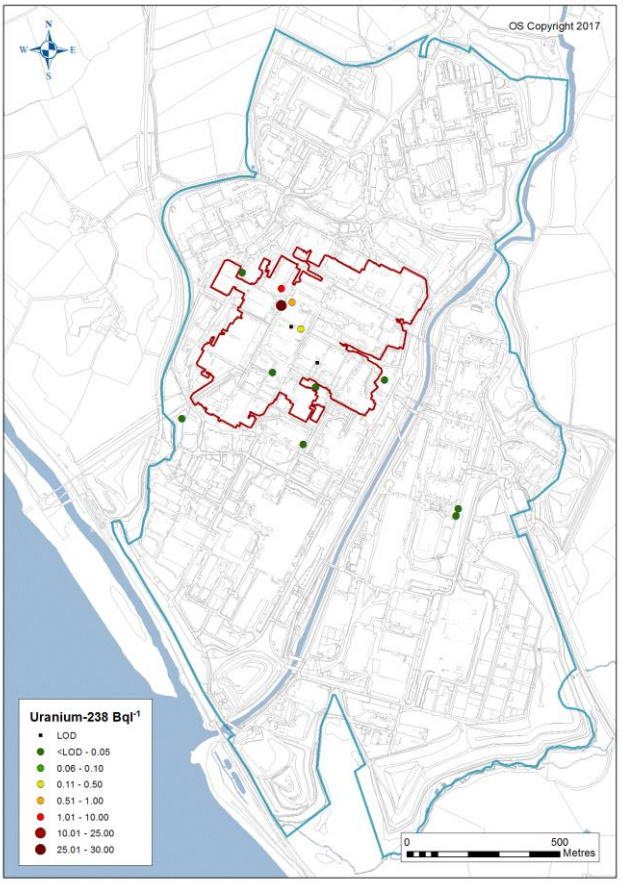
Groundwater samples were analysed for other alpha-emitting radionuclides including plutonium-238, plutonium-239+240, and americium-241. Results show that annual groundwater concentrations for these radionuclides did not exceed their respective WHO drinking water guideline values in any of the monitoring wells in 2015 and 2016.

Figure 2.2
Average Uranium Isotopes Concentrations

A: Average Uranium-234 Activity



B: Average Uranium-238 Activity

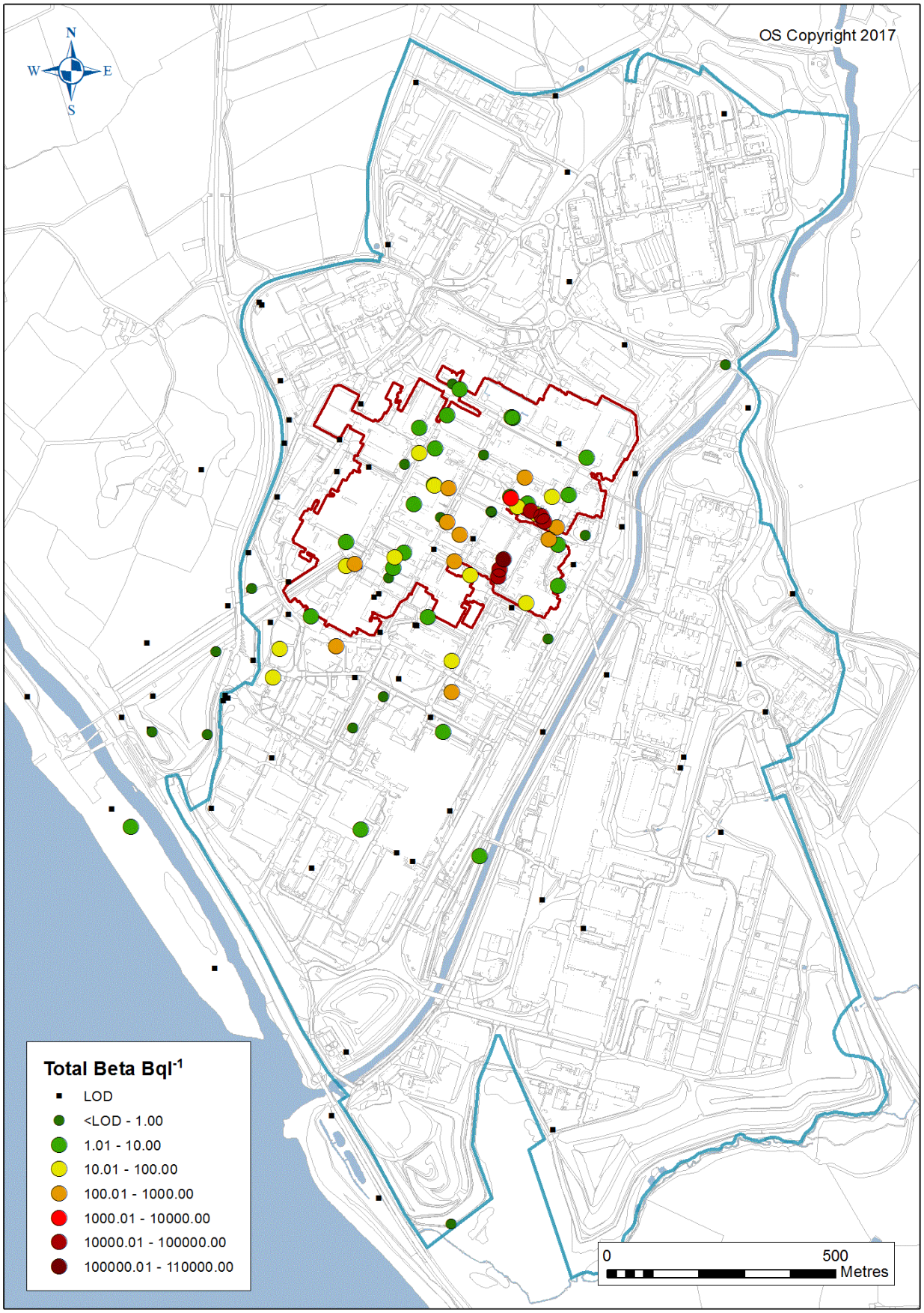


Beta-emitting Radionuclides

Total beta screening results across site are presented in Figure 2.3. These results indicate that many of the groundwater samples with total beta screening activity concentrations are above the WHO drinking water guideline level of 1 Bql^{-1}. In addition these were also above concentrations measured in northern perimeter wells, Table 2.1. Results for individual beta emitting radionuclides across site are represented in Figures 2.4 to 2.10. The majority of samples that exceeded the WHO drinking water guideline values were from monitoring wells located within Separation Area, with a smaller number located outside of this area to the south. The highest 2016 annual average of 105 553 Bql^{-1} and maximum result of 124 000 Bql^{-1} was measured at a monitoring well in the south-east corner of Separation Area. These average and maximum values are lower than those recorded at the same well last year, where highest annual average total beta activity concentration was 132 000 Bql^{-1} with the maximum activity concentration of 149 000 Bql^{-1}.

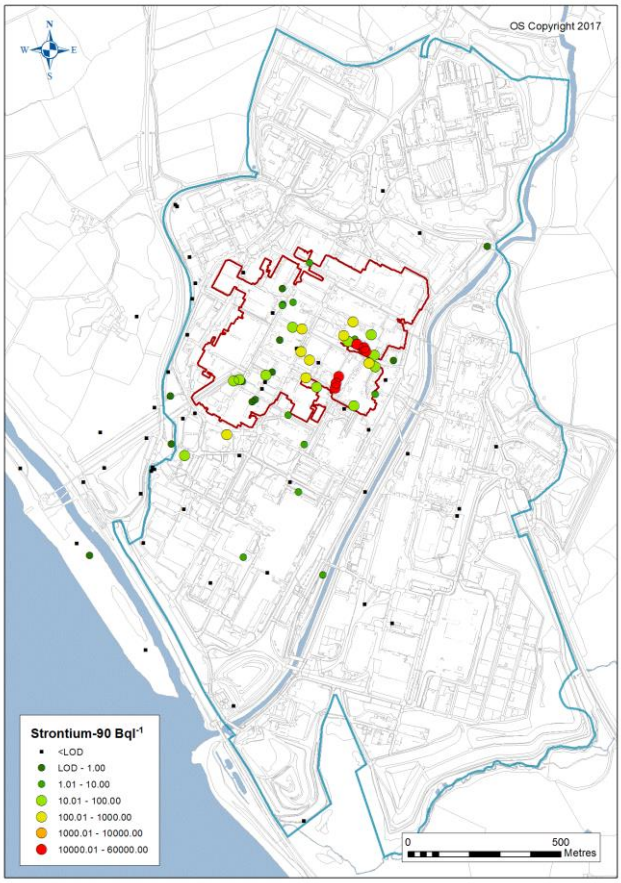
The locations within Separation Area where the highest total beta activity concentrations are observed are in the vicinity of two groups of buildings associated with legacy waste storage activities. Significant leaks to ground occurred in this general area in the 1970s and groundwater samples collected have recorded total beta activity concentrations at over 1 000 000 Bql^{-1}.

Figure 2.3
Average Total Beta Concentrations



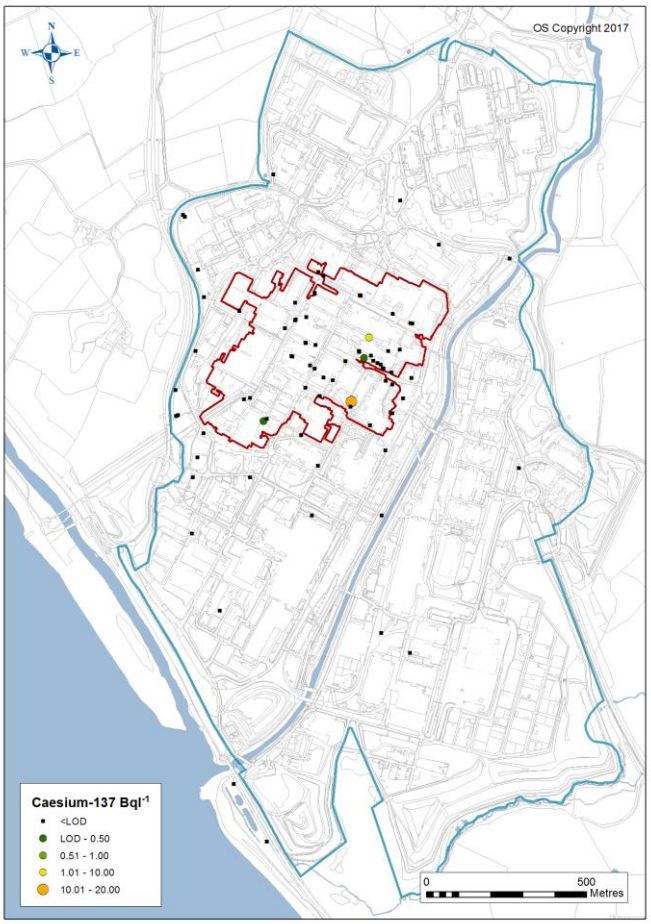
Analyses for the individual beta-emitting radionuclides that contribute to total beta activity found in groundwater samples have been made in selected locations. These results show that strontium-90 is the dominant beta-emitting radionuclide measured in groundwater on site and as such had a similar spatial distribution to total beta activity, Figure 2.4. Fewer samples exceeded the WHO drinking water guideline for strontium-90 than for total beta. The maximum activity concentration for strontium-90 recorded during 2016 was 59 050 Bql^{-1} at monitoring well in the south-east corner of Separation Area, this is lower than the 2015 maximum of 79 000 Bql^{-1}.

Figure 2.4
Average Strontium-90 Concentrations



Average caesium-137 concentrations measured in groundwater samples in 2016 were typically very low, Figure 2.5. Only one sample point exceeded the caesium-137 WHO drinking water guideline of 10 Bql^{-1} with a reported annual average value of 15.94 Bql^{-1}, which is lower than the result of 23.17 Bql^{-1} from 2015. This well is situated in the south-east corner of Separation Area. The maximum caesium-137 activity concentration in 2015 was 41.82 Bql^{-1}, with 23.12 Bql^{-1} measured at the same monitoring well in 2016. Activity concentrations above the LOD were detected at four wells as opposed to only two wells in 2015. All four locations were situated within Separation Area.

Figure 2.5
Average Caesium-137 Concentrations



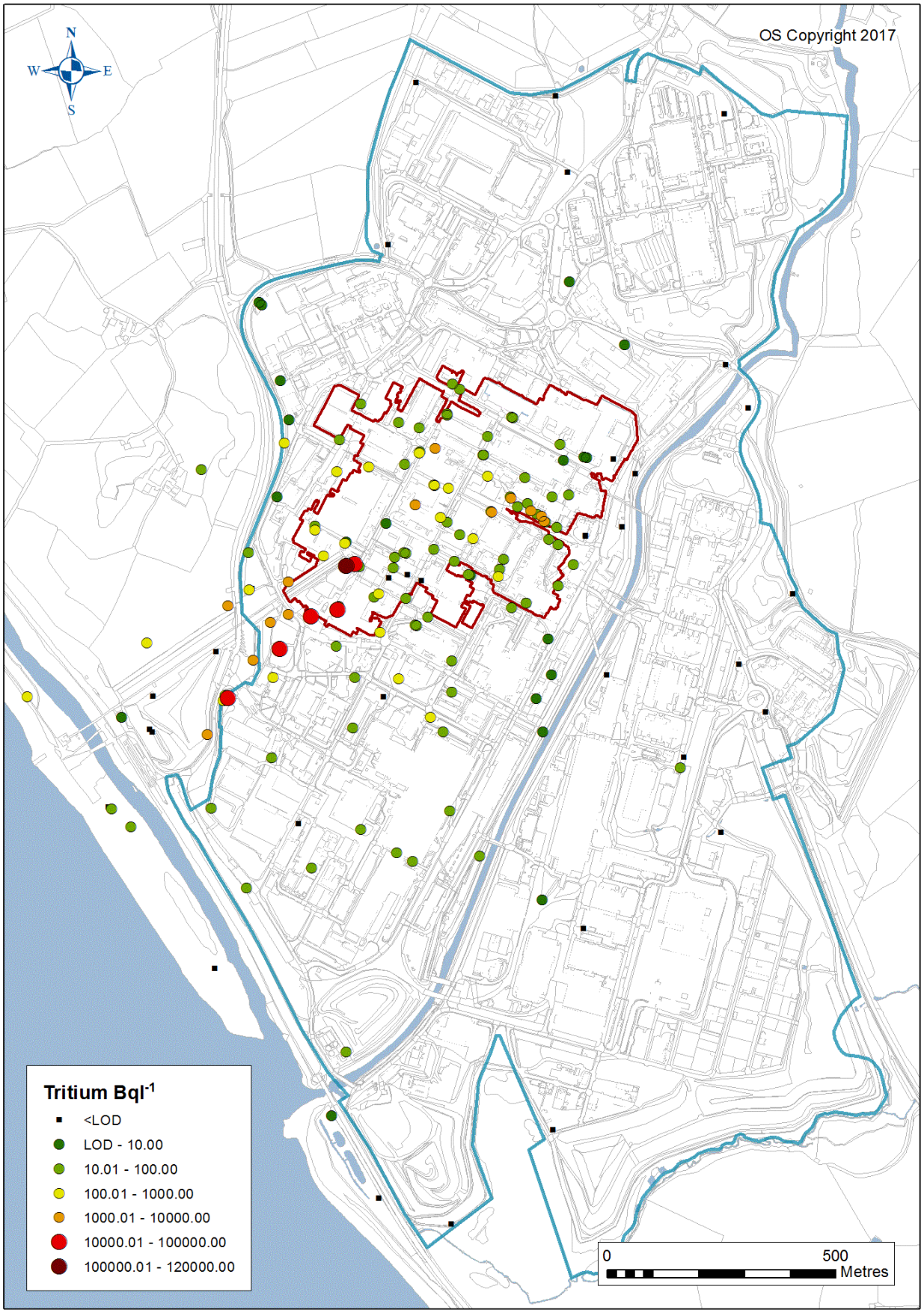
Plutonium-241 was rarely detected in groundwater samples during the monitoring period and measured activities were very low. The 2016 maximum of 0.114 Bql^{-1} was lower than the 2015 measured activity of 0.778 Bql^{-1} at the same monitoring well, situated within north-west corner of Separation Area. This is below the WHO groundwater guideline of 10 Bql^{-1}.

Weak Beta-emitting Radionuclides

Weak beta radionuclides emit energy that is too low to be detected by the total beta analysis. Weak beta radionuclides are therefore measured individually.

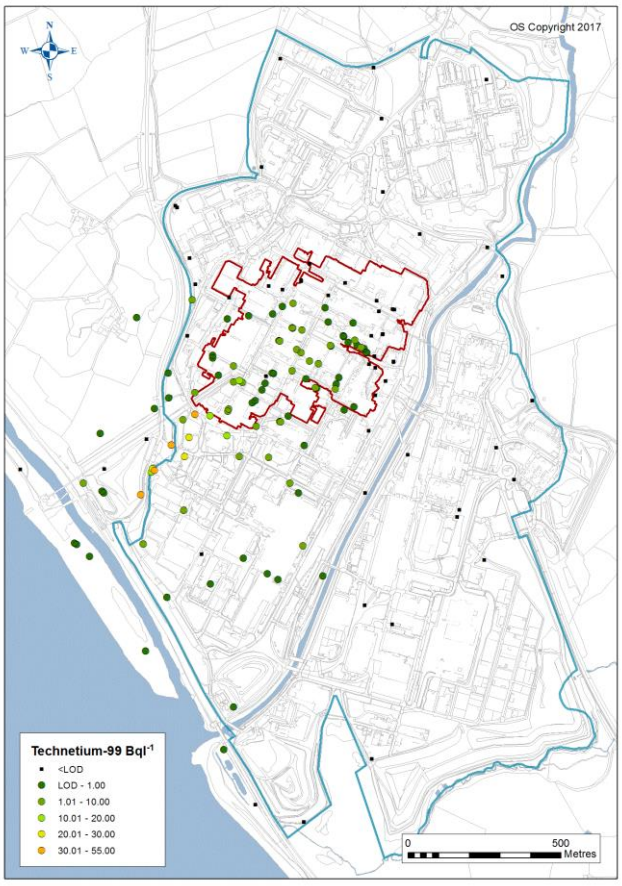
Average tritium concentrations measured within groundwater samples during 2016 are presented in Figure 2.6. Tritium concentrations greater than the detection limit were measured in monitoring wells both within Separation Area and in a predominantly south-westerly direction towards the coast. The WHO drinking water guideline level for tritium is 10 000 Bql^{-1}. Six monitoring wells had an annual average tritium activity concentration above the WHO guideline. The highest annual average activities were recorded at monitoring wells located in the south-west corner of Separation Area, with annual average of 118 000 Bql^{-1}, and a maximum activity of 164 000 Bql^{-1} found in monitoring well 10184. The same well last year had an annual average of 164 000 Bql^{-1} and a maximum activity of 255 000 Bql^{-1}.

Figure 2.6
Average Tritium Concentrations



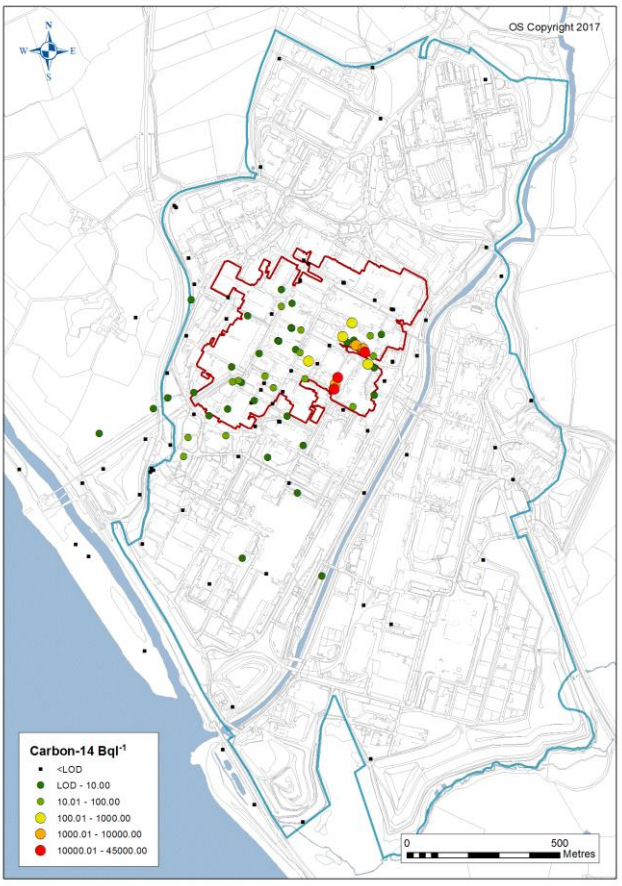
Technetium-99 concentrations measured in groundwater samples during 2016 are presented in Figure 2.7. Results show that technetium-99 was detectable at low concentrations in groundwater samples from within Separation Area, to the south and in new wells west of Separation Area. All annual average results were below the WHO drinking water guideline of 100 Bql^{-1}. However, the majority of results across the site were above levels shown in northern perimeter wells (which were all <LOD). The highest technetium-99 concentrations measured in groundwater were from monitoring wells located south-west of Separation Area. The highest annual average technetium-99 concentration was at monitoring well 9782 with a value of 54.1 Bql^{-1}. The 2015 highest annual average technetium-99 concentration was at monitoring well 6226 with a value of 43.8 Bql^{-1}. This well had an annual average value of 36.85 Bql^{-1} in 2016.

Figure 2.7
Average Technetium-99 Concentrations



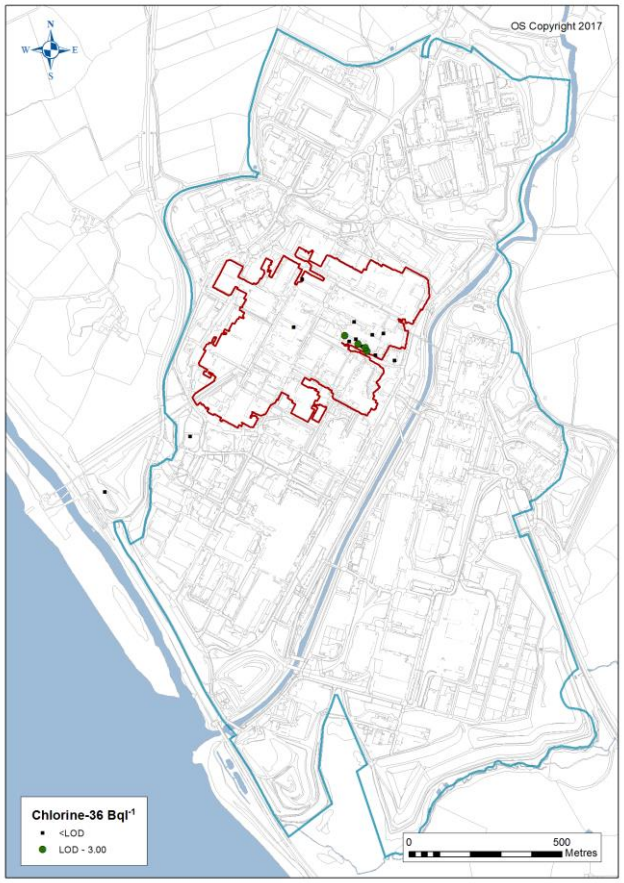
Carbon-14 concentrations during 2016 are presented in Figure 2.8. Results show that carbon-14 was detectable at low levels in groundwater samples collected predominantly from monitoring wells within Separation Area, with the majority of these detectable levels being below the WHO drinking water guideline value of 100 Bql^{-1}. There were ten monitoring wells with average carbon-14 concentrations above the WHO drinking water guideline value, all of these were located within Separation Area. The highest annual average carbon-14 concentration measured during 2016 was 43 825 Bql^{-1} at south-east corner of Separation Area. This value is lower than the highest annual average carbon-14 concentration measured during 2015 which was 51 800 Bql^{-1}. This monitoring well also had the maximum carbon-14 activity concentration measured at 49 200 Bql^{-1} which is lower than 55 300 Bql^{-1} from 2015.

Figure 2.8
Average Carbon-14 Concentrations



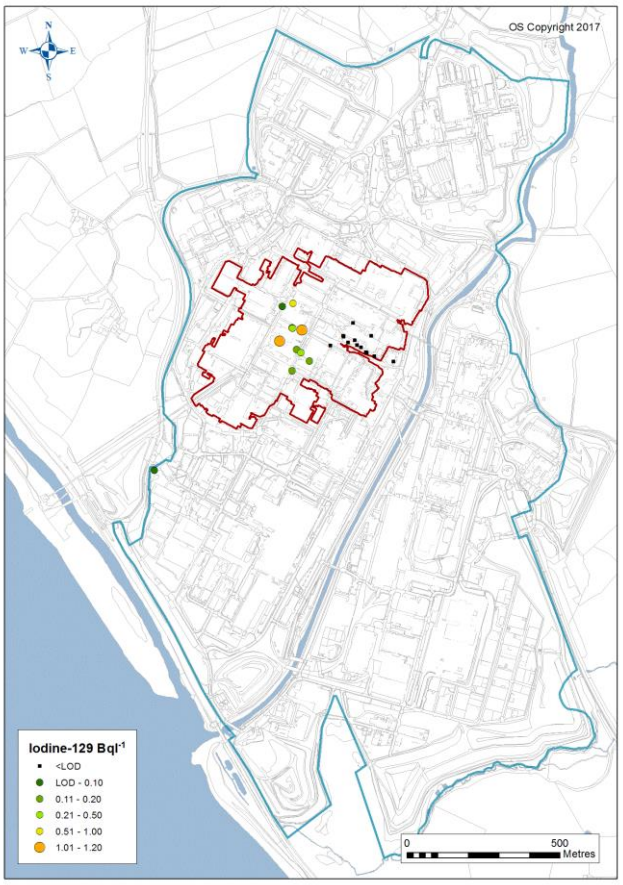
The analysis of chlorine-36, Figure 2.9, indicates that four locations within Separation Area had annual averages marginally greater than the LOD. The highest activity concentration was 2.75 Bql^{-1} recorded at monitoring well 10204. The highest activity concentration in 2015 was 1.23 Bql^{-1} with a maximum value of 1.66 Bql^{-1} recorded at monitoring well 10202. These values are below the WHO drinking water guideline of 100 Bql^{-1}.

Figure 2.9
Average Chlorine-36 Concentrations



Measured iodine-129 groundwater activity concentrations were also low, Figure 2.10. Two monitoring wells (10155 and 10300) had an average iodine-129 activity concentration of 1.19 Bql^{-1} and 1.005 Bql^{-1} respectively, which is slightly above the WHO drinking water guideline value of 1 Bql^{-1}. In comparison to 2015, where one monitoring well (10155) had an annual average iodine-129 activity concentration greater than the WHO value.

Figure 2.10
Average Iodine-129 Concentrations



2.1.2 Variations in Groundwater Technetium-99 Concentrations with Depth

The distribution of technetium-99 groundwater concentrations within the three different hydrogeological units of generally increasing depth across site is summarised in this section. The depth variation of technetium-99 was chosen for illustration as this radionuclide has a wider site distribution than most others and is detected in monitoring wells at a range of depths.

Concentrations are displayed as a series of two dimensional depth slices, in each slice only measurements from sample points screened within the corresponding hydrogeological unit (Appendix A) are displayed.

Groundwater samples collected from the upper drift, Figure 2.11, show that technetium-99 was detected at low levels, lower than the WHO drinking water guideline value of 100 Bql^{-1}. The highest annual average results were measured to the south-west of Separation Area. Groundwater samples collected from the lower drift, Figure 2.12, show that technetium-99 activity concentrations at this depth were also below the WHO guideline level, again with highest levels measured to the south-west of Separation Area. Technetium-99 concentrations measured in groundwater samples from piezometers screened within the sandstone are shown in Figure 2.13. The highest annual average in this lithology was again found in a monitoring well to the south-west of Separation Area.

Overall there appears to be a general trend of increasing depth to maximum technetium-99 concentrations the further down gradient wells are from Separation Area but the pattern is not universal or straightforward.

Figure 2.11
Average Technetium-99 Concentrations in Piezometers Screened within the Upper Drift

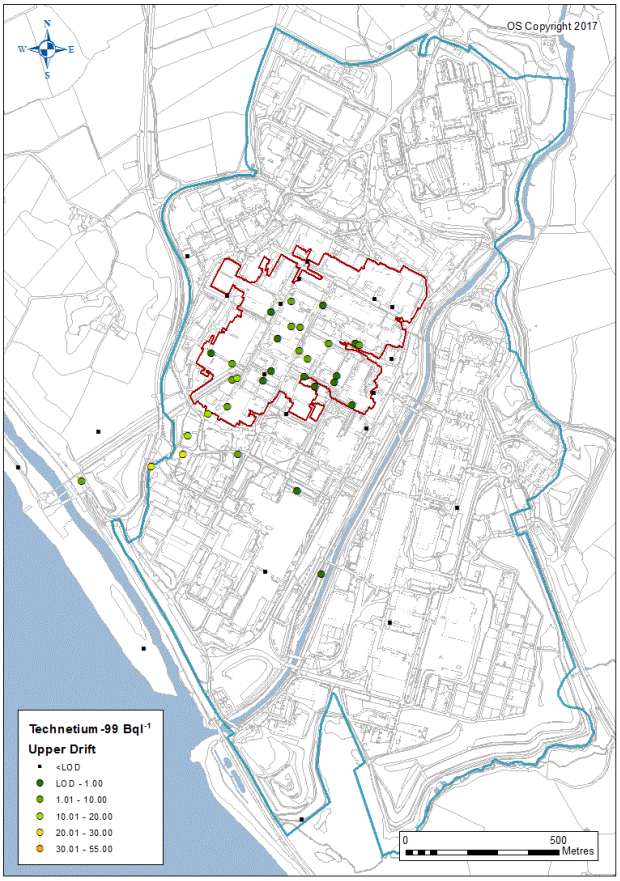


Figure 2.12
Average Technetium-99 Concentrations in Piezometers Screened within the Lower Drift

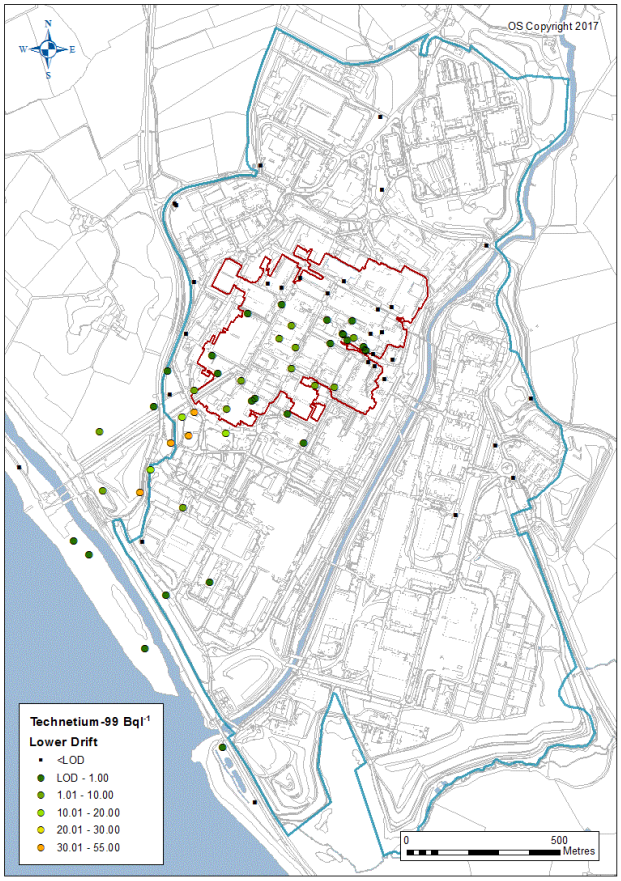
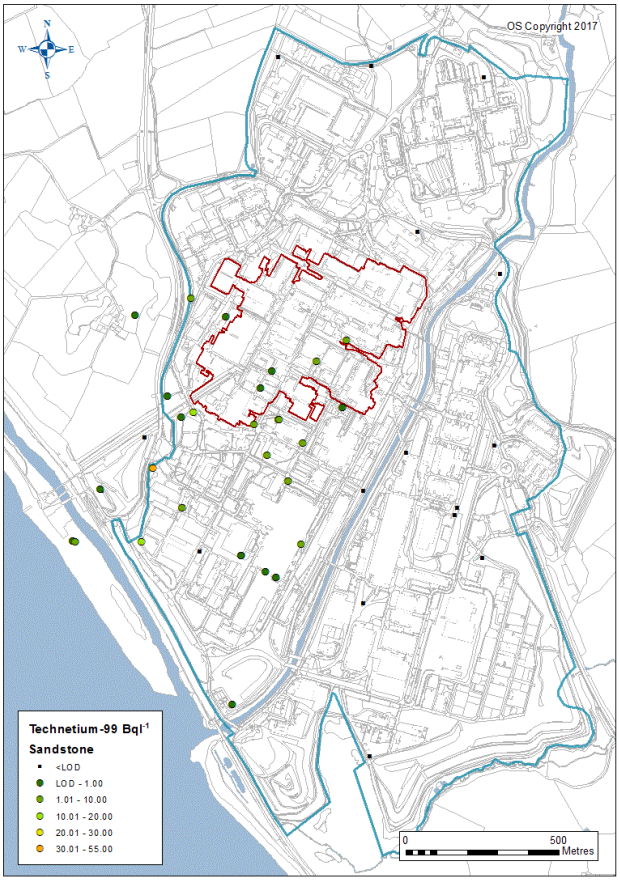


Figure 2.13
Average Technetium-99 Concentrations in Piezometers Screened within the Sandstone



2.1.3 Method Review – Presenting Results from Multi-installation Monitoring Wells

A review of the method for presenting results from dual-installation groundwater monitoring wells was undertaken. This was to evaluate whether activity concentrations for the same analyte were notably different between p1 and p2. The method used could potentially cause an exaggerated smoothing effect by averaging over the whole well, as displayed in Figures 2.1 to 2.10.

The difference between annual average results from each piezometer/analyte combination was calculated. Criteria were set for each analyte to compare the difference and those which exceeded these criteria were flagged. The criteria were as follows:

- 50% of WHO drinking water guideline
- 50% of piezometer annual average (highest average from p1 or p2)

Depending on which was lower, or if they are the same order of magnitude then the following was used:

- 12.5% of WHO drinking water guideline

Table 2.2 presents which criteria were used for each analyte. Applying these criteria to the whole dataset resulted in 16 flagged results, outlined in Table 2.3.

Of these 16, only five had maximum piezometer annual averages higher than the monitoring well classification band shown in Figures 2.1 to 2.10. These were from wells 6113 and 6986 (respective well maximum and minimum piezometer annual averages are highlighted in Table 2.3).

The maximum piezometer annual averages for total beta and technetium-99 would fall into the classification band above; however these levels are within those shown in surrounding wells, Figures 2.3 and 2.7, respectively. Maximum piezometer annual average results for total alpha from 6113 and 6986 would also fall into the classification band above as shown in Figure 2.1, these are higher than levels shown in surrounding wells. Further assessment of these results showed that the maximum piezometer annual average results were only slightly above the minimum classification band level (0.0515 Bql^{-1} and 0.653 Bql^{-1}, respectively).

Thirteen of the minimum piezometer annual average results shown in Table 2.3, fall into bands below those shown in Figure 2.1 to 2.10. These are in line with monitoring well annual average results from surrounding monitoring wells.

It was concluded that no refinement to the method for presenting results from dual installation monitoring wells, (Figure 2.1 to 2.10) was to be made, as averaging results over the whole well had little effect on the figures.

Table 2.2
Criteria Used to Assess the Difference between Piezometer/Analyte Combinations from Dual Installation Wells

Analyte	WHO Drinking Water Guideline (Bql^{-1})	Highest Piezometer Annual Average (Bql^{-1})	Criteria	Criteria Source
Antimony-125	100	All <LOD	-	As all LOD removed
Beryllium-7	10 000	All <LOD	-	As all LOD removed
Caesium-137	10	0.288	0.144	50% of Highest Piezometer Annual Average
Carbon-14	100	39.6	19.8	50% of Highest Piezometer Annual Average
Chlorine-36	100	0.294	0.147	50% of Highest Piezometer Annual Average
Iodine-129	1	0.0136	0.00680	50% of Highest Piezometer Annual Average
Ruthenium-103	100	All <LOD	-	As all LOD removed
Ruthenium-106	10	All <LOD	-	As all LOD removed
Strontium-90	10	29.7	5	50% of WHO drinking water guideline
Technetium-99	100	44.4	12.5	12.5% of WHO drinking water guideline
Tin-126	-	All <LOD	-	As all LOD removed
Total alpha	0.5	0.0653	0.0327	50% of Highest Piezometer Annual Average
Total beta	1	154	0.5	50% of WHO drinking water guideline
Tritium	10000	19100	5000	50% of WHO drinking water guideline
Uranium-234	1	0.0188	0.00940	50% of Highest Piezometer Annual Average
Uranium-236	1	0.00250	0.001250	50% of Highest Piezometer Annual Average
Uranium-238	10	0.0192	0.00960	50% of Highest Piezometer Annual Average

Table 2.3
Flagged Results Where the Difference between Annual Average from Each Piezometer/Analyte Combination Exceeds Set Criteria

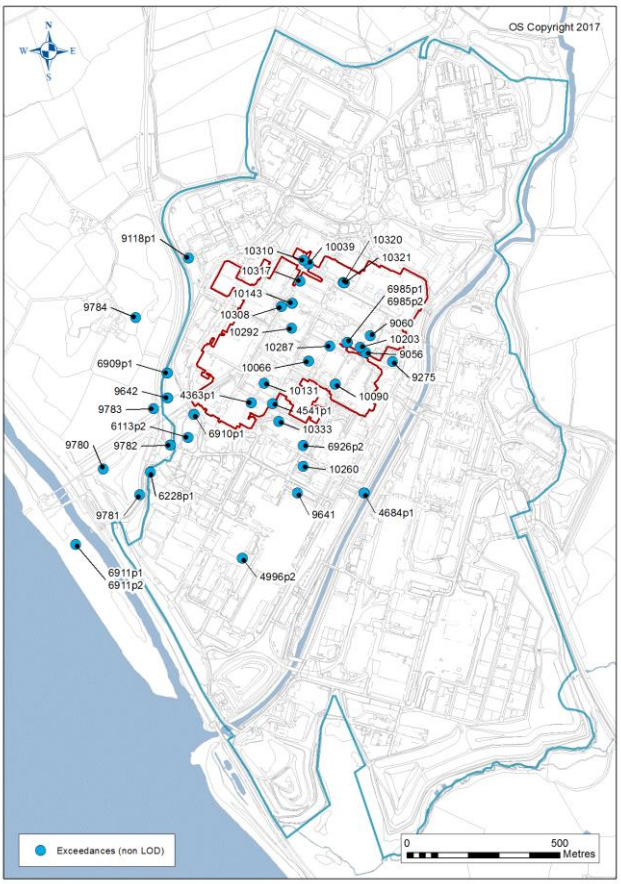
Analyte	Monitoring Well	Monitoring Well Annual Average (Bql^{-1})	Maximum Piezometer Annual Average (Bql^{-1})	Minimum Piezometer Annual Average (Bql^{-1})
Caesium-137	6985	0.188	0.286	0.0879
Carbon-14	6113	20.0	39.6	0.51
Strontium-90	4996	3.63	7.19	0.073
Strontium-90	6985	15.3	29.73	0.93
Technetium-99	6113	27.1	38.4	15.83
Technetium-99	6910	31.0	44.4	17.563
Technetium-99	6986	8.78	16.74	0.82
Total alpha	6113	0.035	0.0515	0.0185
Total alpha	6986	0.0454	0.653	0.0255
Total beta	4542	5.35	7.05	3.642
Total beta	4996	4.58	8.91	0.25
Total beta	6113	76.9	153.63	0.27
Total beta	6973	0.59	0.93	0.24
Total beta	6985	15.1	28.97	1.32
Tritium	6113	10200	19068.99	1375.9
Tritium	6986	3100	6115.13	88.33

Note: Results highlighted in purple indicate where maximum piezometer annual average results are above the monitoring well annual average classification band displayed in Figures 2.1 to 2.10.

2.2 Summary of Analytical Results that Exceed Set Trigger Levels

Using the procedure outlined in Appendix D, results that exceeded the 4σ reporting trigger were assessed in three stages. Details of each investigation are presented in Table D.2. There were 91 radiological exceedances reported to the Environment Agency and Office for Nuclear Regulation between January 2016 and December 2016, of those reported 38 results were below the LOD. The spatial distribution of sample locations where exceedances were reported was generally from within Separation Area and to the south, Figure 2.14.

Figure 2.14
Groundwater Monitoring Well Locations with Analysis Results Greater than the 4σ Trigger Level and Greater than the LOD

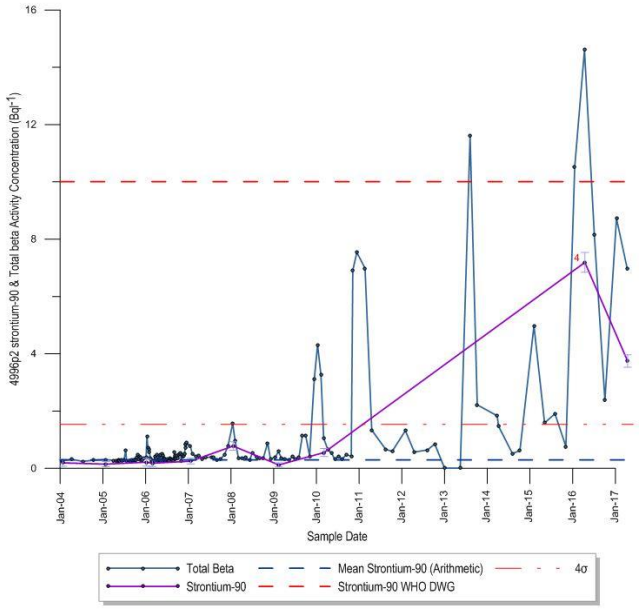


Twenty-two reported results from 2016 were closed after a stage 1 investigation where it was concluded that the reported result was not a change in the groundwater condition and in some cases the results were considered anomalous. Causes of anomalous results may be attributed to a number of factors including possible contamination during sample collection and sample preparation. Table D.2, Appendix D, lists all radiological exceedances greater than the analytical LOD and the stage at which the investigation has been closed. Six exceedance investigations remain ongoing pending new results, one investigation at 4996p2 is presented below as the results indicate a change that is of interest.

4996p2 Strontium-90 exceedance

Result	7.19 Bql^{-1}
Mean (all data prior to exceedance)	0.302Bql^{-1}
Maximum	0.776 Bql^{-1}
Minimum	0.118 Bql^{-1}
4σ	1.24 Bql^{-1}
Range (including analytical uncertainty)	0.045 to 0.924 Bql^{-1}
Number of results	8

Figure 2.15
Strontium-90 and Total Beta Activity Concentrations over Time at Monitoring Well 4996p2



This monitoring well is located to the west of a Thermal Oxide Reprocessing Facility. The exceedance result was over four times above the 4σ trigger value. The subsequent result decreased slightly, however remained at an elevated concentration in comparison to previous results. Both the exceedance and subsequent results were below the WHO drinking water guideline of 10 Bql^{-1}, Figure 2.15. There are a number of positive statistical jumps within the total beta dataset particularly during the winter/early spring, although this seasonal signature breaks down during 2015/2016.

The groundwater results were investigated as part of a broader study into elevated total beta concentrations observed in the site Factory Sewer during 2016. An investigation was undertaken which concluded that the discharge increase in the Factory Sewer was due to historically contaminated groundwater migrating from Separation Area reaching a redundant dewatering drainage network beneath the reprocessing facility. The drainage system was installed to control the elevation of groundwater during plant construction by dewatering the ground. Increased rainfall in October and November 2015 resulted in elevated groundwater levels causing groundwater to enter the drain.

A detailed assessment of groundwater results was undertaken during the investigation, which incorporated the increase in strontium-90 and total beta at 4996p2. The review indicated that the fluctuations in total beta concentration within the Factory Sewer were closely aligned to fluctuations in total beta groundwater concentrations at 4996p2 (Atherton, 2016).

A previous assessment of groundwater contamination in this area of site highlighted the likelihood that the local groundwater contamination represented a plume originating from within Separation Area. The review was updated to determine if further migration of the plume of groundwater in the area had occurred since 2004 (total beta was used due to its higher frequency of data compared to strontium-90). This was found to be the case. The change in total beta concentration from 2011 and 2016 for 4996p2 was however inconsistent when compared to the magnitude of change shown in similar nearby wells. This potentially indicates a pathway within the deep drainage system with historically contaminated groundwater being discharged to ground to the west of the reprocessing facility due to the drainage system being of a perforated design.

A number of recommendations were made during the investigation, including a review of the groundwater monitoring programme in the vicinity of the drainage system. It was concluded that monitoring at 4996p2 would remain unchanged, and that additional monitoring wells should be installed in the vicinity of the reprocessing plant. Recommendations were made to continue inspections of the deep drainage system in the area, as far as practicable. In addition, further work is required to predict the range of future concentrations of radioactivity that could enter the deep drainage system as a result of the migration of contaminated groundwater. Subsequent groundwater monitoring results will continue to be assessed at this location.

2.3 Summary of Maxima

Maximum radionuclide concentrations detected within groundwater samples collected during 2016 are summarised in Table 2.4. The peak values were predominantly from groundwater samples collected from monitoring wells located within Separation Area. The general location of peak concentrations across site has remained similar to previous years.

Table 2.4
Maximum Activities for Groundwater Data 2012 – 2016

			Calendar Year 2012		Calendar Year 2013		Calendar Year 2014		Calendar Year 2015		Calendar Year 2016	
Name	WHO Drinking Water Guideline Bql^{-1}	Detection Limit Bql^{-1}	Maximum result Bql^{-1}	Location of max	Maximum result Bql^{-1}	Location of max	Maximum result Bql^{-1}	location of max	maximum result Bql^{-1}	location of max	maximum result Bql^{-1}	location of max
Total alpha	0.5	0.03	69.8	10308	74.1	10308	79	10308	77.9	10308	71.1	10308
Americium-241	1	0.01	0.0917	10155	0.13	10155	0.117	10155	0.243	10155	0.123	10155
Total beta	1	0.3	132 000	10087	123 000	10087	140 000	10087	149 000	10087	124 000	10087
Carbon-14	100	1	53 000	10087	44 200	10087	69 100	10087	55 300	10087	49 200	10087
Chlorine-36	100	0.29	1.79	6985p1	1.29	6985p1	0.874	10202	1.66	10202	2.75	10204
Caesium-137	10	0.1	29.6	10090	39.8	10090	129	10090	41.8	10090	23.1	10090
Tritium	10 000	5.61	319 000	10184	170 000	10184	153 000	10184	255 000	10184	164 000	10184
Iodine-129	1	0.02	2.26	10155	1.78	10155	1.38	10155	1.30	10155	1.34	10155
Potassium-40	N/A	2.5	1.8	6978p1	1.5	10003	3.38	6978p1	2.17	6978p1	0.984	6981P2
Plutonium-238	1	0.003	0.00324	10155	0.00450	10308	0.00362	10155	0.00390	10155	0.00264	10155
Plutonium-239+240	1	0.003	0.0382	10155	0.0347	10155	0.0347	10155	0.0429	10155	0.214	10155
Plutonium-241	10	0.06	0.0768	10310	0.0824	10155	0.289	10155	0.778	10308	0.1174	10308
Strontium-90	10	0.11	77 100	10087	44 200	10087	84 000	10087	79 000	10087	59 000	10087
Technetium-99	100	0.05	118	6910p2	107	6910p2	70.5	6910p2	58.1	6113p1	62.1	9782
Uranium-234	10	0.005	33.3	10308	34.8	10308	38.8	10308	32.3	10308	28.5	10308
Uranium-235	1	0.0004	1.24	10308	1.35	10308	1.37	10308	1.21	10308	1.19	10308
Uranium-236	1	0.003	1.75	10308	1.76	10308	1.83	10308	1.59	10308	1.43	10308
Uranium-238	10	0.0006	34.3	10308	38.4	10308	39.9	10308	33.5	10308	29.5	10308

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Section 3: Annual Groundwater Monitoring Review

Non-radionuclides

3 Annual Groundwater Monitoring Review – Non-radionuclides

Groundwater data from the period 1st January 2016 to 31st December 2016 was reviewed to examine current conditions and to assess any deterioration in groundwater quality across the Sellafield installation for chemo-toxic pollutants. There has been no evidence of any reduction in groundwater quality during the monitoring period.

3.1 Objectives of the Environmental Permit Groundwater Monitoring

The monitoring of groundwater quality for non-radiological contaminants is a requirement of the Sellafield Environmental Permit for Pollution, Prevention & Control (EPR-PPC). The groundwater data for the period has been reviewed to provide an overview of the general groundwater quality.

The objectives of the environmental monitoring programme for the Sellafield EPR-PPC are:

- monitoring the effectiveness of pollution prevention infrastructure and management procedures,
- determining the movement of pollutants within, and potential migration off, the installation site,
- providing data on long term trends in groundwater quality on a site wide basis.

The measured concentration at each environmental monitoring location will change for each monitoring round even without anthropogenic influences. These concentration changes can be due to natural variation, sampling and/or analytical uncertainties and require the development of a baseline by ensuring a large enough number of sampling events to make any evaluation statistically relevant. By the end of 2012 the non-radiological dataset had the required minimum number of data points to assess the data using the same statistical techniques described in Appendix D.

Environmental Screening Criteria (ESC) are used to provide a context for non-radionuclide concentrations measured in groundwater. These are listed for each determinand in Table B.7, Appendix B. Average results above the ESC are indicated by a larger marker on each figure, where applicable.

3.2 Overview of Non-radiological Groundwater Quality

The EPR-PPC requires that Sellafield Ltd record any changes to the groundwater quality throughout the life of the permit. The overall aim is to maintain a good groundwater quality status as the environmental protection infrastructure on the site is developed and enhanced. Table 3.1 summarises the range and average concentration for the primary determinands in the non-radiological dataset over the last three years. This section also provides a general discussion of the results for each determinand in Table 3.1.

Table 3.1
Summary of Non-radiological Determinand Concentration Ranges in Groundwater for 2014, 2015 and 2016

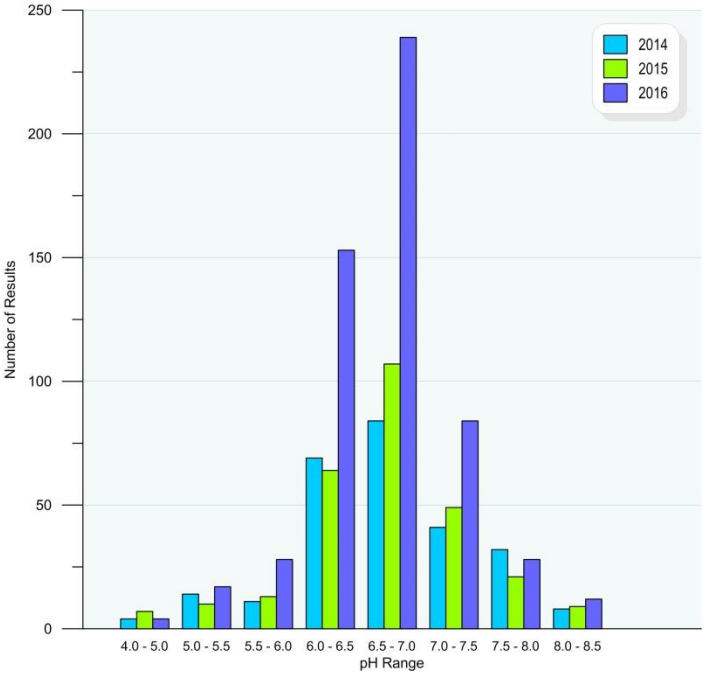
Determinand [1]	Minimum Concentration (mgl^{-1})			Maximum Concentration (mgl^{-1})			Average Concentration (mgl^{-1}) [2]		
	2014	2015	2016	2014	2015	2016	2014	2015	2016
pH [3]	4.87	4.75	4.80	8.33	8.28	8.26	-	-	-
TPH [4]	LOD	LOD	LOD	0.280	0.630	1.90	0.040	0.039	0.151
Sodium	7.71	4.12	3.83	159	157	1 550	38.0	38.2	43.9
Potassium	0.921	0.880	0.739	11.0	10.7	49.7	3.39	3.38	3.27
Iron	0.015	0.020	0.012	25.6	64.0	17.2	0.674	1.29	0.670
Chromium	1.72×10^{-4}	LOD	1.17×10^{-4}	0.038	0.070	0.107	0.003	0.004	0.003
Gadolinium	LOD	LOD	LOD	0.009	0.017	0.016	3.16×10^{-4}	4.76×10^{-4}	4.33×10^{-4}
Ammonium	LOD	LOD	LOD	12.2	12.7	13.6	0.594	0.737	0.774
Nitrate	LOD	LOD	LOD	195	206	199	15.9	15.8	15.1
Sulphate	4.42	3.41	4.42	91.0	73.5	384	26.1	26.9	28.2
Chloride	11.0	7.03	6.06	10 000	3 610	3 190	176	105	79.7

1. *Organic compounds are discussed in the text below.*
2. *Average concentration calculations use LOD values as actual results.*
3. *pH is unitless and as it is measured on a logarithmic scale an average cannot be calculated.*
4. *Total (C6-C40).*

3.2.1 Groundwater Non-radiological Results and Review

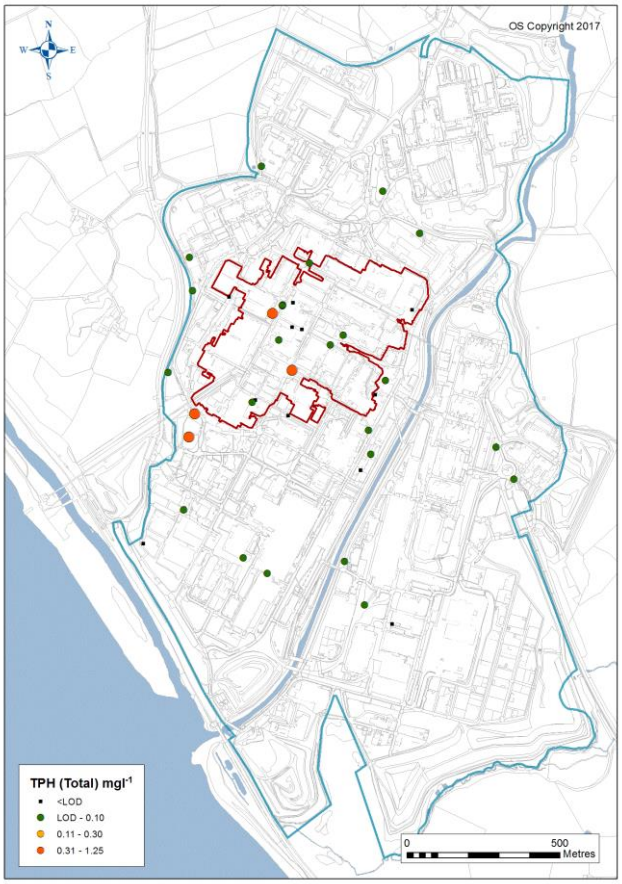
The pH of groundwater is heavily influenced by the geology of the area, the amount of local rainfall and a variety of geochemical interactions. The pH in 2016 ranged from 4.8 to 8.3, Table 3.1. The highest frequencies were recorded between pH 6.5 and pH 7.0 and overall the distribution was similar to that of previous years, Figure 3.1. The increase in frequencies in 2016 was a result of a revision to the groundwater monitoring programme.

Figure 3.1
pH Frequency Distribution



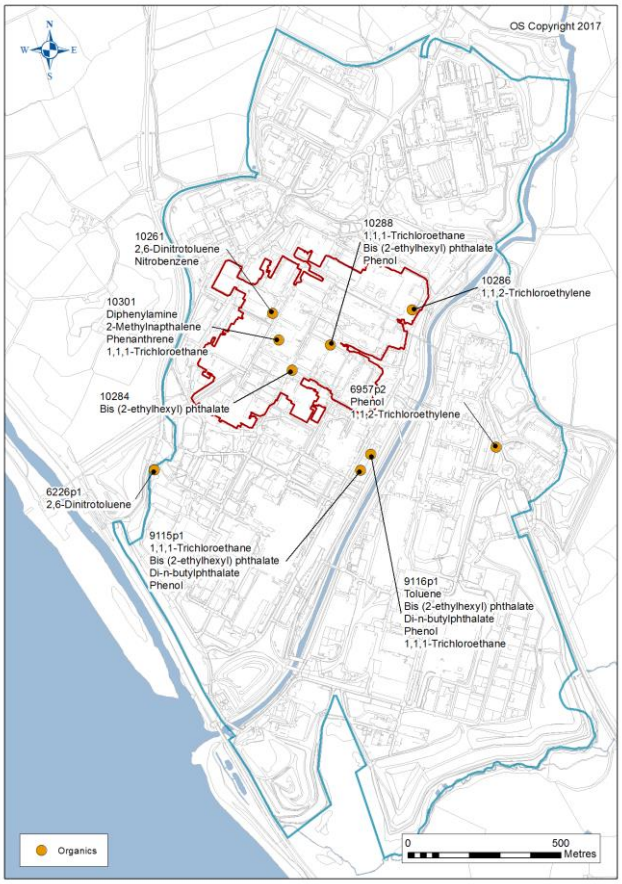
Total petroleum hydrocarbon (TPH) concentrations ranged from below LOD (0.03 mgl^{-1}) to a maximum of 1.9 mgl^{-1} in 2016 (an increase from 0.63 mgl^{-1} in 2015). The average concentration of 0.15 mgl^{-1} has increased, but remains low, Table 3.1. There were positive detections at 27 of the 38 monitoring locations across the site, Figure 3.2, and while this detection rate was higher than in 2015 (13 results above LOD at 43 monitoring locations), it marked a return to the detection rate in 2014 (28 results at 38 locations).

Figure 3.2
Average TPH Concentrations



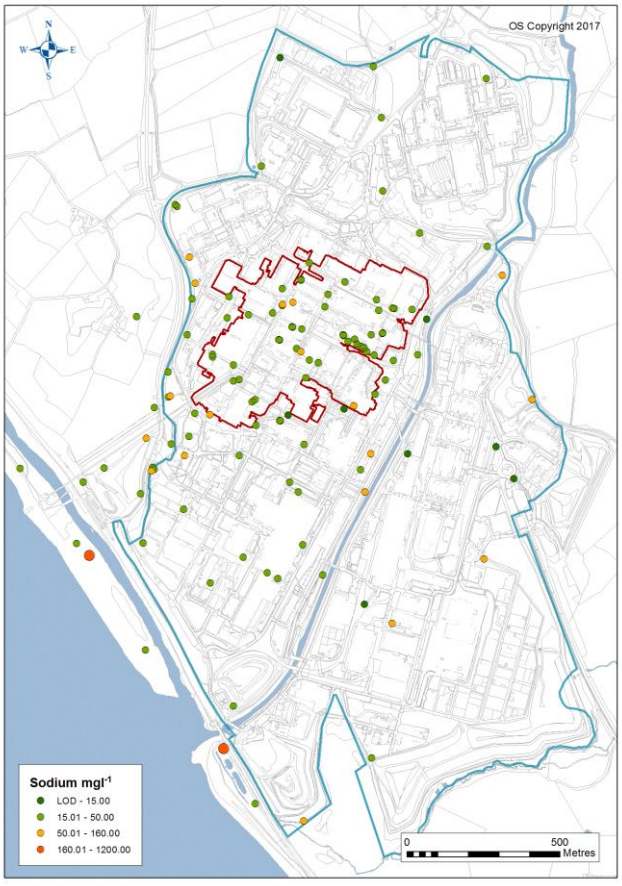
Organic compounds are both numerous and ubiquitous in the environment. The compounds found in 2016 were similar to those found in previous years, but were detected at more locations (nine compared to six locations in 2015), Figure 3.3. The most commonly detected compounds were 1,1,1-trichloroethane, bis(2-ethylhexyl) phthalate and phenol with concentrations ranging from 1 μgl^{-1} to 14 μgl^{-1} for 1,1,1-trichloroethane, 1 μgl^{-1} to 29 μgl^{-1} for bis(2-ethylhexyl) and 1 μgl^{-1} to 90 μgl^{-1} for phenol.

Figure 3.3
Organic Compounds Detected



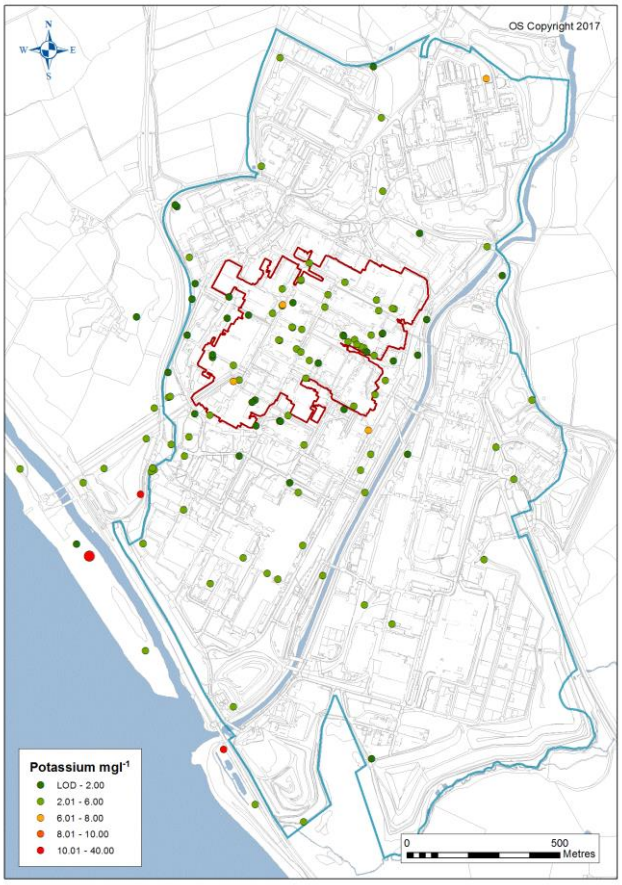
Sodium is widely used across the site in the form of sodium hydroxide, sodium carbonate, sodium ferrocyanide and sodium hypochlorite. All groundwater contains some sodium and sources include intrusion of saline water into the groundwater body, deposition of sea spray onto the ground and the dissolution of sodium from rocks and soils. A background concentration of sodium is therefore expected within groundwater, especially near the coast. The distribution of the concentration of sodium in the site groundwater has remained virtually unchanged over several years, with an increasing gradient from the north end of the site to the coast, Figure 3.4. The maximum concentration increased significantly in 2016 compared to previous years, see Table 3.1. This was after the groundwater monitoring programme was revised to include sodium analysis in monitoring wells located on the Ehen spit and along the coast. There were no results above the ESC of 200 mgl^{-1} at any other location.

Figure 3.4
Average Sodium Concentrations



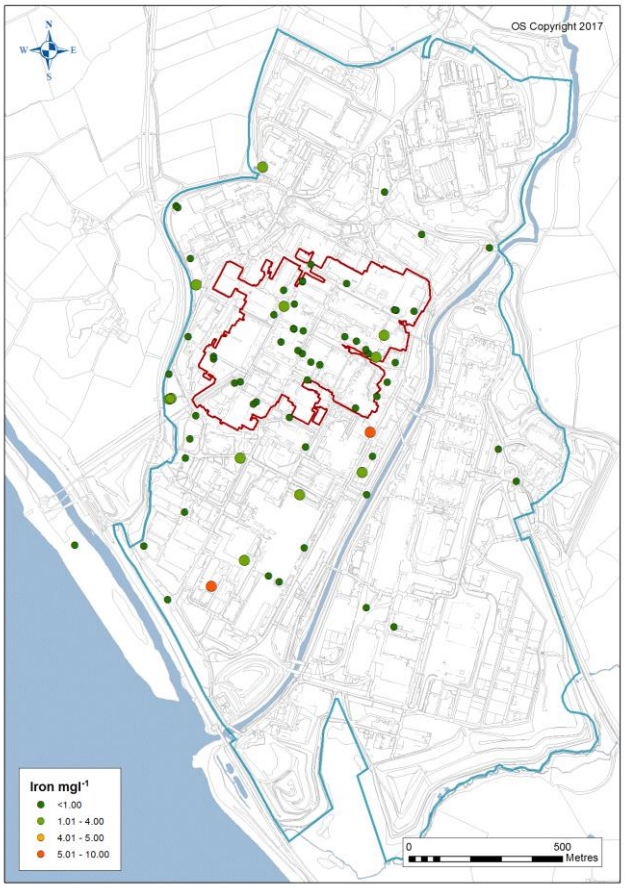
Potassium is not widely used on the site and has been routinely monitored since 2011 mainly to improve upon the characterisation of the general geochemistry of the site groundwater. Natural sources of potassium include intrusion of saline water into groundwater and sea spray. The maximum concentration increased significantly in 2016 compared to previous years (50 mgl^{-1} from 11 mgl^{-1}), Table 3.1, with the highest concentrations found at locations near the coast, Figure 3.5. This was after the groundwater monitoring programme was revised to include potassium analysis in monitoring wells located on the Ehen spit and along the coast and in a new monitoring well situated near to the coast. There were no results above the ESC of 12 mgl^{-1} at any other location.

Figure 3.5
Average Potassium Concentrations



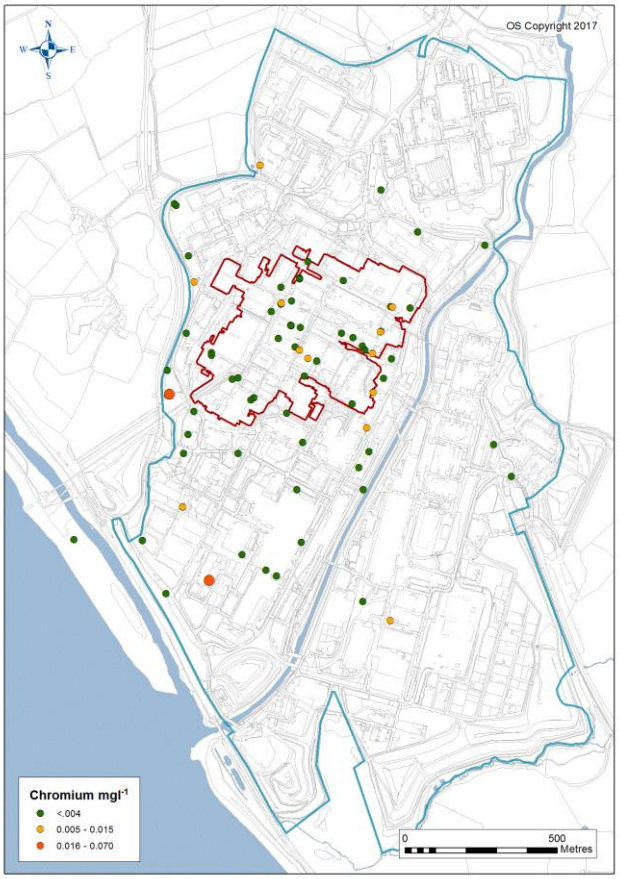
Iron is widely used across the site in the form of ferric nitrate, sodium ferrocyanide, and ferrous sulphamate. Iron is also a naturally occurring element in the environment with variable mobility depending on its oxidation state and ambient pH. Changes in concentration can also indicate other processes such as oxidation of hydrocarbons. The concentration levels have decreased compared to 2015, Table 3.1, with the majority of results again below the ESC of 1 mgl^{-1}, Figure 3.6.

Figure 3.6
Average Iron Concentrations



Chromium is a trace metal occurring at low background levels in most soils. Concentrations were similar to those found in previous years, Figure 3.7. There was an increase in maximum concentration, but this was after the groundwater monitoring programme was revised to include chromium analysis in an additional monitoring well, Table 3.1. Only five results from four locations exceeded the ESC of 0.015 mgl^{-1}.

Figure 3.7
Average Chromium Concentrations



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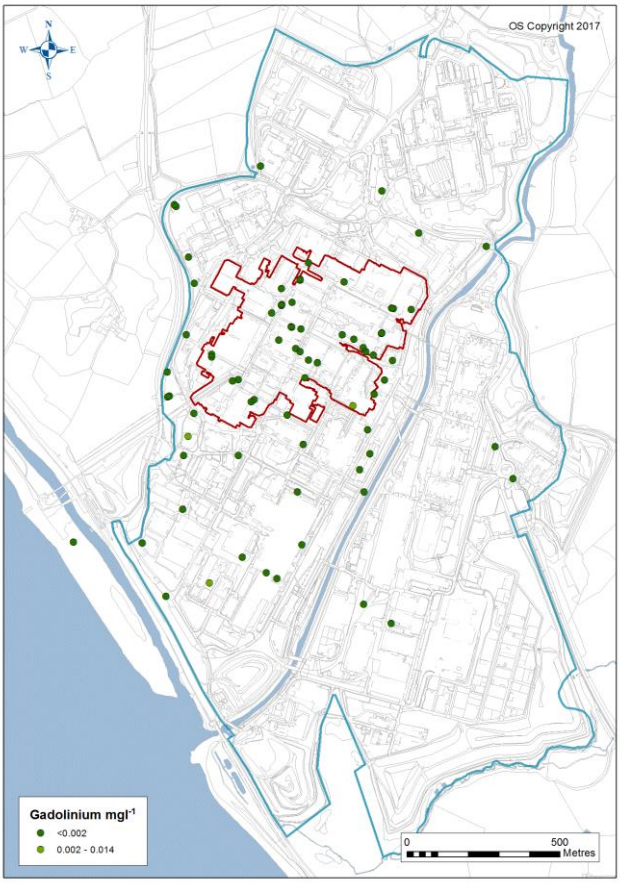
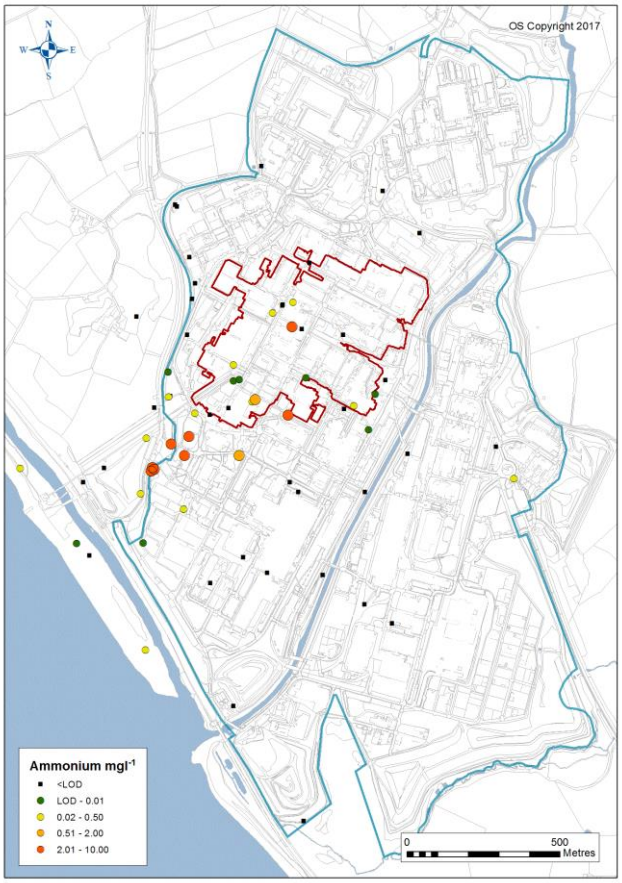
Gadolinium is used in thermal oxide reprocessing and is a component of some highly active liquors stored on site. Gadolinium concentrations in 2016 were similar to those found in 2015, Table 3.1, and levels remained fairly uniform and low, Figure 3.8. There is no ESC for gadolinium.

Figure 3.8
Average Gadolinium Concentrations



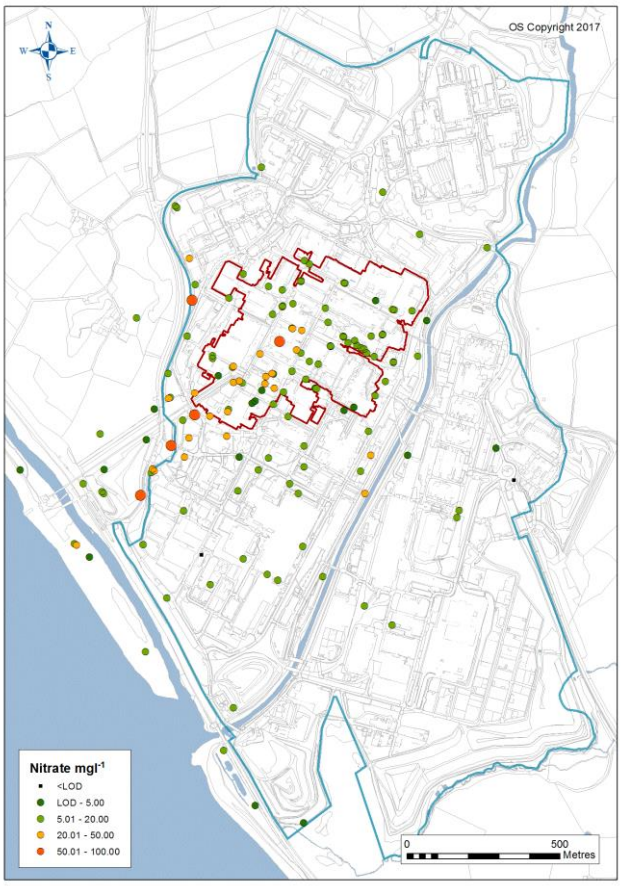
Ammonia is stored in bulk in certain areas on site and is added in low doses to the site steam supply to raise the pH and so prevent corrosion. For the groundwater monitoring programme ammonium is analysed as an indicator of ammonia contamination. Elevated levels of ammonium were evident both in the Separation Area and in the area south-west of the Windscale Trenches, but the average ammonium levels up-gradient of site operations and east of the Separation Area were all below the ESC of 0.5 mgl^{-1}, Figure 3.9. This pattern has been very consistent over several years. Overall, ammonium concentrations were similar to those found in previous years, Table 3.1.

Figure 3.9
Average Ammonium Concentrations



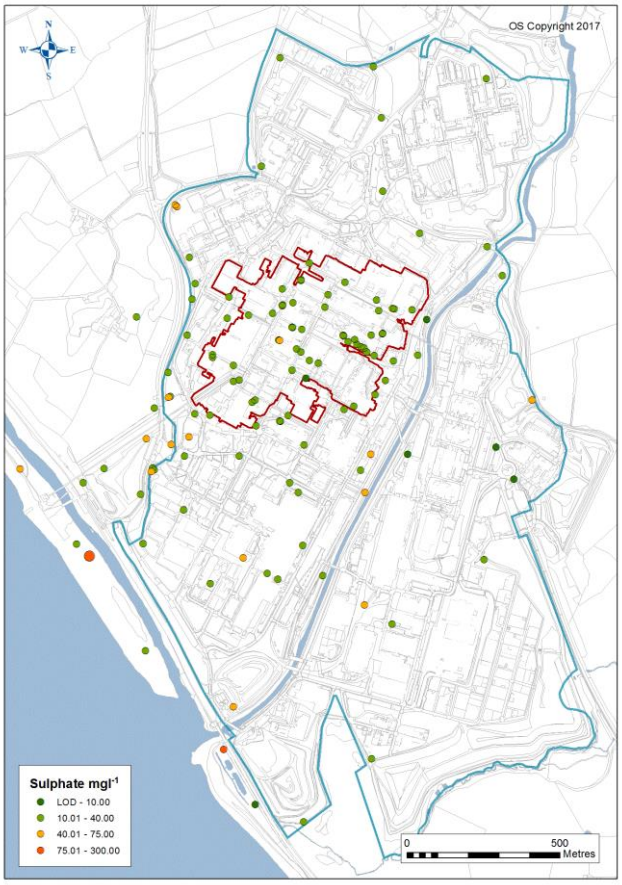
Nitrate compounds widely used across the site include nitric acid, sodium nitrate, lithium nitrate, barium nitrate, gadolinium nitrate, hydrazine nitrate, hydroxylamine nitrate, uranyl nitrate, ferric nitrate, nickel nitrate and plutonium nitrate. There is also the potential for nitrate to be detected in groundwater from off-site sources such as nitrogen fertilisers used in agriculture. The spatial distribution of nitrate concentrations on-site has remained virtually unchanged in recent years, with a distinct area of elevated concentrations extending from the central Separation Area to the south-west towards the coast, Figure 3.10. Concentrations were similar to those found in previous years with average concentrations of 15 mgl^{-1} below the ESC of 50 mgl^{-1}, Table 3.1.

Figure 3.10
Average Nitrate Concentrations



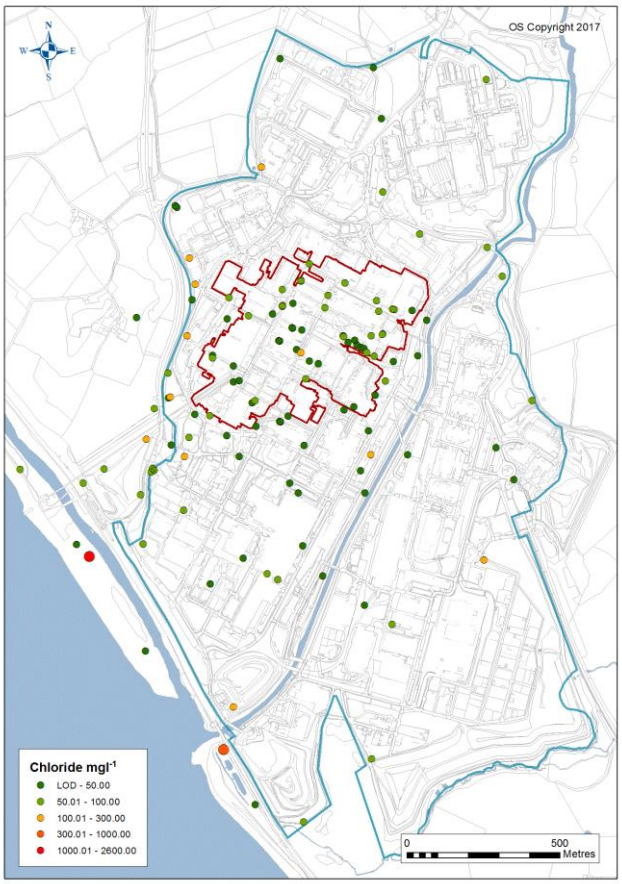
Sulphate compounds used on site include sulphuric acid, ferrous sulphamate and aluminium sulphate. Natural sources of sulphate include intrusion of saline water into groundwater near the coast and sea spray. There is also the potential for sulphate herbicides to have been used in the local area. Average concentrations of sulphate were higher to the south and south-west of the Separation Area, Figure 3.11. The maximum concentration increased significantly in 2016 compared to previous years, Table 3.1. This was after the groundwater monitoring programme was revised to include sulphate analysis in monitoring wells located on the Ehen spit and along the coast. Only one result exceeded the ESC of 250 mgl^{-1} and that was at a monitoring well located on the Ehen spit.

Figure 3.11
Average Sulphate Concentrations



Chloride compounds used on site are limited to hydrochloric acid and sodium hypochlorite. Natural sources of chloride include intrusion of saline water into groundwater near the coast and sea spray. The majority of elevated results were recorded to the west with the highest concentrations found at two monitoring wells, one on the Ehen spit and one further along the coast, Figure 3.12. There were no results above the ESC of 250 mgl^{-1} at any other location. The levels across the site were similar to those found in 2015, Table 3.1.

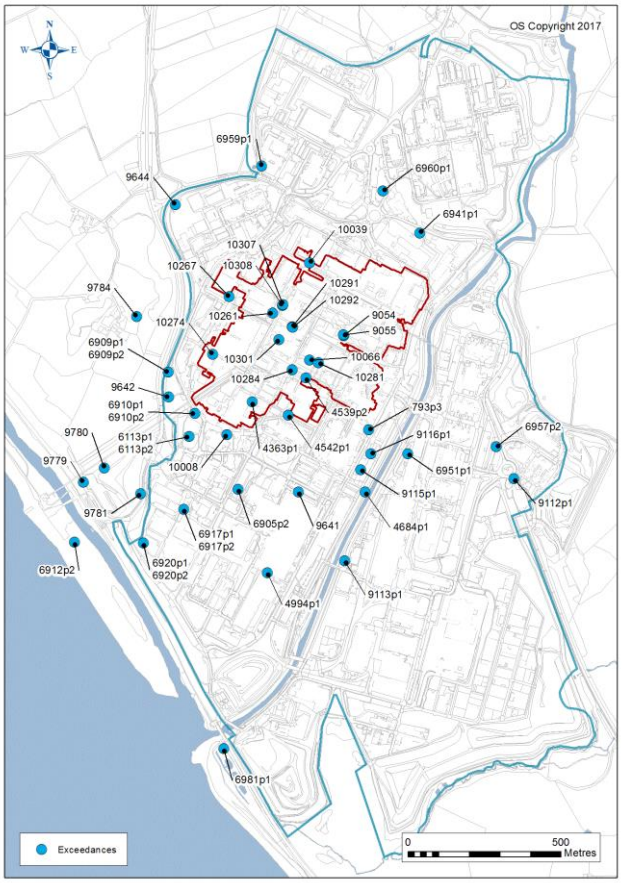
Figure 3.12
Average Chloride Concentrations



3.3 Monitoring Well Results that Exceed the 4σ Trigger Level

Using the procedure outlined in Appendix D, results that exceeded the 4σ reporting trigger were assessed in three stages. Details of each investigation are presented in Table D.3. There were 97 exceedances reported during the review period most of which were not related to areas of potential concern, Figure 3.13, with six currently under investigation. Fifty-six of these exceedance investigations were closed out at the first stage, the majority because the results were considered anomalous.

Figure 3.13
Locations of 4σ Exceedances for Non-radiological Determinands



3.4 Major Ions Analysis

Since 2011, we have collected major ion data for selected groundwater sampling locations across the Sellafield site. This is over and above the analysis required by the EPs, however, we have used it to improve the understanding of groundwater quality across site. The following sections provide a summary of the ionic composition of the groundwater underlying the Sellafield site during 2016.

3.4.1 Groundwater Types

Water is a solvent and dissolves minerals from the rocks which it comes into contact with. Groundwater has a number of dissolved constituents. The major cations in water are calcium, magnesium, sodium and potassium and the major anions are bicarbonate, chloride and sulphate. These chemical constituents almost always make up greater than 95 percent of the ionic balance of water.

A fundamental property of water is that it is electrically neutral. This means that the total number of equivalents for the positive constituents (cations) must equal the total number of equivalents of negative constituents (anions). By measuring the concentrations of these ions in groundwater samples the ionic composition of the water is determined and the chemical quality of the water can be characterised and described.

The ionic composition of water samples is used to classify it into groundwater types based on the dominant dissolved cations and anions present, the dominant dissolved ion must be greater than 50% of the total. For example, water classified as sodium-chloride type contains more than 50 percent of the total cation milliequivalents (meq) as sodium and more than 50% of the total anion meq as chloride. If no cation or anion is dominant, the water is classified as mixed and the most dominant cations and/or anions are described in decreasing order. A summary of the groundwater types for the samples collected between April and June 2016 are shown in Table 3.2 and Figure 3.14. Data from the second quarter only is shown as all locations were sampled for these determinands during this time period, with fewer locations tested for these determinands over the remainder of the year. The assessment of groundwater types was based on major ion data and included minor ion data where available. As expected, there is natural variation in the groundwater types across sampling locations. The majority of the groundwater can be classed as mixed with bicarbonate, calcium, chloride and sodium being the dominant ions at most locations. 16 sample locations can be classed as sodium-chloride type and six can be classed as calcium-bicarbonate.

The data does not indicate that a specific groundwater type is restricted to a particular hydrogeological unit, or a particular depth, however the major ion composition shows that most of the time there is a difference in groundwater types collected at different horizons, *i.e*. there is a difference in groundwater types collected from p1 and p2 piezometers.

Table 3.2
Summary of Groundwater Types for the First Quarter of Sampling Results Collected Between April and June 2016

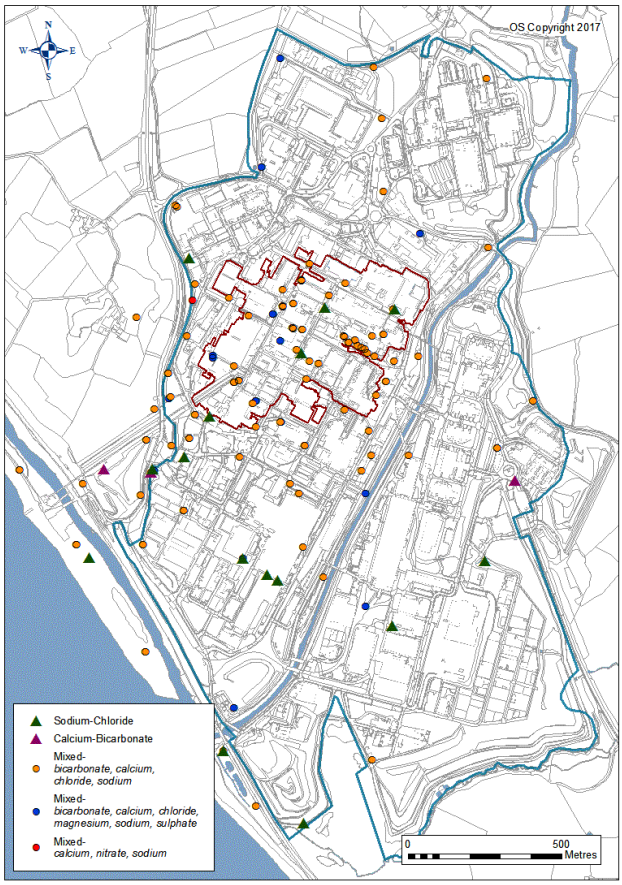
Groundwater major ions	Groundwater type	Piezometer ID
Sodium, chloride	sodium-chloride	9632, 4996p1, 10307, 4994p2, 9118p1, 10065, 10272, 10294, 10351, 4993p1, 6229p1, 6925p1, 6966p1, 6978p1, 6981p2, 9114p1
Calcium, bicarbonate	calcium-bicarbonate	9112p1, 9780, 6228p2, 6962p1, 6975p1, 6975p2
Mixed 1 (bicarbonate, calcium, chloride, sodium)	bicarbonate-calcium-sodium	9646
	calcium-bicarbonate-chloride	9644, 9645, 9783, 6911p1, 6911p2, 6914p1, 6930p1, 6958p1, 6967p1
	calcium-bicarbonate-sodium	9055, 9782, 9784, 10066, 10203, 10204, 10205, 10332, 6985p1, 6985p2
	calcium-chloride-bicarbonate	10039, 10317
	calcium-sodium-bicarbonate	6926p2
	chloride-calcium-sodium	6964p1, 6981p1, 9116p1
	chloride-sodium-calcium	9634, 9643, 10267, 10271, 4363p1, 4539p2, 6113p1, 6113p2, 6908p2, 6909p1, 6909p2, 6917p2, 6228p1, 6920p2
	sodium-bicarbonate-chloride	9633, 10333
	bicarbonate-calcium-sodium-chloride	793p3, 9115p1
	calcium-bicarbonate-sodium-chloride	6957p2, 10290
	calcium-chloride-bicarbonate-sodium	10321, 6914p2, 6957p1, 6960p1, 10316
	calcium-chloride-sodium-bicarbonate	9054, 9060, 9275, 9641, 9781, 10007, 10183, 10359, 6951p1
	calcium-sodium-bicarbonate-chloride	6977p1
	calcium-sodium-chloride-bicarbonate	10202, 10308, 4995p1, 6926p1
	chloride-calcium-sodium-bicarbonate	9056, 10318
	chloride-sodium-calcium-bicarbonate	9059, 9779, 10296, 10336
	sodium-bicarbonate-calcium-chloride	6917p1
	sodium-bicarbonate-chloride-calcium	6980p1
	sodium-calcium-bicarbonate-chloride	10281
	sodium-chloride-calcium-bicarbonate	10184, 10295, 6949P1, 10291, 10305
	sodium-bicarbonate-calcium	10328
	sodium-chloride-bicarbonate	10143, 10292
	sodium-chloride-calcium	10155, 10270, 10325, 6910p2, 6948p1
Mixed 2 (bicarbonate, calcium, chloride, magnesium, sodium, sulphate)	chloride-calcium-magnesium	6959p1, 6979p1
	calcium-bicarbonate-sulphate	4996p2
	sodium-sulphate-bicarbonate-calcium	9642
	sodium-sulphate-calcium	4684p1
	bicarbonate-magnesium-chloride-calcium	6941p1
	calcium-bicarbonate-magnesium-sulphate	6953p1
	calcium-bicarbonate-sodium-sulphate	6977p2
	chloride-sodium-calcium-magnesium	10273, 10274
	chloride-sodium-calcium-sulphate	10261, 6226p1
	sodium-calcium-bicarbonate-sulphate	10300
	sodium-chloride-calcium-magnesium	6920p1
	sodium-chloride-calcium-sulphate	6910p1
	sodium-chloride-magnesium-sulphate	6961p1
	sodium-bicarbonate-sulphate	10334
	sodium-chloride-sulphate	10003
Mixed 3 (calcium, nitrate, sodium)	calcium-nitrate-sodium	10339

3.4.2 Major Ion Groundwater Data

Groundwater sampling yields information that provides a picture of hydrogeological and chemical conditions at a particular monitoring site at that specified point in time. Many natural factors affect the groundwater composition across the Sellafield site. The primary factors include: the source and chemical composition of recharge water, the lithological properties of the geological unit, the chemical reactions occurring within the geological unit, and the residence time of the groundwater.

Each groundwater sample was collected so as to ensure the reliability of analytical determinations. Ionic balances were calculated and examined for each groundwater sample as a quality assurance check of the chemical analyses; samples with ionic balances greater than 10% were excluded from the dataset. During 2016; eight samples had an ionic balance greater than 10%, which represents 6% of the dataset.

Figure 3.14
Groundwater Types Identified from Samples Collected between April and June 2016
(where multi-depth installations are included the deeper piezometer – p1 – is shown)



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Section 4: Review

4 Review

The 2016 groundwater monitoring programme was developed following a comprehensive review. The updated programme achieved the monitoring objectives and demonstrated compliance with the EPR-RSR and EPR-PPC. The Best Available Technique (BAT) for groundwater management is being reviewed and the outcome will inform the future groundwater monitoring strategy in the short to medium term.

4.1 Compliance Review

The Environment Agency CEAR document (Environment Agency, 2016) includes the requirement to review the reasons why any of the following have occurred:

- results are late,
- samples have not been obtained,
- analysis has not been undertaken,
- relevant detection limits have not been achieved,
- radiological assessment has used alternatives to the values and relationships given in Annexes II and III to the Council Directive 96/29/EURATOM of 13 May 1996 (any alternative data used shall be provided).

During the 2016 monitoring period the routine groundwater monitoring programme was scheduled to collect 697 groundwater samples. It was not always possible to obtain a sample from a monitoring well, resulting in 23 samples could that not be collected or otherwise used. In total, missed samples or analyses represented 3% of the planned schedule in 2016.
23 samples were not collected or were not analysed for all determinands for the following reasons:

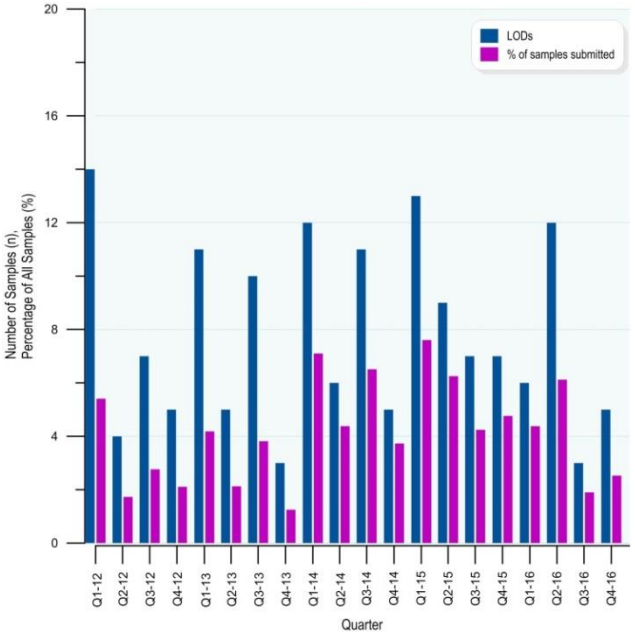
- two samples could not be collected due to the sample point being dry,
- five samples could not be collected due to restricted access (plant construction operations),
- one sample could not be collected as groundwater monitoring well redevelopment work was being undertaken,
- fifteen samples could not be analysed as the sample was not of suitable quality for analysis.

The reason that 12 of 15 samples were not of a suitable quality was they were outside the residence time as a result of increased transit time between sample collection and the arrival at the analytical laboratory. Three of the 15 samples could not be analysed for carbon-14 due to high total dissolved solids (TDS) content in the sample. Details of the piezometers affected are presented in Tables E.1 and E.2, Appendix E.

Laboratory analysis of groundwater samples should achieve a required LOD for each analytical determinand, however a small proportion of analyses did not achieve the required LOD. Figure 4.1 shows that the number of LODs that exceeded the target LOD or the investigation concentration during the monitoring period (26) is lower than in 2015 (36). The majority of the missed LODs were in the analysis of ruthenium-103, ruthenium-106, caesium-137 and total alpha. The primary reason for missed LOD targets in 2016 was due to amended sample geometries (shape and volume of sample in the container) which led to higher minimum detectable amounts (MDA).

The total number of analyses that could not achieve the CEAR specified LOD make up a very small proportion of the 10 256 analyses undertaken during the monitoring period, with 26 LODs that could not be achieved. The full list of analyses which have not achieved an LOD along with explanations are provided in Table E.3, Appendix E.

Figure 4.1
Number of LODs that missed the target Limit of Detection



4.2 Updated Groundwater Monitoring Programme

The Land Quality team continues to make improvements to the monitoring well network through a rolling programme of new well installation and decommissioning of poor quality wells. During 2016 five new piezometers were successfully installed along the western site licence boundary, targeting groundwater in the lower drift and sandstone. The sampling and analysis programme was reviewed during 2015 to ensure that the groundwater monitoring programme continued to meet the site strategic objectives and also meet the requirements of the site Regulators and stakeholders. The outcome of this review informed the development of the sampling and analysis plan implemented in 2016 and records the output of the updated groundwater monitoring programme.

4.3 Summary

This report provides a review of the Sellafield site groundwater monitoring programme conducted during 2016. The review includes detail of the groundwater monitoring network and its development. The 2016 groundwater monitoring programme was the first year of the updated programme following the five year review, completed in 2015, and shows a broader understanding of geochemical indicators.

The peak radiological activity concentrations were predominantly from groundwater samples collected from monitoring wells located within Separation Area. The general location and magnitude of peak concentrations across site remained similar to previous years. The distribution of non-radiological determinands has been consistent over time with a noticeable influence from seawater in groundwater monitoring wells closer to the coast. This indicates there has been no deterioration in groundwater quality during this monitoring period (January – December 2016).

This annual data review indicates that the 2016 groundwater monitoring programme has met the requirements of the CEAR, which accompanies the EPR-RSR and the condition of the EPR-PPC installation.

4.3.1 Look Ahead

Groundwater management, including characterisation and monitoring, will continue into the foreseeable future. In the longer term, the increased understanding of the groundwater system gained through this programme of work will help guide appropriate remediation of Sellafield site contaminated land and groundwater. The Land Quality team will continue the timely analysis of analytical data, and expedite communication on groundwater issues with facilities and plants on Sellafield site, the Regulators and other stakeholders. A review of the 2014 groundwater management BAT assessment is being completed during 2017 and the outcome will inform future development of the groundwater monitoring strategy.

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Section 5: References

5 References

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Appendix A
Sellafield Site Groundwater Monitoring Network Summary Information

Appendix A: Sellafield Site Groundwater Monitoring Network Summary Information

This appendix contains the table for groundwater monitoring well characteristics for sample locations from the 2016 groundwater monitoring programme. Also included is a schematic of a typical well construction shown in Figure A.1.

Table A.1 - Summary of Groundwater Monitoring Well Characteristics

Sample Point (Piezometer[1])	Approximate Surface Elevation (m AOD)	Easting	Northing	Total Depth (m BGL)	Screen Top (m BGL)	Screen Bottom (m BGL)	Screen Strata[2]
10003	19.70	302399	503774	31.45	27.45	31.45	Drift
10004	23.61	303158	504054	30.00	17.43	20.43	Lower Drift
10105	21.34	302970	503910	15.00	12.70	14.60	Lower Drift
10007	21.38	303129	503938	12.00	5.82	11.82	Drift
10008	17.84	302505	503678	24.00	14.22	17.22	Lower Drift
10012	19.90	302401	503818	30.00	25.87	29.87	Drift
10039	24.36	302774	504238	15.00	12.66	14.66	Drift
10065	21.19	302745	503948	10.50	6.70	7.90	Upper Drift
10066	21.28	302775	503921	13.50	9.03	12.03	Upper Drift
10087	20.69	302871	503866	10.50	7.50	10.50	Upper Drift
10090	20.26	302863	503845	9.00	3.05	5.25	Upper Drift
10110	19.12	302512	503765	12.00	8.80	10.80	Upper Drift
10111	19.06	302507	503757	15.00	13.00	15.00	Drift
10130	20.63	302633	503871	10.50	5.66	8.66	Upper Drift
10131	20.13	302630	503849	10.50	7.50	10.50	Drift
10132	20.24	302661	503834	12.00	8.46	10.46	Upper Drift
10138	22.30	302642	504166	25.77	24.27	25.77	Lower Drift
10143	23.06	302722	504110	15.00	11.67	14.67	Upper Drift
10155	22.27	302750	504023	15.00	9.59	12.59	Drift
10183	19.99	302545	503857	12.00	6.06	10.06	Drift
10184	20.76	302527	503852	10.50	7.70	9.70	Made Ground/Drift
10202	22.56	302953	503962	14.98	12.98	14.98	Lower Drift
10203	22.56	302944	503966	15.00	12.96	14.96	Upper Drift
10204	22.58	302931	503972	15.00	13.00	15.00	Upper Drift
10205	22.64	302923	503989	15.07	13.07	15.07	Drift
10260	15.61	302757	503576	7.50	3.21	7.21	Upper Drift
10261	21.62	302654	504075	13.50	8.89	10.89	Upper Drift
10264	20.50	302614	503945	13.50	9.32	12.32	Drift
10265	24.05	302991	504119	29.94	25.94	29.94	Lower Drift
10266	24.07	302994	504118	15.00	8.45	13.45	Upper Drift

Table A.1 - Summary of Groundwater Monitoring Well Characteristics (cont.)

Sample Point (Piezometer[1])	Approximate Surface Elevation (m AOD)	Easting	Northing	Total Depth (m BGL)	Screen Top (m BGL)	Screen Bottom (m BGL)	Screen Strata[2]
10267	22.72	302512	504128	15.22	9.02	15.22	Upper Drift
10269	19.83	302524	503902	30.06	26.06	30.06	Lower Drift
10270	19.92	302527	503905	9.00	5.78	7.78	Upper Drift
10271	24.07	303049	504091	30.00	20.33	22.33	Drift
10272	24.03	303052	504089	13.50	11.30	13.30	Upper Drift
10273	20.76	302459	503931	30.00	23.10	27.10	Drift
10274	20.72	302459	503939	15.38	9.38	15.38	Drift
10275	19.92	302478	503874	30.00	23.16	27.16	Lower Drift
10277	18.92	302555	503851	30.00	22.14	26.14	Lower Drift
10279	20.36	302657	503881	30.00	26.66	29.66	Sandstone
10280	20.35	302654	503882	12.00	5.35	11.35	Upper Drift
10281	21.86	302805	503912	30.21	26.11	30.21	Sandstone
10284	20.49	302719	503888	21.00	18.00	21.00	Drift
10286	23.68	303110	504086	12.90	8.40	12.90	Upper Drift
10287	21.25	302846	503970	30.00	24.20	27.20	Lower Drift
10288	21.25	302844	503971	15.00	9.30	11.30	Upper Drift
10290	21.29	302733	503959	30.00	24.77	28.07	Lower Drift
10291	22.44	302718	504029	30.46	26.46	30.46	Lower Drift
10292	22.42	302720	504028	12.00	6.90	10.90	Upper Drift
10293	23.24	302827	504095	30.10	26.10	30.10	Lower Drift
10294	23.26	302825	504095	13.50	7.82	10.82	Upper Drift
10295	22.25	303015	504009	30.00	26.00	30.00	Lower Drift
10296	22.26	303014	504008	15.00	11.93	14.93	Drift
10297	19.79	302794	503834	25.50	16.55	19.55	Drift
10298	19.81	302798	503832	12.00	4.10	10.10	Upper Drift
10299	21.28	302991	503898	30.00	24.80	26.80	Lower Drift
10300	21.67	302678	503986	27.00	22.00	25.00	Lower Drift
10301	21.63	302675	503987	13.50	9.68	11.68	Drift
10304	19.83	302991	503882	30.26	26.26	30.26	Drift
10305	20.11	302990	503809	12.24	8.24	12.24	Drift
10306	20.30	302859	503829	25.50	18.50	21.50	Drift
10307	22.76	302688	504102	15.00	7.00	12.00	Upper Drift
10308	22.73	302686	504099	30.00	20.00	24.00	Lower Drift
10310	24.39	302759	504250	30.00	27.40	29.40	Lower Drift
10314	24.05	303001	504083	16.50	12.18	16.18	Lower Drift
10315	19.82	302621	503827	30.00	25.94	29.94	Sandstone
10316	24.27	302747	504185	30.32	26.32	30.32	Lower Drift
10317	24.56	302748	504183	15.00	11.00	15.00	Drift
10318	23.95	302837	504135	30.50	27.50	30.50	Lower Drift
10320	24.50	302888	504177	30.17	26.17	30.17	Sandstone (Weathered)

Table A.1 - Summary of Groundwater Monitoring Well Characteristics (cont.)

Sample Point (Piezometer[1])	Approximate Surface Elevation (m AOD)	Easting	Northing	Total Depth (m BGL)	Screen Top (m BGL)	Screen Bottom (m BGL)	Screen Strata[2]
10321	24.50	302891	504417	15.00	10.70	14.70	Drift
10324	15.31	302642	503606	41.50	34.70	38.70	Sandstone (Weathered)
10325	16.37	302712	503522	47.00	26.17	30.17	Sandstone (Weathered)
10328	17.94	302601	503707	60.00	55.48	59.48	Sandstone
10332	19.66	302888	503762	46.50	41.13	45.13	Sandstone
10333	16.94	302678	503723	31.50	23.30	27.30	Sandstone (Weathered)
10334	16.88	302681	503722	34.50	30.97	33.97	Sandstone (Weathered)
10336	21.58	302577	504069	31.50	24.10	30.10	Lower Drift
10337	21.03	302507	504058	55.50	49.00	52.15	Sandstone
10339	20.41	302393	504121	56.00	49.10	53.10	Sandstone
10350	20.22	302920	503772	12.00	7.77	11.77	Upper Drift
10351	19.91	302449	503742	12.72	9.72	12.72	Upper Drift
10352	22.78	302836	504049	39.17	35.17	39.17	Lower Drift
10359	23.31	302686	504154	15.02	11.02	15.02	Drift
4363p1	20.31	302588	503784	24.50	18.50	21.50	Lower Drift
4539p2	20.27	302763	503864	26.00	10.10	12.90	Upper Drift
4540p3	20.49	302692	503822	25.00	5.00	6.00	Upper Drift
4541p1	19.96	302658	503783	24.50	16.90	18.90	Lower Drift
4542p1	19.67	302706	503742	19.64	14.50	17.60	Lower Drift
4542p2	19.67	302706	503742	19.64	4.60	7.40	Upper Drift
4684p1	15.81	302957	503489	9.30	5.00	9.00	Drift/Sandstone
4993p1	14.39	302671	503206	10.20	8.50	10.00	Sandstone
4994p1	14.25	302638	503226	10.20	8.10	10.00	Sandstone
4994p2	14.25	302638	503226	10.20	2.50	5.50	Made Ground
4995p1	15.69	302753	503316	11.20	9.50	10.50	Sandstone
4996p1	15.41	302558	503277	18.80	14.20	17.00	Sandstone
4996p2	15.41	302558	503277	18.80	5.00	7.80	Drift/Sandstone
6113p1	18.20	302382	503670	22.00	17.00	19.00	Drift
6113p2	18.20	302382	503670	22.00	6.50	9.50	Drift
6192p1	18.45	303264	503432	12.05	10.00	11.00	Sandstone
6192p2	18.45	303264	503432	12.05	5.50	6.00	Drift
6193p1	18.22	303252	503410	12.00	10.00	11.00	Sandstone
6193p2	18.22	303252	503410	12.00	5.50	6.50	Drift
6226p1	20.09	302268	503559	36.50	34.67	35.57	Sandstone
6228p1	19.99	302258	503558	27.00	25.15	26.10	Lower Drift
6228p2	19.99	302258	503558	27.00	16.09	17.05	Drift
6229p1	20.02	302260	503569	15.00	12.90	13.80	Drift
6904p1	15.70	302608	503567	20.00	10.00	11.00	Lower Drift
6905p1	17.12	302542	503499	22.07	20.00	21.00	Sandstone
6905p2	17.12	302542	503499	22.07	8.00	9.00	Drift

Table A.1 - Summary of Groundwater Monitoring Well Characteristics (cont.)

Sample Point (Piezometer[1])	Approximate Surface Elevation (m AOD)	Easting	Northing	Total Depth (m BGL)	Screen Top (m BGL)	Screen Bottom (m BGL)	Screen Strata[2]
6906p1	23.42	302559	504207	27.00	25.00	27.00	Drift
6906p2	24.10	302559	504207	27.00	15.00	16.50	Drift
6908p2	22.68	302375	504004	47.20	19.00	20.00	Lower Drift
6909p1	21.72	302314	503882	41.00	34.00	35.00	Lower Drift
6909p2	21.72	302314	503882	41.00	23.60	24.60	Lower Drift
6910p1	20.22	302401	503746	56.50	50.00	55.00	Sandstone
6910p2	20.22	302401	503746	56.50	18.00	20.00	Lower Drift
6911p1	13.97	302014	503322	65.00	63.00	64.00	Sandstone
6911p2	13.97	302014	503322	65.00	49.00	50.00	Sandstone
6912p1	13.95	302008	503325	40.00	38.00	39.00	Sandstone
6912p2	13.95	302008	503325	40.00	29.00	30.00	Lower Drift
6913p1	19.59	302098	503495	75.00	73.00	74.00	Sandstone
6913p2	19.59	302098	503495	75.00	44.50	46.50	Sandstone
6914p1	16.17	302242	503665	68.00	65.00	66.00	Sandstone
6914p2	20.10	302242	503665	68.00	55.00	56.00	Sandstone
6917p1	17.40	302364	503433	20.85	18.85	19.85	Sandstone
6917p2	17.17	302364	503433	20.85	13.50	14.50	Lower Drift
6918p1	15.10	302418	503292	17.50	15.50	16.50	Lower Drift/Sandstone
6919p1	9.98	302310	503149	15.90	11.50	12.50	Drift
6920p1	16.94	302232	503323	24.05	22.00	23.00	Sandstone
6920p2	19.94	302232	503323	24.05	16.00	17.00	Lower Drift
6925p1	5.20	302757	502414	9.00	6.70	7.70	Upper Drift
6926p1	16.97	302757	503645	19.93	17.80	18.80	Sandstone
6926p2	16.97	302757	503645	19.93	7.00	8.00	Lower Drift
6930p1	20.52	303023	503856	29.00	23.65	24.65	Drift
6940p1	27.50	302923	504404	21.55	19.55	20.55	Lower Drift
6941p1	29.22	303132	504338	18.00	16.00	17.00	Sandstone
6945p1	28.47	303404	504199	14.85	12.80	13.80	Sandstone
6948p1	14.40	302819	503218	10.50	8.00	9.00	Drift
6949p1	20.09	302978	502621	17.70	15.70	16.70	Sandstone
6951p1	18.39	303096	503615	14.90	12.90	13.90	Sandstone
6952p1	17.19	303083	503199	9.70	7.60	8.60	Sandstone
6953p1	16.76	302955	503122	11.50	9.50	10.50	Sandstone
6957p1	21.77	303385	503637	25.00	23.00	24.00	Sandstone
6957p2	21.77	303385	503637	25.00	14.00	15.00	Drift
6958p1	31.45	303010	504713	14.50	12.50	13.50	Lower Drift
6959p1	23.89	302610	504559	22.15	20.15	21.15	Drift
6960p1	29.49	303015	504474	18.60	13.80	14.80	Drift
6961p1	37.65	302679	504909	24.70	22.70	23.70	Sandstone
6962p1	33.07	302984	504880	20.50	18.50	19.50	Sandstone

Table A.1 - Summary of Groundwater Monitoring Well Characteristics (cont.)

Sample Point (Piezometer[1])	Approximate Surface Elevation (m AOD)	Easting	Northing	Total Depth (m BGL)	Screen Top (m BGL)	Screen Bottom (m BGL)	Screen Strata[2]
6964p1	48.40	303352	504841	30.00	26.00	29.00	Sandstone
6966p1	22.32	303346	503270	10.10	8.10	9.10	Sandstone
6967p1	32.59	303502	503792	24.55	20.20	21.20	Drift
6972p2	25.69	302146	503863	54.80	16.45	17.45	Upper Drift
6973p1	19.62	302103	503490	40.00	38.00	39.00	Sandstone
6973p2	19.62	302103	503490	40.00	28.30	30.30	Lower Drift
6974p1	23.35	302091	503684	51.00	39.00	40.00	Drift
6974p2	23.35	302091	503684	51.00	23.50	24.50	Drift
6975p1	9.65	301825	503584	41.20	35.00	36.00	Lower Drift
6975p2	7.90	301825	503584	41.20	13.00	14.00	Upper Drift
6977p1	7.50	302240	502973	20.10	16.50	17.50	Lower Drift
6977p2	7.71	302240	502973	20.10	11.00	12.00	Upper Drift
6978p1	8.80	302056	503258	20.80	18.80	19.80	Drift
6979p1	9.10	302527	502791	14.40	12.40	13.40	Drift
6980p1	6.16	302599	502471	15.15	13.00	14.00	Drift
6981p1	6.75	302495	502651	15.80	13.80	14.80	Drift
6981p2	6.75	302495	502651	15.80	6.00	8.00	Drift
6985p1	22.51	302901	503982	47.00	45.00	46.00	Sandstone
6985p2	22.51	302901	503982	47.00	30.00	31.00	Lower Drift
6986p1	21.06	302361	503730	55.00	50.00	53.00	Sandstone
6986p2	21.06	302361	503730	55.00	19.00	22.00	Drift
793p3	19.58	302969	503693	18.03	4.25	6.25	Upper Drift
9054	22.70	302888	504001	30.00	27.00	30.00	Lower Drift
9055	22.71	302885	504003	15.00	11.50	14.50	Drift
9056	22.54	302963	503948	30.00	27.00	30.00	Lower Drift
9057	22.54	302959	503949	13.50	10.50	13.50	Lower Drift
9059	22.53	302987	503937	19.50	11.50	14.50	Drift
9060	22.60	302977	504003	30.00	11.50	15.00	Drift
9063	22.31	302917	504045	30.00	26.00	30.00	Drift
9112p1	23.21	303442	503533	7.89	6.10	7.00	Lower Drift
9113p1	15.32	302890	503265	7.00	3.00	6.00	Upper Drift
9114p1	17.00	303045	503060	16.51	4.00	8.00	Upper Drift
9115p1	16.50	302943	503614	16.81	5.00	9.00	Upper Drift
9116p1	17.00	302975	503614	17.06	8.00	10.00	Upper Drift
9118p1	21.00	302383	504257	21.08	8.50	11.50	Upper Drift
9275	22.11	303050	503920	13.00	9.00	13.00	Upper Drift
9276	22.15	303049	503917	30.40	26.40	30.40	Drift
9631	14.23	302452	503192	20.00	16.00	20.00	Lower Drift
9632	17.44	302367	503609	20.00	16.00	20.00	Drift
9633	17.51	302546	503608	20.00	12.00	16.00	Drift

Table A.1 - Summary of Groundwater Monitoring Well Characteristics (cont.)

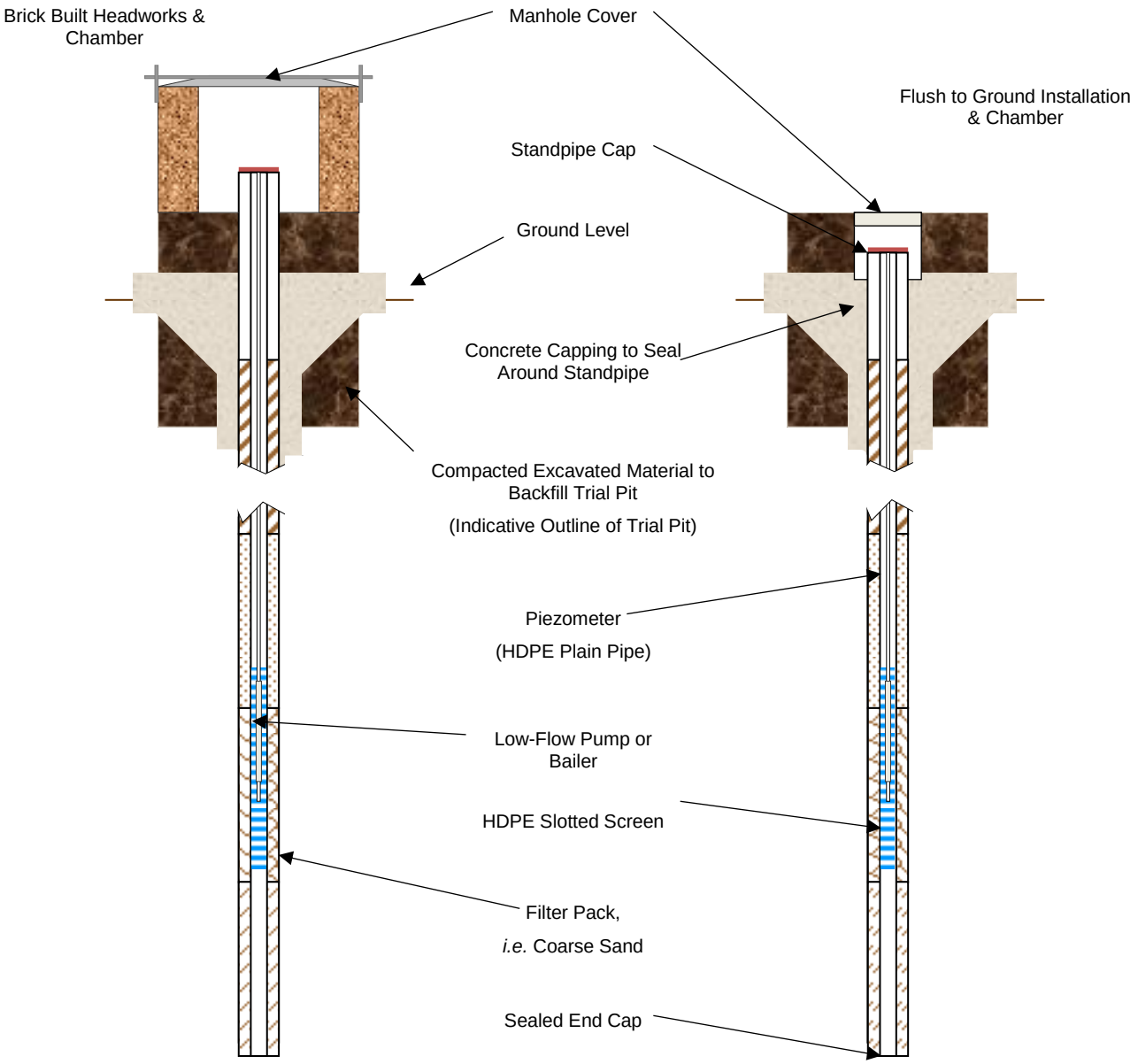
Sample Point (Piezometer[1])	Approximate Surface Elevation (m AOD)	Easting	Northing	Total Depth (m BGL)	Screen Top (m BGL)	Screen Bottom (m BGL)	Screen Strata[2]
9634	21.10	302402	504171	15.00	11.00	15.00	Drift
9641	14.78	302739	503489	11.00	3.80	4.80	Drift
9642	20.84	302315	503800	49.00	46.00	48.00	Sandstone
9643	20.81	302321	503803	16.00	11.50	14.50	Lower Drift
9644	22.59	302337	504429	14.50	13.00	14.00	Lower Drift
9645	22.90	302343	504424	25.00	17.00	18.00	Lower Drift
9646	28.36	303356	504293	9.50	6.50	8.50	Lower Drift
9779	8.01	302036	503522	10.00	8.50	9.50	Upper Drift
9780	24.32	302105	503568	25.00	21.00	24.00	Drift
9781	19.48	302223	503484	30.80	26.00	29.00	Lower Drift
9782	18.12	302324	503647	25.00	21.00	24.00	Lower Drift
9783	19.42	302269	503766	20.00	17.00	19.00	Lower Drift
9784	19.17	302210	504064	63.00	59.00	62.00	Sandstone

1 Multi-level installations in individual groundwater monitoring wells are made up of two or more individual access pipes known as piezometers; each piezometer has a screen interval that monitors a selected depth range. The Sellafield site numbering system refers to the deepest piezometer in an individual groundwater monitoring well as “p1”.

Successively shallower piezometers are labelled as “p2” and “p3” (as appropriate) with the highest number representing the shallowest piezometer.

2 See Section 1 for discussion of Sellafield site subsurface geology.

Figure A.1
Groundwater Monitoring Well Schematic
(typical construction)



Redrawn from Sellafield Ltd Technical Schematics for Well Construction

NOT TO SCALE

Appendix B
Groundwater Monitoring Programme and Environmental Permit (EPR-RSR & EPR-PPC) Summary Information

Appendix B: Groundwater Monitoring Programme and Environmental Permit (EPR- RSR & EPR-PPC) Summary Information

The groundwater monitoring programme includes a range of sample locations to ensure representative coverage of Sellafield site and adjacent areas in both sandstone and drift. This Appendix details individual sampling points (including single installation and multi-level wells), sampling frequencies and analytical suites for sample analyses along with the specified LOD and investigation levels.

WHO drinking water guidelines for radionuclides are also listed for information in addition to environmental criteria for non-radiological determinands. Non-radiological contaminants at Sellafield site are regulated under the EPR-PPC.

This Appendix includes:

- Table B.1 – 2016 Groundwater Monitoring Programme Sample and Analysis Plan
- Table B.2 – Specified Analytical Detection Limits
- Table B.3 – Standard Laboratory Analytical Methods
- Table B.4 – WHO Drinking Water Guidelines
- Table B.5 – Chemicals of Concern (where chemical has been linked to analytical determinands to assess any impact on groundwater)
- Table B.6 – Summary of Analytical Methods and LODs used in the Environmental Permit
- Table B.7 – Environmental Criteria for non-radiological Determinands

Table B.1
2016 Groundwater Monitoring Programme Requirements Summary (1st January 2016 - 31st December 2016)

Sample Point (Piezometer)	Gamma Scan	Total Alpha	Total Beta	Tritium	Strontium-90	Technetium-99	Total Plutonium	Americium-241	Carbon-14	Chlorine-36	Iodine-129	Total Uranium		pH	Carbonate	Bicarbonate	Ammonium	Chloride	Nitrite	Nitrate	Sulphate	Calcium	Magnesium	Sodium	Potassium	Barium	Chromium	Gadolinium	Iron	TPH	SVOC	VO C	Mercury
10003	B	Q	Q	Q	A	Q			Q					Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q							
10004		Q	Q	Q					Q					Q	Q	Q		Q		Q	Q	Q	Q	Q	Q		Q	Q	Q	Q			
10007		Q	Q	Q					Q					Q	Q	Q		Q		Q	Q	Q	Q	Q	Q		Q	Q	Q				
10008		Q	Q	Q	A	Q			Q					Q						Q							Q	Q	Q				
10012		Q	Q	Q		Q			Q					Q						Q													
10039	B	B	B	Q	A				B					Q	Q	Q		Q		Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q			
10065	B	B	B	Q	A	Q			Q		B			Q	A	A		A		Q	A	A	A	A	A	A	Q	Q	Q				
10066	B	B	B	Q	A	Q			Q		B			Q	A	A		A		Q	A	A	A	A	A	A	Q	Q	Q	Q			
10087	Q	Q	Q	Q	A	Q			Q																		Q	Q	Q	Q			
10090	Q	Q	Q	Q	A	Q			Q																		Q	Q	Q	Q			
10105	Q	Q	Q	Q	A	Q			Q					Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q			
10110				Q		Q			Q					Q						Q													

Table B.1:
2016 Groundwater Monitoring Programme Requirements Summary 1st January 2016 - 31st December 2016 (cont.)

Sample Point (Piezometer)	Gamma Scan	Total Alpha	Total Beta	Tritium	Strontium-90	Technetium-99	Total Plutonium	Americium-241	Carbon-14	Chlorine-36	Iodine-129	Total Uranium	pH	Carbonate	Bicarbonate	Ammonium	Chloride	Nitrite	Nitrate	Sulphate	Calcium	Magnesium	Sodium	Potassium	Barium	Chromium	Gadolinium	Iron	TPH	SVOC	VOC	Mercury
10111				Q		Q							Q						Q													
10130		B	B	B	A	A			A				B						B													
10131		B	B	B	A	A			A				B						B													
10132				B					B				B						B													
10138				Q		Q							Q						Q													
10143	B	Q	Q	Q	A	Q			Q		B	A	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q							
10155	Q	B	B	Q	A	B	A	A	Q		B	A	Q	B	B	B	B	B	Q	B	B	B	B	B	B							
10183	B	Q	Q	Q	A	Q			Q				Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q							
10184	B	Q	Q	Q	A	Q			Q				Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q							
10202	B	B	Q	Q	A	Q			Q	A	A		A	A	A		A		A	A	A	A	A	A								
10203	B	B	Q	Q	A	Q			Q	A	A		A	A	A		A		A	A	A	A	A	A								
10204	B	B	Q	Q	A	Q			Q	A	A		A	A	A		A		A	A	A	A	A	A								
10205	B	B	Q	Q	A	Q			Q	A	A		A	A	A		A		A	A	A	A	A	A					Q			
10260		B	B	B									B						B							Q	Q	Q				
10261	B	Q	Q	Q	A	Q			Q				Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q				Q			
10264				Q					Q				Q						Q							Q	Q	Q				
10265	B	B	B	B					B				B						B							Q	Q	Q	Q			
10266				Q		Q							Q	Q	Q		Q			Q	Q	Q	Q	Q		Q	Q	Q	Q			
10267	B	B	B	Q		Q			Q				Q	Q	Q		Q		Q	Q	Q	Q	Q	Q		Q	Q	Q	Q			
10269				B					B				B						B							Q	Q	Q	Q			
10270		B	B	B		B			B				B	B	B	B	B	B	B	B	B	B	B	B		Q	Q	Q	B			
10271	B	B	B	Q		A			Q				Q	B	B		B		Q	B	B	B	B	B	B	B	B	B				
10272	B	B	B	Q		A			Q				Q	B	B		B		Q	B	B	B	B	B	B							
10273				Q		Q							Q	Q	Q		Q		Q	Q	Q	Q	Q	Q	Q							
10274				Q		Q							Q	Q	Q		Q		Q	Q	Q	Q	Q	Q	Q							
10275				Q		Q							Q						Q													
10277		B	B	Q	A	Q			A				Q						Q													
10279		B	B	B	A	A						A	B						B							Q	Q	Q				
10280		B	B	B	A	A						A	B						B							Q	Q	Q				
10281	B	B	B	Q	A	B			Q			A	Q	A	A		A		Q	A	A	A	A	A	A	B	B	B	B			
10284	B	B	B	Q		Q			Q		B		Q						Q							Q	Q	Q	Q			Q
10286																																
10287		B	B	B		B							B						B													
10288	B	B	B	B		B			B		B		B						B													
10290	B	B	B	Q	A	Q			Q		A		Q	A	A		A		Q	A	A	A	A	A	A							
10291	Q	B	B	Q	A	B			Q		B	A	Q	A	A	A	A	A	Q	A	A	A	A	A	B	Q	Q	Q	Q			
10292	B	B	B	Q	A	B			Q	B	B		Q	B	B		B		Q	B	B	B	B	B	B	Q	Q	Q				
10293		B	B	B									B						B							Q	Q	Q	Q	B	B	

Table B.1
2016 Groundwater Monitoring Programme Requirements Summary 1st January 2016 - 31st December 2016 (cont.)

Sample Point (Piezometer)	Gamma Scan	Total Alpha	Total Beta	Tritium	Strontium-90	Technetium-99	Total Plutonium	Americium-241	Carbon-14	Chlorine-36	Iodine-129	Total Uranium	pH	Carbonate	Bicarbonate	Ammonium	Chloride	Nitrite	Nitrate	Sulphate	Calcium	Magnesium	Sodium	Potassium	Barium	Chromium	Gadolinium	Iron	TPH	SVOC	VOC	Mercury
10294				Q		Q							Q	Q	Q		Q			Q	Q	Q	Q	Q								
10295		B	B	Q		Q							Q	Q	Q		Q		B	Q	Q	Q	Q	Q	B	Q	Q	Q	B			
10296	B	B	B	Q		Q			B	B			Q	Q	Q		Q		B	Q	Q	Q	Q	Q	B	Q	Q	Q	Q			Q
10297		B	B	B	A	A						A	B						B													
10298		B	B	B	A	A						A	B						B													
10299	Q	Q	Q	Q	A	Q			Q				Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q							
10300	B	B	B	Q	A	Q			B		B		Q	A	A		A		Q	A	A	A	A	A	A							
10301	B	B	B	Q		Q			Q				Q	B	B		B		Q	B	B	B	B	B								
10305	B	B	B	Q	A	Q			Q				Q	B	B	B	B	B	Q	B	B	B	B	B	B							
10306	Q	Q	Q	Q	A	Q			Q																							
10307	B	Q	Q	Q	A	Q	A		Q			A	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q							
10308	B	Q	Q	Q	A	Q	A		Q		A	A	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q			
10310	B	B	B	Q					Q				Q						Q										Q			
10314				Q		Q							Q	Q	Q		Q			Q	Q	Q	Q	Q		Q	Q	Q				
10315		B	B	B	A	A			A				B						B							Q	Q	Q	Q	Q	Q	
10316	B	Q	Q	Q		A			Q	A			Q	Q	Q		Q		Q	Q	Q	Q	Q	Q	B	Q	Q	Q	Q	Q	Q	
10317	B	Q	Q	Q		B			Q				Q	Q	Q		Q		Q	Q	Q	Q	Q	Q	B	Q	Q	Q	Q			
10318				Q		Q							Q	Q	Q		Q			Q	Q	Q	Q	Q		B	B	B				
10320	B	B	B	Q					Q				Q						Q													
10321	B	B	B	Q		Q			Q				Q	Q	Q		Q		Q	Q	Q	Q	Q	Q	B	Q	Q	Q	Q			
10324		Q	Q	Q		Q			Q				Q						Q													
10325		B	B	B	A	B			B				B	B	B	A	B	A	A	B	B	B	B	B								
10328		B	B	B		B			B				B	B	B		B			B	B	B	B	B								
10332		B	B	B	A	B			B				B	B	B	A	B	A	A	B	B	B	B	B								
10333		B	B	B		B			B				B	B	B		B			B	B	B	B	B								
10334		B	B	B		B			B				B	B	B		B			B	B	B	B	B								
10336		B	B	B		B			B				B	B	B		B			B	B	B	B	B								
10337		B	B	B		B			B				B	B	B		B			B	B	B	B	B		B	B	B	B			
10339		Q	Q	Q	A	Q			Q				Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q								
10350	B	B	B	Q	A	Q			Q				Q	B	B	A	B	A	Q	B	B	B	B	B	B							
10351		Q	Q	Q		Q			Q				Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q								
10352				Q		Q							Q						Q													
10359	B	B	B	Q	A	Q			Q			A	Q	B	B		B		Q	B	B	B	B	B	B							
4363p1	B	Q	Q	Q	A	Q			Q				Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q							
4539p2	B	B	Q	Q	A	Q			Q				B	B	B	B	B	B	B	B	B	B	B	B	B							
4540p3				B					B				B						B													
4541p1				B					B				B						B							B	B	B				
4542p1	B	Q	Q	Q	A	Q			Q				Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q							

Table B.1
2016 Groundwater Monitoring Programme Requirements Summary 1st January 2016 - 31st December 2016 (cont.)

Sample Point (Piezometer)	Gamma Scan	Total Alpha	Total Beta	Tritium	Strontium-90	Technetium-99	Total Plutonium	Americium-241	Carbon-14	Chlorine-36	Iodine-129	Total Uranium		pH	Carbonate	Bicarbonate	Ammonium	Chloride	Nitrite	Nitrate	Sulphate	Calcium	Magnesium	Sodium	Potassium	Barium	Chromium	Gadolinium	Iron	TPH	SVOC	VOC	Mercury
4542p2	B	Q	Q	Q	A	Q			Q					Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	B	B	B				
4684p1	B	Q	Q	Q	A	Q			Q					Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q				
4993p1		A	A	Q		Q								Q	Q	Q		Q		Q	Q	Q	Q	Q	Q	Q	Q	Q	Q				
4994p1		B	B	B	A	B			B					B						B							B	B	B				
4994p2		B	B	Q	A	B			B					Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q				
4995p1		A	A	Q		Q								Q	Q	Q		Q		Q	Q	Q	Q	Q	Q	Q	Q	Q	Q				
4996p1		Q	Q	Q	A	Q			Q					Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	A	A	A				
4996p2		Q	Q	Q	A	Q			Q					Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	A	A	A				
6113p1	B	Q	Q	Q		Q			B	B				Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	A	A	A				
6113p2	B	Q	Q	Q		Q			B	B				Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q				
6192p1		Q	Q	Q	A							A		Q						Q													
6192p2		Q	Q	Q	A							A		Q						Q													
6193p1		Q	Q	Q	A							A		Q						Q							Q	Q	Q				
6193p2		Q	Q	Q	A							A		Q						Q							Q	Q	Q				
6226p1		Q	Q	Q	A	Q			Q		A			Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q								
6228p1		Q	Q	Q	A	Q			Q					Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q		Q	Q	Q	B			
6228p2		Q	Q	Q	A	Q			Q					Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q		B	B	B				
6229p1		Q	Q	Q	A	Q			Q					Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q								
6904p1		B	B	B										B						B													
6905p1		Q	Q	Q										Q						Q							Q	Q	Q	B			
6905p2		Q	Q	Q										Q						Q							Q	Q	Q	B			
6906p1		B	B	B	A							A		B						B													
6906p2		B	B	B	A							A		B						B													
6907p1																																	
6907p1																											Q	Q	Q	B			
6908p2	Q	Q	Q	Q	A	Q			Q					Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q							
6908p2	Q	Q	Q	Q	A	Q			Q					Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q							
6909p1	A	Q	Q	Q	A	Q			Q					Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q							
6909p2	B	Q	Q	Q	A	Q			Q					Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q							
6910p1	B	Q	Q	Q	A	Q			B					Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q							
6910p2	B	Q	Q	Q	A	Q			B					Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	B			
6911p2		B	B	Q	A	Q			Q					Q	B	B	B	B	B	Q	B	B	B	B	B		A	A	A				
6912p1				Q		Q								Q						Q							A	A	A				
6912p2				Q		Q								Q						Q													
6913p1		B	B	Q		B								B						B													
6913p2		B	B	Q		B								B						B													
6914p1		B	B	Q	A	Q			Q					Q	B	B	B	B	B	Q	B	B	B	B	B								
6914p2		B	B	Q	A	Q			Q					Q	B	B	B	B	B	Q	B	B	B	B	B								

Table B.1
2016 Groundwater Monitoring Programme Requirements Summary 1st January 2016 - 31st December 2016 (cont.)

Sample Point (Piezometer)	Gamma Scan	Total Alpha	Total Beta	Tritium	Strontium-90	Technetium-99	Total Plutonium	Americium-241	Carbon-14	Chlorine-36	Iodine-129	Total Uranium	pH	Carbonate	Bicarbonate	Ammonium	Chloride	Nitrite	Nitrate	Sulphate	Calcium	Magnesium	Sodium	Potassium	Barium	Chromium	Gadolinium	Iron	TPH	SVOC	VOC	Mercury
6917p1	B	Q	Q	Q	A	Q			Q				Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q							
6917p2	B	B	B	B	A	B			B				B	B	B	B	B	B	B	B	B	B	B	B	B	Q	Q	Q	A			
6918p1				Q		Q							Q						Q							B	B	B	A			
6919p1				Q		Q							Q						Q							Q	Q	Q				
6920p1		A	A	Q	A	Q			Q				Q	Q	Q	A	Q	A	Q	Q	Q	Q	Q	Q		Q	Q	Q				
6920p2		A	A	Q	A	Q			Q				Q	Q	Q	A	Q	A	Q	Q	Q	Q	Q	Q								
6925p1		A	A	Q	A	Q			Q				Q	Q	Q	A	Q	A	Q	Q	Q	Q	Q	Q								
6926p1	A	A	A	Q	A	Q			A			A	Q	Q	Q		Q		Q	Q	Q	Q	Q	Q	Q							
6926p2	A	A	A	Q	A	Q			A			A	Q	Q	Q		Q		Q	Q	Q	Q	Q	Q	Q							
6930p1	B	B	B	Q	A	Q			B			A	Q	B	B	B	B	B	Q	B	B	B	B	B	B							
6941p1	A	Q	Q	Q	A								Q	Q	Q		Q		Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	B			
6945p1		B	B	B		B			B				B	B	B		B			B	B	B	B	B								
6948p1		Q	Q	Q	A	Q			Q				Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q								
6949p1		B	B	B		B			B				B	B	B		B			B	B	B	B	B								
6951p1		B	B	B	A	B			B				B	B	B	B	B	B	B	B	B	B	B	B								
6953p1	A	Q	Q	Q	A				Q				Q	Q	Q		Q		Q	Q	Q	Q	Q	Q	Q							
6957p1	B	B	B	Q	A	B			B				Q	Q	Q		Q		Q	Q	Q	Q	Q	Q	Q	B	B	B				
6957p2	B	B	B	Q	A				B				Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	B	B	B				
6958p1		Q	Q	Q		Q			Q				Q	Q	Q		Q			Q	Q	Q	Q	Q		Q	Q	Q				
6959p1	B	B	B	Q					B				Q	Q	Q		Q		Q	Q	Q	Q	Q	Q	Q	Q	Q	Q				
6960p1	A	Q	Q	Q	A								Q	Q	Q		Q		Q	Q	Q	Q	Q	Q	Q							
6961p1		B	B	B		B			B				B	B	B		B			B	B	B	B	B								
6962p1		B	B	B		B			B				B	B	B		B			B	B	B	B	B								
6964p1		B	B	B		B			B				B	B	B		B			B	B	B	B	B								
6966p1		B	B	B		B			B				B	B	B		B			B	B	B	B	B		A	A	A				
6967p1		B	B	B		B			B				B	B	B		B			B	B	B	B	B					Q	Q	Q	
6972p2																																
6973p1		B	B	Q		Q				B			Q						Q													
6973p2		B	B	Q		Q				B			Q						Q										B	B	B	
6974p1		Q	Q	Q	A	Q			A				Q						Q							A	A	A				
6974p2		Q	Q	Q	A	Q			A				Q						Q							B	B	B	A			
6975p1		Q	Q	Q	A	B			B				Q	B	B	B	B	B	Q	B	B	B	B	B		B	B	B				
6975p2		Q	Q	Q	A	B			B				Q	B	B	B	B	B	Q	B	B	B	B	B								
6977p1		Q	Q	Q	A	B			B				Q	B	B	B	B	B	Q	B	B	B	B	B								
6977p2		A	A	Q	A	A			A				A	A	A	A	A	A	A	A	A	A	A	A		B	B	B				
6978p1		Q	Q	Q	A	B			B				Q	B	B	B	B	B	Q	B	B	B	B	B		B	B	B				
6979p1		Q	Q	Q	A	B			B				Q	B	B	B	B	B	Q	B	B	B	B	B		A	A	A				
6980p1	B	B	B	Q		B			B				Q	B	B		B		Q	B	B	B	B	B					B	B	B	

Table B.1
2016 Groundwater Monitoring Programme Requirements Summary 1st January 2016 - 31st December 2016 (cont.)

Sample Point (Piezometer)	Gamma Scan	Total Alpha	Total Beta	Tritium	Strontium-90	Technetium-99	Total Plutonium	Americium-241	Carbon-14	Chlorine-36	Iodine-129	Total Uranium		pH	Carbonate	Bicarbonate	Ammonium	Chloride	Nitrite	Nitrate	Sulphate	Calcium	Magnesium	Sodium	Potassium	Barium	Chromium	Gadolinium	Iron	TPH	SVOC	VOC	Mercury
6981p1	B	B	B	Q		B			B					Q	B	B		B		Q	B	B	B	B	B		Q	Q	Q	B			
6981p2	B	B	B	Q		B			B					Q	B	B		B		Q	B	B	B	B	B		Q	Q	Q	B			
6985p1	B	B	Q	Q	A	Q			Q	A	A			A	A	A		A		A	A	A	A	A	A								
6985p2	B	B	Q	Q	A	Q			Q	A	A			A	A	A		A		A	A	A	A	A	A								
6986p1		B	B	Q	A	Q						A		Q						Q													
6986p2		B	B	Q	A	Q						A		Q						Q							B	B	B				
793p3	A	Q	Q	Q	A	Q			A					Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	B	B	B				
9112p1		Q	Q	Q		Q			Q					Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q							
9113p1																																	
9114p1	B	B	B	Q	A	A			B					Q	Q	Q		Q		Q	Q	Q	Q	Q	Q	Q	B	B	B				
9115p1				Q										Q	Q	Q		Q		Q	Q	Q	Q	Q	Q	Q							
9116p1				Q										Q	Q	Q		Q		Q	Q	Q	Q	Q	Q	Q							
9118p1	A	A	A	Q	A	A			A					Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	B	B	B				
9054	B	B	Q	Q	A	Q			Q	A	A			A	A	A		A		A	A	A	A	A	A								
9055	B	Q	Q	Q	A	Q			Q	A	A			Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q							
9056	B	B	Q	Q	A	Q			Q	A	A			A	A	A		A		A	A	A	A	A	A								
9057	B	B	Q	Q	A	Q			Q	A	A			A	A	A		A		A	A	A	A	A	A								
9059	B	B	Q	Q	A	Q			Q	A	A			A	A	A		A		A	A	A	A	A	A								
9060	B	Q	Q	Q	A	Q			Q	A	A			Q	Q	Q		Q		A	Q	Q	Q	Q	Q								
9063	B	Q	Q	Q	A	Q			Q	A	A			Q	Q	Q		Q		A	Q	Q	Q	Q	Q								
9275	B	B	Q	Q	A	Q			Q	B	A			B	B	B		B		B	B	B	B	B	B	B							
9276		B	B	B	A	B			A					B						B													
9631	B	B	B	B	A	B			B					B	B	B	B	B	B	B	B	B	B	B	B	B							
9632	A	Q	Q	Q	A	Q			Q					Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q							
9633	A	Q	Q	Q	A	Q			Q					Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q							
9634	B	B	B	B	A	B			B					B	B	B	B	B	B	B	B	B	B	B	B	B							
9641	A	Q	Q	Q	A	Q			A					Q	Q	Q		Q		Q	Q	Q	Q	Q	Q	Q							
9642	A	A	A	Q	A	Q			A					Q	Q	Q	A	Q	A	Q	Q	Q	Q	Q	Q	Q							
9643	A	A	A	Q	A	Q			Q					Q	A	A	A	A	A	Q	A	A	A	A	A	A							
9644	A	A	A	Q	A	Q			Q					Q	A	A	A	A	A	Q	A	A	A	A	A	A							
9645	A	A	A	Q	A	Q			Q					Q	A	A	A	A	A	Q	A	A	A	A	A	A							
9646	A	A	A	Q	A	A			A					Q	Q	Q		Q		Q	Q	Q	Q	Q	Q	Q							
9779		A	A	Q	A	Q			Q					Q	Q	Q	A	Q	A	Q	Q	Q	Q	Q	Q								
9780		A	A	Q	A	Q			Q					Q	Q	Q	A	Q	A	Q	Q	Q	Q	Q	Q								
9781		Q	Q	Q	A	Q			Q					Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q								
9782		Q	Q	Q	A	Q			Q					Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q								
9783		A	A	Q	A	Q			Q					Q	Q	Q	A	Q	A	Q	Q	Q	Q	Q	Q								
9784		A	A	Q	A	Q			Q					Q	Q	Q	A	Q	A	Q	Q	Q	Q	Q	Q								

Q - Sampled quarterly
B – Sampled biannually
A – Sampled yearly

Total plutonium = plutonium-238, plutonium-239+240and plutonium-240
Total uranium = uranium-234 and uranium-238
Gamma scan = caesium-137, ruthenium-103, ruthenium-106, antimony-125, tin-126, and naturally occurring radionuclides beryllium-7 and potassium-40

Table B.2
Groundwater Monitoring Programme – specified Analytical Detection Limits

	Radionuclide	LOD (Bql^{-1})	Investigation Level (Bql^{-1})
Groundwater	Total alpha	0.03	0.09
	Total beta	0.30	0.90
	Tritium	7.50	10.00
	Carbon-14	1.00	1.50
	Chlorine-36	0.50	0.75
	Strontium-90	0.12	0.20
	Technetium-99	0.06	0.10
	Ruthenium-106	1.20	2.00
	Iodine-129	0.03	0.075
	Caesium-137	0.12	0.20
	Uranium-234	0.005	0.0075
	Uranium-235	0.0004	0.0006
	Uranium-236	0.0025	0.004
	Uranium-238	0.0006	0.0009
	Plutonium-238	0.006	0.01
	Plutonium-239+240	0.006	0.01
	Plutonium-241	0.06	0.10
	Americium-241	0.012	0.036

The LOD is the level at which a given analytical procedure may be relied upon to lead to detection *i.e*. the smallest true value of the measurand which ensures a specified probability (95%) of being detectable by the measurement procedure (AMEC, 2013).

Table B.3
Standard Laboratory Analytical Methods

Radionuclide	Methods for Water Samples
Alpha	The sample is filtered and analysed using a zinc sulphide alpha scintillation counter calibrated against plutonium-239+240.
Beta	A portion of filtered sample is assayed for beta emitters using Cerenkov counting. Where the samples are coloured they are counted using a Geiger-Muller liquid beta counter. Both methods are reported with respect to potassium-40.
Gamma Spectrometry	Determination of radioactivity in water by multi-nuclide gamma ray spectrometry.
Tritium	Tritium is distilled and assayed by liquid scintillation counting. Tritium is assumed to be present only as tritiated water.
Strontium-90	The strontium is separated using ion exchange techniques. Samples are sent for the determination of strontium-90 using a liquid scintillation counter in the Cerenkov mode. The strontium-90 is calculated from the ingrowth of yttrium-90.
Technetium-99	The sample is conditioned and passed through an ion exchange column. The eluate is analysed *via* a gas flow proportional counter. For samples with higher activity levels inductively coupled plasma mass spectrometry (ICP-MS) is used.
Plutonium isotopes and americium-241	An aliquot of the sample is passed through an ion exchange column. Plutonium isotopes (specifically plutonium-238 and plutonium-239+240) are separated and the levels determined by either of alpha spectrometry or, for plutonium-241, by using a low energy photon spectroscopy (LEPS) finish. However, the isotopes can also be separated using ion exchange procedures and levels determined using alpha spectrometry. Americium-241?
Carbon-14	The carbon-14 in the sample is precipitated as a solid and this is analysed using liquid scintillation counting.
Uranium isotopes	The sample is filtered and acidified before being submitted for ICP-MS.
Iodine-129	The iodine in the water is separated using solvent extraction techniques and the iodine-129 is determined by liquid scintillation counting.

Table B.4
WHO Drinking Water Guidelines

Radionuclide	WHO Drinking Water Guidelines 2011 (Bql^{-1})	Radionuclide	WHO Drinking Water Guidelines 2011 (Bql^{-1})
Tritium	10 000	Caesium-129	1 000
Carbon-14	100	Caesium-131	1 000
Sodium-22	100	Caesium-132	100
Chlorine-36	100	Caesium-134	10
Chromium-51	10 000	Caesium-135	100
Iron-55	1 000	Caesium-136	100
Iron-59	100	Caesium137	10
Cobalt-56	100	Uranium-235	1
Cobalt-57	1 000	Uranium-236	1
Cobalt-58	100	Uranium-237	100
Cobalt-60	100	Uranium-238	10
Strontium-85	100	Thorium-229	0.1
Strontium-89	100	Thorium-230	-
Stronitum-90	10	Thorium-234	-
Yttrium-90	100	Plutonium-236	1
Yttrium-91	100	Plutonium-237	1 000
Radium-224	1	Plutonium-238	1
Radium-225	1	Plutonium-239	1
Radium-226	1	Plutonium-240	1
Radium-228	0.1	Plutonium-241	10
Technetium-96	100	Plutonium-242	1
Technetium-97	1 000	Plutonium-244	1
Technetium-99m	100	Americium-241	1
Technetium-99	100	Americium-242	1 000
Total alpha	0.5	Americium-243	1
Total beta/gamma	1		

Table Notes

Guidelines concentrations for substances in the above list are based upon the lifetime cancer risk for an adult obtaining their drinking water solely from this supply for a year. The levels are approximate to an additional lifetime cancer risk of 10^{-5} per annum. Risks from chemical toxicity are excluded.

Table B.5
Chemicals of Concern
(where chemical has been linked to analytical determinands to assess impact on groundwater)

Contaminant of Concern	Determinand
Distillate fuel	TPH
Oil	TPH
Ammonia	Ammonium
Diesel	TPH
Sodium hydroxide	Sodium
Sodium hydroxide	pH
Aluminium sulphate	Sulphate
Sulphuric acid	Sulphate
Sulphuric acid	pH
Hydrochloric acid	Chloride
Hydrochloric acid	pH
Nitric acid	Nitrate
Nitric acid	pH
Sodium carbonate	Sodium
Sodium nitrate	Sodium
Sodium nitrate	Nitrate
Kerosene	TPH
Tributyl phosphate	VOC
Oxalic acid	pH
Paint	VOC
Barium nitrate	Barium
Barium nitrate	Nitrate
Gadolinium nitrate	Gadolinium
Gadolinium nitrate	Nitrate
Hydrazine nitrate	Nitrate
Hydroxylamine nitrate	Nitrate
Uranyl nitrate	Radiological
Uranyl nitrate	Nitrate
Plutonium dioxide	Radiological
Uranium trioxide	Radiological
Solvents	VOC
Solvents	SVOC
Mercury	Mercury
Phosphoric acid	pH
Citric acid	pH
Ferric nitrate	Iron
Ferric nitrate	Nitrate
Nickel nitrate	Nickel
Nickel nitrate	Nitrate
Sodium ferrocyanide	Sodium
Sodium ferrocyanide	Iron
Sodium ferrocyanide	Cyanide
Sodium nickel hexacyanoferrate	Sodium
Sodium nickel hexacyanoferrate	Nickel
Sodium nickel hexacyanoferrate	Cyanide
Sodium nickel hexacyanoferrate	Iron
Sodium hypochlorite	Sodium
Sodium hypochlorite	Chloride
Sodium hypochlorite	pH
Hydrogen peroxide	pH
Plutonium nitrate	Radiological
Plutonium nitrate	Nitrate
Potassium hydroxide	Potassium
Ferrous sulphamate	Iron
Ferrous sulphamate	Sulphate
Raffinate	Radiological
De Rad Tetrafluro-1-propanol/degreaser	VOC
De Rad Tetrafluro-1-propanol/degreaser	SVOC

Table B.6
Summary of Analytical Methods and LODs used in Environmental Permit

Determinand	LOD (mgl^{-1})	Accreditation	Method
pH	0.2 pH units	UKAS	pH electrode
Mercury	0.001	UKAS	ICP-MS
Iron	0.01	UKAS	ICP-MS
Nickel	0.05	UKAS	ICP-MS
Barium	1.0	UKAS	ICP-MS
Chromium	0.0001	UKAS	ICP-MS
Gadolinium	0.000004	UKAS	ICP-MS
Sodium	1.0	UKAS	ICP-OES
Potassium	0.5	UKAS	ICP-OES
Calcium	1.0	UKAS	ICP-OES
Magnesium	0.5	UKAS	ICP-OES
Ammonium	0.004	UKAS	IC
Nitrite	0.1	UKAS	IC
Nitrate	0.5	UKAS	IC
Sulphate	1.0	UKAS	IC
Bromide	0.05	UKAS	IC
Chloride	1.0	UKAS	IC
Carbonate	10.0	N/A	Titration
Bicarbonate	10.0	N/A	Titration
Phenol	0.0005	UKAS	GC-FID
TPH (Total)	0.03	UKAS	GC-FID
VOC	0.001 – 0.05	UKAS	GC-MS
SVOC	0.001 – 0.01	UKAS	GC-MS

Table B.7
ESC for Non-radiological Determinands

Determinand	ESC (mgl^{-1})	Source Reference
Ammonium	0.5	UK Drinking Water Standards
Barium	0.7	WHO drinking water guidelines
Bromide	0.05	LOD
Chloride	250	UK Drinking Water Standards
Chromium	0.015	EQS Saltwater
Iron	1	EQS Saltwater
Mercury	0.001	LOD
Sodium	200	UK Drinking Water Standards
Nickel	0.05	LOD
Nitrite	0.5	UK Drinking Water Standards
Nitrate	50	UK Drinking Water Standards
Phenol	0.0005	LOD
Potassium	12	UK Drinking Water Standards
Sulphate	250	EQS Saltwater
TPH (Total)	0.03	LOD
VOC	0.001 – 0.05	LOD
SVOC	0.001 – 0.05	LOD

Appendix C
Groundwater Data Screening

Appendix C - Groundwater Data Screening

In order to ensure that only data of the highest quality were incorporated into the assessment, a number of preliminary steps were undertaken to review the data and screen out any that were considered substandard. Removed data have been documented as part of this appendix.

Anomalous results

Where a change in groundwater quality was observed in the dataset for 2016, an investigation into this change was instigated. These investigations may include repeat analysis or repeat sampling. Following these investigations, and as part of the review of the whole dataset, some instances were identified where the sample activity was notably higher or lower than the average for that particular well over the last four years. These instances were reviewed in more detail against the dataset and any exceedance investigations. As a result, one radionuclide and 3 non-radionuclide results were omitted from further statistical analysis. The data relating to these results are shown in Table C.1.

In addition to the statistical review of the data, 17 TPH samples were affected by a contaminated laboratory blank. The standard analytical procedure is to blank correct, however on this occasion it resulted in artificially higher values. As such these were removed from the dataset prior to statistical analysis.

Results with elevated analytical limits of detection

Results below the analytical LODs account for nearly 36% of the total results reported in 2016 (radiological and non-radiological determinands). As part of the permit provided by the Environment Agency there is a stipulation that the company take all reasonably practicable measures to achieve the limits of detection, which are specified in Table 3 of the Environment Agency Permit KP3690SX.

When results are reported as limit of detection but they have not achieved the specified LOD stipulated by the Environment Agency, further investigation is carried out to find why. The details of these investigations are provided in Appendix E. In general it is found that the sample taken was of reduced quality, for example a high level of suspended solids may affect the laboratory process, as such the result is removed from the dataset. In 2016, other than some naturally occurring radionuclides, there were 14 results that met this criterion, see Table C.2.

During the production of data tables for this report, the averages, maxima and minima for results from a sample location over the 2016 period have been calculated using LOD results at their reported value.

Table C.1
Anomalous Results Omitted from Statistical Calculations in the 2016 Groundwater Data

Sample Point	Sample Date	LSN	Determinand	Value	Units
10320	05/07/2016	Z057243	Carbon-14	3.12	Bql^{-1}
793p3	12/01/2016	Z051755	Ammonium	0.0568	mgl^{-1}
4684p1	11/07/2016	Z057529	Ammonium	0.0436	mgl^{-1}
6910p1	12/04/2016	Z054529	Ammonium	0.345	mgl^{-1}

Table C.2
LOD Screening for Major Water Quality Parameters

Determinand	WHO Drinking Water Guidelines (4^{th} Edition) (Bql^{-1})	LOD (Bql^{-1})	Number of LOD Results Removed
Uranium-235	1	0.0004	14

Appendix D
Exceedance Information

Appendix D – Exceedance Information

This appendix presents supplementary information regarding exceedance investigations reported during the 2016 review period.

Under the conditions of the CEAR, analytical results must be reported to the Regulators when:
"*any positive environmental monitoring result which exceeds the mean plus 4 standard deviations of the previous 12 results [4σ], for all samples collected or environmental measurements made, and provide details of the investigations the Operator is undertaking to provide an explanation of the result (excluding the natural radionuclides beryllium-7 and potassium-40)*" (Environment Agency, 2016).

In addition there are a number of trigger levels used when assessing the groundwater analytical results that are not reported externally. These apply to LOD and investigation concentrations defined within the Techniques Document (Sellafield Ltd, 2015) and are used to assess quality of analysis and compliance with the groundwater monitoring programme requirements. A review of programme compliance is provided in Section 4 and Appendix E of this report.

Definitions of Trigger Levels

3σ – Result exceeds internal trigger level (mean +3sd of previous 12 results)

4σ – Result exceeds external trigger level (mean +4sd of previous 12 results)

D.1 Protocol for sample analyses that exceed 4σ

When any groundwater sample analytical result exceeds the '4σ' it is reported to the Environment Agency and the Office for Nuclear Regulation. An example calculation to determine a reportable result is given in Table D.1. The method for calculating the exceedance limit uses the following equation:

[arithmetic mean of previous 12 results] + 4 x [standard deviation of previous 12 results]

Table D.1
Example Calculation to Determine Reportable Results

Sample Date	Result	Unit	Limit Calculations	
31/01/2011	81.6	Bql^{-1}		
16/08/2011	45.4	Bql^{-1}		
18/01/2012	32.4	Bql^{-1}		
08/08/2012	29.5	Bql^{-1}		
15/01/2013	50.9	Bql^{-1}		
02/09/2013	43.2	Bql^{-1}		
05/02/2014	44.2	Bql^{-1}		
06/08/2014	48.8	Bql^{-1}		
15/04/2015	45.8	Bql^{-1}		
05/08/2015	60.9	Bql^{-1}		
25/01/2016	50.0	Bql^{-1}	**Mean**	49.3
09/05/2016	59.4	Bql^{-1}	**Standard Deviation**	13.7
07/11/2016	171	Bql^{-1}	**4σ**	104

Each result is investigated and the progress and close out of these investigations are presented to the Environment Agency/Office for Nuclear Regulation on a quarterly basis. All results have been verified and the value of the '4σ' is given in Table D.2 (radiological determinands) and Table D.3 (non-radiological determinands).

The exceedance investigations are spilt into three stages:

Stage 1 - Initial check to ensure the calculation has been applied correctly and how many results were used, whether the exceedance is below the analytical LOD, or if subsequent results have returned to previous levels.

Stage 2 - Statistical review of the time-series data.

Stage 3 - If the result and subsequent results show a trend of interest, further investigations are completed including a review of co-contaminants, responses in adjacent up-gradient and down-gradient wells and determination of any re-sampling or additional analysis requirements.

Wider investigations are undertaken where necessary, for example the investigation in to the Factory Sewer, see Section 2.2.

Table D.2
Results Which Exceed the 4σ Level – Radiological Determinands

Piezometer	Analyte	Sample Date	Result	Mean (arithmetic)	4σ	Unit	Comment
9056	Strontium-90	04/04/2016	0.539	0.0928	0.118	Bql^{-1}	Investigation closed at Stage 1, insufficient number of data points (statistics likely to be sensitive to small changes)
9060	Carbon-14	10/10/2016	37.2	9.17	26.4	Bql^{-1}	Investigation closed out at Stage 3. Repeat analysis was undertaken on the sample, the repeated result was in-line with previous levels.
9275	Carbon-14	03/11/2016	0.657	0.458	0.597	Bql^{-1}	Investigation closed at Stage 2, subsequent result returned <LOD
9641	Tritium	13/04/2016	43	8.72	32	Bql^{-1}	Investigation closed at Stage 1, subsequent results decreased to levels comparable with historical activity concentrations
9642	Technetium-99	07/07/2016	0.827	0.187	0.6	Bql^{-1}	Investigation closed at Stage 1, subsequent results decreased to levels comparable with historical activity concentrations
9642	Total beta	05/01/2016	0.271	0.24	0.27	Bql^{-1}	Investigation closed at Stage 1, insufficient number of data points (statistics likely to be sensitive to small changes)
9780	Carbon-14	01/06/2016	0.764	0.454	0.513	Bql^{-1}	Investigation closed at Stage 1, insufficient number of data points (statistics likely to be sensitive to small changes)
9781	Total beta	08/06/2016	0.541	0.295	0.458	Bql^{-1}	Investigation closed at Stage 1, insufficient number of data points (statistics likely to be sensitive to small changes)
9782	Carbon-14	05/09/2016	1.01	0.528	0.864	Bql^{-1}	Investigation closed at Stage 3. Subsequent results returned to previous levels.
9782	Total alpha	19/01/2016	0.112	0.027	0.0484	Bql^{-1}	Investigation closed at Stage 1, insufficient number of data points (statistics likely to be sensitive to small changes)
9783	Carbon-14	01/06/2016	5.19	0.914	2.33	Bql^{-1}	Investigation closed at Stage 1, insufficient number of data points (statistics likely to be sensitive to small changes)
9784	Strontium-90	01/06/2016	0.118	0.0802	0.103	Bql^{-1}	Investigation closed at Stage 1, insufficient number of data points (statistics likely to be sensitive to small changes)
10039	Tritium	06/04/2016	59.7	31.1	55.6	Bql^{-1}	Investigation closed at Stage 1, subsequent results decreased to levels comparable with historical activity concentrations
10066	Carbon-14	13/01/2016	520	145	392	Bql^{-1}	Investigation closed at Stage 3. Subsequent results returned to previous levels.
10066	Iodine-129	07/10/2016	0.206	0.0858	0.184	Bql^{-1}	Investigation closed at Stage 1, subsequent results decreased to levels comparable with historical activity concentrations
10090	Strontium-90	06/06/2016	10600	4230	7370	Bql^{-1}	Ongoing. Subsequent results will be assessed when available.
10090	Total alpha	23/08/2016	0.0906	0.0291	0.0792	Bql^{-1}	Investigation closed at Stage 1, subsequent results decreased to levels comparable with historical activity concentrations
10131	Total beta	08/11/2016	2.01	0.408	1.83	Bql^{-1}	Subsequent result returned to previous levels. Investigation closed at Stage 1.
10143	Tritium	10/05/2016	5830	570	1450	Bql^{-1}	Investigation progressed to Stage 3. Subsequent results decreased however not yet to previous levels. Subsequent results will continue to be assessed and the investigation will remain ongoing.
10143	Tritium	04/11/2016	12700	1190	7700	Bql^{-1}	Investigation progressed to Stage 3. Subsequent results decreased however not yet to previous levels. Subsequent results will continue to be assessed and the investigation will remain ongoing.
10143	Iodine-129	10/05/2016	0.901	0.53	0.831	Bql^{-1}	Investigation closed at Stage 3. Subsequent result decreased to previous levels.
10203	Tritium	10/10/2016	212	80.4	154	Bql^{-1}	Investigation progressed to Stage 3, the investigation is ongoing.
10260	Total alpha	11/05/2016	0.0395	0.0186	0.0327	Bql^{-1}	Investigation closed at Stage 1, subsequent result was <LOD
10287	Tritium	09/05/2016	1780	1130	1680	Bql^{-1}	Investigation closed at Stage 2, no trends or jumps were shown in the dataset (no subsequent results available)
10292	Tritium	05/08/2016	603	87.1	380	Bql^{-1}	Investigation closed at Stage 3. Subsequent results decreased to previous levels.
10308	Tritium	04/10/2016	172	89.1	139	Bql^{-1}	Investigation progressed to Stage 3, the investigation is ongoing.
10308	Total beta	05/01/2016	49.6	30.9	44.7	Bql^{-1}	Investigation closed at Stage 2, subsequent results decreased to levels comparable with historical activity concentrations.
10310	Total beta	05/10/2016	0.635	0.234	0.263	Bql^{-1}	Investigation closed at Stage 2, subsequent result returned <LOD

Table D.2
Results Which Exceed the 4σ Level – Radiological Determinands (cont.)

Piezometer	Analyte	Sample Date	Result	Mean (arithmetic)	4σ	Unit	Comment
10317	Tritium	03/05/2016	95.9	43.2	74.5	Bql^{-1}	Investigation closed at Stage 1, subsequent results decreased to levels comparable with historical activity concentrations
10320	Carbon-14	05/07/2016	3.12	0.702	2.66	Bql^{-1}	Investigation closed at Stage 1, subsequent result was <LOD
10321	Carbon-14	06/10/2016	0.569	0.446	0.49	Bql^{-1}	Investigation closed at Stage 2, subsequent result returned <LOD
10321	Tritium	05/01/2016	142	54.2	115	Bql^{-1}	Investigation closed at Stage 3, subsequent results returned to previous levels
10321	Total beta	06/10/2016	2.37	0.268	0.415	Bql^{-1}	Investigation closed at Stage 1, subsequent result returned to previous levels.
10333	Tritium	12/05/2016	46.8	12.4	45.1	Bql^{-1}	Investigation closed at Stage 3. Activity concentration low, 3 orders of magnitude below the WHO drinking water guideline of 10 000 Bql^{-1}.
4363P1	Carbon-14	04/08/2016	0.615	0.477	0.601	Bql^{-1}	Investigation closed at Stage 1, subsequent result is <LOD
4363P1	Total alpha	09/05/2016	0.038	0.0156	0.0279	Bql^{-1}	Investigation closed at Stage 1, subsequent result returned to <LOD
4541PP1	Carbon-14	02/11/2016	0.684	0.452	0.504	Bql^{-1}	Investigation closed at Stage 3. Subsequent result returned to previous levels.
4684P1	Carbon-14	11/07/2016	0.536	0.445	0.506	Bql^{-1}	Investigation closed at Stage 1, subsequent result is <LOD
4684P1	Tritium	07/04/2016	13.5	6.65	13.4	Bql^{-1}	Investigation closed at Stage 1, subsequent result is <LOD
4684P1	Total alpha	11/07/2016	0.0723	0.0197	0.0401	Bql^{-1}	Investigation closed at Stage 1, subsequent results decreased to levels comparable with historical activity concentrations
4996P2	Strontium-90	11/04/2016	7.19	0.302	1.24	Bql^{-1}	Investigation progressed to Stage 3. See section 2.2.
4996P2	Total alpha	11/04/2016	0.0591	0.0258	0.0428	Bql^{-1}	Investigation closed at Stage 1, subsequent result is <LOD
6113P2	Tritium	11/04/2016	2510	409	1430	Bql^{-1}	Investigation closed at Stage 2, statistical analysis showed an overall negative trend in the dataset and subsequent results decreased to levels comparable with historical activity concentrations.
6228P1	Tritium	03/06/2016	755	233	637	Bql^{-1}	Investigation closed at Stage 3. Subsequent results returned to previous levels.
6909P1	Tritium	11/04/2016	22.6	12.7	19.5	Bql^{-1}	Investigation closed at Stage 3. It was concluded the increase was likely due to high water levels at that time. Subsequent results returned to previous levels.
6909P1	Tritium	04/07/2016	32.6	13.5	26.7	Bql^{-1}	Investigation closed at Stage 2. result in-line with historical levels and subsequent results returned to previous levels
6910p1	Tritium	12/04/2016	24.0	0.930	7.19	Bql^{-1}	Investigation closed at Stage 3. Subsequent results returned to previous levels.
6910P1	Technetium-99	12/04/2016	50	6.49	40.8	Bql^{-1}	Investigation closed at Stage 3. Subsequent results returned to previous levels.
6911P2	Carbon-14	01/09/2016	0.572	0.448	0.515	Bql^{-1}	Investigation closed at Stage 1, subsequent results decreased to levels comparable with historical activity concentrations
6926P2	Total beta	05/04/2016	13.8	6.03	11.7	Bql^{-1}	Investigation closed at Stage 3. Subsequent result decreased slightly. The increase was likely indicating the western edge of a plume feature observed in the south-eastern part of Separation Area (identified during SCL&GMP). In addition the increase may be related to high groundwater level at the time following high rainfall.
6985P1	Strontium-90	04/04/2016	29.7	2.43	7.04	Bql^{-1}	Investigation closed at Stage 3. Subsequent result returned to previous levels.
6985P2	Caesium-137	10/10/2016	0.513	0.0634	0.158	Bql^{-1}	Investigation closed at Stage 2, subsequent result returned <LOD.
9118P1	Tritium	02/08/2016	9.63	5.4	8.85	Bql^{-1}	Investigation closed at Stage 2, statistical analysis showed no trends or jumps in the dataset and subsequent results returned to previous historical activity concentrations.

Table D.3
Results Which Exceed the 4σ Level – Non-radiological Determinands

Piezometer	Analyte	Sample Date	Result	Mean (arithmetic)	4σ	Unit	Comment
10066	Magnesium	13/01/2016	3.08	1.44	2.88	mgl^{-1}	Exceedance not statistically significant. Investigation closed out at Stage 2.
10267	Nitrate	12/01/2016	16.4	11.6	13.8	mgl^{-1}	Investigation closed at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
10274	Magnesium	07/01/2016	7.02	5.65	6.88	mgl^{-1}	Closed out at Stage 3. Subsequent results returned to previous levels in Q4 2016.
10284	C6 - C40	13/01/2016	0.63	0.0349	0.0822	mgl^{-1}	Insufficient results available to carry out Stage 2 statistical analysis. Returned to near LOD in Q3 2016. Investigation closed out.
10284	C10 - C20	13/01/2016	0.63	0.0168	0.0851	mgl^{-1}	Insufficient results available to carry out Stage 2 statistical analysis. Returned to near LOD in Q3 2016. Investigation closed out.
10301	C6 - C40	13/01/2016	0.17	0.0378	0.121	mgl^{-1}	Subsequent result returned to baseline, exceedance considered anomalous. Investigation closed out at Stage 1.
10301	C20 - C40	13/01/2016	0.076	0.0126	0.0426	mgl^{-1}	Investigation closed out at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
4684P1	Sulphate	18/01/2016	62.8	29	62.7	mgl^{-1}	Investigation closed out at Stage 2. Exceedance not statistically significant.
4994P1	Potassium	18/01/2016	5.11	4.35	5.09	mgl^{-1}	Investigation closed out at Stage 2. Exceedance not statistically significant.
6113P1	C10 - C20	11/01/2016	1	0.01	0.01	mgl^{-1}	Insufficient results available to carry out Stage 2 statistical analysis. Returned to LOD in Q3 2016. Investigation closed out.
6113P1	C6 - C40	11/01/2016	1	0.0306	0.0387	mgl^{-1}	Insufficient results available to carry out Stage 2 statistical analysis. Returned to LOD in Q2 2017. Investigation closed out.
6113P2	Sodium	11/01/2016	116	51.3	107	mgl^{-1}	Investigation closed out at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
6113P2	Gadolinium	11/01/2016	0.00919	0.0019	0.0055	mgl^{-1}	Stage 3 investigation carried out. Returned to previous levels in Q3 2016. Investigation closed out.
6113P2	Calcium	11/01/2016	69.4	33.3	65.9	mgl^{-1}	Subsequent result returned to baseline, exceedance considered anomalous. Investigation closed out at Stage 1.
6113P2	Sulphate	11/01/2016	120	31.9	72.2	mgl^{-1}	Subsequent result returned to baseline, exceedance considered anomalous. Investigation closed out at Stage 1.
6909P2	Ammonium	12/01/2016	0.0075	0.00417	0.00648	mgl^{-1}	Subsequent result returned to baseline, exceedance considered anomalous. Investigation closed out at Stage 1.
6910P2	C10 - C20	11/01/2016	0.83	0.01	0.01	mgl^{-1}	Insufficient results available to carry out Stage 2 statistical analysis. Returned to near LOD in Q3 2016. Investigation closed out.
6910P2	C6 - C40	11/01/2016	0.85	0.0332	0.0628	mgl^{-1}	Insufficient results available to carry out Stage 2 statistical analysis. Returned to LOD in Q2 2017. Investigation closed out.
6917P2	Bicarbonate	15/01/2016	163	37.8	87.4	mgl^{-1}	Investigation closed out at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
6917P2	Iron	15/01/2016	0.414	0.114	0.382	mgl^{-1}	Stage 3 investigation carried out. Returned to previous levels in Q4 2016. Investigation closed out.
6920P1	Ammonium	18/01/2016	0.0089	0.00425	0.00771	mgl^{-1}	Subsequent result returned to baseline, exceedance considered anomalous. Investigation closed out at stage 1.
6920P2	Ammonium	18/01/2016	0.01	0.004	0.004	mgl^{-1}	Subsequent result returned to baseline, exceedance considered anomalous. Investigation closed out at stage 1.
6957P2	C6 - C40	13/01/2016	0.05	0.03	0.03	mgl^{-1}	Subsequent result returned to baseline, exceedance considered anomalous. Investigation closed out at stage 1.
6957P2	C10 - C20	13/01/2016	0.014	0.01	0.01	mgl^{-1}	Subsequent result returned to baseline, exceedance considered anomalous. Investigation closed out at stage 1.
6957P2	C20 - C40	13/01/2016	0.035	0.0113	0.0298	mgl^{-1}	Subsequent result returned to baseline, exceedance considered anomalous. Investigation closed out at stage 1.
6981P1	Nitrate	20/01/2016	15.1	11.6	14.8	mgl^{-1}	Stage 3 investigation carried out. Subsequent result returned to baseline, exceedance considered anomalous. Investigation closed out.

Table D.3
Results Which Exceed the 4σ Level – Non-radiological Determinands (cont.)

Piezometer	Analyte	Sample Date	Result	Mean (arithmetic)	4σ	Unit	Comment
793P3	Ammonium	12/01/2016	0.0568	0.00508	0.0155	mgl^{-1}	Subsequent result returned to baseline, exceedance considered anomalous. Investigation closed out at Stage 1.
9113P1	C6 - C40	12/01/2016	0.07	0.0304	0.0438	mgl^{-1}	Investigation closed at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
9113P1	C20 - C40	12/01/2016	0.055	0.0107	0.0199	mgl^{-1}	Investigation closed at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
9116P1	C6 - C10	11/01/2016	0.065	0.01	0.01	mgl^{-1}	Investigation closed at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
9116P1	C6 - C40	11/01/2016	0.07	0.0288	0.045	mgl^{-1}	Insufficient results available to carry out Stage 2 statistical analysis. Returned to LOD in Q3 2016. Investigation closed out.
9641	Chloride	05/01/2016	59.8	34.2	58.8	mgl^{-1}	Investigation closed at Stage 1. < 6 results used in the exceedance calculation. Subsequent result returned to baseline, exceedance considered anomalous.
9644	Nitrate	05/01/2016	15.6	11	14	mgl^{-1}	Investigation closed at Stage 1. < 6 results used in the exceedance calculation. Subsequent result returned to baseline, exceedance considered anomalous.
9779	Ammonium	19/01/2016	0.0219	0.004	0.004	mgl^{-1}	Investigation closed at Stage 1. < 6 results used in the exceedance calculation.
9779	Gadolinium	19/01/2016	0.00799	0.000796	0.003	mgl^{-1}	Investigation closed at Stage 1. < 6 results used in the exceedance calculation.
9779	Iron	19/01/2016	20.3	2.12	9.42	mgl^{-1}	Investigation closed at Stage 1. < 6 results used in the exceedance calculation.
9779	Chromium	19/01/2016	0.0161	0.00156	0.00326	mgl^{-1}	Investigation closed at Stage 1. < 6 results used in the exceedance calculation.
9779	Barium	19/01/2016	0.241	0.125	0.168	mgl^{-1}	Investigation closed at Stage 1. < 6 results used in the exceedance calculation.
9781	Chromium	19/01/2016	0.0406	0.0057	0.0195	mgl^{-1}	Investigation closed at Stage 1. < 6 results used in the exceedance calculation.
9781	Gadolinium	19/01/2016	0.0115	0.00417	0.011	mgl^{-1}	Investigation closed at Stage 1. < 6 results used in the exceedance calculation.
9784	Chromium	19/01/2016	0.00889	0.0027	0.00847	mgl^{-1}	Investigation closed at Stage 1. < 6 results used in the exceedance calculation.
9054	Nitrate	04/04/2016	14.7	13.6	14.5	mgl^{-1}	Investigation closed at Stage 2. Exceedance not statistically significant. Closed out at Stage 2.
9054	Sulphate	04/04/2016	17.6	16.6	17.2	mgl^{-1}	Investigation closed at Stage 1. < 6 results used in the exceedance calculation.
6905P2	Nitrate	05/04/2016	9.04	7.37	9.02	mgl^{-1}	Investigation closed at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
10039	Sulphate	06/04/2016	27.3	21.2	24.9	mgl^{-1}	Stage 3 investigation carried out. Ongoing.
10039	Iron	06/04/2016	0.57	0.173	0.453	mgl^{-1}	Investigation closed at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
9642	Ammonium	07/04/2016	0.5	0.0122	0.067	mgl^{-1}	Insufficient results available to carry out Stage 2 statistical analysis. Subsequent result returned to baseline, exceedance considered anomalous. Investigation closed out.
9642	Potassium	07/04/2016	6.24	3.5	6.12	mgl^{-1}	Investigation closed at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
4539P2	Chloride	07/04/2016	106	25.4	85.2	mgl^{-1}	Stage 3 investigation carried out. Subsequent result returned to baseline, exceedance considered anomalous. Investigation closed out.
6920P2	Nitrate	07/04/2016	8.17	4.8	7.64	mgl^{-1}	Investigation closed at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
4684P1	Nitrate	07/04/2016	75.4	20.7	49.4	mgl^{-1}	Investigation closed at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
6909P1	C20 - C40	11/04/2016	0.024	0.0108	0.0211	mgl^{-1}	Insufficient results available to carry out Stage 2 statistical analysis. Returned to LOD in Q2 2017. Investigation closed out.
6909P1	C10 - C20	11/04/2016	0.022	0.0104	0.0162	mgl^{-1}	Insufficient results available to carry out Stage 2 statistical analysis. Returned to LOD in Q2 2017. Investigation closed out.
6910P1	C10 - C20	12/04/2016	0.47	0.0113	0.0298	mgl^{-1}	Investigation closed at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.

Table D.3
Results Which Exceed the 4σ Level – Non-radiological Determinands (cont.)

Piezometer	Analyte	Sample Date	Result	Mean (arithmetic)	4σ	Unit	Comment
6910P1	C6 - C40	12/04/2016	0.47	0.0326	0.0737	mgl^{-1}	Insufficient results available to carry out Stage 2 statistical analysis. Returned to LOD in Q2 2017. Investigation closed out.
6910P1	Ammonium	12/04/2016	0.345	0.0234	0.177	mgl^{-1}	Investigation closed at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
6910P1	Sulphate	12/04/2016	36.2	21.6	35	mgl^{-1}	Investigation closed at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
6910P1	Chloride	12/04/2016	43.9	27.3	32.9	mgl^{-1}	Investigation closed at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
6910P2	C6 - C40	12/04/2016	1.3	0.102	1.04	mgl^{-1}	Insufficient results available to carry out Stage 2 statistical analysis. Returned to LOD in Q2 2017. Investigation closed out.
6910P2	C10 - C20	12/04/2016	1.3	0.0783	1.03	mgl^{-1}	Investigation closed at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
10008	Nitrate	14/04/2016	42.1	16.4	41.2	mgl^{-1}	Investigation closed at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
10292	Nitrate	05/05/2016	33.5	15	29.2	mgl^{-1}	Investigation closed at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
10281	Chloride	05/05/2016	28.3	22.9	25.7	mgl^{-1}	Investigation closed out at Stage 1. < 6 results used in the exceedance calculation.
6917P1	Chloride	09/05/2016	54	25.3	47.8	mgl^{-1}	Stage 3 investigation carried out. Ongoing.
10291	Iron	09/05/2016	0.425	0.0963	0.249	mgl^{-1}	Stage 3 investigation carried out. Subsequent result returned to baseline, exceedance considered anomalous. Investigation closed out.
6959P1	C20 - C40	09/05/2016	0.096	0.01	0.01	mgl^{-1}	Insufficient results available to carry out Stage 2 statistical analysis. Subsequent result returned to baseline, exceedance considered anomalous. Investigation closed out.
6959P1	C6 - C40	09/05/2016	0.14	0.0333	0.121	mgl^{-1}	Insufficient results available to carry out Stage 2 statistical analysis. Subsequent result returned to baseline, exceedance considered anomalous. Investigation closed out.
4363P1	Magnesium	09/05/2016	7.4	5.9	7.25	mgl^{-1}	Investigation closed out at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
4363P1	C20 - C40	09/05/2016	0.028	0.01	0.01	mgl^{-1}	Insufficient results available to carry out Stage 2 statistical analysis. Subsequent result returned to baseline, exceedance considered anomalous. Investigation closed out.
9112P1	C10 - C20	10/05/2016	0.03	0.01	0.01	mgl^{-1}	Subsequent result returned to baseline, exceedance considered anomalous. Investigation closed out at Stage 1.
10261	Bicarbonate	10/05/2016	9.5	2.22	3.92	mgl^{-1}	Investigation closed at Stage 1. < 6 results used in the exceedance calculation.
10261	Calcium	10/05/2016	16.9	13.2	16.3	mgl^{-1}	Investigation closed at Stage 1. < 6 results used in the exceedance calculation.
9116P1	C20 - C40	10/05/2016	0.025	0.01	0.01	mgl^{-1}	Investigation closed at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
9115P1	Iron	10/05/2016	4.08	0.718	3.24	mgl^{-1}	Investigation closed at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
9115P1	Chromium	10/05/2016	0.0072	0.00229	0.00701	mgl^{-1}	Investigation closed at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
9780	Chloride	01/06/2016	62	55.5	61.3	mgl^{-1}	Investigation closed at Stage 1. < 6 results used in the exceedance calculation. Subsequent result returned to previous levels.
6912P2	Nitrate	09/06/2016	13.2	10.1	11.5	mgl^{-1}	Investigation closed at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
10039	Chromium	07/07/2016	0.00241	0.00105	0.00221	mgl^{-1}	Investigation closed at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
10308	Sulphate	05/07/2016	21.8	19.3	21.6	mgl^{-1}	Closed out at Stage 3.
4542P1	Sulphate	04/07/2016	15	9.03	13.6	mgl^{-1}	Closed out at Stage 3.

Table D.3
Results Which Exceed the 4σ Level – Non-radiological Determinands (cont.)

Piezometer	Analyte	Sample Date	Result	Mean (arithmetic)	4σ	Unit	Comment
4542P1	Calcium	04/07/2016	10	5.08	8.45	mgl^{-1}	Closed out at Stage 3.
4684P1	Ammonium	11/07/2016	0.0436	0.00433	0.00895	mgl^{-1}	Investigation closed at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
4684P1	Nitrite	11/07/2016	0.409	0.1	0.1	mgl^{-1}	Stage 3 investigation carried out. Returned to previous levels in Q1 2017. Investigation closed out.
10307	C10 - C20	04/10/2016	0.067	0.0109	0.023	mgl^{-1}	Insufficient results available to carry out Stage 2 statistical analysis. Subsequent result returned to baseline, exceedance considered anomalous. Investigation closed out.
10307	C20 - C40	04/10/2016	0.1	0.0178	0.0672	mgl^{-1}	Insufficient results available to carry out Stage 2 statistical analysis. Subsequent result returned to baseline, exceedance considered anomalous. Investigation closed out.
10307	C6 - C40	04/10/2016	0.17	0.0308	0.052	mgl^{-1}	Insufficient results available to carry out Stage 2 statistical analysis. Subsequent result returned to baseline, exceedance considered anomalous. Investigation closed out.
10308	C10 - C20	04/10/2016	0.038	0.01	0.01	mgl^{-1}	Insufficient results available to carry out Stage 2 statistical analysis. Subsequent result returned to baseline, exceedance considered anomalous. Investigation closed out.
10308	C6 - C40	04/10/2016	0.08	0.0314	0.051	mgl^{-1}	Insufficient results available to carry out Stage 2 statistical analysis. Subsequent result returned to baseline, exceedance considered anomalous. Investigation closed out.
10039	C20 - C40	05/10/2016	0.066	0.01	0.01	mgl^{-1}	Insufficient results available to carry out Stage 2 statistical analysis. Subsequent result was higher and a 4σ exceedance. Ongoing.
10039	C6 - C40	05/10/2016	0.1	0.0314	0.0465	mgl^{-1}	Insufficient results available to carry out Stage 2 statistical analysis. Subsequent result was higher and a 4 σ exceedance. Ongoing.
9644	pH	05/10/2016	6.91	6.39	6.79	mgl^{-1}	Investigation closed at Stage 1. < 6 results used in the exceedance calculation. Subsequent result returned to baseline, exceedance considered anomalous.
4684P1	Nitrite	07/10/2016	4.37	0.126	0.483	mgl^{-1}	Investigation closed at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
9055	C20 - C40	10/10/2016	0.063	0.0123	0.0447	mgl^{-1}	Insufficient results available to carry out Stage 2 statistical analysis. Subsequent result was higher and a 3σ exceedance. Ongoing.
6960P1	Sulphate	01/11/2016	28.3	24	27.4	mgl^{-1}	Stage 3 investigation carried out. Returned to previous levels in Q2, 2017. Closed-out.
6941P1	Potassium	01/11/2016	1.66	1.23	1.49	mgl^{-1}	Investigation closed at Stage 1. Subsequent result returned to baseline, exceedance considered anomalous.
6951P1	Chloride	10/11/2016	39.6	17.8	36.7	mgl^{-1}	Stage 3 investigation carried out. Ongoing.

Appendix E
Compliance Review Information

Appendix E: Compliance Review Information

The Environment Agency CEAR document (Environment Agency, 2016) includes the requirement to review why any:

- results were late,
- samples have not been obtained,
- analysis have not been undertaken,
- relevant detection limits have not been obtained.

This appendix provides details of the samples that could not be obtained, any analysis which was not possible and samples which did not achieve the target analytical LOD. This data summary provides further information to that presented in Section 4 of the main report.

Table E.1
Samples that could not be Obtained

Piezometer	Sample Date	Reason Sample Could Not be Collected	Notes
9060	01/01/2016	No access	No access due to local construction work
10305	01/01/2016	No access	No access due to local construction work
6930p1	01/01/2016	No access	No access due to local construction work
4542p1	01/04/2016	No access	No access due to local construction work
4542p2	01/04/2016	No access	No access due to local construction work
9063	01/04/2016	Not sampled	This well was being redeveloped, no sample could be obtained until this work was completed
6972p2	01/01/2016	Sample point dry	No water within screened section at sampling point
6966p1	01/07/2016	Sample point dry	No water within screened section at sampling point

Table E.2
Analysis that could not be Completed

Piezometer	Sample Date	Reason Sample Could Not be Collected	Notes
9057	16/05/2016	Sample unsuitable for analysis	Non-radiological analysis not completed - outside residence time
9063	28/09/2016	Sample unsuitable for analysis	Non-radiological analysis not completed - outside residence time
9063	23/11/2016	Sample unsuitable for analysis	Non-radiological analysis not completed - outside residence time
10087	18/01/2016	Sample unsuitable for analysis	Non-radiological analysis not completed - outside residence time
10090	18/01/2016	Sample unsuitable for analysis	Non-radiological analysis not completed - outside residence time
10105	13/06/2016	Sample unsuitable for analysis	Non-radiological analysis not completed - outside residence time
10105	23/08/2016	Sample unsuitable for analysis	Non-radiological analysis not completed - outside residence time
10105	07/11/2016	Sample unsuitable for analysis	Non-radiological analysis not completed - outside residence time
10299	13/06/2016	Sample unsuitable for analysis	Non-radiological analysis not completed - outside residence time
10299	23/08/2016	Sample unsuitable for analysis	Non-radiological analysis not completed - outside residence time
10299	07/11/2016	Sample unsuitable for analysis	Non-radiological analysis not completed - outside residence time
10306	18/01/2016	Sample unsuitable for analysis	Non-radiological analysis not completed - outside residence time
10350	13/04/2016	Sample unsuitable for analysis	High TDS
10350	07/07/2016	Sample unsuitable for analysis	High TDS
10350	07/10/2016	Sample unsuitable for analysis	High TDS

Table E.3
Results that did not Achieve the LOD

Piezometer	Sample Date	Analysis	Result		LOD/IC	Unit	Code	Notes
10202	11/01/2016	Caesium-137	<	0.12	0.12	Bql^{-1}	D	Amended sample geometry leading to raised MDA
10202	11/01/2016	Ruthenium-106	<	1.30	1.20	Bql^{-1}	D	Amended sample geometry leading to raised MDA
10261	13/01/2016	C20-C40	<	100.00	0.01	μgl^{-1}	D	LOD raised due to dilution of sample, result has been blank corrected
6978p1	14/01/2016	Total alpha	<	0.19	0.09	Bql^{-1}	I	High solid content
10087	18/01/2016	Caesium-137	<	0.28	0.20	Bql^{-1}	I	Amended sample geometry leading to raised MDA
10087	18/01/2016	Ruthenium-106	<	2.91	2.00	Bql^{-1}	I	Amended sample geometry leading to raised MDA
10202	04/04/2016	Iodine-129	<	0.03	0.03	Bql^{-1}	D	Analysed using reduced aliquot of 1.25L not 2.5L due to Beta level.
10202	04/04/2016	Ruthenium-106	<	1.24	1.20	Bql^{-1}	D	Amended sample geometry leading to raised MDA
10204	04/04/2016	Caesium-137	<	0.46	0.20	Bql^{-1}	I	Amended sample geometry leading to raised MDA
10204	04/04/2016	Ruthenium-106	<	8.35	2.00	Bql^{-1}	I	Amended sample geometry leading to raised MDA
10307	12/04/2016	Plutonium-241	<	0.06	0.06	Bql^{-1}	D	Slightly elevated recovery causing LOD to just not being met
9057	16/05/2016	Caesium-137	<	0.13	0.12	Bql^{-1}	D	Amended sample geometry leading to raised MDA
9057	16/05/2016	Ruthenium-106	<	1.43	1.20	Bql^{-1}	D	Amended sample geometry leading to raised MDA
10090	06/06/2016	Ruthenium-106	<	1.37	1.20	Bql^{-1}	D	Amended sample geometry leading to raised MDA
10087	06/06/2016	Caesium-137	<	0.21	0.20	Bql^{-1}	I	Amended sample geometry leading to raised MDA
10087	06/06/2016	Ruthenium-106	<	2.39	2.00	Bql^{-1}	I	Amended sample geometry leading to raised MDA
10306	06/06/2016	Ruthenium-106	<	1.24	1.20	Bql^{-1}	D	Amended sample geometry leading to raised MDA
6978p1	09/06/2016	Total alpha	<	0.19	0.09	Bql^{-1}	I	High solid content
10087	23/08/2016	Caesium-137	<	0.20	0.12	Bql^{-1}	D	Amended sample geometry leading to raised MDA
10087	23/08/2016	Ruthenium-106	<	2.19	2.00	Bql^{-1}	I	Amended sample geometry leading to raised MDA
6978p1	01/09/2016	Total alpha	<	0.18	0.09	Bql^{-1}	I	High solid content
9057	10/10/2016	Ruthenium-106	<	1.28	1.20	Bql^{-1}	D	Amended sample geometry leading to raised MDA
10087	07/11/2016	Caesium-137	<	0.24	0.20	Bql^{-1}	I	Amended sample geometry leading to raised MDA
10087	07/11/2016	Ruthenium-106	<	2.56	2.00	Bql^{-1}	I	Amended sample geometry leading to raised MDA
6978p1	05/12/2016	Total alpha	<	0.15	0.09	Bql^{-1}	I	High solid content
6981p2	07/12/2016	Total alpha	<	0.04	0.03	Bql^{-1}	D	High solid content

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