SOCIETY OF BROWNFIELD RISK ASSESSMENT

Guidance on Assessing Risk to Controlled Waters from UK Land Contamination Under Conditions of Future Climate Change

Version 1.0

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PUBLICATION

This report is published by the Society of Brownfield Risk Assessment (SoBRA). It presents work undertaken by a SoBRA sub-group composed of volunteers listed in the Acknowledgments below. The publication presents clear and practical advice on how to include for the potential effects of climate change in the assessed stages of controlled waters risk assessment for land contamination. 'Controlled waters' is a term used in legislation in England and Wales. The equivalent terminology in Scotland is the 'water environment'. It is understood that Northern Ireland use both terms. Throughout this document the term 'controlled waters' is used to refer to regulated groundwater and surface water throughout the UK.

There is currently significant research and development with respect to further understanding the impacts of future climate change on land contamination risk assessment. This publication provides a summary of available reference sources up to and including 31 January 2022. It is recommended that this publication be reviewed in two years' time in light of any updates to UK legislation, policy and guidance and, if necessary, the approach for considering climate change within controlled waters risk assessments updated.

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1 INTRODUCTION

1.1 Background

The need to incorporate the predicted effects of future climate change[1] into qualitative and quantitative risk assessments is set out within the "Managing and reducing land contamination: guiding principles (GPLC2) FAQ 8" (Environment Agency, 2010), and the National Planning Policy Framework (NPPF) (Ministry of Housing, Communities & Local Government, 2021) for England and Wales. However, there is currently no UK guidance on how to consider the effects of climate change within land contamination risk assessment. At the SoBRA Annual General Meeting held in December 2020, our members voted in favour of creating a new SoBRA sub-group focussed on developing industry guidance to account for conditions of future climate change within controlled waters[2] risk assessment for UK land contamination scenarios.

1.2 Scope

This document presents clear practical guidance on how to include for the potential effects of climate change in controlled waters risk assessment for land contamination. Hereafter, the term 'risk assessment' refers to the assessment of risks posed by land contamination to controlled waters unless stated otherwise. The following aspects are included in this guidance:

- An overview of the United Kingdom (UK) regulatory guidance, and rationale as to why inclusion for the potential effects of climate change, in the stages of controlled waters risk assessment for land contamination, is a necessary consideration.
- How the varying effects (e.g. changes in soil moisture content or short-term over-saturation of soils) associated with a changing climate (e.g. protracted dry periods or extreme rainfall events) could be incorporated into conceptual site modelling and the implications of this to the Source-Pathway-Receptor linkage.
- Identifying the key model parameters that may be affected by climate change for use in controlled waters detailed quantitative risk assessment (DQRA).
- Signposting towards useful data sources to aid the consideration of climate change in risk assessment.
- Example case studies to illustrate how climate change could be considered in risk assessments.

1.3 Legislation, policy and guidance

This section summarises the relevant UK legislation, policy and guidance relating to climate change and land contamination up to and including 31 January 2022. UK legislation and guidance is currently in a state of flux with respect to climate change and it is anticipated that future changes/updates will have specific requirements with respect to climate change and the assessment of risk from contamination. Readers should ensure that any updates to legislation, policy and guidance are considered as part of the risk assessments they undertake.

[1] Whilst it is acknowledged that climate change is something that has already occurred, continues today, and will continue in the future, this document is only concerned with how to incorporate future climate change effects into risk assessment.

[2] Controlled waters is a term used in legislation in England and Wales. Its equivalent in Scotland is the water environment. It is understood that Northern Ireland use both terms. Throughout this document the term 'controlled waters' is used to refer to regulated groundwater and surface water throughout the UK.

1.3.1 Key legislation

Climate change

The Climate Change Act 2008 (HM Government, 2008) and the Climate Change (Scotland) Act 2009 (Scottish Government, 2009)[3] are the key pieces of legislation relating to climate change in the UK. The Climate Change Act 2008 established the Committee on Climate Change (CCC)[4], an independent body, to provide evidence-based advice to the UK Government and Devolved Administrations on emissions targets and to report to Parliament on progress made in reducing greenhouse gas emissions and preparing for climate change. The Act requires a UK Climate Change Risk Assessment (CCRA) to be published every five years to assess 'the risks for the UK from the current and predicted impacts of climate change'[5]. The Act also includes a requirement for the Devolved Administrations to develop national strategic adaptation programmes to manage the effects of unavoidable climate change in response to the CCRA, setting out key actions over five years.

Various climate change adaption plans have been prepared by the UK Government and Devolved Administrations (refer to Appendix A.1). These place requirements on national regulators to address climate related risks to/from flooding, coastal erosion, and water abstraction, but put in place no specific requirements for characterisation and risk assessment of controlled waters. More overarching requirements that can be interpreted as including the effects of climate change on controlled waters risk assessment are in place, i.e. "*mitigating and adapting to climate change"*. However, the various planning regimes only have specific requirements for sustainability, management of flood risks and a need to robustly assess land quality risks.

Land contamination

Part IIA of the Environmental Protection Act 1990 (HM Government, 1990) is the primary legislation in Scotland, England and Wales[6] that relates to the assessment and remediation of land contamination under its current use. There is no reference to considering climate change effects as part of the investigation and assessment of land contamination within this legislation.

For sites undergoing development or a change of use, land contamination issues are addressed through the planning system. Planning policy is devolved but in all jurisdictions the responsibility for the safe development of a site rests with the developer via a 'suitable for use' approach. Appendix 1 provides a detailed summary of the policy currently in place in relation to climate change and land contamination within each of the Devolved Nations in the UK.

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[3] As amended by the Climate Change (Emissions Reduction Targets) (Scotland) Act 2019 (Scottish Government, 2019), increasing the ambition of Scotland's emissions reduction targets to net zero by 2045 and revising interim and annual emissions reduction targets.

[4] Further information on the CCC is available at: https://www.theccc.org.uk/.

[5] The most recent (2022) UK Climate Change Risk Assessment is available at: https://www.gov.uk/government/publications/uk-climate-change-risk-assessment-2022.

[6] The Contaminated Land Regime, which is set out in Part III of the Waste and Contaminated Land (Northern Ireland) Order 1997 (HM Government, 1997), has been enacted but is not yet in force.

1.3.2 Guidance

Appendix 2 (Literature Review) provides a review of current UK and international guidance for considering future climate change effects within land contamination risk assessments.

The general requirement of wider UK land contamination guidance is that a risk assessment should consider all matters that are needed to address the requirements of the regime they are being prepared under. Again, it is not explicitly stated that climate change affects must be considered, but where climate change will affect the Conceptual Site Model (CSM) and influence the risks that are present then the regulators, clients or consultants involved should reasonably expect climate change to be accounted for.

2 OVERVIEW OF FUTURE CLIMATE CHANGE IN THE UK

2.1 Summary of climate change causes and trends in the UK

Climate science is a broad and complex area of study, therefore for brevity this section is intended as a summary of the causes and trends of climate change only. A more comprehensive discussion can be found in Appendix 3.

The UK Met Office defines climate change as "large-scale, long-term shift in the planet's weather patterns and average temperatures" (Met Office 2). Climatic change is usually assessed by averaging data over a 30-year period; the most recent reference period is 1991-2020.

A number of human-induced factors have been linked to climatic change. Rising temperatures are linked to the anthropogenic release of greenhouse gases including carbon dioxide, methane, and nitrous oxide. Additional anthropogenic factors that can exacerbate the effects of climatic change include population growth; deforestation; peat bog degradation; intensification of agriculture; increased surface runoff associated with hardstanding in urban areas such as concrete and asphalt; ageing infrastructure (such as surface and foul water drainage unable to cope with increased discharge during projected periods of heavy rainfall winter months); and increased water consumption.

The Met Office UK Climate Projections (UKCP18) are the most up-to-date climate projections for the UK (Murphy, et al., 2019) (Kendon, et al., 2019), superseding UKCP09 projections (Jenkins et al., 2009). The UKCP09 scenarios are based on the Special Report Emissions Scenarios (SRES) greenhouse gas emission scenarios, whereas the UKCP18 are based on Representative Concentration Pathway (RCP) greenhouse gas emission scenarios (see Appendix 3 for a description of the most relevant RCPs).

The UKCP18 projections have higher spatial resolution, incorporate increased scientific understanding of processes and provide an approach to deal with uncertainties. Generally, the UKCP18 projects that climatic change in the UK will result in more extreme events such as intense rainfall and storm events resulting in flash floods; hotter, drier summers with a higher likelihood of heat waves due to higher temperatures; increased potential evaporation due to higher summer temperatures and consequently a potential increase in drought conditions; milder, wetter, winters and potentially increased groundwater recharge; and rising sea levels (Met Office, 2021a).

The UKCP18 projects that the frequency of dry, warm events will increase in the future as a result of climate change. The UK Met Office publishes the State of the UK Climate Report on an annual basis and can be downloaded from the Met Office website (Met Office, 2021a).

2.2 Available projections of meteorological and sea level change in the UK

This section is concerned with future changes in meteorology and sea level.

Section 2.2.1 describes UKCP18 climate modelling. Later sub-sections (sections 0 to 2.2.4) provide projections for precipitation, temperature, and sea level, for the UK based on the UKCP18 information. The projections are of average effects and do not necessarily include the effects of extreme events. As the effects of climate change vary seasonally and spatially across the UK, careful consideration should be given to the site setting when choosing the appropriate climate model output for use in risk assessment.

2.2.1 UKCP18 Projections

The information provided in this section is derived from the UKCP18 series of reports, which are available on the Met Office website (Met Office Website, 2022). The UKCP18 comprises climate simulations of five possible future increases in average global radiative forcing (per the IPPC-see Appendix 3 for definition and details of RCPs) using a baseline of 1981-2000[7] extending to 2100. Users of the model output are urged by the UKCP18 authors to focus on the RCP scenarios and discount the SRES A1B[8] emissions scenario. Model projections are available at the following scales:

- Global: twenty-eight projections at a 60-kilometre (km) grid resolution;
- Regional: twelve projections at a 12 km grid resolution;
- Local: set of twelve projections at a 2.2 km grid scale downscaled from regional projections scales, using a ‘convection permitting’ climate model (CPM) with a grid spacing of < 5km[9,10].

Additionally, model outputs from a set of probabilistic projections based on SRES scenarios are available. These provide a comprehensive assessment of uncertainties in the UKCP18 and are used to assess model performance. However, due to the number of assumptions used to combine evidence, it is not recommended that the probabilistic outputs are used for risk assessment purposes. Users should instead focus on utilising the UKCP18 RCP projections available at global, regional, and local scales.

Examples of data obtained from the UKCP18 model projections for 2080-2099 are given in Table 2-1.

Table 2-1: Example UKCP18 RCP scenarios with associated predicted 95th percentile temperature and rainfall changes from 1981-2000 to 2080-2099 for the UK region. Source: UKCP18 Overview Report (Lowe, et al., 2019).

RCP scenario	Radiative forcing at 2100 ($W\ m^{-2}$)	Temperature Increase (°C)	Winter Precipitation Increase (%)
RCP2.6 (lowest emission scenario)	2.6	2.6	22
RCP8.5 (highest emission scenario)	8.5	6.5	48

Only RCP8.5 projections are available at global, regional, and local scales. Local projections are also available re-gridded at a 5 km resolution to Ordnance Survey’s British National Grid (OSGB), which is a more robust way of viewing the data as it allows the user to view averaged output of more than one 2.2 km grid square (Met Office, 2021) (it may be possible

[7] Users have the option to choose from 1961-1990 or 1991-2010 as an alternative to the UKCP18 baseline.

[8] SRES A1B is an emissions scenario produced by the IPCC in 2000 and utilised by UKCP in the first iteration of the project (UKCP09). It does not consider recent developments in climate mitigation, and its assumptions are out of date e.g. renewable energy technology developments.

[9] Users have the option to choose from 1981-2010 as an alternative to the UKCP18 baseline.

[10] UKCP Local Projections updated in 2021 to correct error affecting snow, winter temperature and hourly precipitation extremes; ensure re-run datasets are utilised (‘CPM_new’).

to view this data in freely available geographic information system (GIS) software). Users can extract data directly from the Global and Regional projections. However, scaling may be required to extract data from the Local projections, as these are only available in three 20-year time slices (1981-2000, 2021-2040 and 2061-2080).

Risk assessors will need to decide which RCP scenario they wish to use (see Appendix 3). If RCP2.6 is considered the most appropriate, only output from the UKCP global models can be used.

The authors of this guidance recommend the following:

Selecting data based on a Worst-Case Scenario as a conservative approach: e.g. RCP8.5 using the Local Scale. This scale model provides the highest spatial resolution and better resolves extreme precipitation events. Projections are only available until the 2080s.

To support a sensitivity analysis (if required) selecting data based on a Best-Case Scenario: e.g. RCP2.6 using the Global Scale Model is considered appropriate. However, this should be reviewed in accordance with the most up to date available information and used with caution as RCP2.6 uses Global Scale data and therefore has a greater degrees of uncertainty.

Please note: At a Local Scale projection data is currently only available for RCP8.5, and RCP2.6 projection data is currently only available at a Global Scale.

Risk assessors should consider the longevity of the proposed development and decide upon an appropriate future climatic period to include in the DQRA e.g. near future projections to 2050 versus far future projections to 2080 and 2100.

2.2.2 Precipitation

All UKCP RCP projections show that, apart from northeast Scotland, the UK is anticipated to experience greater winter precipitation in the future (see Figure 2-), with all regions experiencing less summer precipitation. The global scale models show greater winter precipitation with the RCP8.5 scenario. Trends are for greater increases in winter precipitation in western coastal areas and greater decreases in summer precipitation in southern coastal areas. Both the CPM and RCM RCP8.5 projections show an increase in winter rainfall extremes and increased atmospheric storminess. The CPM projections in particular show a large increase in the frequency of the most intense winter storms over the North Atlantic and Europe. Model GC3.05-PPE suggests increased winter storminess is associated with a positive phase of North Atlantic Oscillation (NAO) (enhanced westerly winds associated with strengthened meridional gradient) (Lowe, et al., 2019).

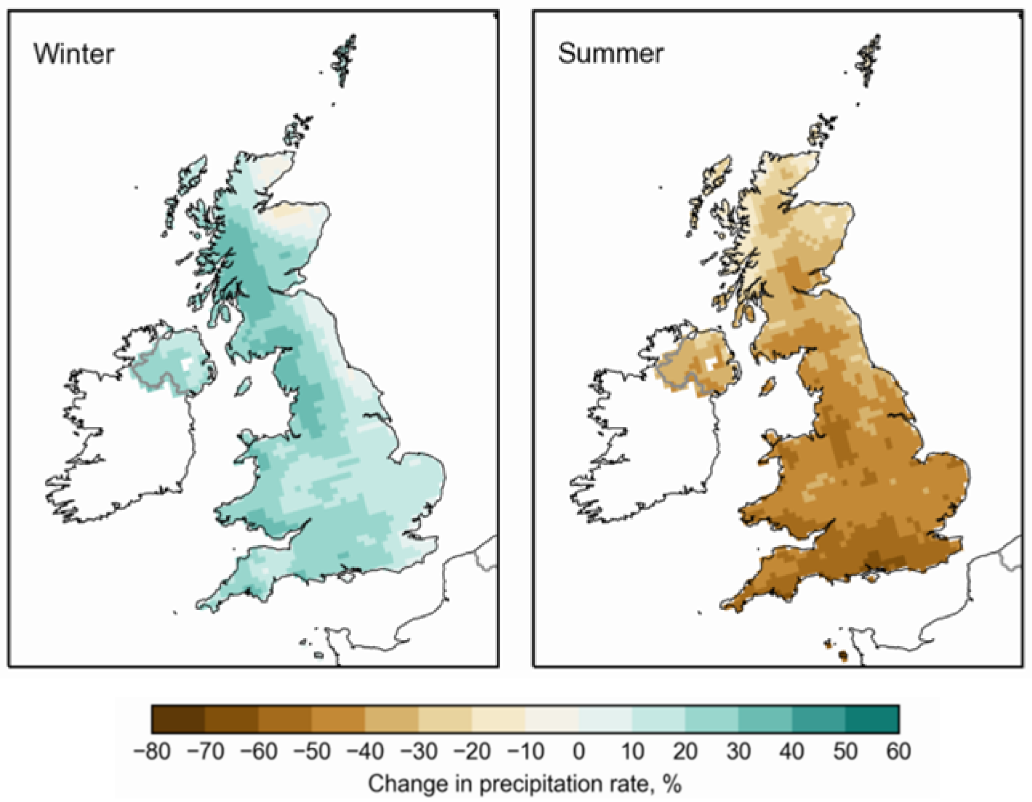

Figure 2-1: Projected seasonal changes in mean precipitation 2060-2080 from baseline (1981-2000). Extract from Figure 2.23, UKCP18 Overview Report (Lowe, et al., 2019). Winter=December to January. Summer=June to August.

2.2.3 Temperature

As average air temperatures increase, the atmosphere's capability to hold moisture increases. The UKCP18 projections show that all areas of the UK will experience warming, with greater warming in summer than in winter. Figure 2- shows that southern England is projected to experience a greater change in air temperature than northern areas of the UK, with more pronounced warming experienced in all regions during 2061-2080. Projected increases in temperature together with increased potential evapotranspiration, particularly in summer months, may have a negative impact on groundwater recharge, groundwater levels and river flow. There is also less snow projected, which may impact groundwater recharge and river flow in upland areas that are fed by snow melt.

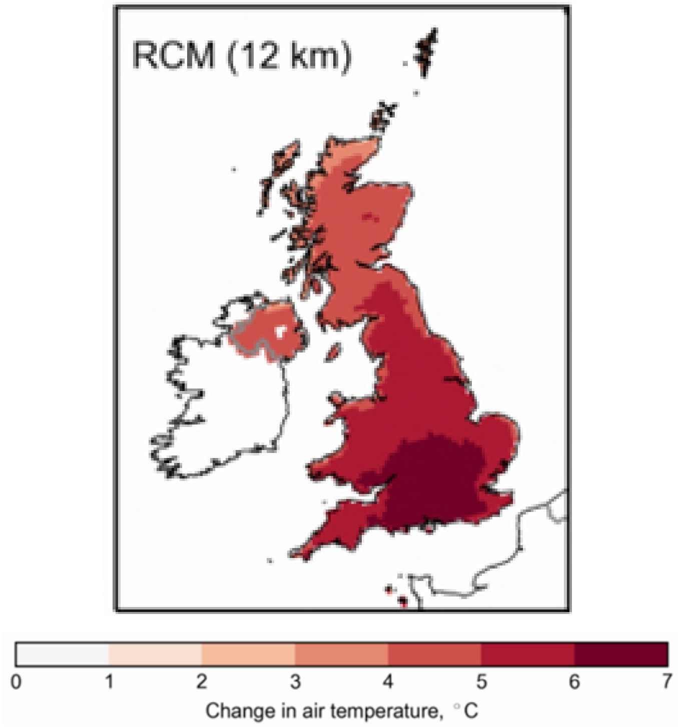

Figure 2-2: Projected average summer air temperature change for 2060-2080 under RCP8.5 (baseline 1981-2000) for the Regional Climate Model (RCM). Extract from Figure 2.20, UKCP18 overview report (Lowe, et al., 2019).

2.2.4 Sea Level Rise

The largest component of global sea level rise is thermal expansion, followed by the contribution from melting glaciers and ice caps in Greenland and the Antarctic. Research suggests that if global emissions are not reduced, UK sea levels could rise up to 1-1.12 metres by 2100 (UKCP18 projections (Fung, et al., 2018) (Palmer, et al., 2018), (see Figure 2-); (Slingo, 2021)) and 4 metres by 2300 (Fung, et al., 2018), although the full extent of seal level rise is not anticipated to occur until the end of 2100. A north-south gradient is observed in projected sea level trends in the UK, with greater sea level rise projected for the south. The north-south gradient is mostly attributed to isostatic uplift changes, with a smaller contribution from Greenland continental ice sheet melt (Fung, et al., 2018). Rising sea levels are also anticipated to result in higher storm surges (Palmer, et al., 2018) (Environment Agency, 2019), particularly where storm events coincide with spring tides. Based on UKCP18 modelling work using the RCP8.5 scenario, it is likely that mean sea level change will only have a small effect on the size of storm surges and increases in water levels will be associated predominately with atmospheric storminess changes (Palmer, et al., 2018)). Projections under RCP8.5 to 2100 suggest a decrease in wave height by 10%. The projected rise in sea levels (and to a lesser extent, the increased frequency and intensity of storms) is also likely to result in increased coastal erosion.

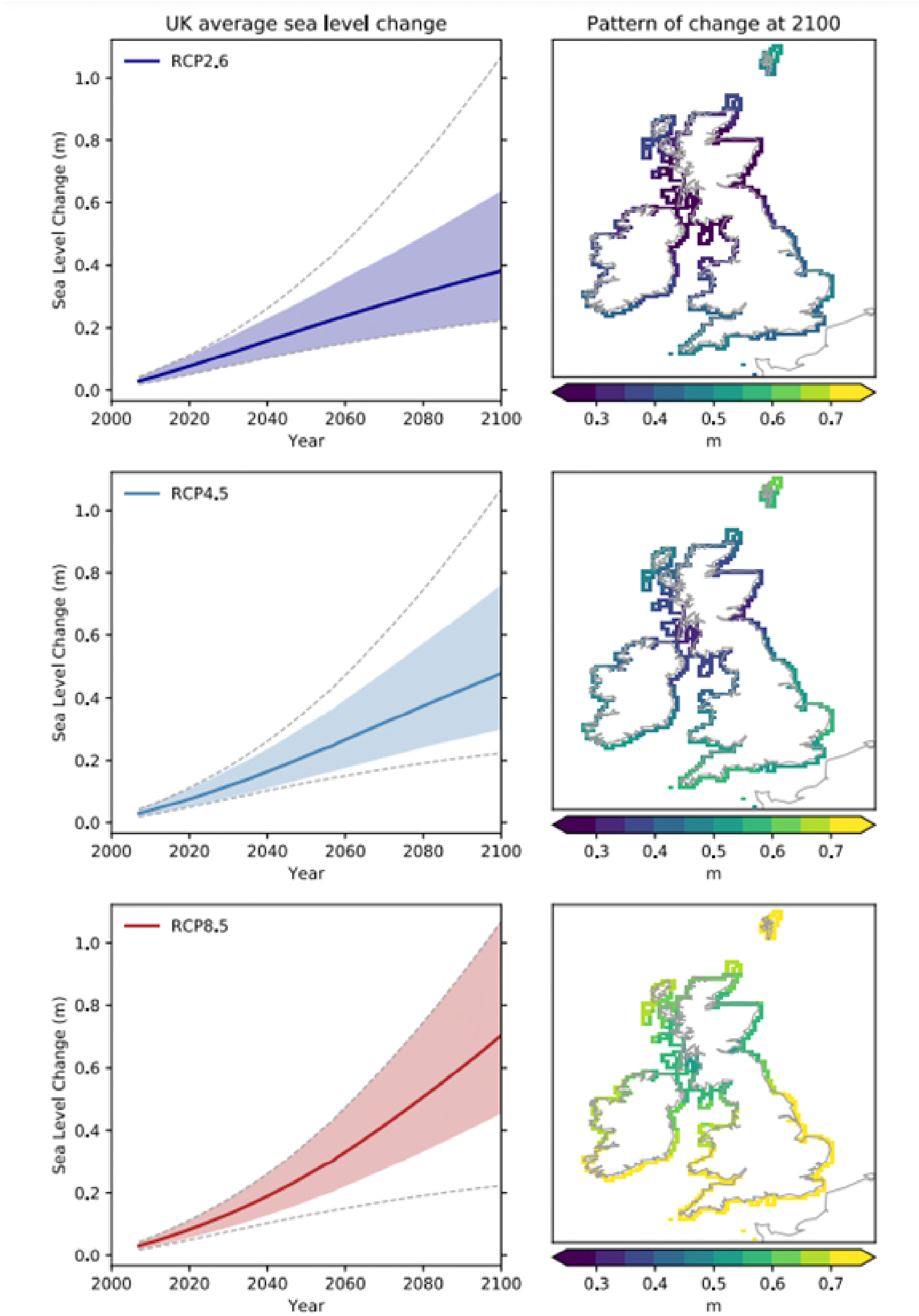

Figure 2-3: Projected sea level rise 2000-2100 for RCP2.6, RCP4.5 and RCP8.5 scenarios based on the average of 49 UK ports (left) and the spatial pattern of projected sea level rise at 2100 relative to a baseline of 1981-2000. Left hand charts: The dotted lines show the range, the bold lines show the median change, and the shaded area the likely range (5th-95th percentile). Right hand charts: regional relative sea level around the UK and Ireland coastline in 2100. Extract from UKCP18 Fact Sheet: Sea level rise and storm surge (Fung, et al., 2018), Figure 1.

2.3 Available projections of climate induced change to groundwater and surface water in the UK

This section is concerned with future climate change effects on groundwater and surface water. UK projections of consequential changes to groundwater dependent terrestrial ecosystems (GWDTE), patterns of land use and water demand have not been made, but in specific circumstances will need to be addressed by a risk assessor.

Developments in remote sensing and continuous monitoring technologies are providing further opportunities to obtain data at higher resolution on parameters such as groundwater levels, water quality, temperature and soil moisture. This data can further enhance our conceptual understanding and how climate change can affect environmental parameters at a site-specific and local scale.

2.3.1 Groundwater Recharge

British Geological Survey (BGS) Report OR17/026 (Mansour & Hughes, 2017) details the BGS distributed recharge model (ZOODRM) run with rainfall and potential evaporation from the BGS Future Flows and Groundwater Level (FFGWL) climate datasets (one ensemble of eleven variants of the HADCM3 Regional Climate Model (RCM)), underpinned by the UKCP09 climate simulations under the SRES A1B Intergovernmental Panel on Climate Change (IPCC) emissions scenario) to produce recharge values for Great Britain (England, Scotland, and Wales). For groundwater bodies in England and Wales, this includes:

- Annual recharge totals produced for specific time periods (simulated historical (1950-2009), 2020s (2010-2039), 2050s (2040-2069) and 2080s (2070-2099));
- Monthly simulated historical recharge values (mean, 25th and 75th percentiles);
- Maximum, minimum and median monthly change factors (percentage difference between monthly average recharge for future climate and historical simulation) for each groundwater body for the eleven ensemble members summarised in maps.

Additionally, monthly recharge values, absolute recharge values for specific time slices, and seasonal/monthly empirical cumulative distribution functions have been produced for River Basin Management Districts (RBMDs) in England and Wales.

The main outcomes from the projections are:

- Strong seasonal signal present in projected recharge data.
- Shortening of the recharge season from 5-7 months (September-April) in the historical simulation (1950-2009) to 3-4 months, observed in all climate ensemble outputs, both in the changes to percentage recharge and monthly differences.
- Total recharge volumes produced for the RBMDs were noted to markedly increase during winter months in the 2080s, with small increases noted in the 2020s and 2050s. Widespread decreases in discharge were noted during summer months in the 2050s and 2020s, smaller decreases and more spatial variability noted in the 2080s.
- A greater amount of recharge is therefore projected to occur in a shorter period of time.
- The FFGWL project team suggest this could lead to a flashier groundwater level response, making aquifers more vulnerable to drought if rainfall fails in one or two months.

In more recently published aspects of the study, Hughes et al. (Hughes, et al., 2021) extend their commentary to what may happen under higher emissions scenario RCP8.5. They comment that the greater variability in the climate and associated uncertainty could affect winter recharge totals and could reduce overall recharge volumes. The authors speculate that if ‘blocking high pressure events’ (where a high pressure cell is dominant and prevents low pressure cells from reaching the UK) were to occur during winter, even for a short duration, this may significantly reduce potential recharge totals.

During the 2050s and particularly the 2080s, an increase in winter rainfall is the main driver behind the projected overall rise in groundwater levels (section 2.3.2). The occurrence of rainfall over a shorter duration is a minor contributor to the same effect. Smaller increases in recharge are projected in autumn and spring due to increased rainfall during these seasons. The authors conclude that wetter winters are projected to result in overall increase in total recharge. More intense rainfall events may lead to increased surface water run-off due to oversaturation of the ground, therefore recharge may not be directly proportional to rainfall.

There is also a spatial element to the changes in recharge, with the data displaying an east-west split across England and Wales (see Figure 2-4). Recharge in eastern RBMDs is concentrated in winter. For example, the Thames and Humber RBMDs show greater increases in total recharge in winter in comparison to RBMDs in the northwest, where the greatest recharge is shown in autumn. Greater increases in winter precipitation are projected in western regions (particularly northwest England and Wales) in comparison to eastern regions (Arnell, Halliday, Battarbee, Skeffington, & Wade, 2015).

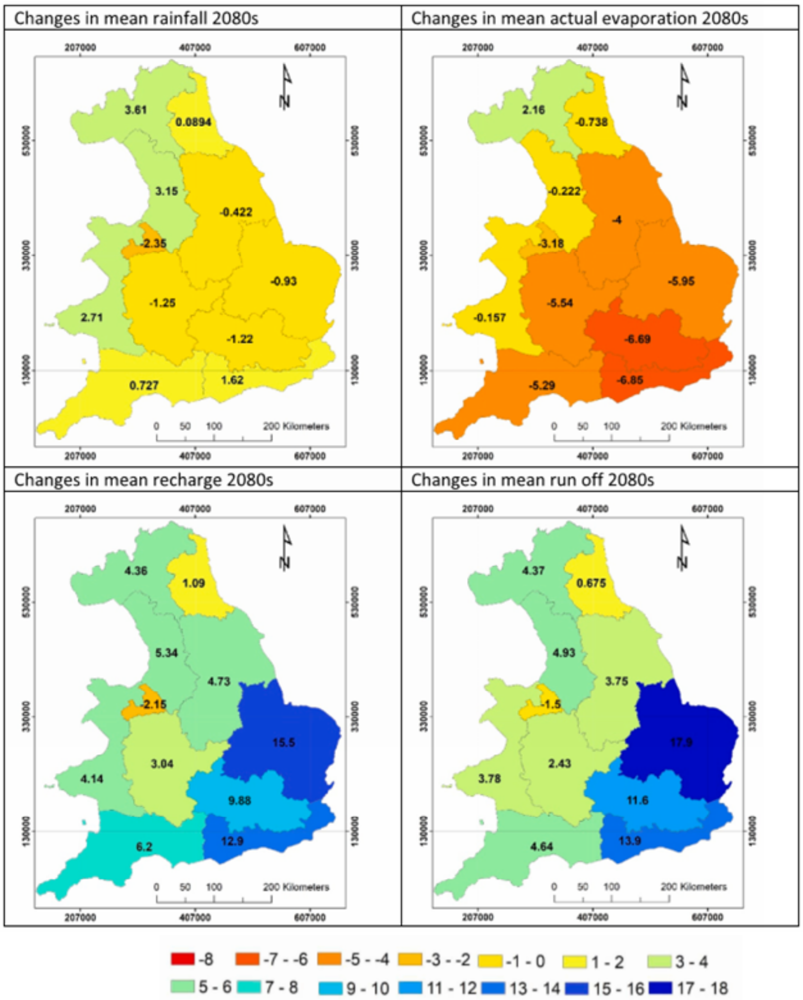

Figure 2-4: Spatial distribution of percentage changes in total rainfall, actual evaporation, recharge and run off for River Basin Management Districts for the 2080s from baseline of either 1961-1990 or 1971-2000. Extract from Figure 4 (Hughes, et al., 2021).

Enhanced Future Flows and Groundwater (eFLaG) (Hannaford, et al., 2022) is a successor to the Future Flows and Groundwater Levels dataset and uses the UKCP18 meteorological data. In 2022, projections of future recharge spatially averaged over 588 groundwater bodies covering England, Wales and Scotland were made freely available as shown in Figure 2-5. The projections are derived from groundwater recharge models (ZOODRM) assuming RCP8.5 emissions scenario from a 12-member ensemble of transient projections of near future (2020–2049) and far future (2050-2079) against the present (baseline: 1989 – 2018). Projections of groundwater recharge are available to view in the eFLaG portal[11]. The groundwater projections are expressed in absolute changes (mm/day) and percentage changes for the 558 groundwater bodies in England, Scotland and Wales. The statistics are summarised as monthly averages and seasonal averages. No data on projected future groundwater recharge is currently available for Northern Ireland.

There are two main sources of information on future recharge projections:

1. The eFLaG project has modelled long term average recharge on a 2 km grid over England, Wales, and Scotland based on UKCP18 projections. Daily recharge (in units of mm/day) to groundwater bodies is available for use under the terms of the Open Government Licence[12] from 1982 to 2080 for each of the twelve ensemble members of high emissions scenario RCP8.5.
2. In England, Wales and southern Scotland[13], there is the British Geological Survey report "*Summary of results for national scale recharge modelling under conditions of predicted climate change*" (Commissioned report OR/17/026). This is based on the somewhat dated UKCP09 projections of climate change in the UK, and an ensemble of simulations under a medium emissions scenario[14] only. Data is available for download via data.gov.uk[15] and licence conditions apply.

[11] Available at: https://eip.ceh.ac.uk/hydrology/eflag/.

[12] Available at: https://catalogue.ceh.ac.uk/datastore/eidchub/1bb90673-ad37-4679-90b9-0126109639a9/Groundwater/ZOODRM/simrcm/.

[13] The data included for Scotland is limited to the cross-border Solway-Tweed River Basin Management District.

[14] Scenario A1B in the Special Report on Emissions Scenarios (Nakicenovic, et al., 2000a) is of rapid economic growth with a balanced emphasis on energy sources and corresponds with an RCP between RCP4.5 and RCP6.0.

[15] Available at: https://data.gov.uk/dataset/f296b638-78d5-4d92-8f56-e4aaae7c0772/national-great-britain-recharge-model-climate-change-runs-11-regional-climate-models

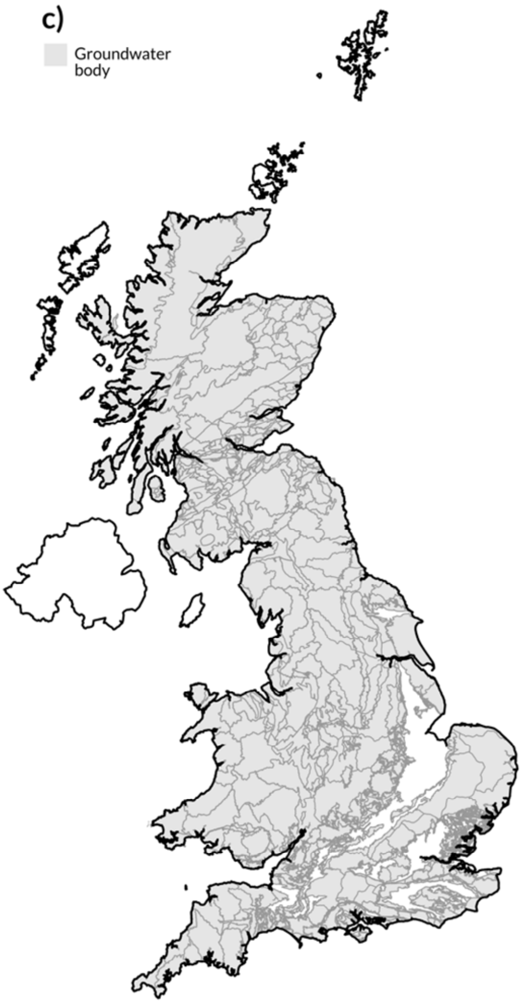

Figure 2-5: Map of the 558 groundwater bodies. Extract from Figure 3 (Hannaford, et al., 2022).

2.3.2 Groundwater Level

The BGS FFGWL project has assessed the impact of climate change on river flows and groundwater levels in Great Britain. Two types of groundwater models have been developed as a part of the project:

- Lumped catchment groundwater models of groundwater level time series at 24 boreholes in main aquifers across Great Britain; and
- A ZOOMQ3D distributed model of the Chalk Aquifer of the Marlborough and Berkshire Downs and Southwest Chilterns.

The FFGWL project used climate projections based on UKCP09, HADRM3 (Met Office Regional model), as a continuous time-series from 1950-2099. Three time-slice and greenhouse gas emission scenario combinations have been produced:

- 2050s under a medium emissions scenario (A1B),
- 2080s under a medium emissions scenario (A1B), and,
- 2050s under a high emission scenario (A1FI).

The FFGWL project uses three types of hydrological and groundwater models:

- Regionalised models: range of catchments considered together, and best overall set of parameters defined. These models have an extended climate range under which to evaluate model parameters.
- Catchment models: model parameters are fined tuned to best reproduce site gauge-flow statistics and local hydrological processes; and,
- Hybrid models: regionalised and calibrated parameters are used.

The eFLaG project (Hannaford, et al., 2022) has made freely available[16] groundwater level projections for 54 boreholes in Principal Aquifers in England, Scotland and Wales, which have been chosen to reflect national-scale representativeness of rainfall, soils, elevation, aquifers etc (Figure 2-). Currently, there is limited data for Scotland and Wales, and no data at all for Northern Ireland however the eFLaG project hopes to increase coverage and the number of boreholes in the future.

The projections are derived from groundwater level models (Aquimod) assuming RCP8.5 emissions scenario from a 12-member ensemble of transient projections of near future (2020–2049) and far future (2050-2079) against the present (baseline: 1989 – 2018). Groundwater level projections are available to view in the eFLaG portal.

Change in water level in response to recharge is proportional to the ratio of the transmissivity of the aquifer to its storage coefficient. The ratio is referred to as the aquifer diffusivity. As an example, the diffusivity of chalk is greater than that of sandstone, and therefore recharge changes related to climate change can be expected to be more evident in chalk aquifers than in sandstone aquifers. eFLaG datasets provide an assessment for bedrock aquifers only, but do not provide data for superficial aquifers. Smaller, shallower aquifers may be more affected by the effects of future climate change than deeper regional scale aquifers.

[16] Available at: https://eip.ceh.ac.uk/hydrology/eflag/.

The current best two sources of information for changes in groundwater level within bedrock aquifers are the following British Geological Survey results of groundwater level modelling:

1. At 24 observation boreholes undertaken as part of the Future Flows project[17] that is underpinned by UKCP09 projections. Data is available for download[18] and for use under licence conditions for:
   - Daily groundwater level data from 1950 to 2099 for each of the eleven ensemble members of a medium emissions scenario (A1B);
   - 10,000 realisations of monthly change in groundwater level in the 2050s under a medium emissions scenario (A1B);
   - 10,000 realisations of monthly change in groundwater level in the 2080s under a medium emissions scenario (A1B); and
   - 10,000 realisations of monthly change in groundwater level in the 2050s under a high emissions scenario (A1FI).
2. At 54 boreholes in principal aquifers in England, Wales, and in select classified groundwater bodies in Scotland, undertaken as part of the eFLaG project[19] that is underpinned by UKCP18 projections. Data is available for download[20] and for use under the terms of the Open Government Licence for:
   - Daily groundwater level data from 1982 to 2080 for each of the twelve ensemble members of a high emissions scenario (RCP8.5).

It should be noted that within both data sets there is no groundwater level change data for superficial aquifers due to the high levels of uncertainty associated with modelling these aquifers. Borehole coverage outside of England is limited.

[17] Available at: https://www2.bgs.ac.uk/groundwater/change/FutureFlows/home.html.

[18] Available at: https://www2.bgs.ac.uk/groundwater/change/FutureFlows/sites.html.

[19] A description of the eFLaG project can be found at: https://www.ceh.ac.uk/our-science/projects/eflag-enhanced-future-flows-and-groundwater.

[20] Available at: https://eip.ceh.ac.uk/hydrology/eflag/. Data are also available in .CSV format: https://catalogue.ceh.ac.uk/datastore/eidchub/1bb90673-ad37-4679-90b9-0126109639a9/Groundwater/AquiMod/simrcm/.

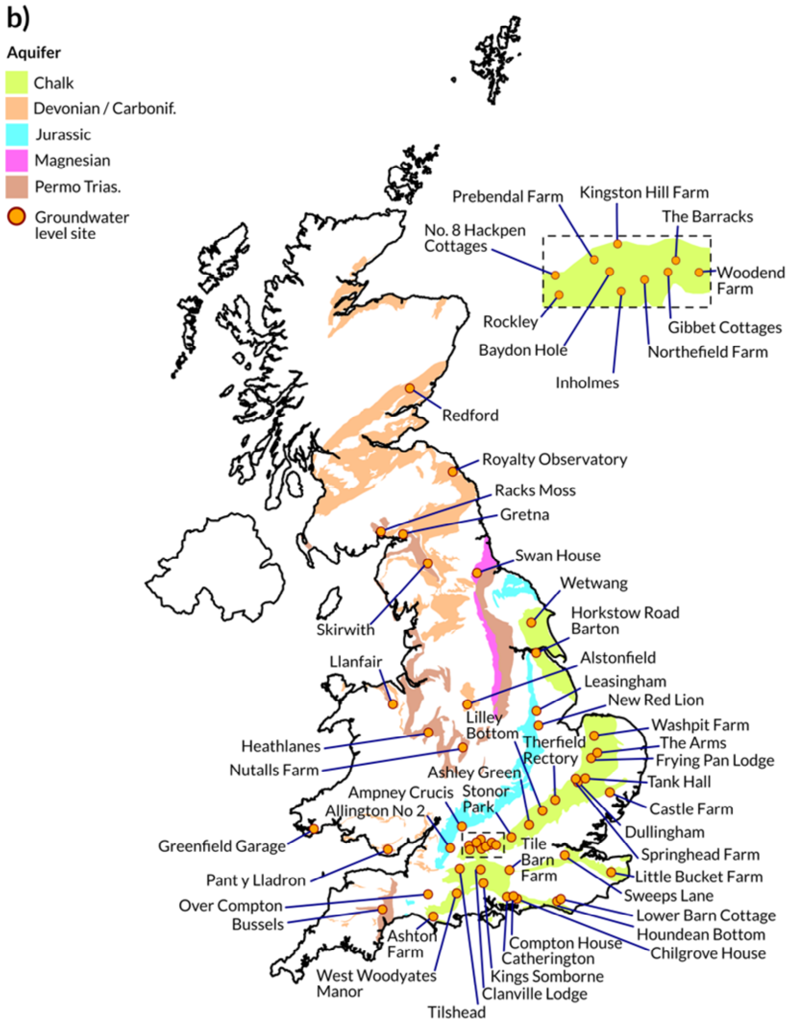

Figure 2-6: Map of the 54 eFLaG boreholes and principal UK aquifers. Extract from Figure 3 (Hannaford, et al., 2022).

2.3.3 Surface Water Flow

The FFGWL product includes eleven time series of daily river flow at 282 river sites from 1951 to 2098 using climate projections based on UKCP09 (Section 2.3.2). The Q95 (the flow exceeded 95% of the time) is projected to decrease by 2050s anywhere in Britain according to all but two ensemble members with small increases in the east and/or centre. The size of decreases is variable, with areas such as northwest Scotland and northwest England showing little change for two ensemble members, to reductions of up to 80% in Wales and northwest England for up to three ensemble members. But most ensemble members do not suggest reductions will exceed 60%.

The eFLaG project (Hannaford, et al., 2022) includes 200 river catchments across the UK (Figure 2-). Historical (1963 to 2018) and projected (1982 to 2080) daily river flow (m^3/s) data is available for the RCP8.5 scenario derived from a range of river flow models (Grid-to-Grid, PDM, GR4J and GR6J). River level projections are available to view in the eFLaG portal[21]. Transient low flow projections are available for Q90, Q70, Q50 and Q30 which are expressed

[21] Available at: https://eip.ceh.ac.uk/hydrology/eflag/.

in absolute changes (m^3/s) and percentage changes. Transient low flows are projected to decrease in most catchments through the 21st century.

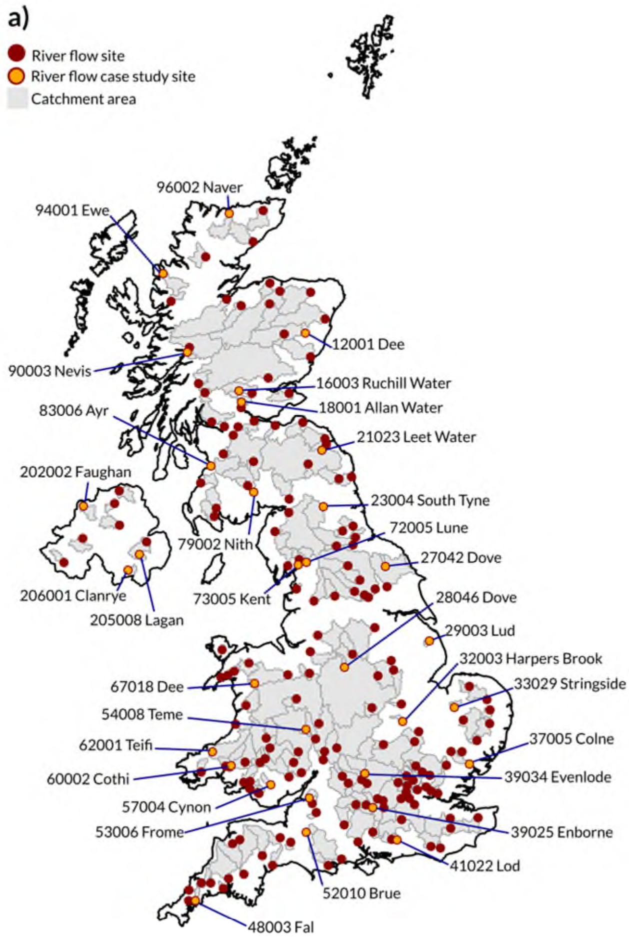

Figure 2-7: Map of the 200 eFLaG river flow sites and their catchment areas. Extract from Figure 3 (Hannaford, et al., 2022).

2.4 Summary

There are a number of authoritative sources modelling the potential climate change impacts on the UK, with the key sources of information being the UKCP18 Climate Change Predictions, and the BGS Future Flows and Groundwater Level dataset, with the latter being superseded in 2022 by the Enhanced Future Flows and Groundwater Level datasets.

The key points are as follows:

- Projected increase in winter precipitation and decrease in summer precipitation, with some spatial variation;
- All areas of the UK to experience warming, with greater summer warming than winter warming and greater impacts to be seen in southern Britain;
- All areas of the UK to experience sea-level rise with greater sea-level rise projected in the south;
- Recharge to groundwater bodies generally to increase, however restricted to shorter recharge windows in winter and potentially greater spatial variability, with potentially increase in vulnerability to droughts;

- The eFLAG project has projected changes to groundwater levels at 54 boreholes within Principal Aquifers and should be consulted for area specific predictions;
- The eFLAG project also projects river flow levels at 200 river catchments and again should be consulted for area specific predictions; and,
- The eFLAG project has projected changes to groundwater recharge within groundwater bodies covering England, Wales and Scotland covering superficial aquifers and should be consulted for area specific predictions.

3 CLIMATE CHANGE AND CONTROLLED WATERS RISK ASSESSMENT

3.1 Approach to Land Contamination Risk Assessments

Land contamination risk assessments are undertaken to identify potential contaminant linkages, and to assess and evaluate whether there is an acceptable level of risk to identified receptors. They use a staged risk-based approach to iteratively improve and gain knowledge of the area under investigation.

Risk assessments are typically undertaken for the purpose of land redevelopment and/or the assessment of environmental liability and assess the likely risk to water both now and into the future. SoBRA recognises that the effects of climate change will cause a progressive change in the environmental conditions that constrain these risk assessments.

The uncertainty in societal choices over the coming years/decades will largely determine the extent, and severity, of climatic change that occurs beyond the end of this century. As such, most publicly available and authoritative datasets only extend to the year 2100. It is therefore recommended that land contamination risk assessments, which extend beyond the end of this century, address the potential effects of climate change qualitatively.

3.2 Addressing Climate Change in a Conceptual Model

BS EN ISO 21365 (British Standards Institute, 2020) identifies the CSM to be a synthesis of all relevant information about a potentially contaminated site (including physical, chemical, and biological processes which control contaminant release and migration) with interpretation as necessary and recognition of uncertainties. The description relies on the concept, of "source-pathway-receptor linkages" (sometimes termed 'contaminant linkages') that are, or might be, present.

Figure 3-1 presents an illustration of CSM components focusing on risks to controlled waters receptors under current climatic conditions. For an illustration of the impact of climate change on a CSM, the reader is referred to Figure 3-2 to Figure 3-4.

CSM components may be affected due to future climatic changes, which may be recognised under the category of 'foreseeable events' as defined in BS EN IS 21365 (British Standards Institute, 2020) clause 5.7. Changes to CSM components could be chronic (long duration processes) e.g. risk to groundwater from increased leachate generation, or acute (rapid events) e.g. erosion of source area or pluvial flooding (refer to Table 3-1 for more detailed description of these processes and their association with climatic events). The relevance of both acute and/or chronic scenarios should be accounted for when considering the potential effects of climatic changes on a CSM.

Furthermore, the Environment Agency's Guiding Principles for Land Contamination (GPLC2) (Environment Agency, 2010) document suggests a "what if" approach to identify new potential contaminant linkages, including changes to and removal of linkages. A number of potential "what-if" scenarios, that may arise as a result of direct (e.g. increased rainfall) and indirect (e.g. coastal erosion) climate change effects, have the potential to influence a CSM. Several of these "what-if" scenarios are presented in Table 3-1. The relevance of these scenarios should be considered by the practitioner on a site-by-site basis through all stages of CSM development.

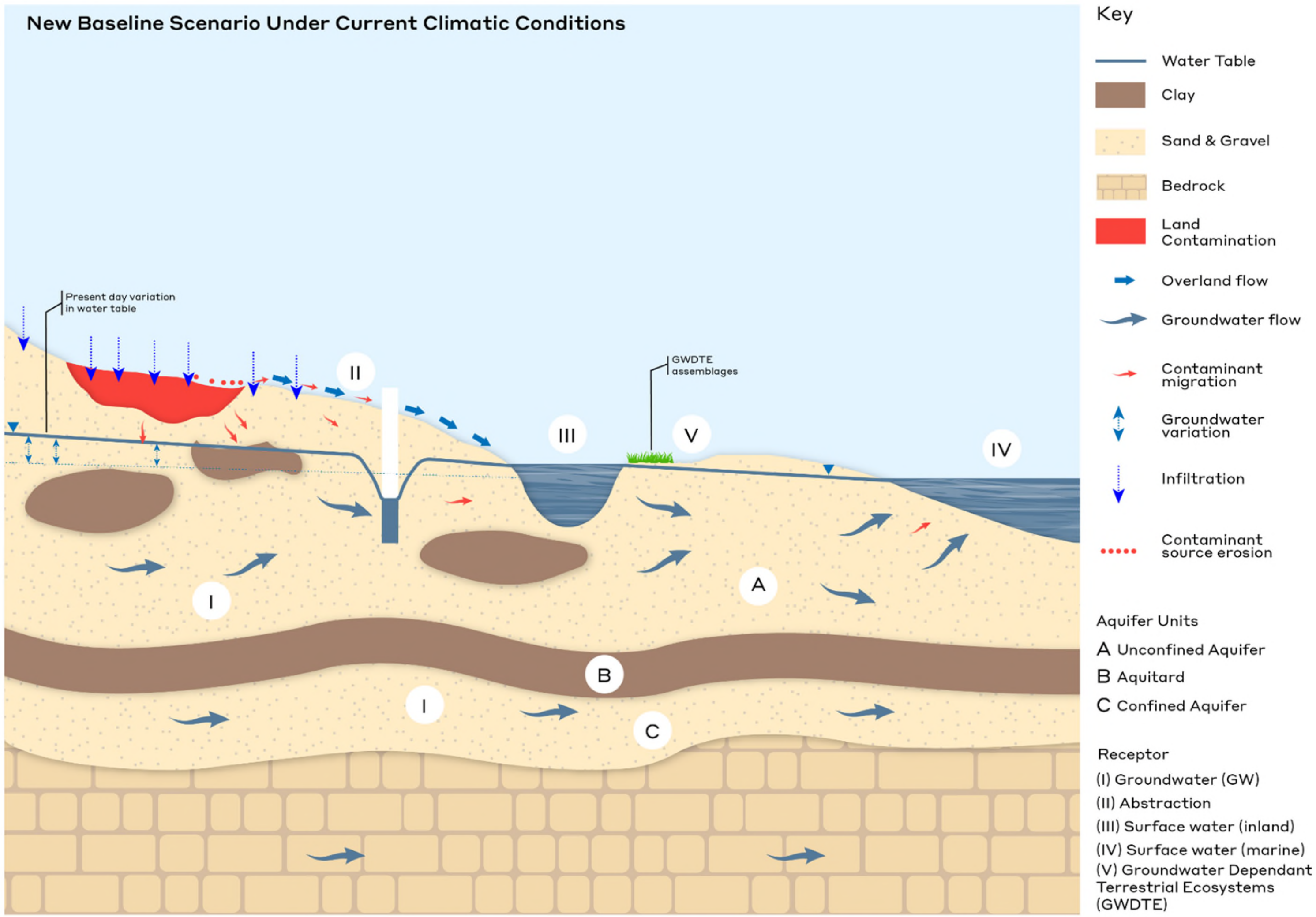

Figure 3-1: Illustrative Conceptual Site Model Relating to a Land Contamination Scenario under Current Climatic Conditions. Note: Figure adapted from "SEPA, Nov. 2020 - Land contamination and impacts on the water environment consultation".

3.3 Addressing Climate Change as part of a Land Contamination Risk Assessment

The risk assessment process should include all current and future 'potential' contaminant linkages identified by the CSM. Risk assessments involve a structured process whereby the severity (magnitude) of potential consequences for receptors (from exposure to contaminants) are combined with qualitative or semi-quantitative assessments of the likelihood (probability) of such consequences. This is undertaken to determine the relative significance of the risk to the receptor.

The risk assessment process is iterative and is refined through desk and/or field-based investigation. The process ends for any given 'potential' contaminant linkage if the evaluated risks are judged to be acceptable (including with appropriate mitigation implemented, and when uncertainties have been considered). Where risks cannot be demonstrated to be acceptable, further assessment e.g. intrusive/non-intrusive field investigation, Detailed Quantitative Risk Assessment (DQRA) or implementation of risk management, may be required.

The risk assessment should therefore present lines of reasoning and justification for any climate change related assumptions made to strengthen the robustness of the assessment.

The outcome of the literature review (Appendix 2) has highlighted that the development of the CSM is key, and typically climate change is averaged over a 30-year period (standard reference period (World Meteorological Organization, 2017)[22]).

Risk assessors should consider the following key elements (after recommendations in CL:AIRE subr:im bulletin 3 (CL:AIRE, 2007)):

- Use at least two contrasting future climate change scenarios for the site location, incorporating climate forecast information for the periods of 2020s (2011 – 2040), 2050s (2041 – 2070) and 2080s (2071 – 2100).
- Make a qualitative assessment of the impact from climate change on sources, pathways, and receptors, and resultant impacts on the contaminant linkages in the conceptual model.
- Readdress the quantitative risk assessment through, for example, changing input parameters to a detailed quantitative risk assessment model.
- Redefine the conceptual model of contaminant linkages based upon the periods 2050s and 2080s, or a timeframe relevant to the specific assessment.

3.3.1 Preliminary Risk Assessment (desk-based assessment)

The first stage of the risk assessment approach is usually desk based and should include development of a preliminary CSM, which will generally be qualitative and based on historical and existing site conditions. Once the preliminary CSM has been developed (for the proposed redevelopment of the site, for instance), climate change can be incorporated by re-evaluating the potential Source-Pathway-Receptor (SPR) linkage assessment to account

[22] World Meteorological Organization recommendation that the 30-year standard reference periods should be updated every decade in order to better reflect the changing climate and its influence on our day-to-day weather experience

for the potential effects of climate change based on projections for the region in which the site is located. As part of this re-evaluation using available data sources, consideration should be given to whether these changes would result in the introduction of new and/or reduced/increased risks that should be accounted for (e.g. increased rainfall could result in higher groundwater levels/greater fluctuations in groundwater level causing increased leaching and migration of potential contamination within materials currently above the groundwater table).

The following conditions should be considered within the preliminary CSM:

- The design life of the proposed development, if relevant (e.g. 60 years);
- The location and elevation of the site in relation to the sea or estuaries and tidally influenced rivers (such as the River Thames);
- The location and elevation of the site in relation to projected increased flooding extents;
- The projected changes to groundwater recharge (e.g. as a result of increased winter rainfall and frequency of intense rainfall events or decrease in seasonal rainfall and drought conditions); and
- The projected changes to regional groundwater level for defined time slices (e.g. near future to 2049 or far future to 2079).

See Appendix 4 for case study examples.

Average air temperature is an important component of climate change in the UK. Transmission of the higher air temperatures into the ground has the potential to affect the chemical, physical (e.g. viscosity) and biochemical (e.g. microbial degradation rates) behaviour of contaminants within soils and possibly shallow groundwater. Soil thermal dynamics are complex, influenced by many factors (soil composition, moisture content, ground cover etc) and can vary greatly between seasons as well as over a short distance and with depth through the soil profile. This makes it difficult to provide meaningful qualitative assessment, especially at the early stages of a risk assessment.

Changes to average air temperature should be considered in controlled waters risk assessment in a manner proportionate to the aim of the risk assessment. Projected increases in temperature may only have relevance at later stages of the risk assessment process when a detailed understanding of site conditions and CSM have been developed. For example, temperature may be relevant in the assessment of shallow Non-Aqueous Phase Liquid (NAPL) sources because it influences NAPL viscosity (and therefore mobility). It is also a variable in the calculation of the effective solubility of the components of a NAPL source.

3.3.2 Generic Quantitative Risk Assessment

Following the iterative approach to risk assessment, once the potential impact of climate change on the site/development has been assessed this can be used to inform a site investigation design. It is likely that data gathered for a site investigation compliant with :2011 +A2:2017 (British Standards Institute, 2017) and BS5930:2015 +A1:2020 (British Standards Institute, 2015) will provide a good basis on which to support ongoing development of the CSM in relation to climate change.

It is anticipated the ground investigation would collect data to allow assessment of:

- Natural variation in groundwater level, ideally to incorporate continuous groundwater monitoring (such as through the use of data loggers) over the winter and summer period to account for potential seasonal variation;
- Any hydraulic connection with a surface water body, wetland or existing abstraction;
- Surface water flow regime, ideally capturing periods of low flow, particularly if a dilution assessment may be required;
- Subsurface infrastructure (e.g. services and drainage channels) within proximity of the water table that may act as a preferential flow pathway;
- Source zone, unsaturated zone, and saturated zone properties; and
- Source delineation (lateral and vertical).

As with the preliminary CSM, following reassessment of the CSM using quantitative data, climate change can be incorporated within this CSM by further re-evaluating the potential SPR linkages in light of data gathered. This could include groundwater level fluctuations, and the presence and location of any contaminant impacted soils/groundwater. Should an unacceptable risk to controlled waters be identified, taking climate change into consideration for the design life of the project (if applicable), then further detailed assessment should be considered to determine whether additional mitigation is required above that required to mitigate current risk.

Recommended considerations for “what-if” scenarios, for which lines of reasoning should be developed, are also presented in Table 3-1. Key scenarios of extreme rainfall events, extreme heat events and sea level rise/coastal erosion are illustrated as Figure 3-2, Figure 3-3 and Figure 3-4 respectively. These, however, are not exhaustive and other factors may be relevant to specific CSMs.

When considering short term extreme weather events (e.g. floods) the cumulative impact will be influenced by the frequency at which they occur.

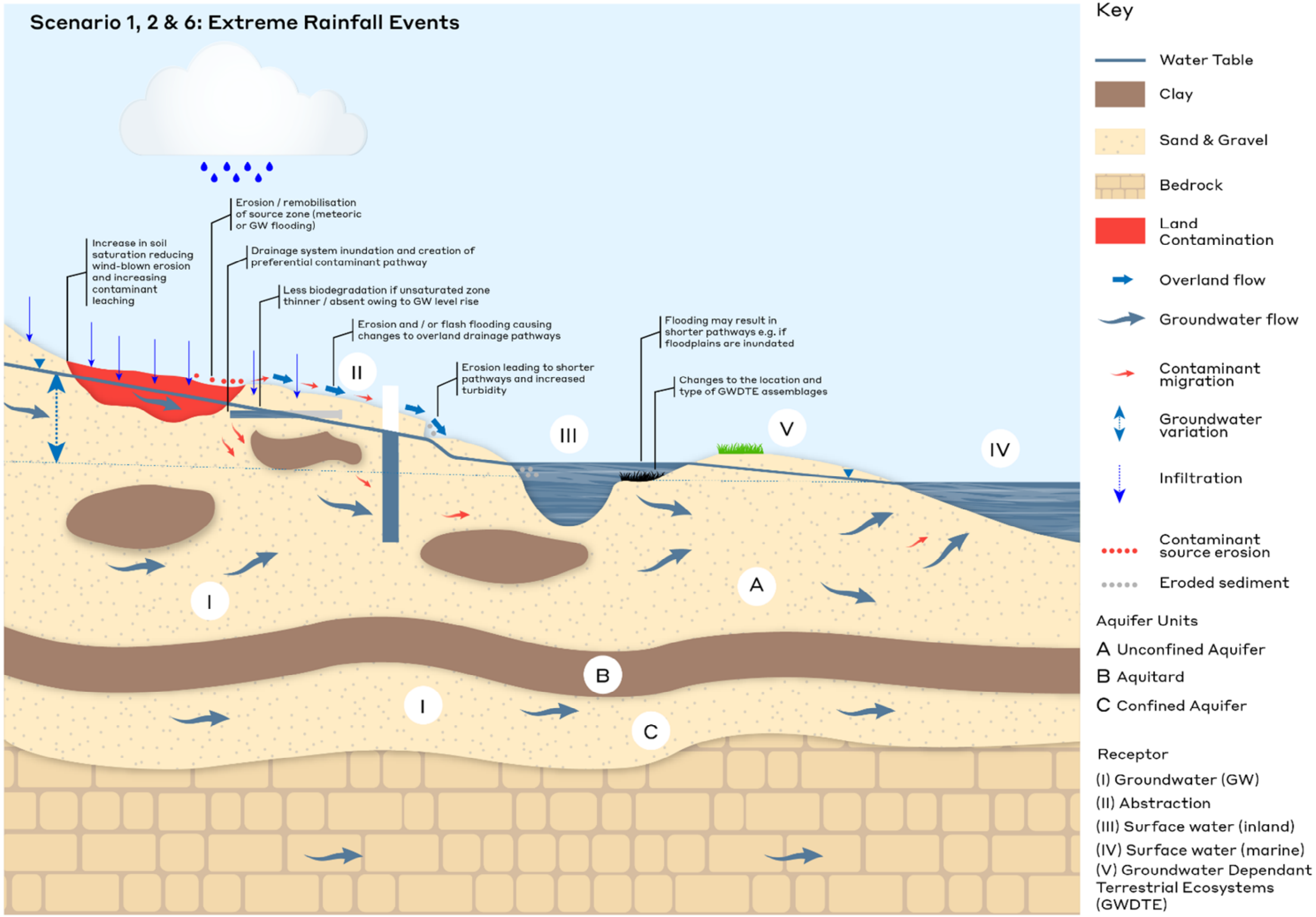

Figure 3-2: Indicative considerations for a CSM attributed to climate change scenarios 1, 2 and 6 - Extreme Rainfall Events

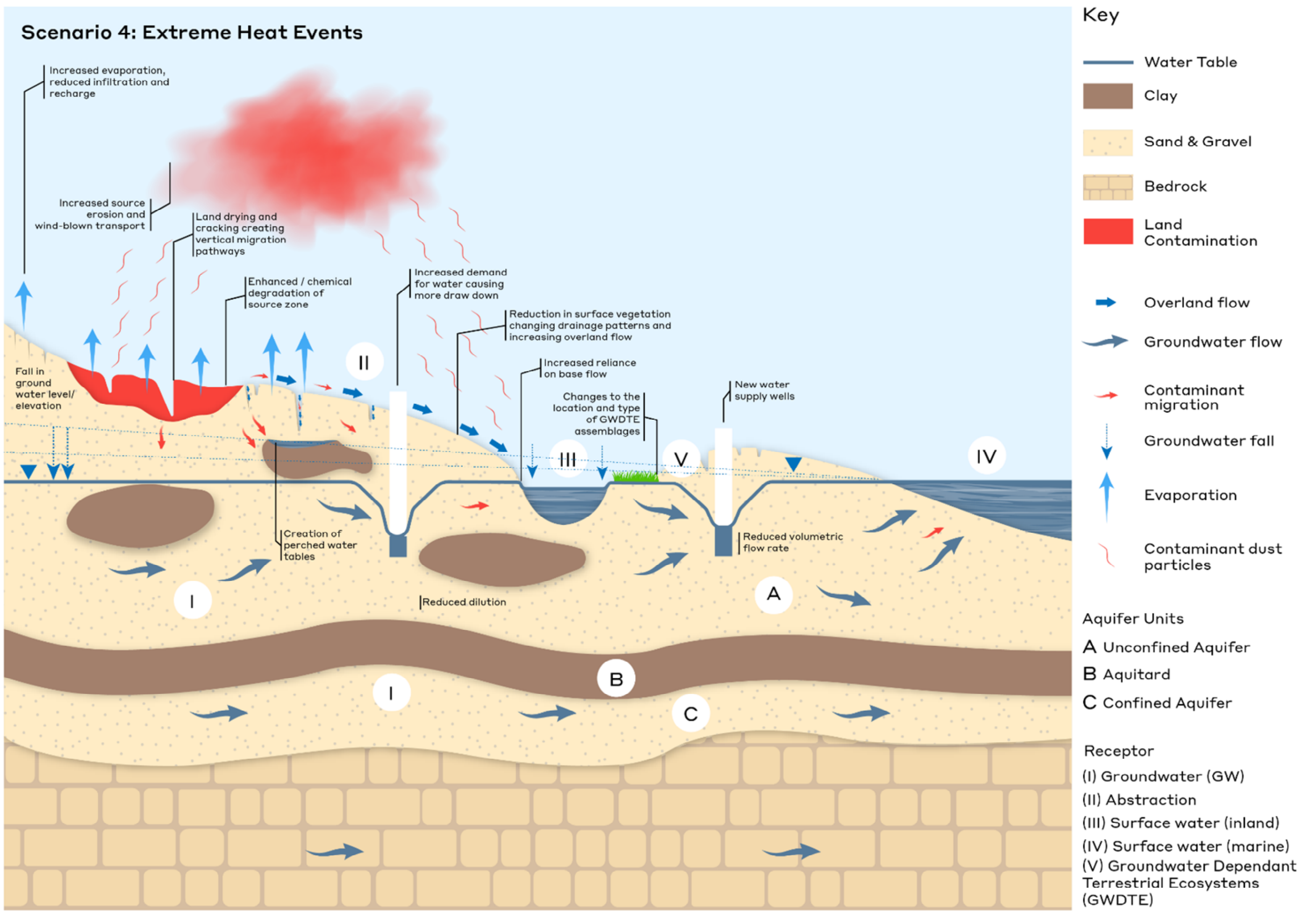

Figure 3-3: Indicative considerations for a CSM attributed to climate change scenario 4 - Extreme Heat Events

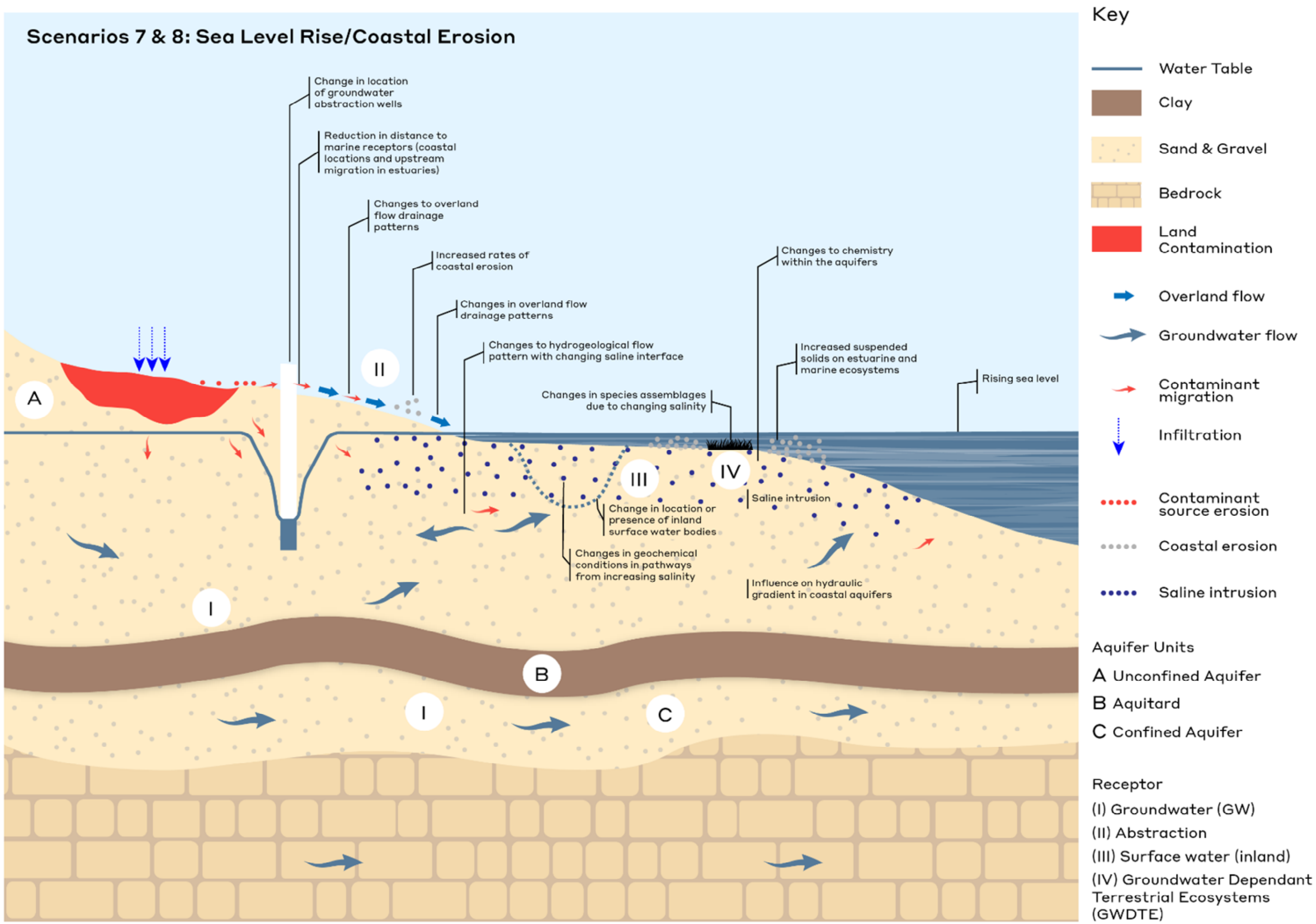

Figure 3-4: Indicative considerations for a CSM attributed to climate change scenarios 7 and 8 – Sea Level Rise/Coastal Erosion

Table 3-1: Example climate change induced effects and considerations for controlled waters aspects of land contamination risk assessments.

Item No.	**Climate change induced effect**	**Possible effects/considerations of climate change induced weather event on CSM components**		
		Source	**Pathway**	**Receptor**
Extreme weather events – consideration of short-term and cumulative effects associated with an increase in magnitude and frequency of events				
1	**Increase in precipitation (extreme events) leading to** • **increased infiltration and a rise in groundwater levels causing groundwater flooding** • **increased runoff causing pluvial flooding** • **fluvial flooding** **(Illustrated as Figure 3-2)** Note. Flooding could affect source zone, pathways, and/or receptors	a) Changes to the mechanisms by which the source may be released, e.g. • Increased leaching of contaminants sorbed to soil and in porewater (mechanism of source release) due to increased soil saturation • Physical erosion of source zone from flooding. Consider: o potential of groundwater emergence e.g., volumetrically, or likelihood of fluvial/pluvial flooding. o soil cohesion. o on-site/local man-made drainage systems and flood risk prevention measures. o pollution events such as tanks overtopping, damage to structures and services etc. b) Physical mobilisation of NAPL c) Mobilisation of contaminant sources upstream of site e.g., contaminated sediment washing onto site as a result of flooding from an offsite source	i. Increase in overland flow (including deposition and resuspension) ii. Change in overland drainage patterns. Consider local topographic profile. Consider amount and type of vegetation iii. Re-infiltration/migration back into sub-surface. iv. Change in water table elevation impacting groundwater pathway length, hydraulic gradients, and dilution potential v. Creation of new springs and/or increased flow within existing springs vi. Potential impacts on groundwater pathways due to construction/maintenance of man-made barriers (i.e., flood defences)	1) Change in surface water body location and flow characteristics 2) Changes in species assemblages in the ecological receptor because of change in surface water supply and/or groundwater discharge locations 3) Contamination of poorly maintained abstraction wells from surface water flooding
2	**Increase in precipitation (extreme events) leading to land-based erosion or changes in the geometry or geomorphology of surface water features** **(Illustrated as Figure 3-2)** Note. Land based erosion could affect source zone, pathways, and/or receptors	a) Physical erosion of land source zone. Consider: • distance of source from river/estuary • vulnerability of riverbank and surrounds to erosion or inundation, • potential for change to topographic profile, • superficial geology material, thickness, cohesion, vegetation type and distribution • on-site/local man-made drainage and bank reinforcement measures • damage to structures or services • flash-flooding events eroding areas away from riverbanks	i. Consider effect of bank erosion on: • overland flow pathway length • groundwater pathway length ii. Increase in overland flow (including deposition and resuspension)	1) Change in surface water body location (proximity to source) 2) Change in groundwater discharge location (from topographic profile change) 3) Effect of suspended solid deposition (from overland flow) on surface water body 4) Changes in species assemblages in the ecological receptor because of change suspended solid and water supply (surface water and groundwater) 5) Erosion of groundwater abstraction well and surround

Item No.	Climate change induced effect	Possible effects/considerations of climate change induced weather event on CSM components		
		Source	**Pathway**	**Receptor**
		b) Mobilisation of additional contaminants of potential concern due to source zone erosion c) Exposure and/or physical migration of NAPL sources		
3	**Extreme cold weather events**	a) Changes to source properties (e.g., solubility and volatility) and behaviour (e.g., mobility and degradation) attributed to alterations in geochemical conditions (e.g., dissolved oxygen concentrations, reaction kinetics) and biochemical conditions (e.g., microbial activity) b) Changes to the mechanisms by which the source may be released, e.g. • Reduced leaching of contaminants sorbed to soil and in porewater during periods of ground freeze (reduced infiltration) • Increased leaching of contaminants sorbed to soil and in porewater during periods of snow melt (increased infiltration) c) Increased water storage in soils or above ground with low accessibility i.e., snow, ice d) Variation in NAPL mass-transfer (e.g., volatilisation/dissolution rates) and physical mobility (e.g., viscosity)	i. Surface freezing and cracking creating/enhancing preferential vertical flow paths ii. Reduction in airborne pathways due to ground freezing and/or snow cover iii. Increased infiltration during periods of snow melt iv. Increased overland flow due to snow melt v. Changes to overland flow drainage rates and patterns due to snow melt and vegetation changes vi. Change in water table elevation impacting groundwater pathway length and dilution potential vii. Changes to organic matter in soil	1) Changes to the location and distribution of surface water courses 2) Changes in species assemblages in the ecological receptor because of reduced temperatures and/or change in water supply volume 3) Changes in aquifer recharge as reduced water demand
4	**Extreme heat events; causing increased evapo(transpi)ration, changes to water demand and supply, fires etc.** **(Illustrated as Figure 3-3)** May also be associated with water scarcity events (see row 5 below)	a) Changes to source properties (e.g., solubility and volatility) and behaviour (e.g., mobility and degradation) attributed to alterations in geochemical conditions (e.g., dissolved oxygen concentrations, reaction kinetics) and biochemical conditions (e.g., microbial activity) b) Changes to the mechanisms by which the source may be released, e.g., • Reduced leaching of contaminants sorbed to soil and in porewater due to reduced infiltration • Wildfires drying soils, vaporising hydrocarbons etc and dispersing via airborne pathways	i. Surface (soil) drying leading to changes in soil properties such as density, porosity or permeability, cracking creating/enhancing preferential vertical/bypass flow paths. Cracking of clay cover systems may lead to increased infiltration and allowing release of volatiles ii. Surface (soil) drying supporting reduced infiltration potential leading to increased surface water run-off and overland flow iii. Loss of vegetation, causing changes to overland drainage patterns iv. Surface (soil) drying and/or vegetation loss encouraging dust generation	1) Changes in groundwater discharge and run-off affecting the location/presence of surface water receptors and flow characteristics (Q95) 2) Changes in species assemblages in the ecological receptor because of increasing temperature, changes to surface water location, and/or changes to groundwater discharge points 3) Water supply wells; including volume of supply and location of new wells 4) Changes to agricultural irrigation, including increased abstraction rates and impacts on crops, as well as evapotranspiration

Item No.	Climate change induced effect	Possible effects/considerations of climate change induced weather event on CSM components		
		Source	**Pathway**	**Receptor**
		• Failure of clay capping (remediation) systems through drying and cracking • Melting of permanent snow/ice e) Variation in NAPL mass-transfer (e.g., volatilisation/dissolution rates) and physical mobility (e.g., viscosity)	v. Changes to local groundwater flow patterns (direction and flux) and levels due to changing abstractions vi. Drop in water table: • Reducing or removing influence of near (sub) surface preferential pathways e.g., drains and culverts, and/or superficial deposits • Impacting groundwater vertical pathway length and dilution potential • Changes to groundwater discharge (springs and baseflow) resulting in associated changes to dilution capacity in surface waters due to decreased flows. vii. Changes to organic matter in soil in event of wildfire viii. Wildfire-induced airborne pathways	
5	**Decrease in precipitation (extreme events or seasonal) leading to:** • **Decreased infiltration and a fall in groundwater levels** • **Decrease in baseflow in surface waters** • **Changes in water demand, water scarcity, and potentially drought if persistent/severe** **Increased wind intensity at times of water scarcity also considered.** May also be associated with extreme heat events (see row 4 above)	a) Changes to contaminant (chemical) degradation from decreased source zone saturation and/or changes in geochemical conditions b) Changes to the mechanisms by which the source may be released, e.g. • Decreased leaching of contaminants sorbed to soil and in porewater due to decreased infiltration • Physical erosion of source zone from drier soils • Increased wind intensity causing: o Aeolian erosion of source zone creating increased dust generation o Removal or uprooting of flora (e.g., trees blown over), increasing exposed soils • Failure of clay capping (remediation) systems through drying and cracking c) Increased variations in water table causing more extensive NAPL smearing and NAPL behaviour.	i. Surface (soil) drying leading to changes in soil properties such as density, porosity or permeability, cracking creating/enhancing preferential vertical/bypass flow paths. Cracking of clay cover systems may lead to increased infiltration and allowing release of volatiles ii. Surface (soil) drying influencing overland flow and physical erosion of surface soils iii. Loss of vegetation through drought, causing changes to overland drainage patterns iv. Surface (soil) drying and/or vegetation loss encouraging dust generation v. Changes to local groundwater flow patterns (direction and flux) and levels due to changing abstractions vi. Drop in water table: • Reducing or removing influence of near (sub) surface preferential pathways e.g., drains and culverts, and/or superficial deposits	1) Changes in groundwater discharge and run-off affecting the location/presence of surface water receptors and flow characteristics (Q95) 2) Changes to the location and distribution of surface water features or wetlands 3) Changes in species assemblages in the ecological receptor because of changes in surface water supply and/or groundwater discharge locations 4) Water supply wells; including volume of supply and location of new wells 5) Changes to agricultural irrigation, including increased abstraction rates and impacts on crops, as well as evapotranspiration 6) Effect of aeolian solid deposition (air-borne pathways) on surface water body

<table>
<tr><th rowspan="2">Item No.</th><th rowspan="2">Climate change induced effect</th><th colspan="3">Possible effects/considerations of climate change induced weather event on CSM components</th></tr>
<tr><th>Source</th><th>Pathway</th><th>Receptor</th></tr>
<tr><td></td><td></td><td></td><td>• Increasing thickness of unsaturated zone, influencing biodegradation
• Impacting groundwater pathway length, hydraulic gradients, and dilution potential
• Changes to groundwater discharge (springs and baseflow) resulting in associated changes to dilution capacity in surface waters due to decreased flows
vii. Proliferation of air-borne pathways due to increased wind intensity at times of water scarcity (consideration of wind direction and speed)</td><td></td></tr>
<tr><td colspan="5">Long-Term Climate Change Effects</td></tr>
<tr><td>6</td><td>Increase in precipitation (annual average) leading to
• increased infiltration and a rise in groundwater levels (seasonal or long-term)
• increased runoff and mobilisation of source zone contaminants

(Illustrated as Figure 3-2)</td><td>a) Changes to contaminant (chemical) degradation from increased source zone saturation and/or changes in geochemical conditions
b) Changes to the mechanisms by which the source may be released, e.g.,
• Increased leaching of contaminants sorbed to soil and in porewater
• Physical erosion of source zone from rainfall events dependent on soil saturation and cohesion
• Re-mobilisation of contaminants in the unsaturated zone
c) Increased variations in water table causing more extensive NAPL smearing and potential NAPL mobilisation.</td><td>i. Increase in overland flow including mobilisation of source zone contaminants
ii. Change to overland flow drainage patterns
iii. Rise in water table:
• introducing new near (sub) surface pathways e.g., drains and culverts, and/or activating higher permeability zones (e.g., gravel bands)
• creating new springs and/or increasing flows at existing springs
• impacting groundwater pathway length, hydraulic gradients, and dilution potential</td><td>1) Changes to the location and distribution of surface water features or wetlands
2) Changes in species assemblages in ecological receptor because of change in surface water supply and/or groundwater discharge locations</td></tr>
</table>

<table>
<tr><th rowspan="2">Item No.</th><th rowspan="2">Climate change induced effect</th><th colspan="3">Possible effects/considerations of climate change induced weather event on CSM components</th></tr>
<tr><th>Source</th><th>Pathway</th><th>Receptor</th></tr>
<tr><td>7</td><td>Sea level rise causing marine inundation and saline intrusion. If sea level rises relative to groundwater level, saltwater can enter the aquifer

(Illustrated as Figure 3-4.)

(Exclusion: source zone erosion)</td><td>a) Changes in contaminant (chemical) degradation because of sea spray or saline groundwater intrusion affecting soil geochemistry. Consider:
• Proximity of source from coast
• Proximity of source to groundwater saline-freshwater interface</td><td>i. Reduction in overland flow pathway length
ii. Reduction in groundwater pathway length
iii. Change to overland flow drainage patterns
iv. Changes to hydraulic gradients in coastal groundwater
v. Change to local hydrogeological flow pattern with changing saline interface (because of groundwater density) and potential tidal influence
vi. Changes to geochemical conditions in pathways from increasing salinity e.g., mobility, toxicity, partitioning and degradation rates</td><td>1) Reduction in distance to marine receptor, both at coastal locations and upstream migration of tidal limits at river mouths and estuaries
2) Change to (including removal of) inland surface water body receptor locations
3) Change to groundwater (aquifer) chemistry because of saline intrusion
4) Change in distribution and location of abstraction wells (as supply and demand changes in coastal settings)
5) Changes in species assemblages in the ecological receptor because of changing groundwater salinity, water supply or suspended solids</td></tr>
<tr><td>8</td><td>Sea level rise and increase in storm intensity and frequency causing coastal erosion. Rising sea levels and increased wave heights accelerate coastal erosion particularly along coastlines made from softer sediment.

(Illustrated as Figure 3-4.

Note. Coastal erosion could affect source zone, pathways, and/or receptors</td><td>a) Erosion of source zones located near to the coast e.g., historical landfills. Consider:
• Distance of source to coast
• Predicted extent of sea level rise or potential sea level retreat
• Local topographic profile
• Vulnerability of the coast to erosion. Consider:
o Superficial geology type and thickness,
o Soil and/or superficial deposit cohesion,
o Vegetation type and distribution
• Design of any current or planned sea defences
o Nature of any current or planned sea defence action plans e.g., waste treatment or relocation
b) Possible mobilisation of additional contaminants of potential concern due to source zone erosion</td><td>i. Consider effect of coastal erosion on:
• Overland flow pathway length
• Groundwater pathway length
ii. Contaminant/sediment deposition and resuspension in overland flow. Consider:
• Overland drainage patterns
• Vegetation cover type and distribution</td><td>1) Change in location or presence of inland surface water bodies e.g., estuaries and rivers
2) Change in location or presence of groundwater abstraction wells
3) Effect of suspended solids on estuarine or marine ecosystems</td></tr>
</table>

*Also consider Source Protection Zones (SPZ) when assessing abstraction wells as receptors.

3.3.3 Detailed Quantitative Risk Assessment

DQRA is required for SPR linkages where earlier tiers of risk assessment do not demonstrate the risk is acceptable and further assessment is required to inform risk mitigation decisions. The commercially available environmental simulation models in the UK for the assessment of risks to controlled waters from land contamination, such as the Remedial Targets Methodology worksheet ('P20')[23] and ConSim[24], assume environmental conditions remain constant. This is at odds with the evidence that the effects of further climate change are projected to vary over time. SPR linkages are thereby expected to change with time.

This poses a challenge for the risk assessor with standard tools ill-equipped to model changes to parameter values with time. Distributed flow models (such as MODFLOW and FEFLOW), as well as compartmental modelling environments (such as GoldSim), allow for time variant values of model parameters, but model data requirements and/or the time required to develop such models mean use of such tools is unlikely to be proportionate for many routine land contamination risk assessments. Clearly tools need to be developed to model the transient effects of further climate change, but until such time, it is recommended that existing non-transient parameter tools are employed, except where risks are borderline acceptable. Where risks are borderline acceptable, it may be appropriate to use an existing transient modelling approach instead as this is the situation in which the value of the transient modelling is likely to be greatest (in terms of identifying whether climate change risk mitigation is necessary).

The future effects of climate change can be approximated using existing tools by assessment of the sensitivity of the results of commercially available environmental simulation models to the changed values of environmental parameters. Model environmental parameters could be assigned values appropriate to conditions under future climate change. The approach, of course, neglects the progressive change in environmental parameter values which together could be both favourable and unfavourable towards protection of controlled waters. However, modelling could be undertaken for specific time periods such as the near-term, the 2050s, and the 2080s, and the model results then combined to allow assessment, even if temporally coarse, of how risk changes into the future. In effect, such a modelling approach brings forward the effects of future climate change to today. Care is needed when modelling situations where contaminants can be expected to rapidly flush from the source zone, and therefore will only be present in minor amounts during future time periods being considered.

A site-specific assessment of potential changes to source dimensions, source concentrations, pathway lengths and receptor designations (as well as the presence of specific SPR linkages), as a result of future climate change, should be undertaken. While physical-chemical properties of contaminant transport and source NAPL behaviour may be influenced by temperature changes, it is judged that only near-surface soils and shallow groundwater will experience warming, with deeper soils being unaffected. Furthermore, the projected magnitude of atmospheric average temperature increases (up to around 4°C) are small compared with the variation in temperatures for which literature sources provide values for physical-chemical properties used in sub-surface modelling. For instance, reference to the annual average temperature of UK soils of 10 °C is typical for Henry's Law constants, reference temperatures for solubility are typically between 20 and 25 °C and room temperature is assumed for Koc/Kd values. Consideration of changes to physical-chemical contaminant properties by future climate change is therefore considered unlikely to be a

[23] Available at: https://www.gov.uk/government/publications/remedial-targets-worksheet-v22a-user-manual. (Environment Agency, 2006).

[24] Available at: http://www.consim.co.uk/. (Golder Associates Ltd, 2009).

key consideration when undertaking DQRA for dissolved phase contaminants, however, under particular site conditions these factors may need to be considered, e.g. presence of a NAPL source.

For almost all sites, consideration of the values of the following four parameters under conditions or consequences of climate change is likely to be necessary within DQRA:

- Recharge;
- Groundwater elevation (and thereby unsaturated and saturated zone thicknesses);
- Hydraulic gradient; and
- Surface water flow.

Changes to recharge, groundwater elevation and hydraulic gradient are usually correlated. This is because changes to recharge upgradient and through a source zone changes the flow of groundwater beneath a source zone. Given the permeability of the ground does not usually change, Darcy's Law requires a corresponding change to the saturated zone thickness and/or hydraulic gradient. For most DQRAs, it will therefore be necessary to understand changes in recharge and changes in groundwater elevation. The effects of future climate change in the UK are projected to be spatially variable and it is therefore necessary to seek an understanding of the changes in recharge and groundwater elevation as close as possible to the site being assessed.

Sections 2.3.1 and 2.3.2 outlines the available data sources available to understand future changes to recharge and groundwater level in the UK. It is noted that groundwater level data within the BGS Future Flows and eFLaG projects are based on bedrock aquifers and that coverage outside of England is limited. Where land contamination subject to risk assessment lies above an aquifer different to that monitored by modelled boreholes, a degree of judgement is required to determine the relevance of future changes in groundwater level projected by the British Geological Survey. In these instances, the geological setting and the groundwater body should be considered. Unconfined shallow aquifers will likely be more susceptible to changes in recharge patterns and changes in surface waters, at least in the short term, than aquifers that are confined or present at depth. Furthermore, transmissive aquifers will buffer the influence of increased or decreased recharge more readily than those that are less transmissive and/or have lower storage (for instance, because they are dependent on fracture flow). The uncertainty that such judgement introduces should be reflected in the range of values (unsaturated/saturated zone thickness, and/or hydraulic gradient) used in the risk modelling. The uncertainty will be greater for sites in Northern Ireland and Scotland where there is a paucity of modelled boreholes in the Future Flows and eFLaG datasets.

When undertaking a Level 4 assessment comprising dilution within the receiving surface water body then consideration should be given to projected low river flow data. Section 2.3.3 details the information sources available for river flow projections in the UK.

The maximum duration over which the evolution of parameter values can reasonably be quantified is to approximately the end of this century i.e. 2100. It is important to apply professional judgement to the results of models that calculate concentrations and other results over longer timescales.

In order to assist risk assessors in their selection of values for input parameters when undertaking controlled waters DQRA a number of useful data sources are provided in Section 5.

In summary, risk assessors should include the following key elements (as applicable) in a controlled waters risk assessment for a site where climate change has been identified as a relevant consideration:

- Once the preliminary CSM has been developed, climate change should be incorporated by re-evaluating the potential SPR linkage assessment to account for the potential effects of climate change based on projections for the region in which the site is located.
    - Where practicable consider using at least two contrasting future climate change scenarios for the site location, incorporating climate forecast information for the periods of 2020s (2011 – 2040), 2050s (2041 – 2070) and 2080s (2071 – 2100) dependent on timeframe relevant to the specific assessment.
    - Make a qualitative assessment of the impact from climate change on sources, pathways, and receptors, and resultant impacts on the contaminant linkages in the conceptual model.
- Use quantitative data to re-address the generic quantitative risk assessment for medium to long term climate change effects. For short-term extreme weather events the use of “what if” scenarios should be considered.
- Standard commercially available simulation models in the UK for the assessment of risks to controlled waters from land contamination tools are ill-equipped to model temporal changes to parameter values. As this is a typical characteristic of climate change effects, this can be mitigated by:
    - Modelling for specific time periods such as the near-term, the 2050s, and the 2080s, and the model results then combined to allow assessment, even if temporally coarse, of how risk changes into the future.
    - Considering potential changes to source dimensions, source concentrations, pathway lengths and receptor designations (as well as the presence of specific SPR linkages), as a result of future climate change during those periods.
    - Considering the values of the following four parameters under conditions or consequences of climate change:
        - Recharge;
        - Groundwater elevation (and thereby unsaturated and saturated zone thicknesses);
        - Hydraulic gradient; and
        - Surface water flow.
    - Considering projected low river flow data when undertaking a Level 4 assessment comprising dilution within the receiving surface water body.

4 GLOSSARY

ASTM	American Society for Testing and Materials
BGS	British Geological Survey
CCC	Committee on Climate Change
CCRA	Climate Change Risk Assessment
CIRAM	Climate Impacts Risk Assessment Methodology
CL:AIRE	Contaminated Land: Applications in Real Environments
COP	Conference of the Parties (to the United Nations Framework Convention on Climate Change)
CPM	Convection Permitting Climate Model
CSM	Conceptual Site Model
DQRA	Detailed Quantitative Risk Assessment
EA	Environment Agency
eFLaG	Enhanced Future Flows and Groundwater
FFGWL	Future Flows and Groundwater Level
GPLCs	Guiding Principles for Land Contamination
GQRA	Generic Quantitative Risk Assessment
GWDTE	Groundwater Dependent Terrestrial Ecosystems
HADRM3	Met Office Hadley Centre Regional Climate Model
IPCC	Intergovernmental Panel on Climate Change
ITRC	Interstate Technology Regulatory Council
LCRM	Land Contamination: Risk Management
MoD	Ministry of Defence
NAP	National Adaption Programme
NAPL	Non-Aqueous Phase Liquid
NCCARF	National Climate Change Adaptation Research Facility
NICAPP2	Northern Ireland Climate Change Adaptation Programme
NIEA	Northern Ireland Environment Agency
NPPF	National Planning Policy Framework
NRW	Natural Resources Wales
PAN	Planning Advice Note
PRA	Preliminary Risk Assessment
PPG	Planning Policy Guidance
RCM	Regional Climate Model
RBM	River Basin Management Districts
RBMP	River Basin Management Plan
RCP	Representative Concentration Pathway
SEPA	Scottish Environment Protection Agency
SoBRA	Society of Brownfield Risk Assessment
SPR	Source-Pathway-Receptor
SRES	Special Report on Emissions Scenarios
SRR	Sustainable Resilient Remediation
SSP	Shared Socioeconomic Pathway
SuRF-UK	Sustainable Remediation Forum UK
UK	United Kingdom
UKCP	UK Climate Projections
ZOODRM	Zooming Object Oriented Distributed Recharge Model

5 DATA SOURCES

5.1 Useful links

UK Met Office

- UK Climate Projections (UKCP) data - https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/data/index
- State of the UK Climate Annual Reports - https://www.metoffice.gov.uk/research/climate/maps-and-data/about/state-of-climate
- UK Marine Climate Change Projections - https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/summaries/marine-climate-change-projections

British Geological Survey (BGS) (open licence, others available under licence)

- GeoClimate UKCP18 Open (using RCP8.5, available for 2030s and 2070s) - https://www.bgs.ac.uk/datasets/geoclimateukcp18-open/
- G-BASE (geochemistry of Great Britain) - https://www.bgs.ac.uk/geology-projects/applied-geochemistry/g-base/
- GeoScour Open (overview of the natural characteristics and properties of catchment and riverine environments for the assessment of river scour in Great Britain) - https://www.bgs.ac.uk/datasets/bgs-geoscour-open/
- Geology 625k (generalised geological map) - https://www.bgs.ac.uk/datasets/bgs-geology-625k-digmapgb/

Intergovernmental Panel on Climate Change (IPPC)

- Data distribution centre - https://www.ipcc-data.org/
- 2021 report (AR6) - https://www.ipcc.ch/report/ar6/wg1/

UK Centre for Ecology and Hydrology (CEH)

- eFLaG (projection of river flow, groundwater level, and groundwater recharge time series for catchments, boreholes and groundwater bodies in Great Britain and Northern Ireland. 1981 to 2080) - https://catalogue.ceh.ac.uk/documents/1bb90673-ad37-4679-90b9-0126109639a9
- eFLaG portal - https://eip.ceh.ac.uk/hydrology/eflag/
- Environmental information data centre - https://eidc.ac.uk/finddata. Includes such datasets as:
    - estimates of daily and monthly rainfall for Great Britain and Northern Ireland (1890 to 2019)
    - estimates of river flow for Great Britain driven by UKCP18 Regional (12km) data (1980 to 2080)
    - estimates of soil moisture for Great Britain and Northern Ireland from observed data (1980 to 2011)
    - daily hydrometeorological and soil data including potential evapotranspiration (2013 to 2019)
    - potential evapotranspiration from UKCP18 regional (12km) data (1980 to 2080)

Others

- Gridded climate datasets for Europe (long term data available at a daily resolution) - https://www.ecad.eu/. See also www.euro4m.eu
- Coastal risk screening tool - coastal.climatecentral.org/map

5.2 Full reference list

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APPENDIX 1

Legislation & Policy

A1 Legislation and policy within UK administrations

This appendix outlines the legislation and policy currently in place in relation to climate change and land contamination within each of the Devolved Nations in the UK.

A1.1 England

The Department for Environment, Food and Rural Affairs (Defra)'s Climate Change: Second National Adaption Programme (NAP) (2018-2023) (Department for Environment, Food & Rural Affairs, 2018) sets out the actions the government is, and will be, taking to address the risks and opportunities posed by the changing climate. This NAP is primarily for England as well as covering UK reserved matters. Currently the NAP places requirements on the Environment Agency (EA) to address climate related risks to/from flooding, coastal erosion, and water abstraction, but places no specific requirements on the EA or Defra with respect to characterisation and risk assessment of controlled waters.

The NAP places requirements on the planning regime via the National Planning Policy Framework (NPPF) (Ministry of Housing, Communities & Local Government, 2021), and relevant planning practice guidance (PPG) documents[25]. The NPPF's environmental objective is:

"*to protect and enhance our natural, built and historic environment; including making effective use of land, improving biodiversity, using natural resources prudently, minimising wate and pollution, and mitigating and adapting to climate change, including moving to a low carbon economy*".

This can be interpreted as including the incorporation of the effects of climate change on controlled waters risk assessment; however, the NPPF and PPG are specific only where they relate to overarching sustainability requirements and the management of flood risks.

The English planning regime makes addressing climate change one of the core land use principles that underpin plan making and decision making. Within the NPPF, Chapter 14 outlines the anticipated approach associated with the 'consideration of meeting the challenge of climate change, flooding and coastal change'. In particular paragraph 153 of the NPPF states that, "*Plans for development should take a proactive approach to mitigating and adapting to climate change, taking into account the long-term implications for flood risk, coastal change, water supply, biodiversity and landscapes, and the risk of overheating from rising temperatures"*. Within the PPG, under examples of how climate change can be addressed through the Local Plan, examples include, "*Considering future climate risks when allocating development sites to ensure risks are understood over the development's lifetime*" and "*Considering availability of water and water infrastructure for the lifetime of the development and design responses to promote water efficiency and protect water quality*".

Taking climate change into account within Local Plans and Local Development Plans is a requirement of NPPF and PPG. This means that Local Plans/Local Development Plans could, if a Local Planning Authority was so minded, be a mechanism for requiring climate change to be considered in land contamination risk assessment.

Existing River Basin Management Plans (RBMP) published in 2016 are currently being updated. The updated plans consider climate change to be a critical challenge that requires urgent action and

[25] Available at: https://www.gov.uk/government/collections/planning-practice-guidance.

investment in order to limit future deterioration in the quality of the water environment (Environment Agency, 2021).

A1.2 Wales

The Prosperity for All: A Climate Conscious Wales (a climate change adaptation plan for Wales) (Llywodraeth Cymru/Welsh Government, 2019) report ("CCW") establishes the devolved Government's approach to discharging the requirements placed on Welsh Ministers in the Climate Change Act, for the period 2020–2025, including through working with stakeholders and partner agencies such as Natural Resources Wales (NRW). CCW references the following legislation/documents:

- Environment Act Wales (Llywodraeth Cymru/Welsh Government, 2016), which sets out the legal framework for the management of natural resources and developing Wales as a low carbon and environmentally sustainable economy.
- Wellbeing of Future Generations (Wales) Act 2015 (Llywodraeth Cymru/Welsh Government, 2015), which aims to improve the social, economic, environmental, and cultural well-being of Wales.
- Prosperity for All: A Low Carbon Wales (Llywodraeth Cymru/Welsh Government, 2019) climate mitigation plan, which sets out 100 policies and proposals aiming to comply with the Welsh Government's first carbon budget and establish further emissions reductions in future.

Planning Policy for Wales 11 (Llywodraeth Cymru/Welsh Government, 2021), sets out several planning policies that contribute toward climate change adaptation.

Whilst Technical Advice Note (TAN) 15 (Llywodraeth Cymru/Welsh Government, 2021) will not become adopted policy until June 1st, 2023, and whilst its focus is on development, flooding and coastal erosion, it has implications for land contamination and decision-making with respect to planning, development, and infrastructure.

The River Basin Management Plan for Western Wales, the Dee and the cross-border Severn are currently undergoing consultation. The existing 2015 – 2021 RBMP (Cyfoeth Naturiol Cymru/Natural Resources Wales, 2022) and those out for consultation consider climate change adaptation to be critical to the resilience of ecosystems and water management. River basin management planning is noted to be a long-term process and addressing climate change risk needs to be incorporated throughout, in particular in the assessment of pressures and selection of mitigation measures.

None of the legislation or policy documents specifically refer to climate change in the context of the management of land contamination or controlled waters.

A1.3 Scotland

The Second Scottish Climate Change Adaptation Programme 2019-2024 (Scottish Government, 2019) outlines how Scotland is preparing for the impacts of climate change over the five-year period. It uses an outcomes-based approach, derived from both the United Nations Sustainable Development Goals and Scotland's National Performance Framework (Scottish Government, 2022), to promote collaboration and engagement between sectors with respect to climate change adaptation and includes cross-cutting policies such as River Basin Management Plans (RBMP) and Local Flood Risk Management Plans. While there is no direct reference to the impacts of climate change on the land contamination sector, the following outcomes are broadly relevant:

- "Outcome 4: Our society's supporting systems are resilient to climate change" makes reference to the need for resilient infrastructure, including potable water supply, and refers to the Hydro Nation research workstreams. Risks to health from poor quality water are identified as a concern.
- "Outcome 5: Our natural environment is valued, enjoyed protected and enhanced and has increased resilience to climate change" makes reference to RBMPs which detail Scotland's objectives and action programmes for protecting and improving the water environment, including the integration of climate change when developing improvement measures to address pressure on the water environment in each river basin district. The water body classification process includes work on identification and assessment of pollution pressures, including land contamination, that are impacting on water body status, although it is noted that for land contamination to have an impact at water body scale it would usually be the result of a cumulative effect of multiple sites within a catchment and not from a single site.
- "Outcome 6: Our coastal and marine environment is valued, enjoyed, protected and enhanced and has increased resilience to climate change" includes reference to rising sea levels, increased coastal erosion and erosion-enhanced flooding which is being researched by Dynamic Coast.
- "Outcome 7: Our international networks are adaptable to climate change" makes reference to food safety being affected as the increased risk of flooding and other extreme weather events could increase the risk of environmental contamination. This is being considered by the Food Standards Agency.

The RBMP for Scotland for the period 2021-2027 (Scottish Environment Protection Agency, 2021) and an update to the cross-border Solway-Tweed RBMP (Scottish Government, 2021) include reference to the impacts of climate change in relation to water resources such as demand on water, water availability, raw water quality and risk of sewer and surface flooding in towns. A number of actions for improvement are provided to safeguard and ameliorate the resilience of water resources in response to climate change. The RBMPs do not explicitly refer to impacts on the water environment from land contamination sources but refer to seeking to improve the water environment through regeneration and development planning.

The Scottish Government National Planning Framework 3 (Scottish Government, 2014) considers that adapting to climate change is a key planning outcome to ensure that Scotland's environment and infrastructure become more resilient to the impacts of climate change. The planning system plays a key role in addressing historical contamination in Scotland. Planning Advice Note (PAN) 33: Development of Contaminated Land (Scottish Government, 2017) provides advice on the implications for the planning system and the development of land affected by contamination. PAN33 sets out the principle that the responsibility for the safe development of a site rests with the developer via the 'suitable for use' approach. This includes ensuring that the land is suitable for its current and proposed future use. It limits requirements for remediation to the work necessary to prevent unacceptable risks to human health and the environment in relation to the current use or future use of the land for which planning permission is being sought. However, there is no mention of considering climate change as part of assessing the site's current or future suitability.

As part of delivering its One Planet Prosperity (Scottish Government) regulatory strategy, the Scottish Environment Protection Agency (SEPA) consider climate change to be one of the biggest challenges in environmental regulation and aspires for businesses to go beyond compliance by developing sustainable and innovative practices.

A1.4 Northern Ireland

The Northern Ireland Climate Change Adaptation Programme 2019-2024 (NICCAP2) (Department of Agriculture, Environment and Rural Affairs, 2019) was published in September 2019. Natural Capital, which includes Terrestrial/Coastal/Marine/Freshwater ecosystems, soils, and biodiversity, is one of the five key priority areas. The risks to controlled waters receptors from increased contamination released as a result climate change are considered in relation to:

- food resilience (Outcome Objective I1): risks to supply chain as a result of environmental contamination associated with increased flooding, increased pesticide, and foodborne pathogens.
- saline intrusion (Outcome Objective NC1): risk to coastal aquifers from saline intrusion as a result of climate change.

Delivery Action Plans have been produced to contribute towards the objectives of the NICCAP2 to manage the risks, and opportunities of climate change in relation to the key priority areas. However, no specific framework or guidance is provided for the assessment of land contamination in relation to climate change.

The Northern Ireland Environment Agency (NIEA) recognise that climate change is a challenge for Northern Ireland. The NIEA Business Plan 2020-2021 (Northern Ireland Environment Agency, 2020) outlines NIEA's role to support and influence policy development on issues such as climate change. RBMPs include measures to address the implications of climate change on the water environment. They ensure NIEA take into account climate change factors when developing and implementing actions to improve the water environment and protect waters from deterioration.

APPENDIX 2

Literature Review

A2 Guidance and approaches to considering climate change within land contamination risk assessment

This appendix is a review of available UK and International guidance about how climate change could be incorporated within land contamination risk assessment.

A2.1 Current UK approaches & guidance

Scientific consensus has established that our climate is changing, and climate resilience is being considered in some areas of environmental assessment. For example, the Environment Agency has published guidance (Environment Agency, 2021) to request that an "adapting to climate change risk assessment" is completed when applying or renewing an environmental permit for sites that are anticipated to be occupied in 2050. Key land contamination guidance documents, e.g. the Environment Agency's Land Contamination: Risk Management (LCRM) (Environment Agency, 2021), require robust characterisation and risk assessment of sites. The overarching requirements of these documents mean that the effects of climate change should be considered within a site's conceptual site model (CSM) and, if potentially unacceptable risks are identified, the effects of climate change should be considered in any site-specific risk assessments that are prepared in accordance with key land contamination guidance.

A2.1.1 Regulatory Guidance

The current approach in England and Wales to risk assessment and management of brownfield sites is risk-based using a source - pathway - receptor linkage approach as defined in LCRM. LCRM refers to climate change as part of a sustainable approach to land contamination risk management. It recommends that climate change impacts are considered as part of an overall sustainability assessment at the Tier 1 preliminary risk assessment stage. At the Tier 2 generic quantitative risk assessment stage thought should be given to the influence that weather and natural patterns may have on site conditions, including seasonal variations in water levels, tidal impacts, potential for or evidence of previous flooding, as well as considering the implications of climate change. LCRM supports a sustainable approach and signposts to the Sustainable Remediation Forum UK (SuRF-UK) (CL:AIRE, 2010) for assessing the sustainability of soil and groundwater remediation.

The Environment Agency's Guiding Principles for Land Contamination 2 (GPLC) (Environment Agency, 2010) provides a brief introduction to incorporating climate change into risk assessments. Section 1.8 sets out that the "*general principles* [of climate] *can be considered qualitatively*", that "*Risks from contamination that are acceptable now might not be in the future – you need to factor climate change into your risk assessments*" and that "*Potential environmental effects of climate change should be considered when a site is developed*". For example, GPLC2 suggests considering the likely impacts of changing temperature and water balance on the sources, pathways and receptors identified at the conceptual site model development stage. Where necessary, risk assessments are required to include information or parameters representative of future climate forecast 'what if..?' scenarios, to 'future-proof' environmental assessments. Government guidance is sign posted within the GPLC2 as stating this, but the guidance listed is either withdrawn (Planning Policy Statements 1-23 and Planning Response to Climate Change: Advice on Better Practice (CLG)) or updated current versions of the documents (Planning Policy Wales, 2002) listed set out no explicit requirements.

Climate change is not addressed by the EA's Remedial Targets Methodology or within SEPA's Position Statement (WAT-PS-10-01) 'Assigning Groundwater Assessment Criteria for Pollutant Inputs' (Scottish Environment Protection Agency, 2014). Revision of the latter has recently (2021) been through consultation. The consultation responses indicate that additional guidance will be incorporated in this revision in relation to accounting for climate change in the water environment risk assessment process (Scottish Environment Protection Agency, 2021).

A2.1.2 British Standards

BS 10175:2011+A2:2017 (British Standards Institute, 2017), a standard created to provide recommendations and guidance on how to investigate land potentially affected by contamination, does not make any reference to climate change; the standard is currently (2022) under review. BS EN ISO 21365: 2020 (British Standards Institute, 2020) states that part of the formulation of a conceptual model should be the identification of "*foreseeable events which could affect contaminant impacts or create new exposure pathways*". It goes on to state that "*detailed knowledge will be required about the site to identify possible foreseeable impacts on contaminant behaviour*". Although not specific to land contamination, BS EN ISO 14091:2021 (British Standards Institute, 2021) provides guidelines for undertaking risk assessments, where the process can improve planning of adaptation to climate change and inform the implementation and monitoring of climate change adaptation activities. It advises that:

- adaptation is usually more effective when initiated at an early stage of project development, and when undertaken as a planned process rather than in response to experienced impacts; and
- better knowledge of climate change risks will make it easier and less costly to respond.

The advice is pertinent to land contamination.

A2.1.3 Other Guidance and Sources

1. **CL:AIRE, subr:im bulletin (SUB 3), March 2007. Climate Change, Pollutant Linkage and Brownfield Regeneration** (CL:AIRE, 2007)

Contaminated Land: Applications in Real Environments (CL:AIRE) published a bulletin considering the impact of climate change on land affected by contamination and brownfield regeneration. It is noted that aspects of this document are now out of date; however, many of the general principles are still considered relevant. Following a literature review and stakeholder engagement it was recognised that certain climate change scenarios (low and high emissions) would have significant impacts on current and future land contamination and remediation systems. A conceptual adaptation strategy was developed to address the impact of climate change in the current risk-based land contamination management regulatory framework. It comprised the following stages:

Stage 1: Risk assessment based on current situation.

Stage 2: Risk assessment based on climate change.

Stage 3: Risk management based on current position.

Stage 4: Risk management based on climate change.

With respect to Stage 2 the following key elements, relevant to controlled waters, were recommended:

- The use of at least two contrasting future climate change scenarios for the site location, for example, incorporating climate forecast information for the periods of 2050s (2041 – 2070) and 2080s (2071 – 2100).

- Making a qualitative assessment of the impact from climate change on sources, pathways, and receptors; and resultant impacts on the pollutant linkages in the conceptual model.
- Readdressing the quantitative risk assessment through, for example, changing input parameters to detailed quantitative risk assessment.
- Redefining the conceptual model of pollutant linkages based upon the periods 2050 and 2080.
- In the event that the future climate forecasts over the periods of 2050 and 2080 indicate a potential increase in identified risk, then a further stage of assessment of risk management options is recommended, with due consideration to the time-sensitivity of any proposed remedial options.

The work undertaken during the SUBR:IM programme demonstrated the value of a combination of experimental and modelling approaches, which together have the potential to deliver the most robust solutions when considering potential impacts of climate change in their decision-making process. There have been no further updates, or any evidence produced to suggest that the SUBR:IM adaptation strategy has been put into practice.

2. **Ministry of Defence and Defence Infrastructure Organisation, 2010, withdrawn March 2021. MOD sustainability and environmental appraisal tools (SEAT) handbook, Section 7 Climate Impacts Risk Assessment Methodology (CIRAM)** (Ministry of Defence and Defence Infrastructure Organisation, 2010)

The Ministry of Defence (MoD) produced a sustainability and environmental appraisal tool to assess the climate change risks to its estate, which comprises approximately 1.8% of the UK mainland. CIRAM was designed to improve the resilience of MoD establishments to climate related hazards, and was peer reviewed by Defra and UKCIP. To ensure consistency in the climate projection data set utilised within the assessment CIRAM adopted the projected climate change data averages for the period 2040-2069 relative to a 1961-1990 baseline and using the 'high emissions ratio' based on the UKCP09 dataset. It was recognised that different climate change variables have differing levels of certainty as outlined within the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (Intergovernmental Panel on Climate Change, 2014). MoD establishments were advised to plan and design for those variables projected with a higher degree of certainty (e.g. rising temperatures, heat waves and sea levels). The sensitivity of the risk to those variables where there is lower certainty (e.g. increasing storm surge heights) should be tested and robustness of the assets assessed against the projected change. The CIRAM process was reviewed every 5 years in line with the UK Climate Change Act 2008. The MoD 'Sustainability and environmental appraisal tools handbook' that includes CIRAM was withdrawn in March 2021 and replaced with the Sustainability and Climate Change: MoD Collection of publications (last updated in January 2022) (Ministry of Defence, 2022), including the MoD Climate Change and Sustainability Strategic Approach (Ministry of Defence, 2021) and A Changing Climate: Exploring the Implications of Climate Change for UK Defence and Security (RAND Corporation, 2020). However, these replacement documents do not provide guidance or methodology.

A2.2 International Approaches

Similar to the UK, international approaches to the assessment of climate change impact on groundwaters and surface waters typically focus on the management of water resources and flood risk assessment. Guidance about how climate change effects should be assessed in relation to land contamination has been prepared (to the authors' knowledge) for the United States of America (USA) and Australia only, as detailed in the sections below.

Whilst the majority of the impacts and climate mechanisms referred to within the guidance documents are common across all geographies, the UK has, and is projected to maintain, a temperate climate. The USA and Australia have a wide variety of climates due their large geographical size, spans in latitude, and range of geographic features, including mountains and deserts. In the USA, climates include semi-arid, tropical, oceanic, sub-tropical and sub-arctic, with a temperate climate from the Southern Plains and lower Midwest eastward to the Middle Atlantic states (Virginia to southern Connecticut). Most of Australia is desert or semi-arid with tropical climate in the northern part of the country and a temperate climate in the south-east and south-west corners. The UK therefore has different climate considerations than the USA and Australia and will experience lesser climate extremes. Some of the mechanisms detailed in the guidance documents will be of less relevance in a UK context (e.g. hurricanes and tornadoes (noting that high winds caused by storms can result in significant damage), glaciers, and permafrost); however, the discussion around the impacts of climate change in relation to the risk assessment process is considered to be pertinent.

United States of America

American Society for Testing and Materials (ASTM)

Several ASTM guidance documents have been prepared in relation to climate resilience. Climate resilience refers to efforts by entities, organisations, or individuals to prepare for or adjust to future extreme weather-related physical conditions. Of particular relevance, *ASTM E3249-21 Standard Guide for Remedial Action Resilience to Climate Impacts* (Americal Society for Testing and Materials, 2021), discusses considering climate effects when evaluating contaminated sites by desk-based studies and site assessment through to developing and implementing remedial strategies.

The aim of the guidance is to ensure that climate resiliency is considered upfront at the start of the land contamination risk assessment rather than in the final stages of the remediation process. The CSM is determined to be the most important mechanism to integrate consideration of climate impacts. The CSM assists in informing all aspects of site decision making sequentially from the initial desk-based screening assessment, the site investigation, feasibility study, design, and implementation. The CSM should be continuously developed and refined, while considering new knowledge about climate factors and potential impacts to the site.

Several considerations are provided in relation to assessing potential climate impacts on contaminants and contaminant migration including:

- Past and anticipated future flooding
- Sea level rise
- Droughts, which may result in excessive local groundwater abstraction and/or erosion
- Storms
- Changes in precipitation patterns
- High wind events leading to wind scour and erosion
- Extreme temperatures which may result in changes in the physical-chemical behaviour of the contaminant (e.g. volatilisation, solubility, mobility, etc)
- Distribution of contaminants due to wildfires via air borne pathways
- Changes in groundwater or surface water use, particularly reduced flow or recharge which may increase concentrations of contaminants of concern and increase the temperature of the water body

- Failure and/or loss of integrity of engineered controls (e.g. capping systems, treatment systems)

During remedial selection and design, ASTM recommends that users consider current conditions and reasonably expected future conditions over the timeframe the remedial system is considered within their assessment. It is noted that in some cases multiple climate and site related events can cause cascading impacts on and off-site. Several case studies detailing how climate impacts have affected the clean-up of sites are provided.

Interstate Technology Regulatory Council (ITRC)

The American ITRC has produced Sustainable Resilient Remediation (SRR) (Interstate Technology & Regulatory Council, 2021) guidance to provide resources for regulators, stakeholders, consultants, and responsible parties. Its aim is to help integrate sustainability and resilience practices through all stages of remediation projects. The SRR CSM is considered critical to the development and implementation of remedial approaches and should provide the necessary underpinning information for remediation that is protective of human health and the environment. This is both in anticipation of more frequent and severe weather events, wildfires, and other climate change linked impacts and in consideration of important social and economic influences to the site and community. Stakeholder engagement (e.g. emergency personnel, utility providers and hazardous waste management specialists) is stated critical to the social dimension of SRR. The CSM should be updated iteratively to account for stakeholder views and new site information as the project progresses. It should also provide for remedial influences beyond chemical hazards and physical environment conditions. The SRR CSM uses forecasted changes in the frequency and severity of extreme weather events, wildfires, and longer-term changes (e.g. temperature, precipitation trends and rising sea-level) at the site level to assess future direct and indirect impacts to remediation. As part of the site's exposure assessment at least the following factors should be assessed in relation to climate change and extreme weather event related impacts (depending on location):

- changing precipitation patterns
- changing extremes and severe weather (i.e. hurricanes, tornadoes, hot and cold temperatures)
- evapotranspiration and droughts
- rising sea levels and salt-water intrusion
- changes in air temperature
- ocean temperature and acidification
- atmospheric water vapour content
- changing snow cover and decreasing glaciers
- permanent and temporal changes in the groundwater table elevation
- changing wildfire patterns and intensity
- landslides
- permafrost stability
- wind

As part of the site investigation phase, site specific data should be collected to help evaluate a site's vulnerability to climate change and extreme weather events during the remedial action and long-term management of the remediation strategy. The location and type of site will inform the data collection requirements. Examples are provided in relation to data collection needs, including:

- where there are concerns about contaminants in sediments, additional data may need to be collected relating to wind and wave action, drainage patterns of runoff into surface water, interactions at the groundwater to surface water interface, historical rates of erosion and sediment deposition, and sediment properties that may affect sediment and contaminant transport (e.g. sediment grain size and compaction).

- for upland sites data needed may include historical records of storm events and drainage patterns, site flooding or standing water, and occurrence of erosion and landslides attributed to storm events.
- if a site is vulnerable to inundation, additional data may need to be collected to develop detailed surface contour maps for predicting inundation patterns and identifying vulnerable areas.
- if the site is near the coast, site-specific data (for example, currents, wind, and wave action) may be needed to further evaluate the potential for inundation.
- if salt-water intrusion is a potential impact to the remedy, it may be necessary to collect and evaluate water quality data (such as pH and conductivity).

Further guidance is provided in relation to the active remediation phases and site close out. In addition, a number of tool kits and references are presented within the guidance to assist users in applying SRR to their projects. However, little detail is provided in relation to how these assessments are best undertaken.

Australia

Australian National Climate Change Adaptation Research Facility

In Australia, CoastAdapt in association with the Australian Government and National Climate Change Adaptation Research Facility (NCCARF) have produced an Impact Sheet (Morton, 2016) which identifies likely impacts of climate change in relation to contaminated land. The aim of the document is to stimulate debate on the impacts that climate change will have on the development and management of contaminated land sites in Australia.

The document outlines impacts of climate change on contaminated land as a result of temperature change, sea level rise, extreme weather events (including storms, cyclones, and heatwaves), coastal erosion and shoreline recession and provides a process for assessing the vulnerability of coastal zones to climate change to assist decision makers in climate change adaption. The paper goes on to discuss the impact of climate change on risk assessment of land contamination including how climate change can impact ecosystems, affect the toxicity of chemicals due to changes in physiochemical interactions, as well as the ability of biota to adapt to both of these stresses. The paper recommends there be further research and development in order to understand and reduce the negative impacts of climate change on current remediation methods[26].

[26] LCRM has not currently been formally adopted in Scotland and SEPA advise that CLR11 (Environment Agency, 2004) (although withdrawn) should continue to be referenced in the interim.

APPENDIX 3

Climate change causes and trends in the UK

A3 Climate change causes and trends in the UK

The UK Met Office defines climate change as “large-scale, long-term shift in the planet’s weather patterns and average temperatures” (Met Office 2). Climatic change is usually assessed by averaging data over a 30-year period; the most recent reference period is 1991-2020.

A number of human-induced factors have been linked to climatic change. Rising temperatures are linked to the anthropogenic release of greenhouse gases including carbon dioxide, methane, and nitrous oxide. Since the mid-seventeenth century, the industrial revolution resulted in the increased burning of fossil fuels (such as coal, oil, and gas) for energy production and other industrial activities, which have spread across the globe. Greenhouse gases have progressively accumulated in the atmosphere, trapping heat from the sun, and causing the earth to heat in a process commonly referred to as “the greenhouse effect”. Additional anthropogenic factors that can exacerbate the effects of climatic change include population growth; deforestation; peat bog degradation; intensification of agriculture; increased surface runoff associated with hardstanding in urban areas such as concrete and asphalt; ageing infrastructure (such as surface and foul water drainage unable to cope with increased discharge during projected periods of heavy rainfall winter months); and increased water consumption.

The UK has signed up to the 2015 Paris Agreement, an international agreement to reach global peak greenhouse gas emissions as soon as possible, with the goal of limiting the increase in average global temperatures to a maximum of 2 degrees Celsius (°C), aiming for 1.5 °C if possible (United Nations, 2015). The most recent UN Climate Summit (COP26, Glasgow, November 2021) concluded with the ‘Glasgow Climate Pact’ to keep to the goal of 1.5 °C and a global agreement to accelerate action on climate change this decade27. England, Wales and Northern Ireland have set a goal of net zero carbon emissions by 205028, with Scotland setting an earlier target of 2045 (Scottish Government, 2019).

Average global temperatures have increased by circa 1 °C since the beginning of the industrial revolution (Intergovernmental Panel on Climate Change, 2021). Recently released climate model forecasts suggest average global surface air temperatures are currently on course to exceed 1.5 °C relative to 1850-1900, with a 40-60 % chance of this occurring in the next 5 years (Intergovernmental Panel on Climate Change, 2021). Along with rising average global surface air temperatures, the upper atmosphere is projected to hold more moisture, and climatic change has been linked to the observed increased frequency and intensity of storm hydrological extreme events in both drought and flooding.

Future global climate change has been numerically modelled by the Intergovernmental Panel on Climate Change (IPCC) to the year 2100 based on potential anthropogenic greenhouse gas emissions scenarios. The modelling output results in projections, which can then be utilised by national agencies to determine the potential impacts of climatic change at country, regional and local scales. There is a rapid turnover of climate change publications within academia and from other regulatory and guidance bodies. It is important to recognise the uncertainties associated with the multiplicity of projections, modelling choices and downscaling when utilising model output.

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[27] More information available at: https://www.gov.uk/government/news/cop-26-ends-with-global-agreement-to-speed-up-action-on-climate-change.

[28] Business, Energy & Industrial Strategy (HM Government, 2021) describes ‘net zero emissions’ as balancing emissions of greenhouse gases with the amount of gas absorbed by natural carbon sinks such as forests and emerging technologies such as carbon capture.

The IPCC has developed several iterations of global greenhouse gas emissions scenarios based on projected climate change, socio-economic factors such as energy consumption and population growth, technology developments and human ability to adapt to climate change. These scenarios have changed over time and are listed below:

- 2001 IPCC Reports AR3 (Intergovernmental Panel on Climate Change, 2001) and AR4 (Intergovernmental Panel on Climate Change, 2007): Special Report on Emissions Scenarios (SRES).
- 2014 IPCC AR5 Report (Intergovernmental Panel on Climate Change, 2014): Representative Concentration Pathways (RCP).
- 2021 IPCC AR6 Report (Intergovernmental Panel on Climate Change, 2021): Shared Socioeconomic Pathways (SSP).

The SRES scenarios have been divided into four storylines or 'families' (A1, A2, B1 and B2) that consider future changes to population, economic development and technological change. The A1 family is further subdivided into three scenarios based on developments in alternative energy technology. The main storylines are:

- A1: rapid economic growth, peak in population growth in mid-century then decline, rapid production of new and efficient technologies.
- A2: slowly continuously increasing global population, regional economic development, slow economic growth, and technology change.
- B1: peak in global population mid mid-century then decline, rapid global changes in economic growth.
- B2: global population growth lower than A2, intermediate levels of economic development.

The three technology subgroups are:

- A1FI: Fossil fuel intensive energy sources.
- A1T: Predominately non fossil energy sources.
- A1B: Balance across all sources.

The most relevant RCPs are:

- RCP 1.9: global warming limited to below 1.5 °C, per the goal of the Paris Agreement (United Nations, 2015).
- RCP 2.6: requires decreasing carbon dioxide concentrations by 2020 and net zero concentrations by 2100, methane concentrations halve by 2020, and sulphur dioxide concentrations reduce by 10%. This scenario requires net carbon loss to be achieved.
- RCP 4.5: intermediate scenario, where carbon dioxide emissions peak by 2045, reaching half the levels of 2050 by 2100; a halt to the increase in methane by 2050 with a decline to 75% 2040 levels by 2100; sulphur dioxide emissions decrease by 20% of 1980-1990 levels. This is considered by some academics (Laherrère, 2019) to be the most plausible baseline scenario with no active climate policies limiting the production of greenhouse gases.
- RCP 8.5: worst case scenario, where greenhouse gas emissions continue to rise throughout the 21st century.

The SSPs are:

- SSP1: Sustainability (Taking the Green Road): More sustainable pathway, shift away from economic growth to human well-being and reduction in global inequality. Lower consumption and material growth, lower resource and energy intensity.

- SSP2: Middle of the Road: Social, economic and technological trends do not change from historical patterns, uneven development and income growth. Slow progress towards sustainable development goals. Decline in intensity of resource and energy use. Moderate population growth.
- SSP3: Regional Rivalry (A Rocky Road): Nationalism, competitiveness and regional conflicts resulting in domestic and regional policies. Energy and food security goals developed on a national basis by countries, at the expense of a broader development basis. Population growth is low in industrialised countries and high in developing countries. Strong environmental degradation in some areas as a result of low international priorities to address environmental concerns.
- SSP4: Inequality (A Road Divided): Increased inequality within and between countries as a result of highly uneven investments in human capital, increased disparities between economic opportunity and political power. Large gap between internationally connected, high-tech, knowledge and capital-intensive countries and lower income, poorly educated societies that adhere to labour intensive low technology economy. Technology development is high in high-tech economy and sectors. Conflict and unrest are common. Diversification in energy, investment in both carbon intensive and low-carbon energy sources. Environmental policies focus on local issues around middle- and high-income areas.
- SSP5: Fossil-Fuelled Development (Taking the Highway): Rapid technological progress and human capital development as a path to sustainable development. Increasingly integrated global markets. High investment in health and education. Exploitation of abundant fossil fuel resources, adoption of resource and energy intensive lifestyles globally. Rapid economic growth. Peak with subsequent decline in global population in twenty first century. Successful management of local pollution problems.

Figure A3-1 summarises temperature projections for SRES and RCP scenarios.

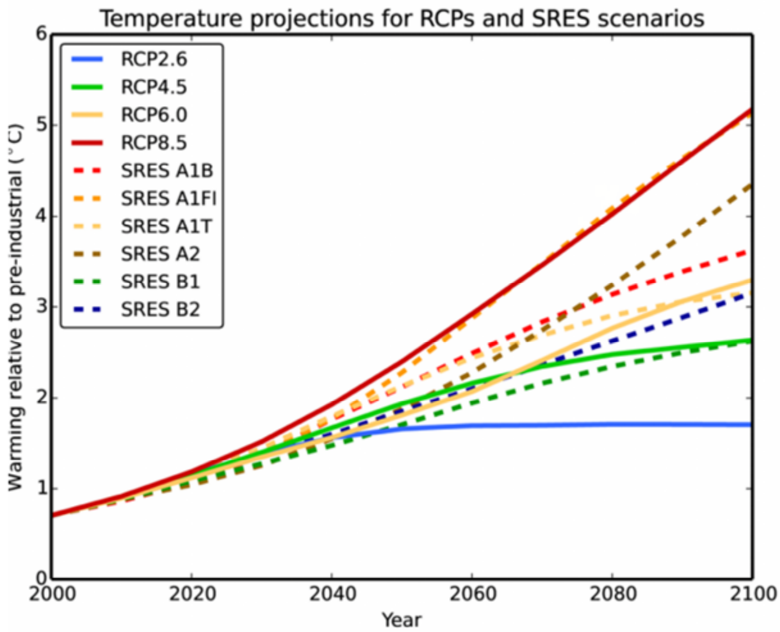

Figure A3-1: Global mean temperature projections from climate model MAGICC6 relative to a pre-industrial average (1850-1900) for RCP2.6 (blue), RCP4.5 (green), RCP6.0 (yellow) and RCP8.5 (red) and the older SRES scenarios (dashed coloured lines) from UKCP18 guidance (Met Office, 2018)

Table A3-1 and Figure A3-2 summarises the projected surface temperature increases associated with five SSP scenarios utilised in IPCC AR6:

Table A3-1: Global surface temperature projections associated with SSP1-SSP5 for three selected 20-year time periods. Temperature differences are relative to average global surface 1850-1900. Scenarios are referred to as SSPx-y where x refers to the SSP (Socio-economic pathway) underlying the scenario and y refers to the approximate level of radiative forcing in Wm-2. After Table SP1M, IPCC AR6.

Scenario	Projected Greenhouse Gas Emission	Near Term (2021-2040)		Mid Term (2041-2060)		Long Term (2081-2100)	
		Best Estimate (°C)	Likely Range (°C)	Best Estimate (°C)	Likely Range (°C)	Best Estimate (°C)	Likely Range (°C)
SSP1-1.9	Very Low	1.5	1.2 - 1.7	1.6	1.2 - 2.0	1.4	1.0 - 1.8
SSP1-2.6	Very Low	1.5	1.2 - 1.8	1.7	1.3 - 2.2	1.8	1.3 - 2.4
SSP2-4.5	High	1.5	1.2 - 1.8	2.0	1.6 - 2.5	2.7	2.1 - 3.5
SSP3-7.0	High	1.5	1.2 - 1.8	2.1	1.7 - 2.6	3.6	2.8 - 4.6
SSP5-8.5	Very High	1.6	1.3-1.9	2.4	1.9 - 3.0	4.4	3.3 - 5.7

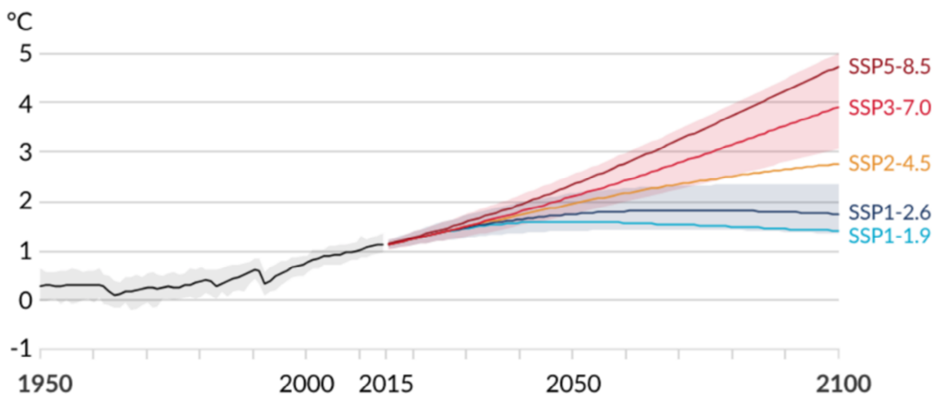

Figure A3-2: Global surface temperature change projections for the five SSPs (coloured lines), relative to 1850-1900. Extract from IPPC AR6. Shaded areas represent uncertainty associated with the projections. Black line represents the historical simulation to provide context for the future projections.

SRES were developed using multiple models to reflect the underlying uncertainty associated with the driving forces behind future emissions (Nakićenović, et al., 2000). SRES scenarios do not consider any current or future measures to limit greenhouse gas emissions, and overestimate fossil fuel resource availability and future production outputs (Hook, Sivertsson, & Aleklett, 2010). RCPs are described in terms of radiative forcing (Wm-2) projected to the year 2100 compared to pre-industrial conditions (1750) and are utilised in the earlier scientific reports. SSPs are qualitative descriptions of alternative socio-economic global changes up to 2100, providing potential projections in global populations, economic growth, urbanisation, fossil fuel use, and technology development utilised in the more recent IPCC reports.

The Met Office UK Climate Projections (UKCP18) are the most up up-to-date climate projections for the UK (Murphy, et al., 2019), superseding UKCP09 projections (Jenkins et al., 2009) (Kendon, et al., 2019). The UKCP09 scenarios are based on SRES greenhouse gas emission scenarios, whereas the UKCP18 are based on RCP greenhouse gas emission scenarios.

The UKCP18 projections have higher spatial resolution, incorporate increased scientific understanding of processes and provide an approach to deal with uncertainties. Generally, the UKCP18 projects that climatic change in the UK will result in more extreme events such as intense rainfall and storm events resulting in flash floods; hotter, drier summers with a higher likelihood of heat waves due to higher temperatures; increased potential evaporation due to higher summer temperatures and consequently a potential increase in drought conditions; milder, wetter winters and potentially increased groundwater recharge; and rising sea levels, (Lowe, et al., 2019).

The UKCP18 projects that the frequency of dry, warm events will increase in the future as a result of climate change. Rossby waves (also known as planetary waves), large waves that occur in the atmosphere (and ocean) and redistribute heat from the tropics to the poles, in the middle to high latitudes have been observed to become 'wavier' in nature, leading to 'atmospheric blocking' over the UK. Blocking events are meteorological events with 'persistent, quasi-stationary high atmospheric pressure blocking the usual westerly flow and/or storm tracks', resulting in longer periods of warm, dry weather during summer (June, July and August). Blocking events have been linked to the occurrence of wildfires in the UK. Unfortunately, such events are underestimated in climate model projections. While considered generally to be rare events, blocking events have a potentially high impact due to their persistent nature and association with heat waves (Woollings, et al., 2018).

The UK Met Office publishes the State of the UK Climate Report on an annual basis and can be downloaded from the Met Office website (Met Office, 2021a).

APPENDIX 4

Case Study Examples

Example 1: Proposed residential development (design life of 60 years) on brownfield site located in Littlehampton, south coast of England.

It should be noted the site used within this case study example is not based on an existing site. Where placenames have been used it is for illustrative purposes only and is not representative of any actual site conditions or actual risk.

Site Setting

The site is located in Littlehampton, West Sussex within a predominantly residential area. It currently comprises a generally flat and level 1 hectare site, roughly rectangular in shape, covered by concrete crush, grass and scrub. Historical site uses include a shoe factory and smithy. A number of light industrial uses (historical and current) have been identified within the surrounding area.

BGS geological mapping indicates superficial deposits underlying the site are River Terrace Deposits (designated as a Secondary A Aquifer) which is underlain by the Lewes Nodular Chalk Formation, Seaford Chalk Formation, Newhaven Chalk Formation, Culver Chalk Formation and Portsdown Chalk Formation (Undifferentiated) (designated as a Principal Aquifer). Made Ground is also likely to be present as a result of previous development and site uses.

Historical borehole logs in proximity to the site indicate the River Terrace Deposits are present to a depth of approximately 7m below ground level (m bgl) with underlying Chalk to depths >60m bgl. Groundwater was indicated to be present from of 4m bgl within the River Terrace Deposits.

A groundwater abstraction is located report to be present 200m north of the site although the site is not within a Source Protection Zone.

Hydrogeological Model

Made Ground is likely to be present underlying the site as a result of historical development. Perched groundwater may be present associated with lenses of permeable material that are recharged by surface water infiltration within the Made Ground.

The superficial deposits comprise River Terrace Deposits designated as a Secondary A Aquifer with underlying bedrock geology of Chalk designated as a Principal Aquifer. It is considered likely that these aquifers are generally in hydraulic continuity and groundwater may be present from 4m bgl within the River Terrace Deposits.

Groundwater is likely to flow to the south towards the English Channel located 100m to the south of the site and may be tidally influenced. The site is not within a Source Protection Zone, although a groundwater abstraction is located 200m north of the site, up-hydraulic gradient.

Future Climate Change under RCP8.5 Scenario

Sea Level Rise/Flood Risk

The site is currently located approximately 100m from the English Channel (to the south of the site) and is at an elevation approximately 10m AOD. Under RCP8.5 sea level along the coast in proximity to the site is projected to rise by >0.7m by 2100[29] which could bring the sea within approximately 60m of the site during spring tides or storm surges[30].

The site is located within Flood Zone 3[31] indicating it is at a high risk of flooding from rivers and the sea. Note that climate change may result in changes to the frequency of extreme weather events and associated flooding.

Projected Changes to Groundwater Level

The site is located within Littlehampton Anticline East Groundwater catchment which falls under the WFD definition of groundwater body. The eFLaG project far-future (2050-2079) projections for groundwater recharge within this catchment report a 0.2mm per day increase for the winter months for this groundwater body. No change to current recharge is indicated for other seasons. This indicates potential future increases in groundwater level, at least during winter, relative to the current baseline.

Far-future median projections for the nearest monitored borehole within the Chalk aquifer (Houndean Bottom) indicates no significant groundwater level changes for this bedrock aquifer.

Potential Sources

Potential Sources of Contamination include**:**

On-Site:

- Made Ground associated with historical development, including hydrocarbon contamination
- Historical Industrial Site uses (shoe factory and smithy)

Off-Site:

- Current and former commercial and industrial uses
- Historical Landfill Sites (including registered sites, infilled quarries and land raising)

Potential Pathways*

Potential Pathways include:

- Leaching of contamination into groundwater from soil followed by lateral migration of groundwater to the wider groundwater environment or surface water; and
- Migration of groundwater through preferential pathways such as utility service trenches / sewers.

Potential Receptors*

- Groundwater within the River Terrace Deposits (Secondary A Aquifer);
- Groundwater within the Chalk Formation (Principal Aquifer);
- Groundwater abstraction; and
- Surface water (English Channel)

[29] https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/summaries/marine-climate-change-projections
[30] https://coastal.climatecentral.org/map
[31] https://flood-map-for-planning.service.gov.uk/location

Preliminary Conceptual Site Model*

Table 1 – Preliminary CSM

Potential Sources	Potential Pathways	Potential Receptors	Comments
• Made Ground associated with historical development, including hydrocarbon contamination • Historical Industrial Site uses (shoe factory and smithy)	• Vertical leaching from impacted Made Ground • Lateral migration of impacted groundwater derived from on-Site and off-Site sources.	• Secondary A Aquifer (River Terrace Deposits) • Principal aquifer (Chalk) • Groundwater abstraction • Surface water (English Channel)	Groundwater may be present underlying the site at a depth of 4m bgl within River Terrace Deposits and may be tidally influenced due to the proximity to the English Channel. Areas of the site are unsealed by hardstanding and there is potential for contaminants from historical site uses to leach from Made Ground into the underlying Secondary A and Principal Aquifers through infiltration of rainwater. Groundwater flow direction is likely towards the English Channel located 100m to the south, impacted groundwater may migrate off-site and impact aquifers within the wider area and ultimately the English Channel. A groundwater abstraction is located 200m north of the site; the site is not within an SPZ and the abstraction is located up hydraulic gradient, therefore it is considered unlikely to be affected by contaminant impacted groundwater. ***Under RCP8.5 Climate Change Projections*** *Winter rainfall levels (and intensity) are projected to increase by 60% within the lifespan of the proposed development which may increase leaching of existing contaminants from Made Ground. Groundwater recharge within the catchment through infiltration may also increase during winter bringing the groundwater level to within Made Ground and therefore promote increased leaching of contaminants and reduce potential attenuation.* *Sea levels are also anticipated to rise by >0.7m by 2100 in this area, along with the potential for flooding which could further mobilise contaminants within the Made Ground. Higher sea levels would decrease the distance of the site from the sea and could alter current groundwater flow patterns and hydraulic gradient creating larger tidal fluctuations within groundwater underlying the site. Groundwater quality and chemistry could also be affected by saline intrusion. The abstraction well located off-site to the north could also be brought within the influence of the site due to changes in groundwater flow patterns.*
	• Migration of groundwater through preferential pathways such as utility service trenches / sewers	• Secondary A Aquifer (River Terrace Deposits) • Principal aquifer (Chalk) • Groundwater abstraction • Surface water (English Channel)	Groundwater underlying the site is anticipated to be present at 4m bgl within the River Terrace Deposits, below anticipated levels of proposed utility service trenches /sewers. Therefore proposed utilities are considered unlikely to act as a preferential pathway affecting off-site Controlled Water receptors. ***Under RCP8.5 Climate Change Projections***

Potential Sources	Potential Pathways	Potential Receptors	Comments
			Likely higher groundwater levels during winter combined with higher sea level has the potential to cause inundation of future utility service trenches/sewers. Any contaminants present within groundwater underlying the site could then migrate off-site using this preferential pathway. However, groundwater levels are not projected to remain at shallow depths and therefore these events would likely be short term during extreme weather events.

Note: Standard font relates to the risk under current climatic conditions. *Italic font* refers to risks which concern conditions under future climate change.

*Controlled Water pathways and receptors only

Potential recommendations to take account of projected climate change conditions:

- Any future ground investigation should include continuous groundwater monitoring over the winter period to gain better understanding of existing groundwater regime.

Example 2: Part IIA Assessment of a coastal historical landfill in Eastern England

It should be noted the site used within this case study example is not based on an existing site. Where placenames have been used it is for illustrative purposes only and is not representative of any actual site conditions or actual risk.

Site Setting

The site is currently open ground subject to informal recreation activities. A review of historical mapping indicates that the site was formerly sand dunes in the backshore area, prior to the sand dunes being removed to form a golf course in the early 1900s. The site was subsequently utilised as a historical landfill and infilled sometime in the early 1960s and subsequently developed into a campground prior to the current land-use of the site.

Historical borehole logs indicate 3-4m of landfill materials (predominantly ash with plastic, glass, brick, metal, rubber, cloth, carpet etc), overlying Blown Sands consisting of medium sands. The historical logs reported groundwater within the Blown Sands underlying the landfill materials. A review of historical records indicates no known engineered cap or lining to the landfill.

The superficial deposits consist of Blown Sands, overlying Bedrock consisting of the Sands and Gravels of the Crag Formation.

A beach and the North Sea are located to the east of the site. The high-water mark on published mapping is currently shown as 25m to the east of the site.

Hydrogeological Model

Made Ground is likely to be present across the site owing to the land-use as a historical landfill, with the potential for perched water within any low-permeability zones, recharged by infiltrating groundwater as no engineered cap is known to be present. Historical borehole logs indicate a potential groundwater table located just below the base of the landfill materials within the Blown Sands.

The Blown Sands are classified as a Secondary A Aquifer, and the Crag Formation strata are classified as a Principal Aquifer, although due to its proximity to the sea it is unlikely to be of use for potable water supply due to saline intrusion risks. The site is not within a SPZ and there are no licensed groundwater abstractions within 1000m of the site.

Groundwater is likely to flow east towards the North Sea, and it is probable, given the recorded geology, that groundwater within the Superficial Deposits and Principal Aquifer are in hydraulic continuity.

Future Climate Change under RCP8.5 Scenario

Sea Level Rise/Flood Risk/Coastal Erosion

The site is in proximity to the North Sea, with the mean high-water mark currently located approximately 25m to the east of the site, at an elevation approximately 4m AOD. Under RCP8.5 sea level along the coast in proximity to the site is projected to rise by 0.76m by 2100 (50% percentile), with a 95% percentile range of 0.52 – 1.2m.[32]

The National Coastal Erosion Risk Mapping (2018)[33] indicates that the site is in an area of No Active Intervention, with a long-term (2105) shoreline retreat distance of 75m anticipated (50% percentile), with a 95% percentile range of 53 – 97m anticipated. The above predictions would, without mitigation measures, result in the shoreline being within the landfill in the future.

The site is located within Flood Zone 3 indicating it is at a high risk of flooding from rivers and the sea. Note that climate change may result in changes to the frequency and severity of extreme weather events and associated flooding.

Projected Changes to Groundwater Level

The Site is located within the Broadland Rivers Chalk and Crag Groundwater catchment. The eFLaG project[34] far-future (2050-2079) projections for groundwater recharge within this catchment report a median 5-10% increase for the winter months for this groundwater body, and a median 40-50% decrease in summer recharge (albeit from a very low baseline). This indicates little potential future increases in groundwater level due to recharge relative to the current baseline. However, given the site location adjacent to the sea, groundwater levels beneath the site are likely to rise as a result of the overall projected rise in sea-levels. The salinity of the groundwater may also be influenced by sea level rise and coastal erosion.

Potential Sources

Potential Sources of Contamination include:

On-Site:

- S01: Landfilled waste, which may include household, commercial and industrial wastes, petroleum hydrocarbons and asbestos.

Potential Pathways*

Potential Pathways include:

- P01: Leaching of contamination into groundwater from soil due to rainfall infiltration and subsequent migration of groundwater to the wider groundwater environment or surface water;
- P02: Leaching of contamination by lateral migration of groundwater through landfill materials and subsequent migration of groundwater to the wider groundwater environment or surface water; and
- P03: Physical erosion of the landfill materials and direct exposure of landfill materials to the surface water environment.

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[32] https://ukclimateprojections-ui.metoffice.gov.uk/ui/home

[33] National Coastal Erosion Risk Mapping (arcgis.com)

[34] https://eip.ceh.ac.uk/hydrology/eflag/

Potential Receptors*

- R01: Groundwater within the Blown Sands (Secondary A Alluvium) and Crag Formation (Principal Aquifer);
- R02: Surface water (North Sea).

*Controlled Water pathways and receptors only

Preliminary Conceptual Site Model

Table 1 – Preliminary CSM

Sources	Possible Pathways	Receptors	Probability	Consequence	Risk Level	Comments
S01: Landfilled waste, which may include household, commercial and industrial wastes, petroleum hydrocarbons and asbestos	P01: Leaching of contamination into groundwater from soil due to rainfall infiltration and subsequent migration of groundwater to the wider groundwater environment or surface water	R01: Groundwater within the Blown Sands (Secondary A Alluvium) and Crag Formation (Principal Aquifer) R02: Surface water (North Sea).	Likely *(Likely)*	Medium *(Medium)*	Moderate *(Moderate)*	Made Ground associated with the site use may contain leachable contaminants. The current site conditions comprise areas of soft landscaping which enables infiltration and increases the risk of leaching into the sensitive aquifers below the site and subsequent migration to the North Sea. ***Under RCP8.5 Climate Change Projections*** *Under a RCP8.5 scenario, the direct recharge (i.e. infiltrating rainfall) is not expected to significantly increase. As such, there is no change in the risk assessment for this element of the CSM.*
	P02: Leaching of contamination by lateral migration of groundwater through landfill materials and subsequent migration of groundwater to the wider groundwater environment or surface water	R01: Groundwater within the Blown Sands (Secondary A Alluvium) and Crag Formation (Principal Aquifer) R02: Surface water (North Sea)	Low likelihood *(Likely)*	Medium *(Medium)*	Low *(Moderate)*	The available information suggests that groundwater levels are below the base of the landfill. As such, direct leaching via lateral migration of groundwater through potentially contaminated landfill materials is considered to be of low likelihood, with a low risk level. ***Under RCP8.5 Climate Change Projections*** *Under a RCP8.5 scenario, sea levels are expected to rise circa 0.7m in the vicinity of the sea. As a result, groundwater levels are expected to increase below the site, such that potentially contaminated landfill material may come into direct contact with groundwater. Furthermore, tidal influences are anticipated to increase as the coast moves closer to the landfill hence ground water rises at high tide are likely to be in excess of the 0.7m projected rise. Salinity changes if coast moves closer through saline intrusion / sea spray etc may also change mobility of some contaminants*
	P03: Physical erosion of the landfill materials and direct exposure of landfill materials to the surface water environment.	R02: Surface water (North Sea).	Unlikely *(High Likelihood)*	Medium *(Medium)*	Very Low Risk *(High Risk)*	The site is current located some 50m from the North Sea and there is no current evidence of direct exposure of landfill materials to the North Sea. ***Under RCP8.5 Climate Change Projections***

						Coastal erosion projections incorporating projected sea-level rise indicate expected erosion of circa 75m from existing coastline. On this basis, it is anticipated that over time, without mitigation measures, the landfill will become directly exposed to the North Sea and consequently a high risk that contaminated materials may become directly exposed to the North Sea. *Further to the above long-term effects of future climate change, individual storm events are projected to become more frequent and/or intense, and combined with a general rise in sea levels results in an increased acute risk of individual storm events washing away the landfill.*

Note: Standard font relates to the risk under current climatic conditions. *Italic font* refers to risks which concern conditions under future climate change.

Conclusions and Recommendations

Based on historical and current land uses and in accordance with LC:RM:

- The overall risk from land contamination at the site is considered to be moderate for the current development and conditions, as there is a risk of rainwater infiltration leading to leaching of contaminated soils within the former landfill.
- Taking into account projected future climate change, the overall risk from land contamination at the site is considered to increase to *high risk*, as there is a further risk of groundwater rising into the landfill materials and erosion resulting in direct exposure of landfill materials to the North Sea.

Given the above, there is considered to be insufficient information available to determine whether the site would be classified as Contaminated Land under Part 2A of the EPA 1990, and appropriate intrusive investigations are recommended. The investigation should be designed to address the following areas of uncertainty:

1. Composition and chemical nature of the landfill materials;
2. Groundwater (and leachate if present) conditions up-gradient and down-gradient of the landfill; and,
3. Groundwater and leachate levels, incorporating long-term monitoring and at a sufficient resolution to characterise any tidal variations.

A site-specific assessment of anticipated coastal erosion rates at the site is also recommended.

Example 3: Proposed commercial development with basement (design life of 60 years) on former industrial site located in Glasgow, Scotland.

It should be noted the site used within this case study example is not based on an existing site. Where placenames have been used it is for illustrative purposes only and is not representative of any actual site conditions or actual risk.

Site Setting

The site comprises a vacant area of land comprising soft landscaping which is generally level and sloping gently to the south. Former site uses included an abattoir, mills and chemical works. The site is located within an industrial area with historical surrounding site uses including a chemical works, brewery and a foundry. A historical landfill is located 200 west of the site.

Superficial deposits underlying the site are Raised Marine Deposits comprising 'finely layered clay and silt' of the Clyde Clay Formation. Underlying bedrock geology comprises Scottish Lower Coal Measures (cyclical sequences of sandstones, siltstones and mudstones with coal and fireclay). The Coal Authority interactive map does not indicate shallow mine workings at the site however maps indicate shafts and unrecorded shallow workings approximately 250m east of the site.

A number of previous investigations have been undertaken at the site. Encountered geology during these investigations indicated Made Ground thicknesses of 0.5-5.5m (consisting of predominantly ash and gravel fill material with some localities of sandy clay), underlain by clays and silts to 4.8-11.2m below ground level (m bgl), and stiff clay (possibly Glacial Till) to depths of 5-12.5m bgl. The depth to rockhead is 10-20m bgl across the site. Groundwater monitoring indicated groundwater was encountered at depths varying between 0.9m and 11.3m indicating that perched bodies of groundwater may be encountered in the granular Made Ground. Visual and olfactory evidence of hydrocarbon impact has been reported within Made Ground across the site.

The superficial groundwater body underlying the site is listed as the 'Glasgow Sand and Gravel groundwater body (150718)' and is noted to be of 'good' status dominated by intergranular flow. The underlying bedrock aquifer is listed as the 'Glasgow and Motherwell groundwater body (150677)' and is noted to be of "Poor" status classified by SEPA as a moderately productive aquifer dominated by intergranular and fracture flow.

No groundwater abstractions are within 1km of the site. The nearest surface water is the River Clyde located 500m to the south.

Hydrogeological Model

Made Ground is known to be present underlying the site with thicknesses of 0.5-5.5m as a result of historical development. Historical ground investigations have reported areas of shallow groundwater likely to be perched groundwater associated with lenses of permeable material that are recharged by infiltration through the Made Ground.

The superficial deposits comprise Raised Marine Deposits with underlying bedrock geology of Scottish Lower Coal Measures (classified as a moderately productive aquifer). It is considered possible that the aquifers may be in hydraulic connection; as groundwater has been monitored at depths ranging from 0.9m to 11.3m, the connection may be discontinuous where lower permeability layers of cohesive clays and silts are present.

Groundwater is anticipated to follow topography and flow to the south towards the River Clyde.

Future Climate Change under RCP8.5 Scenario

Sea Level Rise/Flood Risk

The site is not located within close proximity of the Firth of Clyde or an area at risk of coastal flooding (including coastal flooding via the River Clyde[35]).

The site is currently located approximately 500m from the River Clyde (to the south of the site) and is and not within an area projected as being likely to be at risk from river flooding[36].

The intensity of future rainfall has not been projected, however due to the shallow groundwater table indicated on site from historical ground investigations, groundwater flooding may be likely under future climate change conditions especially in areas of soft landscaping and should also be accounted for within proposed basement design.

Projected Changes to Groundwater Level

The site is located within the Glasgow and Motherwell Groundwater Body. The eFLaG project far-future (2050-2079) projections for groundwater recharge within this catchment report a 0.3mm per day increase for the winter months for this groundwater body. No change to current recharge is indicated for spring however a reduction of summer and autumn recharge of -0.1mm per day is projected. This indicates the greatest potential future increases in groundwater level are during winter relative to the current baseline with potentially greater fluctuations in groundwater level throughout the year in comparison to current conditions.

Potential Sources

Potential Sources of Contamination include**:**

On-Site:

- Made Ground of unknown provenance / demolition of previous structures.
- Chemical releases associated with former site uses including abattoir, mills and chemical works.

Off-Site:

- Current and former commercial and industrial uses (including brewery, chemical works and foundry).
- Historical Landfill Site (located 200m west of the site).

Potential Pathways*

Potential Pathways include:

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35 https://scottishepa.maps.arcgis.com/apps/webappviewer/index.html

36 https://scottishepa.maps.arcgis.com/apps/webappviewer/index.html

- Leaching of contamination into groundwater from soil followed by lateral migration of groundwater to the wider groundwater environment or surface water; and
- Migration of groundwater through preferential pathways such as utility service trenches / and foul sewers.

Potential Receptors*

- Shallow groundwater in the superficial Raised Marine Deposits;
- Groundwater within the Scottish Lower Coal Measures bedrock aquifer; and,
- Surface water (River Clyde)

* Water Environment pathways and receptors only

Preliminary Conceptual Site Model

Table 1 – Preliminary CSM

Potential Sources	Potential Pathways	Potential Receptors	Comments
• Made Ground of unknown provenance / demolition of previous structures. • Chemical releases associated with former site uses including abattoir, mills and chemical works.	• Vertical leaching from impacted Made Ground • Lateral migration of impacted groundwater derived from on-Site and off-Site sources.	• Groundwater within the Raised Marine Deposits • Groundwater within the Scottish Lower Coal Measures • Surface water (River Clyde)	The site has a significant history of potentially contaminating site uses, previous investigations have identified Made Ground up to 5.5m in thickness comprising ash and gravel fill as well as evidence of hydrocarbon impact. Groundwater has been recorded at depths between 0.9m bgl and 11.3m bgl and there may be limited continuity between aquifer units of the Raised Marine Deposits and Scottish Lower Coal Measures with pockets of discontinuous perched groundwater within Made Ground. Although the Raised Marine Deposits are comprised of clays and silts which are likely to be of low permeability restricting the vertical migration of contaminants into groundwater in the underlying bedrock aquifer, hydrocarbon impact potentially present within the Made Ground could migrate vertically impacting deeper aquifers. However, the increase in hardstanding and building cover over the site following development will likely further reduce the infiltration of precipitation and therefore reduce the mobility of any subsurface contamination. Due to the distance to the River Clyde located 500m to the south it is considered likely that dispersal and attenuation would reduce the potential for material impact to this receptor. ***Under RCP8.5 Climate Change Projections*** *Winter recharge is projected to increase by 0.3mm per day and is likely to increase groundwater levels and potentially cause groundwater flooding(as a short term event). Higher groundwater levels and increased rainfall may also increase leaching and mobility of any contaminants (such as hydrocarbons reported within previous investigations) within the Made Ground degrading underling groundwater quality and Future Resource Potential.*
	• Migration of groundwater through preferential pathways such as future utility service trenches / or foul sewers	• Groundwater within the Raise Marine Deposits • Groundwater within the Scottish Lower Coal Measures • Surface water (River Clyde)	Shallow groundwater has been reported underlying the site within 0.9m of surface although it is currently unknown whether this is present as pockets of perched groundwater or a coherent groundwater body present within the Made Ground. Therefore, subsurface utilities and sewers to have the potential to be inundated by groundwater and act as a preferential pathway for contaminants affecting off-site water environment receptors, including the River Clyde (via sewers and surface water discharge). ***Under RCP8.5 Climate Change Projections*** *Increased winter recharge or extreme rainfall events could potentially cause groundwater flooding and increase the frequency and likelihood of inundation of utility service trenches / foul sewers.*

Note: Standard font relates to the risk under current climatic conditions. *Italic font* refers to risks which concern conditions under future climate change.

Potential recommendations to take account of projected climate change conditions:

- Further ground investigation should include continuous groundwater monitoring to characterise groundwater regime over 6-12 months (over the winter period) and to understand potential hydraulic connection between aquifer units, particularly in the near-surface deposits. Monitoring should particularly be undertaken within the footprint of the proposed basement.
- The potential for future groundwater flooding should be considered within future design of the proposed development and drainage strategy.