

SOCIETY OF BROWNFIELD RISK ASSESSMENT

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

Version 2.0

February 2026

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 the potential effects of climate change in 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.

Whilst the guidance provides a methodology for assessing risk of future climate change to controlled waters receptors, the methodology could be adopted by, and applied to, other areas of risk assessment. This report is made available on the understanding that neither the contributors nor the publishing organisation is engaged in providing a specific professional service. Whilst every effort has been made to ensure the accuracy and completeness of the work and this document, no warranty as to fitness for purpose is provided or implied. Neither SoBRA, nor the authors of the report, accept any liability whatsoever for any loss or damage arising in any way from its use or interpretation, or from reliance on any views contained herein.

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 supersedes version 1.0 dated August 2022 and includes updated references to guidance and policy (e.g. LCRM, NPF4 and WAT-PS-10-02) and climate change databases to 30 June 2025. It is however noted that climate science and research is rapidly evolving and as such guidance and databases are regularly reviewed and updated. Therefore, users should make sure they are using the most up to date scientific data. It is also important that users understand the limitations and uncertainties associated with future climate projections within their risk assessment.

As recognised by the SoBRA Summer Workshop 2022 report (SoBRA, 2022), consideration of the impacts of future climate change and extreme weather events on risks to controlled waters forms just one part of a wider adjustment that is required in our approach to brownfield risk assessment. Climate change considerations are also needed to address ground gas, soil vapour, non-aqueous phase liquid (NAPL) and carbon accounting.

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Published by the Society of Brownfield Risk Assessment www.sobra.org.uk.

The Society of Brownfield Risk Assessment is a Registered Charity: No. 1180875.

ISBN number: 978-1-0684225-0-8

REVISIONS

Version	Publication Date	Revisions
1.0	August 2022	-
2.0	February 2026	Updated with additional guidance and climate databases published up to 30 June 2025. New sections in relation to climate change projections available for soil moisture, flood risk, coastal erosion and extreme weather. Further consideration of how extreme weather could influence the conceptual site model including revisions to Figures 3-2, 3-3, and 3-4, Table 3-1 and updates to the worked examples included in Appendix 4.

ACKNOWLEDGMENTS

SoBRA wishes to thank the following individuals for their considerable assistance in the successful delivery of this document:

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SoBRA also wishes to thank the Executive Committee for their steer, encouragement, and review.

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- Appendix 2 Literature Review
- Appendix 3 Climate Change Causes and Trends in the UK
- Appendix 4 Worked Examples

1 INTRODUCTION

1.1 Background

The need to incorporate the projected effects of future climate change¹ into qualitative and quantitative risk assessments is set out within the following UK guidance:

- “Land Contamination Risk Management (LCRM)” guidance (Environment Agency, 2025),
- “Managing and reducing land contamination: guiding principles (GPLC2) FAQ 8” (Environment Agency, 2010) (now withdrawn),
- National Planning Policy Framework (NPPF) (Ministry of Housing, Communities & Local Government, 2024) for England and Wales, and
- National Planning Framework 4 (NPF4) (Scottish Government, 2023) for Scotland.
- “Assigning Groundwater Assessment Criteria for Pollutant Inputs. WAT-PS-10-02 / WAT-G-071” (Scottish Environment Protection Agency, 2025)²

However, prior to the initial publication of this guidance document in August 2022, there was 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 waters³ 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.

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 SEPA updated their document references for groundwater guidance when the Environmental Authorisation (Scotland) Regulations became active on 1 November 2025. This post-dates the cutoff date for the literature review but pre-dates publication of this SoBRA guidance. It is therefore considered appropriate to acknowledge that the SEPA guidance document WAT-PS-10-02 has now become WAT-G-071. It is noted that only the document reference number has been updated with the technical content of the guidance remaining unchanged.

³ 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.

- 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.
- Worked examples 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 30 June 2025. 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.

1.3.1 Key legislation

Climate change

The Climate Change Act 2008 (HM Government, 2008) and the Climate Change (Scotland) Act 2009 (Scottish Government, 2009)⁴ 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)⁵, 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’⁶. 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 adaptation plans have been prepared by the UK Government and Devolved Administrations (refer to Appendix 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.

⁴ 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.

⁵ Further information on the CCC is available at: <https://www.theccc.org.uk/>.

⁶ The most recent (2022) UK Climate Change Risk Assessment is available at: <https://www.gov.uk/government/publications/uk-climate-change-risk-assessment-2022>.

Land contamination

Part IIA of the Environmental Protection Act 1990 (HM Government, 1990) is the primary legislation in Scotland, England and Wales⁷ that relates to the assessment and remediation of land contamination under the land's 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.

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. Until recently guidance has 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. The Environment Agency's LCRM (Environment Agency, 2025), now includes a requirement to "*factor in climate change impacts, including extreme weather events to ensure site works and any long term remediation is sustainably robust*".

In addition, SEPA's guidance (Scottish Environment Protection Agency, 2025) for assessing risks to groundwater from land contamination states that "*You should consider climate change impacts and potential extreme events whilst developing the conceptual site model as well as during any detailed quantitative modelling or sensitivity analysis.*".

⁷ 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.

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, n.d.). 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 UK Health Security Agency defines extreme weather as “exceptionally adverse, severe, unusual or unexpected weather conditions for the season or location” (UK Health Security Agency, 2024). The following definitions may be helpful when identifying extreme weather events:

- Drought is characterised by a prolonged period of abnormally dry weather creating a shortage of water. The two most notable droughts in the last 50 years in England were characterised by dry winters (winter rainfall deficit) followed by hot dry summers over 1 or 2 successive years (Environment Agency, 2025). The Met Office includes reference to the following types of drought (Met Office, 2021b):
 - Meteorological drought: when rainfall in an area is below the average for that region,
 - Agricultural drought: when lack of rainfall or dry soil affects farming and crop growth,
 - Ecological drought: like agricultural drought, but when lack of water affects the local environment,
 - Hydrological drought: when water supplies such as streams and reservoirs are low, which can be caused by several factors including lack of snow melt and low rainfall. Hydrological drought usually occurs to due to water scarcity over greater than 12 months, however rainfall deficits accumulated over a 12-

month period could lead to different types of drought and drought impacts and are subject to the rainfall vulnerability of a region.

- The Drought Severity Index, a measure of drought severity, is calculated with 12-month rainfall deficit provided as a percentage of the mean annual climatological total rainfall (1981-2000) for that location.
- Severe drought is defined by the UK Met Office as droughts that are at least as severe as the drought of 2010-2012, where there was a 12-month rainfall deficit of 24% of mean annual rainfall for the 1981-2000 period.
- Heatwaves are defined by the UK Met Office as when a location records a period of at least three consecutive days with daily maximum temperatures meeting or exceeding the heatwave temperature threshold (between 25-28°C, dependent on the UK county); hot weather is when temperatures exceed 25°C; the annual count of hot summer days are the number of days per year when the maximum daily temperature exceeds 30°C; the annual count of extreme summer days are the number of days per year where the maximum daily temperature is above 35°C.
- Heavy rainfall / flood events are defined by the UK Met Office as the rainfall events exceeding 50mm, and the number of days where rainfall exceeds 95-99% of the 1961-1990 average.
- A wind storm is defined by the UK Met Office as an event where the following wind speeds are exceeded: 10 on the Beaufort wind scale, 27m/s (60mph). A violent wind storm exceeds the following wind speeds: 11 on the Beaufort wind scale, 31m/s (69mph).

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 weather events such as intense rainfall and storm events resulting in flash floods; hotter, drier summers with a higher likelihood of heat waves; 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 it 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 2.2.2 to 2.2.4) provide projections for precipitation, temperature, and sea level rise, 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 5 number (No.) possible future increases in average global radiative forcing (per the IPCC-see Appendix 3 for definition and details of RCPs) using a baseline of 1981-2000⁸ extending to 2100. Users of the model output are urged by the UKCP18 authors to focus on the RCP scenarios and discount the SRES A1B⁹ emissions scenario. Model projections are available at the following scales:

- Global: 28 No. projections at a 60-kilometre (km) grid resolution;
- Regional: 12 No. projections at a 12 km grid resolution;
- Local: set of 12 No. 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^{10,11}.

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

⁸ Users have the option to choose from 1961-1990 or 1991-2010 as an alternative to the UKCP18 baseline.

⁹ 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.

¹⁰ Users have the option to choose from 1981-2010 as an alternative to the UKCP18 baseline.

¹¹ 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’).

(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 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). Projection data is currently available only for RCP8.5 at a Local Scale, and RCP2.6 projection data is currently available only at a Global Scale.

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 available only 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 degree of uncertainty.
- 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 2-1), 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).

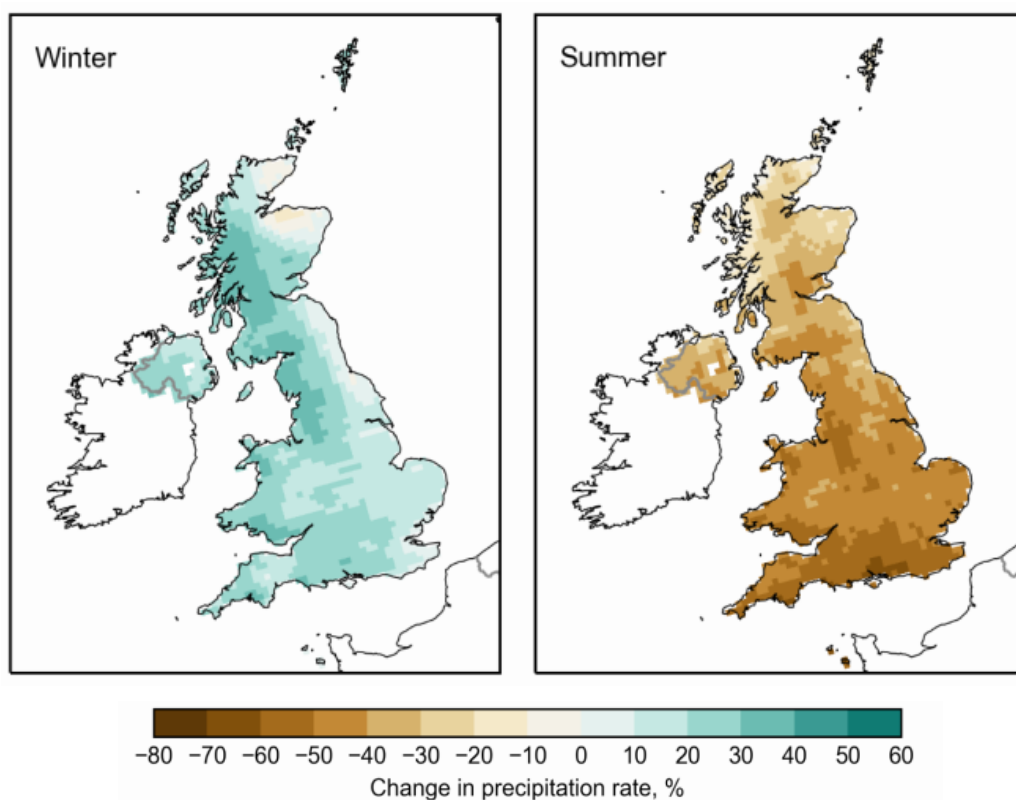


Figure 2-1: Projected seasonal changes in mean precipitation 2060-2080 from baseline (1981-2000). After Figure 2.23, UKCP18 Overview Report (Lowe, et al., 2019). Winter=December to January. Summer=June to August. © Crown copyright 2019, the Met Office

The [Climate Risk Indicator \(CRI\) Explorer](#) (The University of Reading, 2023) summarises UKCP18 projections for a variety of climate indicators, including rainfall. Rainfall patterns across the UK are not uniform and vary on seasonal and regional scales and will continue to vary in the future. Average rainfall is generally expected to increase in the winter months but reduce in the summer months. In terms of annual average rainfall projections, wetter conditions are anticipated in the north-west of the UK and drier conditions in the eastern and southern regions (Figure 2-2).

SoBRA consider the information presented in the CRI explorer (The University of Reading, 2023) to provide the most readily accessible data set in relation to understanding future rainfall projections in the UK. We would recommend that the following options are initially selected when viewing rainfall projections in the CRI explorer:

- Indicator category: Climate.
- Indicator: Rainfall.
- Variant: Annual (note that rainfall can also be considered on a seasonal basis).
- Metric: % change.
- Scenario: RCP8.5.
- Strand: UKCP18 Regional.
- Member: Median.
- Spatial resolution: 12 x 12 km (offers finest resolution, if the resolution doesn't cover the site of interest consider Local Authority spatial scale).
- Time period: 2071 – 2100 is considered to be representative of the far future and typically provides most extreme changes and could be considered as worst case. Other timescales are available.

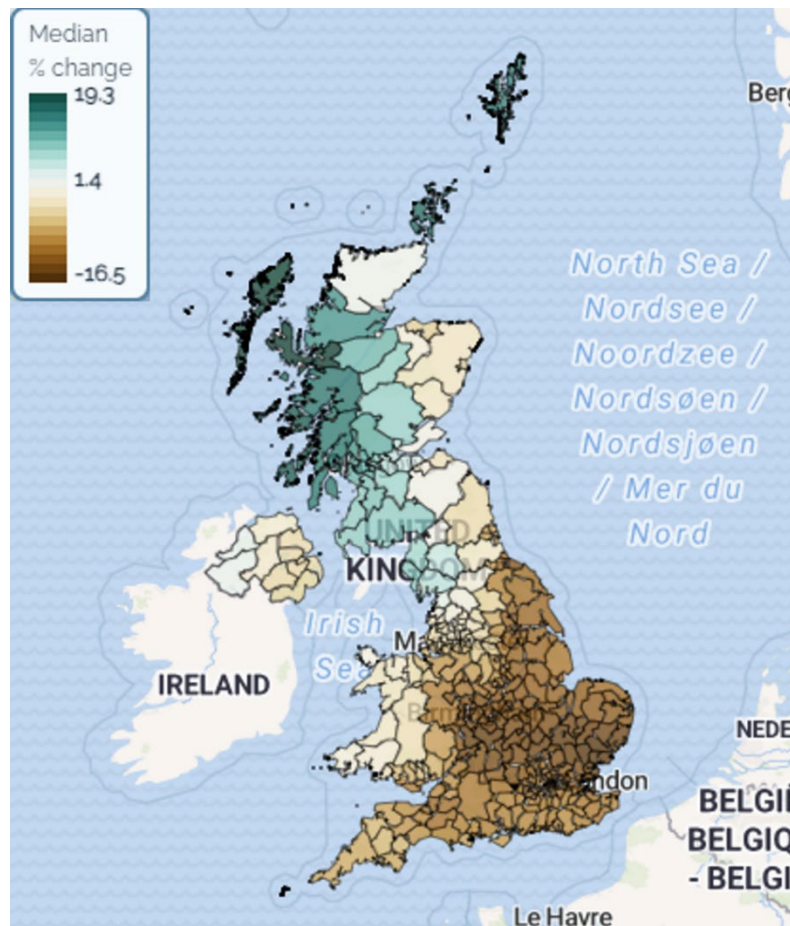


Figure 2-2: Map showing annual rainfall in a Local Authority spatial scale (time period 2071-2100) from the Climate Risk Indicator explorer (The University of Reading, 2023). Figure credited to University of Reading, used under CC-BY licence 4.0, <https://uk-cri.org/>.

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 2-3 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.

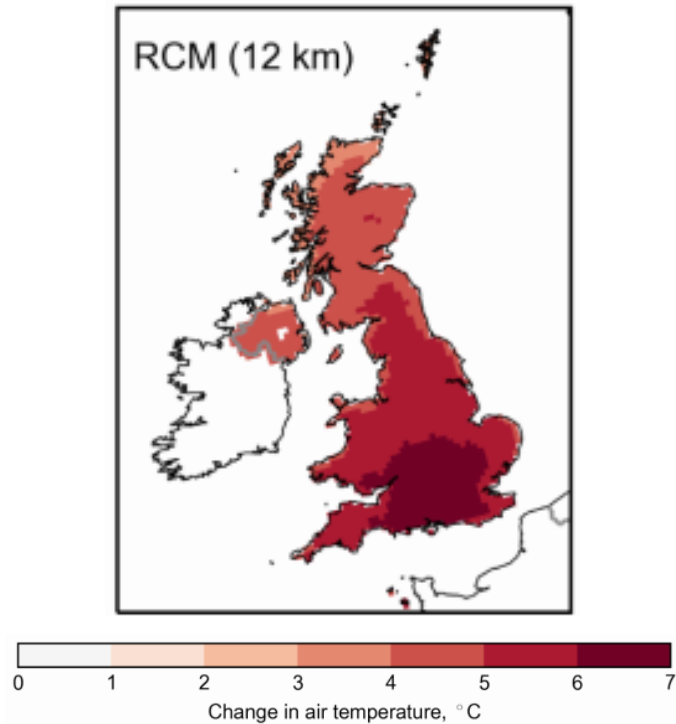


Figure 2-3 : Projected average summer air temperature change for 2060-2080 under RCP8.5 (baseline 1981-2000) for the Regional Climate Model (RCM), after figure 2.20, UKCP18 overview report (Lowe, et al., 2019). © Crown copyright 2019, the Met Office

SoBRA consider the information presented in the CRI explorer (The University of Reading, 2023) to provide the most readily accessible data set in relation to understanding future temperature projections in the UK. Figure 2-4 from the CRI explorer indicates the median change in temperature (reported as a % change from baseline to the far future (2071-2100)) within each Local Authority area in the UK. We would recommend that the same options are selected in CRI as has been outlined in the orange box in Section 2.2.2 with the exception that the variant selected is average temperature.

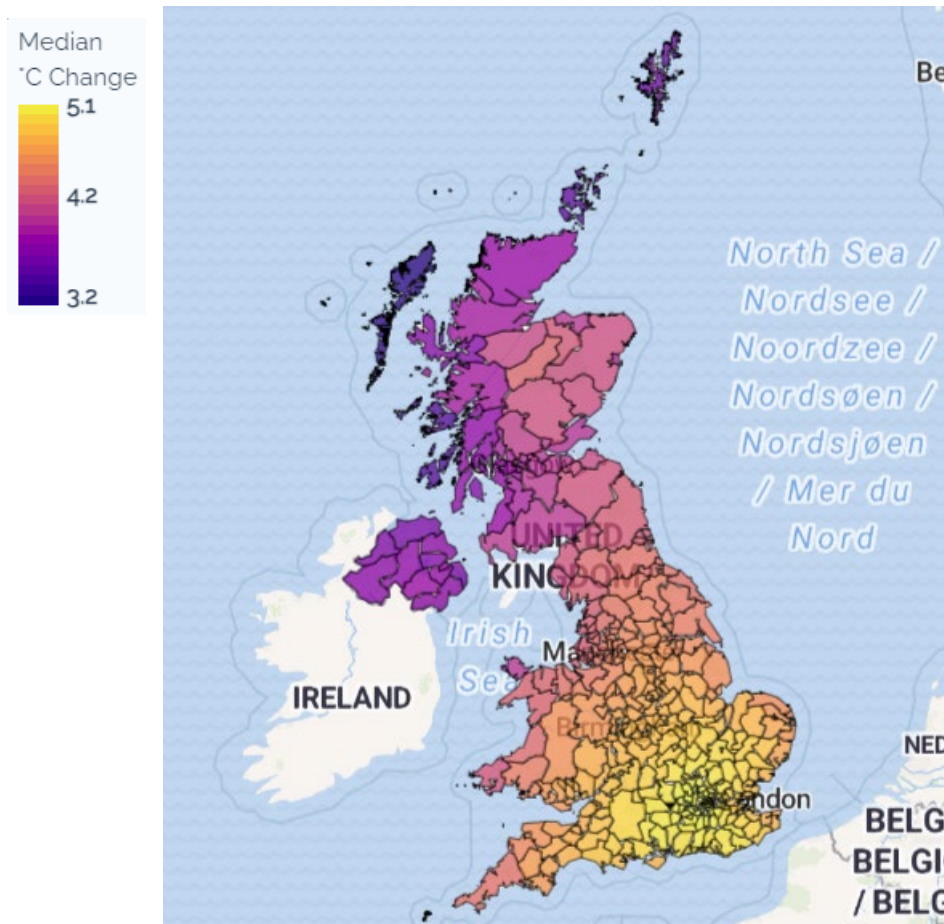


Figure 2-4 : Map showing annual average temperature projections based on UKCP18 Regional RCP8.5 data at a Local Authority spatial scale (time period 2071-2100) from the Climate Risk Indicator explorer (The University of Reading, 2023). Figure credited to University of Reading, used under CC-BY licence 4.0, <https://uk-cri.org/>.

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 2-5); (Slingo, 2021)) and 4 metres by 2300 (Fung, et al., 2018), although the full extent of sea 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.

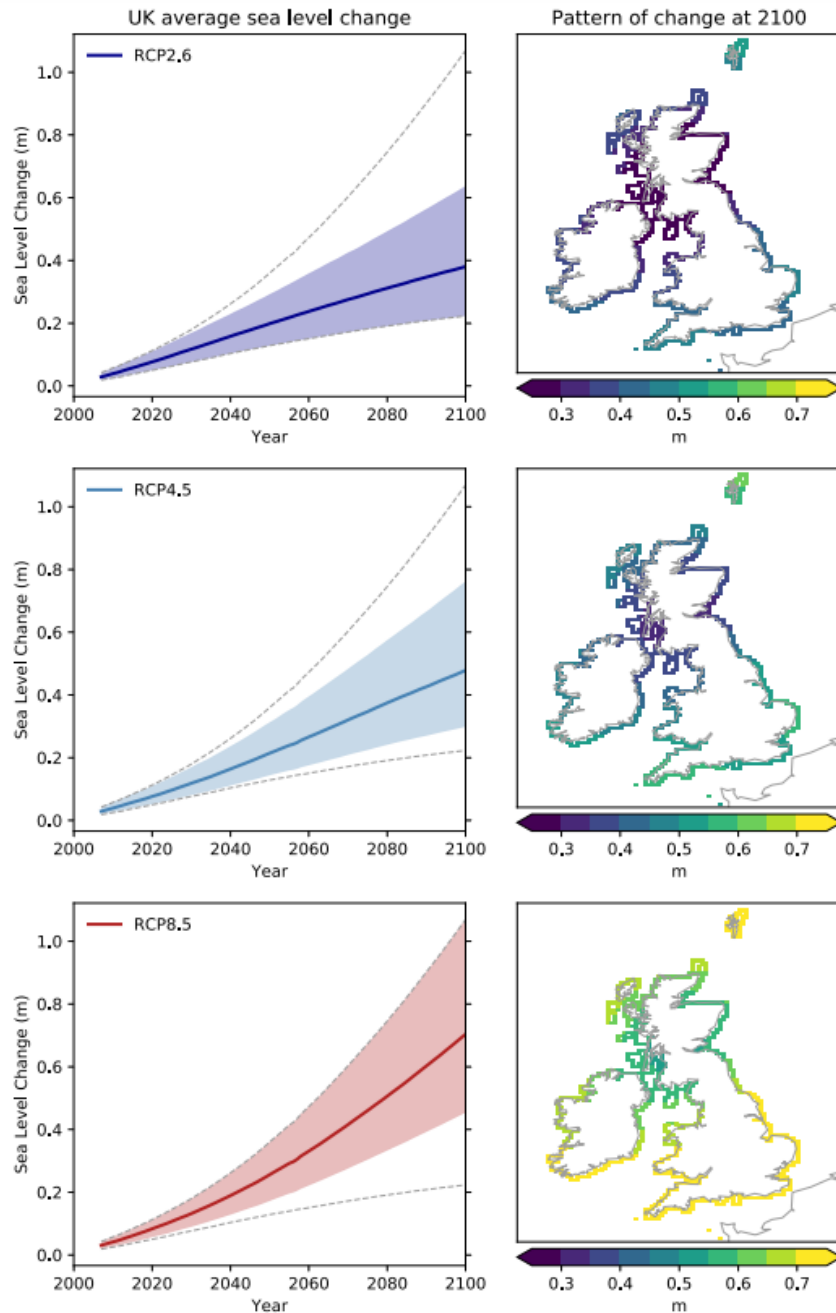


Figure 2-5 : Projected sea level rise 2000-2100 for RCP2.6, RCP4.5 and RCP8.5 scenarios based on the average of 49 UK ports (left) and the spatial pattern of projected sea level rise at 2100 relative to a baseline of 1981-2000. Left hand charts: The dotted lines show the range, the bold lines show the 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. UKCP18 Fact Sheet: Sea level rise and storm surge (Fung, et al., 2018), after Figure 1. © Crown copyright 2018, the Met Office

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 conceptual understanding and how climate change can affect environmental parameters at a site-specific and local scale.

2.3.1 Soil Moisture

Soil moisture is influenced by rainfall, temperature, soil structure and composition, vegetation, and land use. The European Space Agency Soil Moisture project generates long-term global soil moisture records from remote sensing to allow climate-related changes to be assessed (The European Space Agency, 2020). CEH operate the COSMOS network of soil moisture monitoring sites across the UK (CEH, 2024). The Met Office published a factsheet in 2020 on Soil Moisture and the Water Balance summarising the key information from the UKCP18 Climate Projections (Pirret, J.S.R., Fung, F., Lowe, J.A., McInnes, R.N., Mitchell, J.F.B. and Murphy, J.M., 2020). The predicted impacts of climate change on soil moisture are expected to be later drying of soil in spring, drier soil in the late summer, and slower recovery in the autumn. The magnitudes of the changes are predicted to be greatest in the south and east of the UK. Note the modelling used in the projections does not account for any potential change in vegetation type due to climate change.

The potential significance of changes in soil moisture due to climate change will depend on the soil type (e.g. granular versus cohesive) and nature of the site under consideration. Changes in soil moisture due to climate change may have implications for run-off and for the timing and magnitude of groundwater recharge which could influence the leachability of contaminants within the soil. Changes to soil moisture may also potentially influence the uptake of contaminants by plant root systems. The predicted changes may be of negligible significance for sites that are predominantly covered by buildings and hardstanding, or where groundwater recharge is predominantly controlled by artificial drainage arrangements e.g. run-off discharged to soakaways or similar, designed to withstand extreme rainfall. The predicted changes may be of greater significance for sites that are predominantly covered by vegetation, particularly if seasonal variations in groundwater levels are critical to the CSM.

2.3.2 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 11 No. 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 11 No. 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 2.3.3). 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 2-6). 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 (Hughes, et al., 2021).

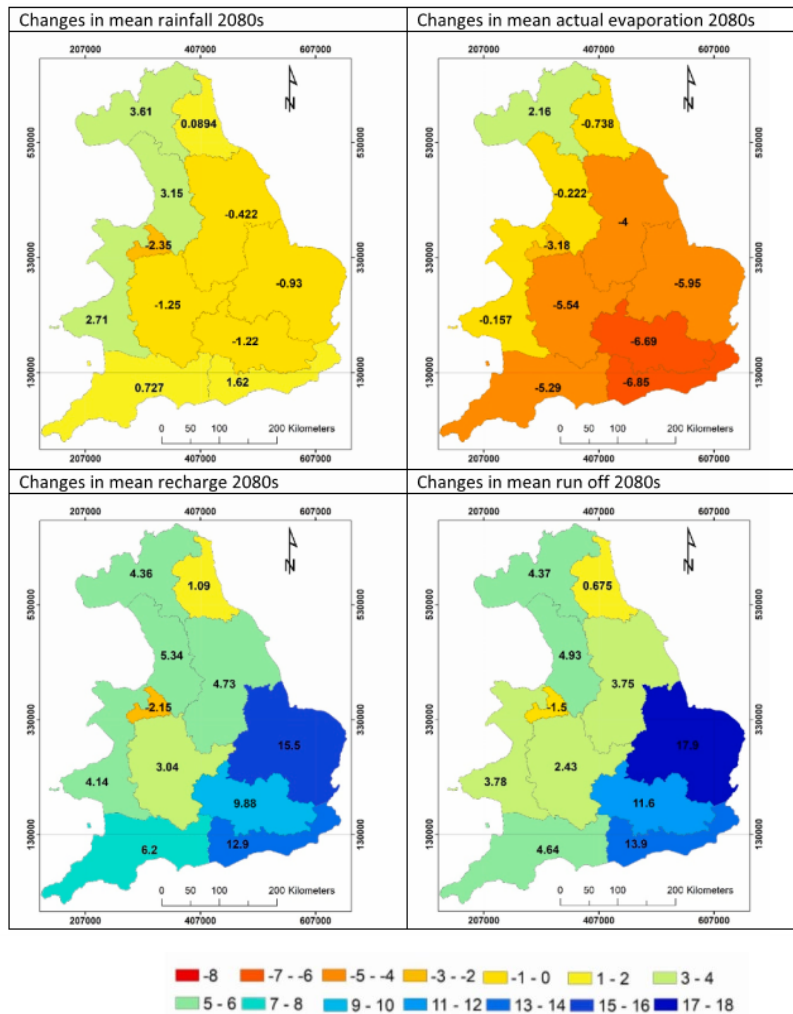


Figure 2-6 : Spatial distribution of percentage changes in total rainfall, actual evaporation, recharge and run off for River Basin Management Districts for the 2080s from baseline of either 1961-1990 or 1971-2000. Extract of Figure 4 (Hughes, et al., 2021). Figure reproduced under CC-BY licence 4.0.

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 2-7. The projections are derived from groundwater recharge models (ZODRM) 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 portal¹². 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

¹² Available at: <https://eip.ceh.ac.uk/hydrology/eflag/>.

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 Licence¹³ from 1982 to 2080 for each of the twelve ensemble members of high emissions scenario RCP8.5.
2. In England, Wales and southern Scotland¹⁴, 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 scenario¹⁵ only. Data is available for download via data.gov.uk¹⁶ and licence conditions apply.

¹³ Available at: <https://catalogue.ceh.ac.uk/datastore/eidchub/1bb90673-ad37-4679-90b9-0126109639a9/Groundwater/ZOODRM/simrcm/>.

¹⁴ The data included for Scotland is limited to the cross-border Solway-Tweed River Basin Management District.

¹⁵ 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.

¹⁶ 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 2-7 : Map of the 558 groundwater bodies. Extract from Figure 3 (Hannaford, et al., 2022). Figure reproduced under CC-BY licence 4.0.

2.3.3 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 finely 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 available¹⁷ 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 2-8). 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.

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:

¹⁷ Available at: <https://eip.ceh.ac.uk/hydrology/eflag/>.

1. At 24 observation boreholes undertaken as part of the Future Flows project¹⁸ that is underpinned by UKCP09 projections data is available for download¹⁹ 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 project²⁰ that is underpinned by UKCP18 projections data is available for download²¹ and for use under the terms of the Open Government Licence for:
 - Daily projected 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.

¹⁸ Available at: <https://www2.bgs.ac.uk/groundwater/change/FutureFlows/home.html>.

¹⁹ Available at: <https://www2.bgs.ac.uk/groundwater/change/FutureFlows/sites.html>.

²⁰ A description of the eFLaG project can be found at: <https://www.ceh.ac.uk/our-science/projects/eflag-enhanced-future-flows-and-groundwater>.

²¹ 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/>.

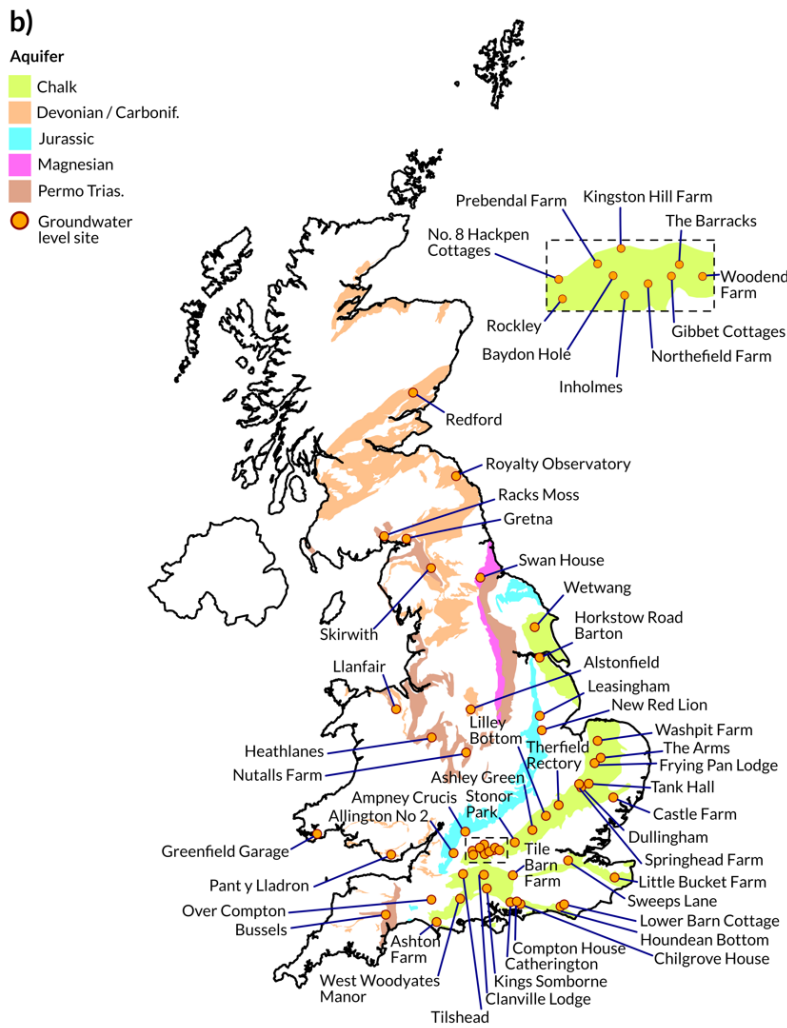


Figure 2-8 : Map of the 54 eFLaG boreholes and principal UK aquifers. Extract from Figure 3 (Hannaford, et al., 2022). Figure reproduced under CC-BY licence 4.0.

2.3.4 Surface Water Flow

The FFGWL project includes eleven time series of daily river flow at 282 river sites from 1951 to 2098 using climate projections based on UKCP09 (Section 2.3.3). The Q95 (the flow exceeded 95% of the time) is projected to decrease by 2050s anywhere in Britain according to all but two scenarios 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 2-9). 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

portal²². Transient low flow projections are available for Q90, Q70, Q50 and Q30 which are expressed in absolute changes (m³/s) and percentage changes. Transient low flows are projected to decrease in most catchments through the 21st century.

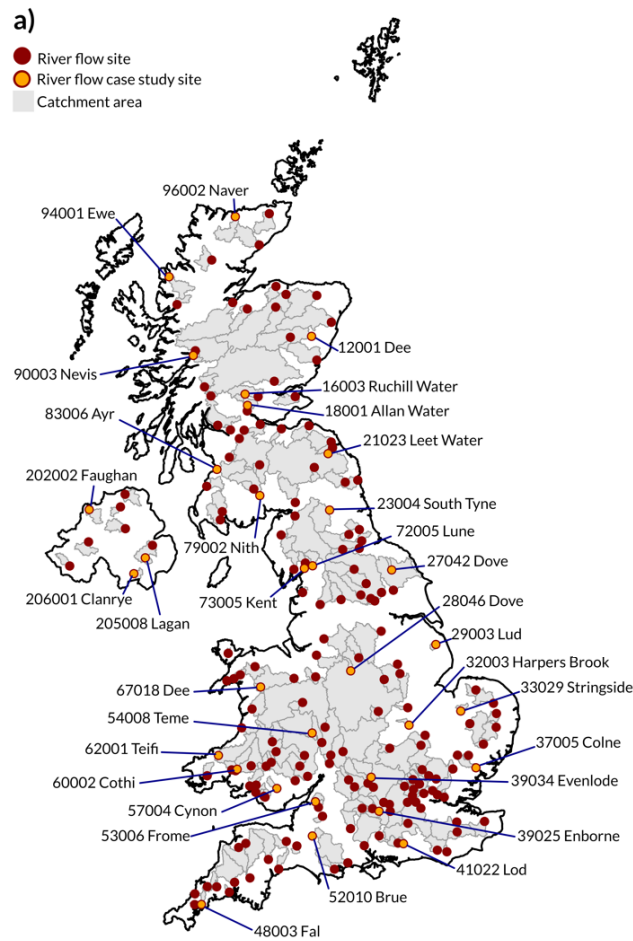


Figure 2-9 : Map of the 200 eFLaG river flow sites and their catchment areas. Extract from Figure 3 (Hannaford, et al., 2022). Figure reproduced under CC-BY licence 4.0.

2.3.5 Flood Risk

The Environment Agency's national flood risk assessment (NaFRA) for England provides information on current and future flood risk from rivers, the sea and from surface water, including potential flood depths (Environment Agency, 2024). The NaFRA also considers how climate change may increase the chance of flooding in an area based on UKCP18 projections. National flood risk assessments are also available for Scotland (Scottish Environment Protection Agency, 2018), Wales (NRW, 2019) and Northern Ireland (Northern Ireland Department for Infrastructure, 2018), although these don't currently consider climate change.

It is a requirement of planning policy that risks from flooding are considered as part of new developments within the UK. Supporting planning guidance for flooding has been issued by

²² Available at: <https://eip.ceh.ac.uk/hydrology/eflag/>.

each of the devolved nations in relation to how climate risk mitigation and adaptation should be considered, as outlined in Appendix 1.

Long term flood risk information is currently provided by the Environment Agency, SEPA, NRW and Northern Ireland Government via online mapping services. The maps consider future flood risk from surface water, rivers and the sea, as further detailed in the sections below. The following data services are available for each of the UK nations:

- England: The Environment Agency [Long Term Flood Risk map](#) was updated in January 2025 (Environment Agency, 2025) and the [Flood map for planning](#) was updated in March 2025 (Environment Agency, 2025) to incorporate the findings of the NaFRA (Environment Agency, 2025).
- Scotland: The [SEPA future flood maps](#) were updated in February 2025 (Scottish Environment Protection Agency, 2025), with a significant update being the inclusion of future climate scenarios (Scottish Environment Protection Agency, 2025).
- Wales: [NRW Flood map for planning](#) is updated by NRW every six months (in May and November) (Natural Resource Wales, 2025).
- Northern Ireland: [Flood Maps for Northern Ireland](#) - it is not clear when the Northern Ireland maps were last updated (Northern Ireland Government Department for Infrastructure, n.d.).

It is important to note that different mapping assumptions are made between the UK nations. Refer to the individual mapping sources for further information on the mapping assumptions made.

The Environment Agency and SEPA maps allow users to explore how climate change may increase the chance of flooding in an area based on UKCP RCP8.5. At the time of writing, climate change was not considered in the flood maps produced for Wales and Northern Ireland.

Surface Water Flooding

Surface water flooding in this context is defined as flooding that results from the overwhelming of the local drainage network due to the volume and intensity of rainfall. This is not the same as the risk of flooding from rivers which is dealt with in the next section.

The Environment Agency provides mapping showing the risk of flooding from surface water (termed RoFSW) (Environment Agency, 2025). It accounts for local topography and rainfall patterns, as well as historical data. Climate change is accounted for based on a mid-range (50th percentile) allowance within the RCP 8.5 emission scenario for the time period 2040 to 2060. The mapping shows where flooding is likely to occur based on 1 in 30, 1 in 100 and 1 in 1000 chances of occurrence in any given year for a stated flood water depth.

SEPA also consider future climate change allowances within their surface water and small water course future flood maps which were updated in March 2025. The maps reflect projected changes in rainfall based on the FUTURE-DRAINAGE research project (JBA Consulting, 2021) which uses UKCP18 local projections for a high emissions scenario for the 2070 time horizon considering a medium likelihood (0.5% chance of flooding).

At the time of writing the NRW and NIEA surface water flood maps do not currently consider future climate change.

River and Sea Flooding

The Environment Agency updated the long term river and sea flood risk maps in January 2025 to include the NaFRA data (Environment Agency, 2024). Climate change projections are incorporated into the modelling for the first time, with 50th percentile projections from the UKCP18 RCP 8.5 scenario used considering the time period 2036 to 2069. The mapping shows both the present day modelled flood extent and separately projections on the basis of climate change assumptions for 1 in 100 and 1 in 1000 annual likelihoods of flooding.

SEPA's river and coastal future flood maps reflect risks from future flooding assessed on a medium likelihood (0.5% chance of flooding) to the 2080s. The river flood maps consider projected increases in peak river flows for the high emissions scenario 67th percentile for the 2080s based on UKCP09 data. SEPA's coastal future flood maps reflect the projected increases in mean sea levels for a high emissions scenario 95th percentile confidence limit based on UKCP09 data; coastal flood mapping is gradually being updated, on a region-by-region approach, to reflect UKCP18. SEPA recognise that UKCP09 projections have since been superseded by the UKCP18 climate projections and they plan to review the future flood map climate change allowances within future updates. The sea level rise and peak river flows may therefore be higher than that mapped in the future river and flood maps (Scottish Environment Protection Agency, 2025).

At the time of writing NRW and NIEA river and coastal flood maps do not currently consider future climate change.

Groundwater flooding

The flood maps available in the UK do not account for groundwater flooding. However, the Environment Agency provides groundwater flood alerts for areas where groundwater flooding is known to be a specific risk, such as Chalk aquifer regions e.g. Hampshire, Kent, South London, Sussex, Thames and Wessex (Environment Agency, 2023) (Environment Agency, 2022), although these do not account for projected changes as a result of climate change.

The BGS notes that although groundwater poses a smaller scale of risk than other sources of flooding, in some areas this risk is significant (McKenzie, 2015), particularly in river catchments where groundwater flow provides a significant contribution to base flow. High groundwater levels can contribute to river and surface water flooding by contributing to river base flow and saturating the ground, thus limiting the amount of rain that can soak away. The duration of groundwater flooding can also be longer than that associated with river and surface water flooding. The BGS provides a '[susceptibility to groundwater flooding](#)' dataset which was last updated (at the time of writing) in April 2025. BGS are also undertaking research in relation to groundwater flooding (BGS, n.d.). Note that the groundwater flooding risk is mapped qualitatively under three classes: (A) limited potential, (B) potential for flooding of below ground structures, and (C) potential for flooding to occur at surface. The methodology used for Scotland is different to that used for England and Wales as permeable superficial deposit flooding areas have been extended to include areas where very high and high permeability superficial deposits overlie bedrock with moderate

permeability. This differs from the methodology for England and Wales where the flood areas are only defined if the underlying bedrock is of low or very low permeability. The change for Scotland is designed to provide a better fit between observed and modelled data. However, the groundwater flood maps do not currently consider how climate change may change the susceptibility of a site to groundwater flooding.

2.3.6 Coastal erosion

The Environment Agency have prepared 20 No. Shoreline Management Plans (SMPs) which are updated on an annual basis and identify the most sustainable approach to managing flood and coastal erosion around the English coast over the short (up to 2025), medium (up to 2055) and long term (up to 2105) (Environment Agency, 2024). The [National Coastal Erosion Risk Map \(NCERM\)](#) for England (Department for Environment Food & Rural Affairs, n.d.) summarises the projected coastal erosion rates and SMP for each stretch of coastline up to 2105.

NRW have prepared 4 No. SMPs (NRW, 2024), including two that are cross-border with England, and these are available to view on [NRW's flood and coastal erosion maps](#) (Natural Resource Wales, n.d.). The [NRW flood map for planning](#) provides a summary of coastal erosion risk for the short (up to 2025), medium (up to 2055) and long term (up to 2105) (Natural Resource Wales, 2025).

In Scotland information on coastal erosion and flood risk management is set out in plans for 14 No. Local Plan Districts (LPDs) adjoining the Scottish coast and associated estuaries (Scottish Environment Protection Agency, 2024). The [SEPA flood risk map](#) (Scottish Environment Protection Agency, 2025) enables users to view areas with the LPD and the associated coastal flood risk. The [Dynamic Coast](#) project provides strategic evidence based on the extent of coastal erosion in Scotland, although it is noted that this focusses on recent or new coastal erosion impacts rather than projecting future changes (University of Glasgow School of Geographical and Earth Sciences, n.d.).

In Northern Ireland the influence of climate change on sea level rise and coastal erosion is understood to be an important consideration. A baseline study and gap analysis of coastal erosion risk management in Northern Ireland has been prepared (DAERA, 2018). However, at present there does not appear to be a platform to view potential erosion rates and flood risk in a similar manner to the other nations.

Climate Central have developed a [coastal risk screening tool](#) for the United Kingdom and Ireland comprising an interactive map which shows areas threatened by sea level rise and coastal flooding (Climate Central, n.d.). The map allows users to explore how different scenarios could affect sea level rise and coastal flooding for example by adjusting water level above the high tide line (up to 10 m). The water level selected could be selected from the UKCP18 projections for sea level rise outlined in Figure 2-5.

2.4 Future extreme weather projections indicators

Extreme weather events have the potential to result in short-term (acute) effects as a result of:

- Extreme precipitation.
- Extreme cold weather.

- Extreme heat.
- Drought.

Extremes of precipitation and cold weather are more likely to occur in the winter months and extreme heat and drought are more likely to occur in the summer months. It is however noted that ‘climate whiplash’ is being increasingly experienced where weather can change from extreme drought conditions to heavy rainfall, particularly during the summer. Table 2-2 summarises the projected future changes associated with the UK climate and weather events.

Table 2-2: Changes to the UK climate and weather events. Source: Met Office (Met Office, 2022).

UK climate and weather events	Future changes in intensity or frequency
Warm spells	Increase
Cold spells	Decrease
Heavy rain	Increase
Dry spells	Increase (summer)
Wind storms	Some, but not all, evidence supports an increase

The UK CRI explorer presents UKCP18 future climate projections for a variety of climate risk indicators which illustrate how the intensity or frequency of extreme weather may change to the end of the century including:

- ‘Record breaking weather’ allows users to explore changes to the number of months per year at least as hot as the hottest month between 1981 and 2010; and the number of months per year at least as wet as the wettest month between 1981 and 2010,
- ‘Temperature extremes’ includes metrics associated with the occurrence of Met Office heatwaves, cold weather alerts and very hot days ($T_{max} > 35^{\circ}\text{C}$),
- ‘Water’ indicators include projected future changes associated with river flood, low river flows, 12-month river flow drought and 24-month river drought,

- 'Wildfire' includes changes to the number of days above the Met Office Fire Severity Index threshold.

The Met Office projects that extremes of hot, dry weather and heavy rain are likely to increase in the UK and as such due consideration of the impact of these extreme weather events should be considered in the risk assessment process. While the severity of an extreme weather event is difficult to project it is noted that the frequency of such weather can be considered in relation to the frequency and intensity of such events. The potential for the cumulative impacts of extreme weather should also be considered.

As extreme cold weather is expected to decrease in the UK it is considered that this scenario is of less consequence to the outcomes of a controlled water land contamination risk assessment.

2.5 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, Climate Risk Indicators 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. Coastal risks from sea level rise, inundation and erosion are summarised within SMPs or LPDs and by Climate Central.

The key points are as follows:

- A 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 England;
- 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;
- eFLAG project data is available for groundwater levels at 54 boreholes within Principal Aquifers and should be consulted for area specific predictions;
- eFLAG project data is available for river flow levels in 200 river catchments and again should be consulted for area specific predictions; and,
- eFLAG project is available for 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 identify potential contaminant linkages, and assess and evaluate whether there is an acceptable level of risk to identified receptors. Risk assessments are staged with more detailed assessment being undertaken in later stages where the risk of pollution cannot be demonstrated to be acceptable by simpler assessment in earlier stages.

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 and extreme weather events will change 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 and extreme weather events on a CSM.

The Environment Agency’s LCRM Guidance (Environment Agency, 2025) indicates that climate change should be considered within all stages of risk assessment, as further detailed in Appendix 2. At the Preliminary Risk Assessment stage, in the development of the site’s initial CSM, consideration should be given to how climate change and extreme weather events could impact:

- The physical and chemical behaviour of contaminants likely to be present,
- The interaction of the site and ground conditions, groundwater, surface water and ground gases and vapours,

-
- Possible combined or cumulative factors of different contaminants interacting with each other.

Furthermore, the Environment Agency's Guiding Principles for Land Contamination (GPLC2) (Environment Agency, 2010) suggest a "what if..?" approach to identify new potential contaminant linkages, including changes to and removal of linkages. While GPLC2 has since been withdrawn it is considered that the use of the "what if..?" approach remains useful when considering climate change effects. 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.

SEPA's groundwater guidance (Scottish Environment Protection Agency, 2025) indicates that assessment of potential climate change and extreme weather events needs to be site-specific as it is dependent on the environmental setting as well as the timescales of the scenario being assessed. The degree of uncertainty that is considered tolerable for the assessment also requires consideration. The guidance notes that not all potential climate change impacts will be of significance for every site or for every activity. Reporting of CSM and DQRA should include justification as to why potential climate change impacts have been included or discounted. The guidance indicates that the following climate change impacts could be considered to support the assessment:

- Changes in precipitation, both annual average and individual rainfall events.
- Changes in frequency or magnitude of extreme events such as floods and droughts.
- Changes in sea level & coastal erosion.
- Changes in groundwater levels including seasonal trends.
- Changes in air and water temperature, which may influence contaminant mobility and microbial activity.
- Changes to ecosystems.

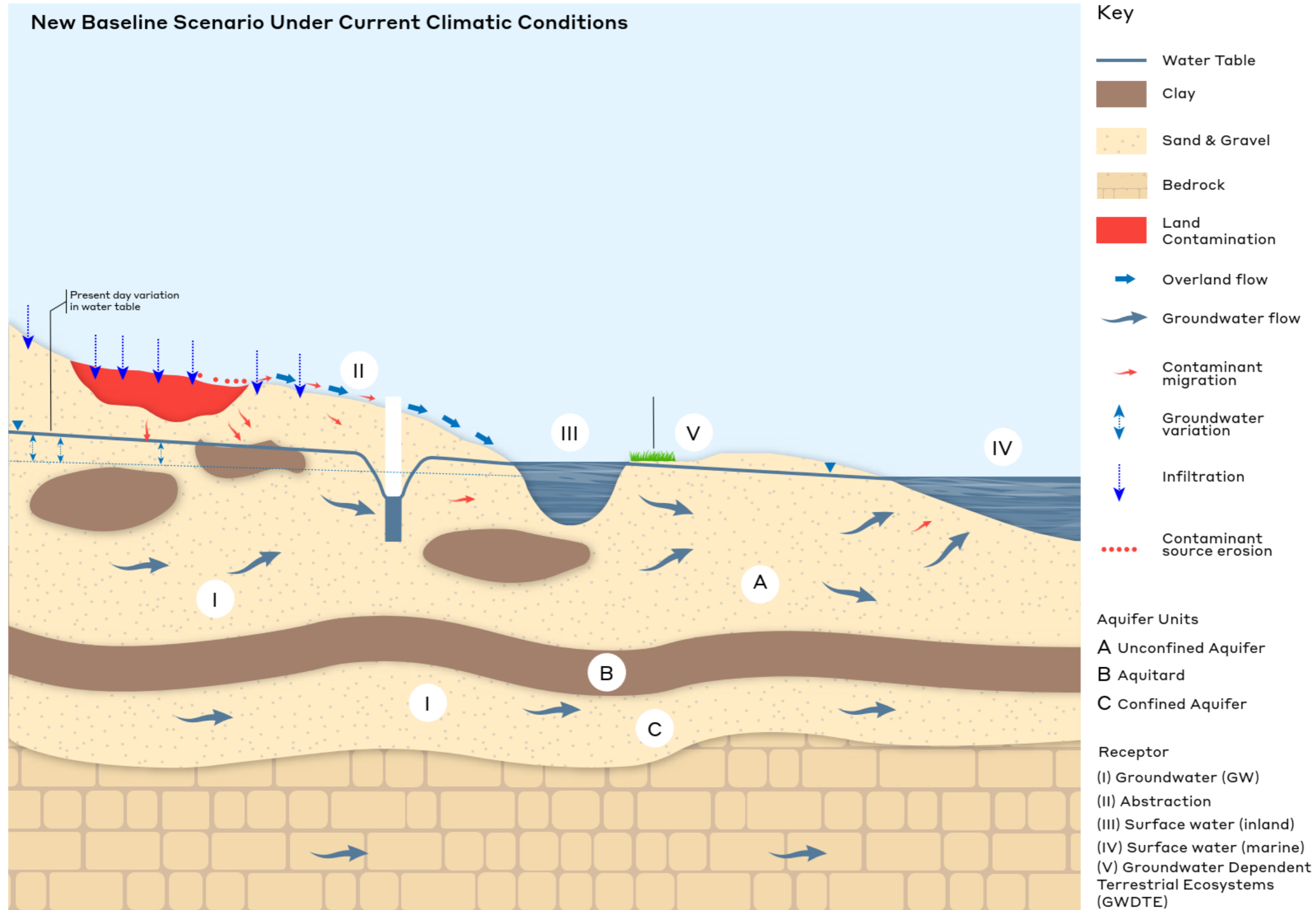


Figure 3-1 : Illustrative Conceptual Site Model Relating to a Land Contamination Scenario under Current Climatic Conditions. Note: Figure adapted from “SEPA, Nov. 2020 - Land contamination and impacts on the water environment consultation”.

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

In accordance with LCRM (Environment Agency, 2025), 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, as defined in LCRM, is iterative and can be 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). Risk assessments are tiered (or staged) with successive tiers involving more detailed assessment. Where risks cannot be demonstrated to be acceptable, further assessment e.g. intrusive/non-intrusive field investigation, further tier(s) of risk assessment or implementation of risk management, may be required. At all stages, LCRM is explicit in that consideration should be given to how future climate change and extreme weather events could impact the assessment or the decision-making process.

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)²³).

Risk assessors should consider the following key elements, which is in line with EA guidance (Environment Agency, 2023) and recommendations in CL:AIRE SUBR:IM bulletin 3 (CL:AIRE, 2007)):

- Use at least two contrasting future climate change scenarios (one of which should be worst case) for the site location, incorporating climate forecast information for the periods of 2050s (2041 – 2070) and 2080s (2071 – 2100).
- Make a qualitative assessment of the impact from climate change and extreme weather events 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.

²³ World Meteorological Organization recommends 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.

3.3.1 Preliminary Risk Assessment (desk-based assessment)

In accordance with LCRM (Environment Agency, 2025), the first stage of the risk assessment 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 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 rainfall and/or 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) for defined time slices (e.g. near future to 2049 or far future to 2079). It is considered that a $\pm 5\%$ projected future change in annual rainfall, and potentially up to $\pm 10\%$ if the site is located in an urban environment away from sensitive controlled waters receptor (e.g. groundwater dependent terrestrial ecosystems and surface water courses), is within the anticipated variation that is considered within land contamination risk assessment. As such annual rainfall and/or groundwater recharge projections that are less than 5%, or potentially 10% for urban sites located away from sensitive controlled waters are not considered to significantly influence the CSM;
- The projected changes to regional groundwater level for defined time slices (e.g. near future to 2049 or far future to 2079); and
- Extreme weather events.

See Appendix 4 for worked examples.

Average air temperature is an important component of climate change in the UK. Transmission of 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 BS10175 (British Standards Institute, 2017) and BS5930 (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.

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. The risk associated with extreme weather events should be addressed using “what if..?” scenarios. Recommended considerations for the “what if..?” scenarios are also presented in Table 3-1. The frequency with which extreme weather events occur will influence their cumulative impact.

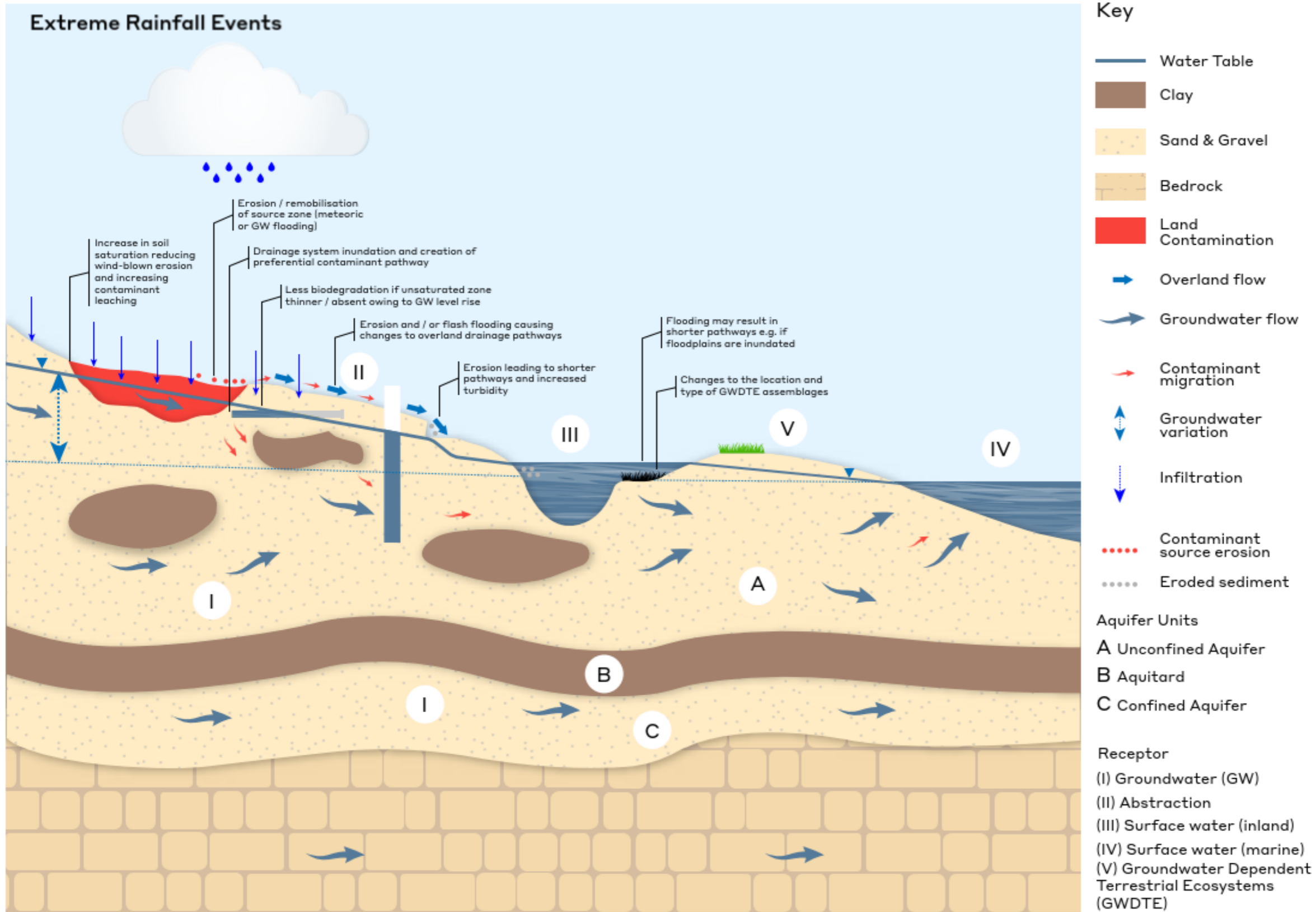


Figure 3-2: Indicative considerations for a CSM attributed to climate change induced changes to rainfall (scenarios 1 and 5).

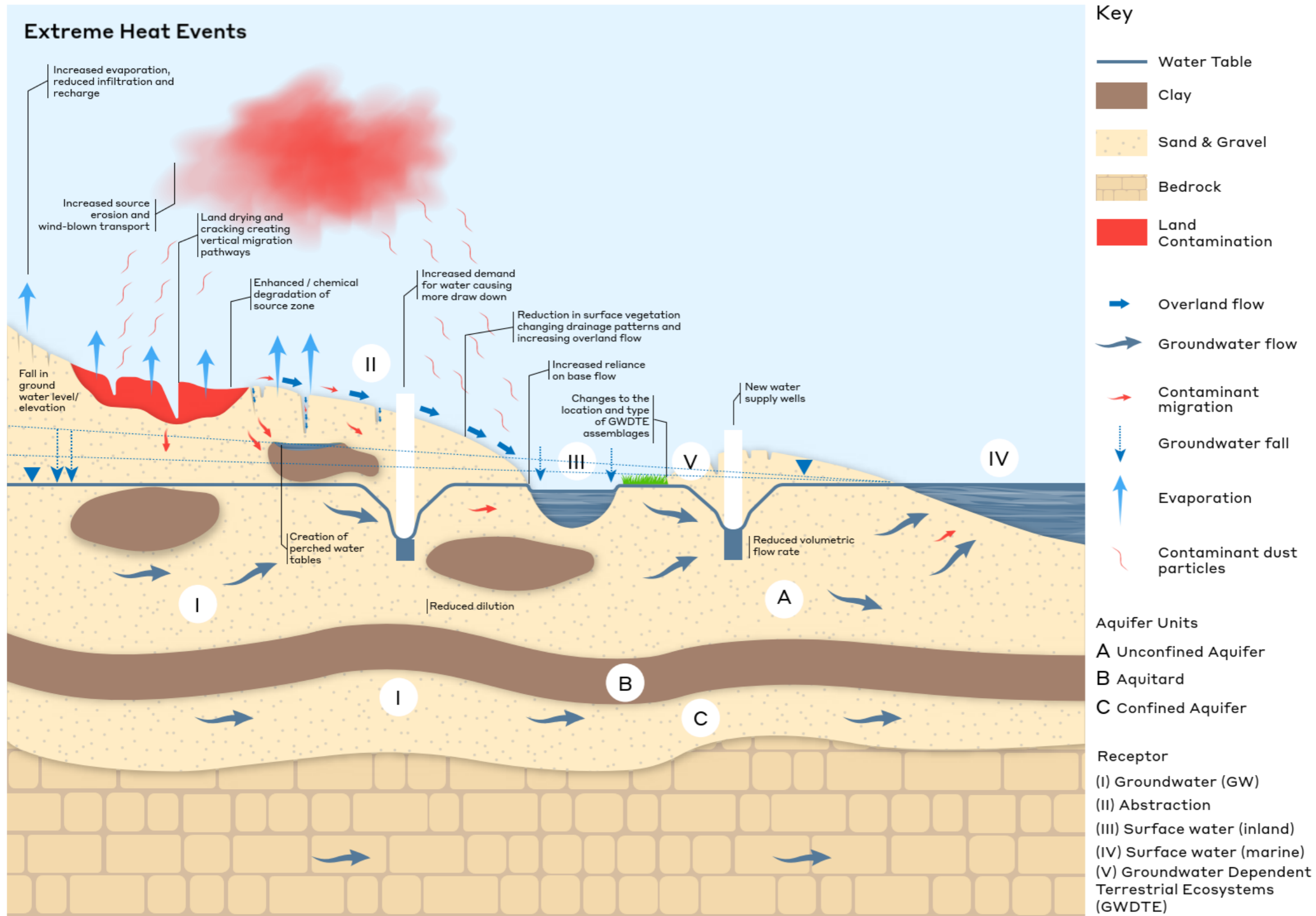


Figure 3-3: Indicative considerations for a CSM attributed to climate change induced extreme heat (Scenario 3 and 4).

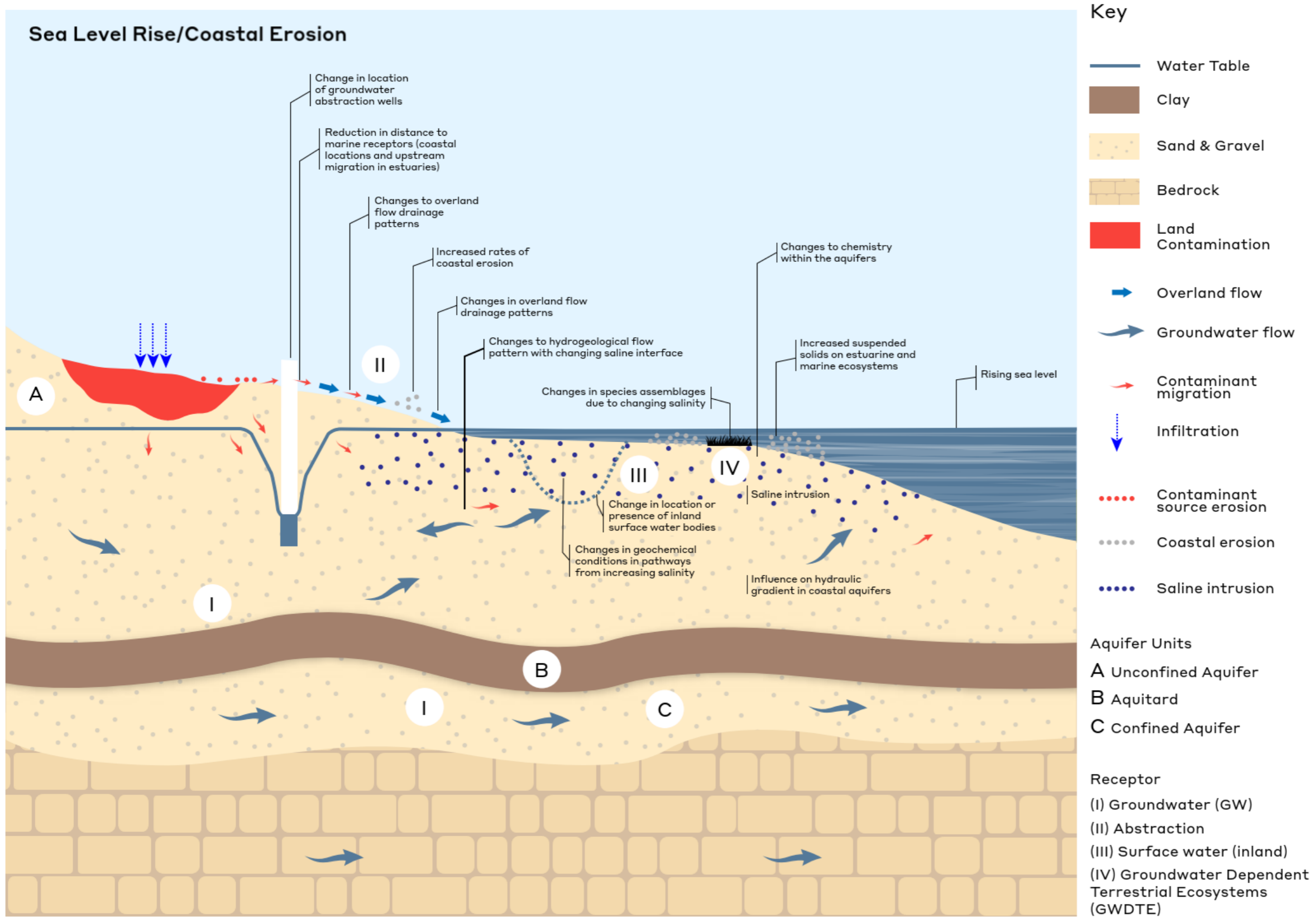


Figure 3-4: Indicative considerations for a CSM attributed to climate change induced sea level rise / coastal erosion (Scenario 6 and 7).

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

Scenario 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 acute effects – assessed qualitatively using ‘what if..?’ scenarios				
1	<p>Extreme precipitation leading to</p> <ul style="list-style-type: none"> increased infiltration and a rise in groundwater levels causing groundwater flooding increased runoff causing pluvial flooding fluvial flooding land-based erosion or changes in the geometry or geomorphology of surface water features <p>(Illustrated as Figure 3-2) Note. Flooding and/or land-based erosion could affect source zone, pathways, and/or receptors</p>	<p>a) Changes to the mechanisms by which the source may be released, e.g.</p> <ul style="list-style-type: none"> 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: <ul style="list-style-type: none"> potential of groundwater emergence e.g. volumetrically, or likelihood of fluvial/pluvial flooding on-site/local man-made drainage systems and flood risk prevention measures distance of source from river/estuary/coast vulnerability of riverbank and surrounds to erosion or inundation potential for change to topographic profile superficial geology material, thickness, cohesion, vegetation type and distribution flash-flooding events eroding areas away from riverbanks <p>b) Mobilisation of additional contaminants of potential concern due to source zone erosion</p> <p>c) Exposure and/or physical migration of NAPL sources</p>	<ul style="list-style-type: none"> i. Short-term increase in overland flow (including deposition and resuspension) ii. Change in overland drainage patterns iii. Consider local topographic profile. Consider amount and type of vegetation iv. Re-infiltration/migration back into sub-surface v. Short-term change in water table elevation impacting groundwater pathway length, hydraulic gradient, and dilution potential vi. Temporary new springs and/or increased flow within existing springs (pathway to surface water) 	<ul style="list-style-type: none"> 1) Temporary change in surface water body location and flow characteristics including the effect of suspended solid deposition (from overland flow) 2) Temporary changes in species assemblages in the ecological receptor because of change in surface water supply and/or groundwater discharge locations 3) Temporary change in groundwater discharge location (from topographic profile change) including temporary new springs and/or increased flow within existing springs
2	<p>Extreme cold weather</p>	<p>a) Short-term 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)</p> <p>b) Short-term changes to the mechanisms by which the source may be released, e.g.</p> <ul style="list-style-type: none"> 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) <p>c) Temporary water storage in soils or above ground with low accessibility i.e. snow, ice</p> <p>d) Temporary variation in NAPL mass-transfer (e.g. volatilisation/dissolution rates) and physical mobility (e.g. viscosity)</p>	<ul style="list-style-type: none"> i. Surface freezing and cracking creating/enhancing preferential vertical flow paths ii. Temporary reduction in airborne pathways due to ground freezing and/or snow cover iii. Temporary increased infiltration during periods of snow melt iv. Temporary overland flow due to snow melt v. Short-term changes to overland flow drainage rates and patterns due to snow melt and vegetation changes vi. Temporary change in water table elevation impacting groundwater pathway length and dilution potential 	<ul style="list-style-type: none"> 1) Short-term changes to the location and distribution of surface water courses 2) Temporary changes in species assemblages in the ecological receptor because of extreme cold weather and/or a temporary change in water supply volume 3) Temporary changes in aquifer recharge due to frozen ground

Scenario No.	Climate change induced effect	Possible effects/considerations of climate change induced weather event on CSM components		
		Source	Pathway	Receptor
3	<p>Extreme heat; causing short-term increased evapo(transpi)ration, changes to water demand and supply, fires etc. (Illustrated as Figure 3-3)</p> <p>May also be associated with water scarcity events (see row 5 below)</p>	<p>a) Short-term changes to near-surface 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)</p> <p>b) Changes to the mechanisms by which near-surface parts of the source may be released, e.g.</p> <ul style="list-style-type: none"> • 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 • Failure of clay capping (remediation) systems through drying and cracking • Melting of permanent snow/ice <p>e) Variation in near-surface NAPL mass-transfer (e.g. volatilisation/dissolution rates) and physical mobility (e.g. viscosity)</p>	<p>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 allow release of volatiles</p> <p>ii. Surface (soil) drying supporting reduced infiltration potentially leading to increased surface water run-off and overland flow</p> <p>iii. Loss of vegetation, causing changes to overland drainage patterns</p> <p>iv. Surface (soil) drying and/or vegetation loss encouraging dust generation</p> <p>v. Short-term changes to local groundwater flow patterns (direction and flux) and levels due to temporary changes to abstractions</p> <p>vi. Short-term drop in water table:</p> <ul style="list-style-type: none"> • 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 • Changing groundwater discharge (springs and baseflow) resulting in associated temporary changes to dilution capacity in surface waters due to decreased flows. <p>vii. Changes to organic matter in soil in event of wildfire</p> <p>viii. Wildfire-induced airborne pathways</p>	<p>1) Temporary changes in groundwater discharge and run-off affecting the location/presence of surface water receptors and flow characteristics (Q95)</p> <p>2) Temporary changes in species assemblages in the ecological receptor because of increasing temperature, changes to surface water location, and/or changes to groundwater discharge points</p> <p>3) Temporary increase in abstraction rates from water supply wells</p> <p>4) Changes to agricultural irrigation, including temporary increased abstraction rates as well as evapotranspiration</p>
4	<p>Decrease in precipitation leading to:</p> <ul style="list-style-type: none"> • 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 <p>Effects of increased wind intensity at times of water scarcity also considered (short-term increase in aeolian erosion and deposition).</p> <p>May also be associated with extreme heat events (see row 4 above)</p>	<p>a) Temporary changes to contaminant (chemical) degradation from decreased source zone saturation and/or changes in geochemical conditions</p> <p>b) Temporary changes to the mechanisms by which the source may be released, e.g.</p> <ul style="list-style-type: none"> • 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: <ul style="list-style-type: none"> ○ Aeolian erosion of source zone creating increased dust generation ○ Removal or uprooting of flora (e.g. trees blown over), increasing exposed soils • Loss of integrity of clay capping (remediation) systems through drying and cracking 	<p>Short-term effects on pathway properties/characteristics including:</p> <p>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</p> <p>ii. Surface (soil) drying influencing overland flow and physical erosion of surface soils</p> <p>iii. Loss of vegetation through drought, causing changes to overland drainage patterns</p> <p>iv. Surface (soil) drying and/or vegetation loss encouraging dust generation</p> <p>v. Changes to local groundwater flow patterns (direction and flux) and levels due to changing abstractions</p> <p>vi. Drop in water table:</p>	<p>1) Temporary changes in groundwater discharge and run-off affecting the location/presence of surface water receptors and flow characteristics (Q95)</p> <p>2) Temporary changes to the location and distribution of surface water features or wetlands</p> <p>3) Temporary changes in species assemblages in the ecological receptor because of changes in surface water supply and/or groundwater discharge locations</p> <p>4) Temporary increase in abstraction rates from water supply wells; including location of new wells</p> <p>5) Temporary changes to agricultural irrigation, including increased abstraction rates and impacts on crops, as well as evapotranspiration</p> <p>6) Effect of aeolian solid deposition (short-term increase in air-borne pathways) on surface water body</p>

Scenario No.	Climate change induced effect	Possible effects/considerations of climate change induced weather event on CSM components		
		Source	Pathway	Receptor
			<ul style="list-style-type: none"> Reducing or removing influence of near (sub) surface preferential pathways e.g. drains and culverts, and/or superficial deposits 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 <p>vii. Proliferation of air-borne pathways due to increased wind intensity at times of water scarcity (consideration of wind direction and speed)</p>	
Long-Term Climate Change Effects (including the cumulative effect over years of extreme weather events) – assessed quantitatively by considering climate change projections				
5	<p>Long-term changes to (annual average) precipitation leading to changes in</p> <ul style="list-style-type: none"> Infiltration and groundwater levels (seasonal or long-term) Runoff and mobilisation of source zone contaminants <p>(Illustrated as Figure 3-2) [Note: annual rainfall and/or groundwater recharge projections <+/-5%, or potentially <+/-10% for urban sites located away from sensitive controlled waters are not considered to significantly influence the CSM]</p>	<p>a) Changes to contaminant (chemical) degradation from changes in source zone saturation and/or changes in geochemical conditions</p> <p>b) Changes to the mechanisms by which the source may be released, e.g.</p> <ul style="list-style-type: none"> Changes in leaching of contaminants sorbed to soil and in porewater Change to physical erosion of source zone from rainfall events dependent on soil saturation and cohesion Potential for re-mobilisation of contaminants in the unsaturated zone <p>c) Variations in water table affecting NAPL smearing and potential NAPL mobilisation.</p>	<p>i. Changes in overland flow affecting mobilisation of source zone contaminants</p> <p>ii. Change to overland flow drainage patterns</p> <p>iii. Changes to water table elevation affecting:</p> <ul style="list-style-type: none"> Plausibility of preferential pathways e.g. near (sub) surface pathways e.g. drains and culverts, and/or activating higher permeability zones (e.g. gravel bands) Location of spring issues and/or flows at existing springs Groundwater pathway length, hydraulic gradient, and dilution potential 	<p>1) Changes to the location and distribution of springs, surface water features or wetlands</p> <p>2) Changes in species assemblages in ecological receptor because of change in surface water supply and/or groundwater discharge</p>
6	<p>Sea level rise causing marine inundation and saline intrusion (if sea rises higher than groundwater, saltwater can enter the aquifer)</p> <p>(Illustrated as Figure 3-4) (Exclusion: source zone erosion)</p>	<p>a) Changes in contaminant (chemical) degradation and sorption because of sea spray or saline groundwater intrusion affecting soil geochemistry. Consider:</p> <ul style="list-style-type: none"> Proximity of source from coast Proximity of source to groundwater saline-freshwater interface 	<p>i. Reduction in overland flow pathway length</p> <p>ii. Reduction in groundwater pathway length</p> <p>iii. Change to overland flow drainage patterns</p> <p>iv. Change to hydraulic gradient in coastal groundwater</p> <p>v. Change to local hydrogeological flow pattern with changing saline interface (because of groundwater density) and potential tidal influence</p> <p>vi. Changes to geochemical conditions in pathways from increasing salinity e.g. mobility, toxicity, partitioning and degradation rates</p>	<p>1) Reduction in distance to marine receptor, both at coastal locations and upstream migration of tidal limits at river mouths and estuaries</p> <p>2) Change to (including removal of) inland surface water body receptor locations</p> <p>3) Change to groundwater (aquifer) chemistry because of saline intrusion</p> <p>4) Change in distribution and location of abstraction wells (as supply and demand changes in coastal settings). Associated implications on Source Protection Zones (SPZ).</p> <p>5) Changes in species assemblages in the ecological receptor because of changing groundwater salinity, water supply or suspended solids</p>

Scenario No.	Climate change induced effect	Possible effects/considerations of climate change induced weather event on CSM components		
		Source	Pathway	Receptor
7	<p>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)</p> <p>Note. Coastal erosion could affect source zone, pathways, and/or receptors</p>	<p>a) Erosion of source zones located near to the coast e.g. historical landfills. Consider:</p> <ul style="list-style-type: none"> • Distance of source to coast • Predicted extent of sea level rise or potential coastline retreat • Local topographic profile • Vulnerability of the coast to erosion. Consider: <ul style="list-style-type: none"> ○ Superficial geology type and thickness, ○ Soil and/or superficial deposit cohesion, ○ Vegetation type and distribution • Design of any current or planned sea defences <ul style="list-style-type: none"> ○ Nature of any current or planned sea defence action plans e.g. waste treatment or relocation <p>b) Possible mobilisation of additional contaminants of potential concern due to source zone erosion</p>	<p>i. Consider effect of coastal erosion on:</p> <ul style="list-style-type: none"> • Overland flow pathway length • Groundwater pathway length <p>ii. Contaminant/sediment deposition and resuspension in overland flow. Consider:</p> <ul style="list-style-type: none"> • Overland drainage patterns • Vegetation cover type and distribution 	<p>1) Change in location or presence of inland surface water bodies e.g. estuaries and rivers</p> <p>2) Change in location or presence of groundwater abstraction wells and associated implications on SPZs</p> <p>3) Effect of suspended solids on estuarine or marine ecosystems</p>

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')²⁴ and ConSim²⁵, 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 K_{oc}/K_d values. Consideration of changes to physical-chemical

²⁴ Available at: <https://www.gov.uk/government/publications/remedial-targets-worksheet-v22a-user-manual>. (Environment Agency, 2006).

²⁵ Available at: <https://www.wsp.com/en-gb/services/environment-agency-toolkits>. (Golder Associates (UK) Ltd, 2009).

contaminant properties by future climate change is therefore considered unlikely to be a 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 2.3.2 and 2.3.3 outline 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 2.3.4 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 2050s (2041 – 2070) and 2080s (2071 – 2100) dependent on timeframe relevant to the specific assessment.
 - Assess the impact from climate change on sources, pathways, and receptors, and resultant impacts on the contaminant linkages in the conceptual model. This could be qualitative, semi-quantitative or quantitative depending on the site.
- 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
CRI	Climate Risk Indicators
COP	Conference of the Parties (to the United Nations Framework Convention on Climate Change)
CPM	Convection Permitting Climate Model
CRI	Climate Risk Indicators
CSM	Conceptual Site Model
DAERA	Department of Agriculture, Environment & Rural Affairs (Northern Ireland)
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
NPF4	National Planning Framework 4

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

Intergovernmental Panel on Climate Change (IPCC)

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

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>
- Climate Dashboard - <https://climate.metoffice.cloud/>

Other sources of climate change projections

- Climate Risk Indicators (CRI) explorer - <https://uk-cri.org/>
- Local Climate Adaptation Tool (LCAT) - <https://www.lcat.uk/>
- Gridded climate datasets for Europe (long term data available at a daily resolution) - <https://www.ecad.eu/>. See also www.euro4m.eu

British Geological Survey (BGS) (open licence, others available under licence) – available to view via GeoIndex portal

- GeoCoast Open (represents the natural geological coastline as if no coastal defences or made ground are present and provides information on erosion, flooding, habitat and other vulnerabilities) - <https://www.bgs.ac.uk/datasets/geocoast-open/>
- 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/>.
- Susceptibility to groundwater flooding data set - <https://www2.bgs.ac.uk/groundwater/datainfo/GFSD.html>.

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)

UK flood risk maps

- SEPA Future Flood Maps - <https://map.sepa.org.uk/floodmaps/FloodRisk/FutureFloodMaps>
- Environment Agency long term flood risk for England - <https://www.gov.uk/check-long-term-flood-risk>
- Environment Agency flood map for planning - <https://flood-map-for-planning.service.gov.uk/>
- NRW flood map for planning - <https://flood-map-for-planning.naturalresources.wales/>
- Northern Ireland flood maps - <https://www.infrastructure-ni.gov.uk/topics/flood-maps-ni>

Sea level and coastal erosion maps

- Coastal risk screening tool - coastal.climatecentral.org/map
- National Coastal Erosion Risk Mapping for England - <https://www.gov.uk/check-coastal-erosion-management-in-your-area>
- National coastal erosion risk map for Scotland - <https://www.dynamiccoast.com/>

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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) (2023 - 2028) (Department for Environment, Food & Rural Affairs, 2024) 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, 2024), and relevant planning practice guidance (PPG) documents²⁶. 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 waste 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 158 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 2022 are currently being updated. The updated plans consider climate change to be a critical challenge that requires urgent action and

²⁶ 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, 2022).

A1.2 Wales

The Prosperity for All: A Climate Conscious Wales (a climate change adaptation plan for Wales) (Llywodraeth Cymru/Welsh Government, 2022) 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, and identifies challenges such as climate change.
- 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 12 (Llywodraeth Cymru/Welsh Government, 2024), sets out several planning policies that contribute toward climate change adaptation.

Whilst Technical Advice Note (TAN) 15 (Llywodraeth Cymru/Welsh Government, 2025) focuses 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 (August 2024) undergoing consultation; the River Basin Management Plan for the cross-border Severn was updated in 2022. 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.

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 4 (Scottish Government, 2023) seeks to ensure Scotland’s places are more resilient to climate change impacts. Local development plans should support adaptation to the current and future impacts of climate change by taking into account climate risks, guiding development away from vulnerable areas, and enabling places to adapt to those risks. Development proposals are expected to be sited and designed to adapt to current and future risks from climate change. Development proposals to retrofit measures to existing developments that support adaptation to climate change will be supported. The policy on climate mitigation and adaptation is linked to all the other policies within NPF4. The connection between the policies on the reuse of brownfield, vacant and derelict land and empty buildings and the overarching policy of climate mitigation and adaption is explicitly stated. NPF4 also includes policies require climate change impacts to be taken into consideration in relation to coastal communities and assets, areas at risk of flooding, and in relation to adaptation to extreme temperatures.

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.

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. SEPA help Scotland adapt to the changing climate by working with operators and other stakeholders to improve climate resilience.

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.

In June 2022 the Climate Change Act (Northern Ireland) (Northern Ireland Assembly, 2022) received royal assent. The Act creates a target for net-zero greenhouse gases by 2050 however does not explicitly mention land contamination or Controlled Waters/water quality. The Act legally requires that all Northern Ireland Departments contribute to delivering its targets, carbon budgets and climate action plans. The Department for Agriculture, Environment and Rural Affairs (DAERA) is required to produce 5-year climate action plans which must contain targets to be achieved for soil quality and biodiversity, which may be impacted by land contamination.

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, 2025), 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, Wales, Northern Ireland and Scotland to risk assessment and management of historical land contamination is risk-based using a source - pathway - receptor linkage approach as defined in LCRM (Environment Agency, 2025). Updates to LCRM since 2023 have incorporated more information on the importance of taking climate change into account through the risk assessment process. LCRM refers to factoring in climate change impacts, including extreme weather events as part of an overall sustainable approach to land contamination risk management to ensure site works and any long-term remediation is sustainably robust.

At Tier 1 risk assessment LCRM recommends that climate change impacts are considered in the choice of risk evaluation criteria within a PRA when identifying the types of contaminants likely to be present; the interaction of the site and ground conditions, groundwater, surface water and ground gases and vapours; and the possible combined or cumulative factors of different contaminants interacting with each other. Ultimately it recommends consideration of how climate change and extreme weather events could impact all aspects of a CSM, including potential source contaminants, their migration pathways and identified receptors with specific consideration given to the hydrogeological and hydrological properties of the system.

At the Tier 2 generic quantitative risk assessment stage, in the selection and application of generic assessment criteria, 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 and extreme weather events.

When defining objectives and deciding what information is required to inform a Tier 3 detailed quantitative risk assessment (DQRA), consideration should be given to how climate change and extreme weather events could impact technical factors including specific complexities of the site, the CSM and/or ground conditions and processes, contaminant linkages, existing groundwater impacts

and plume characteristics, combined or cumulative factors, changes in circumstances and uncertainties.

While the Environment Agency's Guiding Principles for Land Contamination 2 (GPLC) (Environment Agency, 2010) has now been withdrawn, it 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.

Climate change is not currently addressed by the EA's Remedial Targets Methodology (Environment Agency, 2006), although it does note that meteorological data is required to enable input parameter selection when undertaking modelling, particularly in relation to recharge.

SEPA's Position Statement (WAT-PS-10-02 / WAT-G-071 ²⁷) 'Assigning Groundwater Assessment Criteria for Pollutant Inputs' (Scottish Environment Protection Agency, 2025) recommends that climate change impacts and potential extreme events are considered during the development of the conceptual site model as well as during any detailed quantitative modelling or sensitivity analysis. The following factors should be considered to determine the significance (if any) of potential climate change impacts which will be dependent on the environmental setting, the timescale of the scenario being assessed and the tolerability of uncertainty in the assessment results:

- Changes in precipitation, both annual average and individual rainfall events;
- Changes in frequency or magnitude of extreme events such as floods and droughts;
- Changes in sea level and coastal erosion;
- Changes in groundwater levels including seasonal trends;
- Changes in air and water temperature, which may influence contaminant mobility and microbial activity;
- Changes to ecosystems.

LCRM (Environment Agency, 2025) signposts to the Sustainable Remediation Forum UK (SuRF-UK) (CL:AIRE, 2010) for assessing the sustainability of soil and groundwater remediation. In particular SuRF-UK bulletin 5 "Resilience and Adaptation for Sustainable Remediation" (SuRF-UK, 2023) includes reference to examples of impacts of climate change on soil and groundwater risk management activities and remediation technologies such as changes to the behaviour of contamination sources

²⁷ SEPA updated their document references for groundwater guidance when the Environmental Authorisation (Scotland) Regulations became active on 1 November 2025. This post-dates the cutoff date for the literature review but pre-dates publication of this SoBRA guidance. It is therefore considered appropriate to acknowledge that the SEPA guidance document WAT-PS-10-02 will be referred to as WAT-G-071 going forward. It is noted that only the document reference number has been updated with the technical content of the guidance remaining unchanged.

and within the groundwater body. It also recognises that climate change impacts could affect remediation measures such as damage to capping systems e.g. due to extreme precipitation.

The Environment Agency has published guidance for their staff to identify and communicate the risks from a changing climate within their regulatory decision making process (Environment Agency, 2023). The guidance has been published publicly on gov.uk to assist relevant stakeholders when engaging with the Environment Agency on relevant projects. The guidance comprises a climate impacts tool to provide a simple description of current and potential future challenges to the climate for 4 scenarios:

1. Present day (The climate has already changed).
2. Mid-century (+2°C by 2050).
3. Managed transition (+2°C by 2100).
4. Runaway change (+4°C by 2100).

The tool also provides more information on a large range of climate impacts, including cascading risks to the environment, society, and infrastructure. The key question to consider when using the tool is *“could our outcomes or objectives be delivered under this level of climate change?”* or *“knowing this impact information, would or could we do anything differently?”*. The guidance provides a range of information sources where data on future climate change can be obtained including the UK Climate Risk Indicators (CRI) explorer.

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.

3. CL:AIRE, October 2021. Good Practice for Risk Assessment for Coal Mine Gas Emissions.
(CL:AIRE, 2021)

CL:AIRE's guidance document recommends that climate change and regional groundwater conditions are considered within the conceptual site models underpinning mine gas risk assessments. The authors refer to foreseeable long- and short-term events such as flooding, changes in groundwater level and extreme weather conditions. Chapter 11 and Figure 11.1 of the document describe the effect of groundwater level changes on dissolved mine gases. Use of the BGS FFGL project as a resource when assessing the impact of climate change on river flows and groundwater levels is mentioned. Chapter 14 on potential uncertainties directs the risk assessor to consider the impact of climate change on mine gas risk.

Appendix 3.1 of the CL:AIRE guidance recommends a site-specific assessment of the impact of climate change, including factors such as: barometric pressure drops (24mbar over 24 hours) associated with storm events / depressions; the impact of increased summer atmospheric temperatures having the potential to reduce or reverse gas flow up shafts, and the exposure of flooded mine workings by the potential drop in groundwater levels during periods of increased dry weather. The authors recommend a graphical CSM including known / predicted groundwater changes. Groundwater monitoring is considered to be an important part of the risk assessment if a detailed mine gas risk assessment is required (see Note 3 on the decision support tool presented in Figure 13.1). Case studies and key CSM considerations are provided in Appendix 4.

4. SoBRA, June 2023. The Climate Emergency: Practical Considerations in Brownfield Risk Assessment, Summer Workshop 2022 Report. (SoBRA, 2022)

SoBRA held a summer workshop on 22nd June 2022 in relation to the Climate Emergency: Practical Considerations in Brownfield Risk Assessment. This included a series of workshops to consider how climate change could be considered in relation to: controlled waters (led by this subgroup); ground gas and soil vapour; non-aqueous phase liquid (NAPL) and natural source zone depletion (NSZD); and carbon accounting. The publication presents the conclusions and recommendations of the workshop presentations and workshop sessions on how to consider and account for potential effects of climate change in land contamination risk assessment. The workshops emphasised the importance of considering climate change effects and implications on the CSM through all stages of risk-based decision making. It is possible that climate change effects could be screened out at PRA stage. Good site characterisation and conceptualisation is essential. This involves ensuring relevant data is gathered during the site investigation to inform pollutant linkages and how they may be influenced by extreme weather and long-term shifts in weather patterns.

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* (American 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 resilience 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 adaptation. 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.

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, n.d.). 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 decade²⁸. England, Wales and Northern Ireland have set a goal of net zero carbon emissions by 2050²⁹, 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

²⁸ More information available at: <https://www.gov.uk/government/news/cop-26-ends-with-global-agreement-to-speed-up-action-on-climate-change>.

²⁹ 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.

and guidance bodies. It is important to recognise the uncertainties associated with the multiplicity of projections, modelling choices and downscaling when utilising model output.

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 A3-5-1 summarises temperature projections for SRES and RCP scenarios.

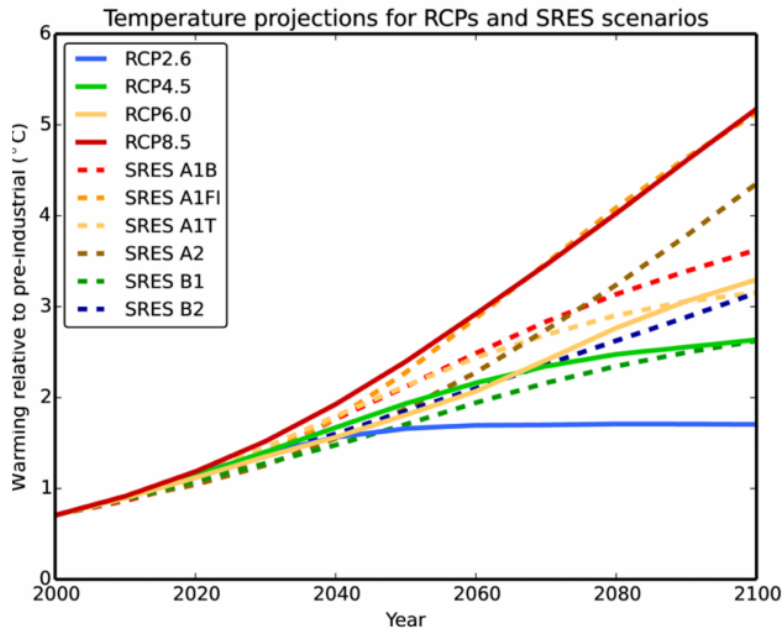


Figure A3-1: Global mean temperature projections from climate model MAGICC6 relative to a pre-industrial average (1850-1900) for RCP2.6 (blue), RCP4.5 (green), RCP6.0 (yellow) and RCP8.5 (red) and the older SRES scenarios (dashed coloured lines) from UKCP18 guidance (Met Office, 2018). © Crown copyright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

Table A3-1 and Figure A3-1 summarise the projected surface temperature increases associated with five SSP scenarios utilised in IPCC AR6 (Intergovernmental Panel on Climate Change, 2021):

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 SPM.1, IPCC AR6 (Intergovernmental Panel on Climate Change, 2021).

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

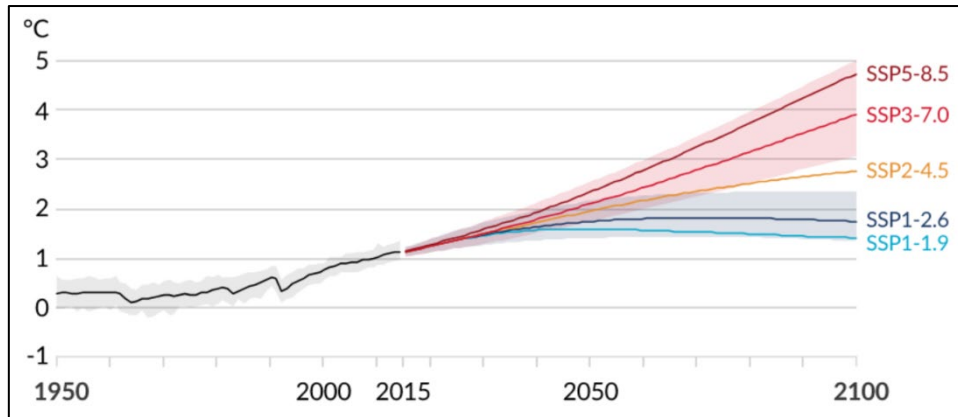


Figure A3-5-2: Global surface temperature change projections for the five SSPs (coloured lines), relative to 1850-1900. Shaded areas represent uncertainty associated with the projections. Black line represents the historical simulation to provide context for the future projections. Reproduced from Figure SPM.8(a), IPCC AR6 (Intergovernmental Panel on Climate Change, 2021)).

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-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 e.g. (Met Office, 2021a).

APPENDIX 4
Worked 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 worked 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 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. Several 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 are 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.

Logs of boreholes 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 is indicated to be present from 4m bgl within the River Terrace Deposits.

Hydrogeological Model

Made Ground is likely to be present at 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 to 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 likely that groundwater can readily flow between these aquifers.

Groundwater may be tidally influenced and likely flows towards the English Channel located 100m to the south. The site is located just out with the total catchment Source Protection Zone, associated with a groundwater abstraction located 200m north of the site and up-hydraulic gradient.

Future Climate Change under RCP8.5 Scenario

Sea Level Rise/ Coastal Erosion

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 2100³⁰ which could bring the sea within approximately 60m of the site during spring tides or storm surges³¹.

The site is located within the Beachy Head to Selsey Bill Shoreline Management Plan (SMP)³² which indicates:

- the percentage of coastline at risk from inundation is 19.77% for the 2050's and 19.91% for the 2100's.
- the mean percentage of coastline affected by cliff erosion is 59.35% increasing to 70.6% for worst case. However, the coastline close to the site comprises a sandy beach with no rock cliffs and as such it is judged that cliff erosion will not affect the site.
- the coastline is located within erosion domain J which has a high susceptibility to erosion with the backshore area present above the high-water mark. However, the National Coastal Erosion Risk Mapping (2018)³³ indicates that the coastline near to the site has a seawall defence in place and providing that this is maintained and interventions put in place the shoreline is not anticipated to retreat.

Flood Risk

The site is located within Flood Zone 3³⁴ indicating it is currently at a high risk of flooding from rivers and the sea. The long term flood³⁵ risk for the site indicates that the site will remain prone to flooding in the future. The 2, 10 and 30-year river future flood projections³⁶ for the south-east of England are all projected to stay at a similar or lower level, suggesting the site will not be at an increased likelihood of flooding as a result of climate change. As such, flood risk associated with climate change has not been considered further within the CSM.

Projected Changes to Rainfall

The site is located within the Arun Local Authority Area. According to projections available for UKCP18 RCP8.5 Regional data on the UK CRI website³⁷, median annual rainfall is expected to decrease from baseline by 2% for the near future (2021 – 2050) and by 8% for the far future (2071 – 2100). It is noted that winter rainfall is expected to increase by 8% for the near future (2021 – 2050) and by 32% for the far future (2071 – 2100). An overall decline in rainfall is projected for other seasons with the most significant decrease occurring in the summer when rainfall is projected to decrease by 16% for the near future (2021 – 2050) and by 56% for the far future (2071 – 2100).

Projected Changes to Groundwater Recharge and Groundwater Level

The site is located within Littlehampton Anticline East Groundwater catchment which falls under the WFD definition of a groundwater body. The eFLaG³⁸ project near-future (2021 - 2050) projections are for groundwater recharge in this catchment to increase by 0.1mm per day (9.6%) during the winter months and in the far-future (2050-2079) this increases to 0.2mm per day (27.8%). No change to current recharge is

³⁰ <https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/summaries/marine-climate-change-projections>

³¹ <https://coastal.climatecentral.org/map>

³² SMP projections are available as a data layer via the GeoCoast Open dataset available on the BGS GeoIndex portal <https://www.bgs.ac.uk/map-viewers/geoindex-onshore/>

³³ National Coastal Erosion Risk Mapping (<https://environment.data.gov.uk/shoreline-planning/unit/SMP12/4D18>)

³⁴ <https://flood-map-for-planning.service.gov.uk/location>

³⁵ <https://check-long-term-flood-risk.service.gov.uk/map>

³⁶ <https://uk-cri.org/>

³⁷ <https://uk-cri.org/>

³⁸ <https://eip.ceh.ac.uk/hydrology/eflag/>

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) are for no significant groundwater level changes. A -0.3% change (effectively no change in groundwater elevation) is projected for the near future (2021- 2050) and a 1.8% change (approximately 0.2 m change in groundwater elevation) projected for the far future (2050 – 2079). It is however noted that these changes do not consider additional pressures on the Chalk aquifer, such as potential future changes to the abstraction rate from the nearby water supply.

Extreme weather event considerations

Extreme weather has the potential to occur at any site with extremes of precipitation and cold weather more likely to occur in the winter months and extreme heat and drought more likely to occur in the summer months. Met Office UKCP18 regional projections for a high emissions scenario (RCP8.5) at Local Authority Area spatial resolution available on the UK CRI explorer indicate that median extreme weather event indicators for the site area projected to change as follows:

- Extreme precipitation: the wettest month is projected to increase from 0.04 months per year (2011-2040) to 0.11 months per year (2071 – 2100). It is therefore considered that there will be an increased likelihood of extreme precipitation, particularly in the winter months, which should be considered further in the CSM.
- Extreme cold weather: Met Office cold weather alerts are projected to decrease from a median of 1.8 events/year (2011-2040) to 0.4 events per year (2071 – 2100). The frequency of frost days ($T_{min} < 0^{\circ}C$) are projected to decrease from 34.0 days/year (2011-2040) to 10.5 days/year (2071 – 2100). This suggests that the site is unlikely to be at an increased risk from extreme cold weather events and as such this hasn't been considered further in the assessment.
- Extreme heat: the hottest month is projected to increase from 0.4 months per year (2011-2040) to 3.4 months per year by 2100. Met Office heat waves for the south-east of England are projected to increase from 2.0 events per year (2011-2040) to 5.6 events per year (2071-2100). The number of very hot days ($T_{max} > 35^{\circ}C$) is projected to increase from 0.2 days per year (2011-2040) to 8.5 days per year (2071-2100). This may have implications for water demand resulting in changes to abstraction rates associated with the nearby groundwater abstraction.
- Drought: the proportion of time rivers will experience an extreme 2-year drought in the south-east of England is projected to increase from 0.09 (2011-2040) to 0.34 (2071-2100). Soil moisture content is projected to decrease by -9.4% at the end of the century versus the baseline (1981 – 2010). This may have implications for water demand resulting in changes to abstraction rates associated with the nearby groundwater abstraction.

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)

*Controlled Water pathways and receptors only

Preliminary Conceptual Site Model

Table 1 – Preliminary CSM

Potential Sources	Potential Pathways	Potential Receptors	Comments
<ul style="list-style-type: none"> Made Ground associated with historical development, including hydrocarbon contamination Historical Industrial Site uses (shoe factory and smithy) 	<ul style="list-style-type: none"> Vertical leaching from impacted Made Ground Lateral migration of impacted groundwater derived from on-Site and off-Site sources. 	<ul style="list-style-type: none"> Secondary A Aquifer (River Terrace Deposits) Principal aquifer (Chalk) Groundwater abstraction Surface water (English Channel) 	<p>Groundwater is present 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.</p> <p>The site is located within a flood risk area. Flooding could mobilise contaminants within the Made Ground and/or result in deposition of contaminants from off-site sources.</p> <p>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.</p> <p>Under RCP8.5 Climate Change Projections</p> <p><i>The site is in an urban environment and as the projected change in annual rainfall is less than 10% it is considered that changes in rainfall associated with future climate change are unlikely to significantly influence leaching and groundwater migration pathways. However, 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. The increase in upgradient groundwater recharge will increase groundwater flow beneath the site and thereby the potential for dilution of leaching contaminants.</i></p> <p><i>Sea levels are projected to rise by >0.7m by 2100 in this area. Higher sea levels would decrease the distance of the site from the sea and therefore potentially affect groundwater quality and chemistry. Whilst current groundwater flow direction is unlikely to be changed, the hydraulic gradient could be higher and larger groundwater tidal fluctuations could occur. 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.</i></p> <p>Extreme weather events</p> <p><i>Extreme precipitation may locally influence leaching and groundwater migration pathways. Increased leaching of contaminants could occur due to an increase in soil saturation, however, the increase in upgradient groundwater recharge will increase groundwater flow beneath the site and thereby the potential for dilution of leaching contaminants. Near surface contamination could be mobilised from unsealed surfaces due to source zone erosion with overland flow resulting in contaminants entering drainage and/or migrating off-site. As groundwater levels are 4m bgl it is unlikely that extreme precipitation would result in groundwater flooding and/or significant changes with respect to water table elevation in relation to the source.</i></p> <p><i>Extreme heat may locally result in wildfires associated with the scrub on site. This may result in vegetation loss, causing changes to the stability of the source zone potentially leading to increased leaching during precipitation. Wildfires may result in near surface contaminants becoming airborne and being deposited across a wider area, although this is unlikely to result in increased leaching.</i></p>

Potential Sources	Potential Pathways	Potential Receptors	Comments
			<i>Drought is considered unlikely to influence the leaching and groundwater migration pathways due to the depth of the water table (4 m bgl). Any associated reduction in groundwater level as a result of drought would be counterbalanced by the reduction in groundwater flow beneath the site. However, extreme heat and drought conditions are projected to become more prevalent in the south-east of England. This may have implications for water demand and could result in either increased abstraction rates or the installation of new abstraction wells associated with the existing water supply which may bring the total catchment within the site boundary.</i>
	<ul style="list-style-type: none"> Migration of groundwater through preferential pathways such as utility service trenches / sewers 	<ul style="list-style-type: none"> Secondary A Aquifer (River Terrace Deposits) Principal aquifer (Chalk) Groundwater abstraction Surface water (English Channel) 	<p>Groundwater is 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 Waters receptors.</p> <p><i>Under RCP8.5 Climate Change Projections</i></p> <p><i>The site is in an urban environment and as the projected change in annual rainfall is less than 10% it is considered that changes in rainfall associated with climate change are unlikely to significantly result in groundwater levels increasing to within the levels of service trenches/sewers.</i></p> <p><i>Extreme weather events</i></p> <p><i>Extreme precipitation resulting in 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 be mobilised and migrate off-site via this preferential pathway.</i></p> <p><i>Extreme heat and drought events are not considered to influence this contaminant linkage due to the depth of groundwater at the site (4 m bgl).</i></p>

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

Potential recommendations to take account of projected climate change conditions:

- Any future ground investigation should include the installation of groundwater monitoring wells to determine depth to groundwater with groundwater level monitoring visits completed over an appropriate period to better understand the existing groundwater regime and seasonal influences on groundwater levels.
- Continuous groundwater level monitoring could be considered over the autumn and winter period to provide a better understanding of the aquifer response to extreme precipitation events.
- A flood risk assessment (FRA) should be completed for the site that takes into account potential future changes that may be associated with climate change, in accordance with Environment Agency guidance.
- If possible, discussions should be had with the operator of the groundwater abstraction to understand whether they have any long term contingency plans associated with maintaining groundwater supply in the area as a result of potentially increased water demand associated with climate change and extreme weather.
- As part of the redevelopment consideration should be given to installing a stable ground cover system with appropriate drainage and managed landscaped areas to help minimise the effects of extreme weather. Utility service trenches should be designed to prevent the flow of water within them. Sewer systems should be engineered to handle rising discharge levels.

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

It should be noted the site used within this worked 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 used for informal recreation activities which is managed and maintained by the local authority. 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 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 sand. The historical borehole logs reported groundwater within the Blown Sands underlying the landfill materials. A review of historical records indicates no 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. The site slopes towards the beach and there is an approximately 1–2 m change in ground level between the site's eastern boundary and surrounding land.

The assessment is required by the Local Authority to understand whether the site currently or may in future meet the classified as contaminated land as defined under Part 2A of the Environmental Protection Act 1990.

Hydrogeological Model

Made Ground is likely to be present across the site owing to the historical land-use as a 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/ Coastal Erosion

The site is close 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.³⁹

The National Coastal Erosion Risk Mapping (2018)⁴⁰ 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 projections would, without mitigation measures, result in the shoreline moving to within the landfill in the future and active erosion and mobilisation of landfill materials.

Flood Risk

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

Projected Changes to Rainfall

The site is located within the Dover Local Authority Area. According to projections available for UKCP18 RCP8.5 Regional data⁴¹ (Local Authority spatial resolution), median annual rainfall is expected to decrease from baseline by approximately 4% for the near future (2021 – 2050) and by 15% for the far future (2071 – 2100). It is noted that winter rainfall is expected to increase by approximately 4% for the near future (2021 – 2050) and by 20% for the far future (2071 – 2100). For other seasons an overall decline in rainfall is projected with the most significant decrease occurring in the summer when rainfall is projected to decrease by 9% for the near future (2021 – 2050) and by 47% for the far future (2071 – 2100).

Projected Changes to Groundwater Recharge and Groundwater Level

The Site is located within the Broadland Rivers Chalk and Crag Groundwater catchment. The eFLaG project⁴² far-future (2050-2079) projections for groundwater recharge within this catchment are for a median 5-10% increase for the winter months for this groundwater body, and for 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 projected rise in sea levels. The salinity of the groundwater may also be influenced by sea level rise and coastal erosion.

Extreme weather event considerations

Extreme weather has the potential to occur at any site with extremes of precipitation and cold weather more likely to occur in the winter months and extreme heat and drought more likely to occur in the summer months. Met Office UKCP18 regional projections for a high emissions scenario (RCP8.5) at Local Authority Area spatial resolution available on the UK CRI website indicate that median extreme weather event indicators for the site area projected to change as follows:

³⁹ <https://ukclimateprojections-ui.metoffice.gov.uk/ui/home>

⁴⁰ [National Coastal Erosion Risk Mapping \(arcgis.com\)](#)

⁴¹ <https://uk-cri.org/>

⁴² <https://eip.ceh.ac.uk/hydrology/eflag/>

- Extreme precipitation: the wettest month is projected to increase from 0.012 months per year (2011-2040) to 0.016 months per year (2071 – 2100). It is therefore considered unlikely that the site is at increased risk from extreme precipitation events and as such this hasn't been considered further in the assessment.
- Extreme cold weather: Met Office cold weather alerts are projected to decrease from a median of 1.78 events/year (2011-2040) to 0.39 events per year (2071 – 2100). This suggests that the site is unlikely to be at an increased risk from extreme cold weather events and as such this hasn't been considered further in the assessment.
- Extreme heat: the hottest month is projected to increase from 0.4 months per year (2011-2040) to 3.0 months per year by 2100. Met Office heat waves are projected to increase from 1.3 events per year (2011-2040) to 5.2 events per year (2071-2100). The number of very hot days (Tmax>35°C) is projected to increase from 0.1 days per year (2011-2040) to 3.7 days per year (2071-2100). This may have implications for water demand. However, the site is not currently located in an SPZ and it is unlikely to have future resource potential due to the proximity of the site to the sea. The significance of extreme heat on the CSM is therefore reduced and has not been considered further in the assessment.
- Drought: the proportion of time rivers will experience a 2-year extreme drought in the south-east of England is projected to increase from 0.09 (2011-2040) to 0.34 (2071-2100). Soil moisture content is projected to decrease by -9.4% at the end of the century versus the baseline (1981 – 2010). As the site is not located in proximity to a river this has not been considered further in the CSM.

Potential Sources

Potential on-site sources of contamination include:

- 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.

Potential Receptors*

Potential receptors include:

- R01: Groundwater within the Blown Sands (Secondary A Aquifer) 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 Aquifer) and Crag Formation (Principal Aquifer) R02: Surface water (North Sea).	Likely (Likely)	Medium (Medium)	Moderate (Moderate)	<p>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.</p> <p>Under RCP8.5 Climate Change Projections</p> <p><i>Under a RCP8.5 scenario, the direct recharge (i.e. infiltrating rainfall) is not expected to significantly increase on an annual basis; however, A median increase in precipitation of 20% is projected for winter by 2100. Overall, there is considered to be no change in the assessed risk for this element of the CSM. However, seasonal variation may need to be considered for long-term management options.</i></p> <p>Extreme weather events</p> <p><i>Extreme precipitation may locally influence leaching and groundwater migration pathways. Increased leaching of contaminants could occur due to an increase in soil saturation. Conversely, there will be an increase in upgradient groundwater recharge which will increase groundwater flow beneath the site and thereby the potential for dilution of leaching contaminants. Extreme precipitation is not considered to increase significantly based on projections.</i></p> <p><i>Extreme cold is considered unlikely to significantly affect the site due to its location in the south-east of England and its proximity to the coast.</i></p> <p><i>Extreme heat is considered unlikely to affect this linkage. The presence of the majority of the contamination at depth means the loss to atmosphere of volatile contaminants during a short-lived extreme heat event is unlikely to significantly change the leaching of contamination to groundwater.</i></p> <p><i>Drought is considered unlikely to directly influence the leaching and groundwater migration pathways. A drought will temporarily reduce the infiltration of rainwater to the ground and thereby temporarily reduce leaching of contaminants to groundwater. However, the benefit is marginal and short-lived. Conversely, a reduction in upgradient groundwater recharge which will reduce groundwater flow beneath the site and thereby the potential for dilution of leaching contaminants. Potential for changes in groundwater dynamics over longer term projections due to increased pressure on water resources.</i></p>

Sources	Possible Pathways	Receptors	Probability	Consequence	Risk Level	Comments
S01: Landfilled waste, which may include household, commercial and industrial wastes, petroleum hydrocarbons and asbestos	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 Aquifer) and Crag Formation (Principal Aquifer) R02: Surface water (North Sea)	Low likelihood <i>(Likely)</i>	Medium <i>(Medium)</i>	Low <i>(Moderate)</i>	<p>The available information suggests that groundwater levels are below the base of the landfill. As such, the likelihood of direct leaching via lateral migration of groundwater through potentially contaminated landfill is judged to be low, which when combined with the medium consequence results in a low assessed level of risk.</p> <p>Under RCP8.5 Climate Change Projections</p> <p><i>Under a RCP8.5 scenario, sea levels are expected to rise circa 0.7m in the vicinity of the site. 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 groundwater 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.</i></p> <p>Extreme weather events</p> <p><i>Extreme precipitation may result in groundwater levels rising above the base of the landfill and coupled with increased winter precipitation and sea level rise could result in the formation of 'springs' along the eastern site boundary with the introduction of overland flow pathways mobilising contaminants off-site towards the beach and the North Sea. Extreme precipitation is not considered to increase significantly based on projections and as such this is not considered to require further consideration.</i></p> <p><i>Extreme cold, extreme heat and drought are not anticipated to influence this contaminant linkage.</i></p>
	P03: Physical erosion of the landfill materials and direct exposure of landfill materials to the surface water environment.	R02: Surface water (North Sea)	Unlikely <i>(High Likelihood)</i>	Medium <i>(Medium)</i>	Very Low Risk <i>(High Risk)</i>	<p>The site is current located some 25m from the North Sea and there is no current evidence of direct exposure of landfill materials to the North Sea.</p> <p>Under RCP8.5 Climate Change Projections</p> <p><i>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 there is assessed a high risk that contaminated materials may become directly exposed to the North Sea.</i></p> <p>Extreme weather events</p> <p><i>Individual storm events with associated extreme precipitation 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, particularly storm surges associated with high spring tides washing away the landfill. In addition, drought conditions coupled with increased wind intensity could also exacerbate the physical erosion of the surface of the source zone.</i></p> <p><i>Extreme cold and extreme heat are not anticipated to influence this contaminant linkage.</i></p>

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

Conclusions and Recommendations

Based on historical and current land uses and in accordance with LCRM:

- The overall risk from land contamination at the site is assessed to be moderate for the current scenario and conditions, as there is a risk of rainwater infiltration leading to leaching of contaminated soils within the former landfill.
- Considering projected future climate change, the overall risk from land contamination at the site is assessed to increase to *high*, as there is an additional risk of groundwater rising into the landfill materials and erosion resulting in direct exposure of landfill materials to the North Sea. The influence of extreme weather, particularly in relation to storm surge events coinciding with high spring tides will make the site more susceptible to this.

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 Environmental Protection Act 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;
3. Groundwater and leachate levels, incorporating long-term monitoring to understand seasonal variation, aquifer responses to extreme precipitation and at a sufficient resolution to characterise any tidal variations;
4. Monitoring the eastern face of the site for evidence of 'spring' features immediately following extreme precipitation events; and
5. Undertaking a site stability assessment and associated long-term geotechnical monitoring, particularly along the eastern site boundary, where it is susceptible to erosion.

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

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

It should be noted the site used within this worked 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 Mining Remediation 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.

Several 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 0.5m and 11.3m indicating that perched bodies of groundwater may be encountered in the granular Made Ground. Hydrophilic vegetation and boggy ground have been observed within a low-lying area of the site, suggesting that groundwater is potentially very shallow in this area with the potential for localised groundwater flooding. 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 and is 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 continuity; 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. Surface water ponding is anticipated in the south of the site.

Future Climate Change under RCP8.5 Scenario

Sea Level Rise/Flood Risk

The site is not located near the Firth of Clyde or an area at risk of future coastal flooding (including coastal flooding via the River Clyde⁴³).

The site is currently located approximately 500m from the River Clyde (to the south of the site) and is not within an area projected as being likely to be at risk from future river flooding⁴⁴.

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

Projected Changes to Rainfall

The site is located within the 12x12 km spatial unit AL-47 within the Glasgow City Council local authority area. According to projections available for UKCP18 RCP8.5 Regional data⁴⁵, median annual rainfall is projected to remain fairly stable with only a 0.9% change in baseline for the near future (2021–2050), increasing to approximately 2% for the far future (2071–2100). Spring, autumn and winter rainfall is projected to increase, with the greatest increase reported for winter (by 3% for the near future (2021–2050) and by 12% for the far future (2071 – 2100)). An overall decline in rainfall is projected for the summer with rainfall projected to decrease by approximately 7% for the near future (2021–2050) and by 31 % for the far future (2071–2100).

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 are for a 0.3mm per day increase for the winter months for this groundwater body (13.4% change from baseline). No change to current recharge is indicated for spring. However, a minor 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.

⁴³ <https://map.sepa.org.uk/floodmaps/FloodRisk/FutureFloodMaps/>

⁴⁴ <https://map.sepa.org.uk/floodmaps/FloodRisk/FutureFloodMaps/>

⁴⁵ <https://uk-cri.org/>

Extreme weather event considerations

Extreme weather events have the potential to result in short-term (acute) effects as a result of:

- Extreme precipitation. The CRI record-breaking weather 'wettest months' indicator predicts 0.1 months / year in the near future and 0.4 months / year in the far future.
- Extreme cold weather. The CRI website does not have a record-breaking prediction for extreme cold. The frequency of extreme cold events is not predicted to increase. Therefore, this has not been taken forward in this assessment.
- Extreme heat. The CRI record-breaking 'hottest day' indicator predicts 0.7 days / year in the near future and 6 days / year in the far future.
- Drought. The CRI recording breaking 'hottest month' indicator predicts 0.5 months / year in the near future and 3 months / year in the far future.

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).
- Shafts and unrecorded coal workings (located 250m east of the site).

Potential Pathways*

Potential pathways include:

- Leaching of contamination into groundwater from soil followed by lateral migration of groundwater to the wider groundwater environment via intergranular and fracture flow; and
- Migration of groundwater through preferential pathways such as permeable backfill surrounding utility service trenches.

Potential Receptors*

Potential receptors include:

- Shallow groundwater in the superficial Raised Marine Deposits; and
- Groundwater within the Scottish Lower Coal Measures bedrock aquifer.

*Water environment pathways and receptors only

Preliminary Conceptual Site Model

Table 1 – Preliminary CSM

Potential Sources	Potential Pathways	Potential Receptors	Comments
<ul style="list-style-type: none"> Made Ground of unknown provenance / demolition of previous structures. Chemical releases associated with former site uses including abattoir, mills and chemical works. 	<ul style="list-style-type: none"> Vertical leaching from impacted Made Ground Lateral migration of impacted groundwater derived from on-Site and off-Site sources. 	<ul style="list-style-type: none"> Groundwater within the Raised Marine Deposits Groundwater within the Scottish Lower Coal Measures 	<p>The site has a 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 0.5m 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.</p> <p>Although the Raised Marine Deposits are comprised of clays and silts which are likely to have 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.</p> <p>Due to the distance to the River Clyde, which is located 500m to the south, it is considered likely that dispersal and attenuation would reduce the potential for material impact to this receptor.</p> <p>Under RCP8.5 Climate Change Projections</p> <p><i>Future annual precipitation is not projected to significantly increase from baseline conditions. In addition, winter recharge is considered to be minimal (13% from baseline for the far future). It is therefore judged that future climate change is unlikely to significantly change the risk associated with this pollutant linkage.</i></p> <p>Extreme weather events</p> <p><i>Extreme precipitation coupled with higher rates of precipitation, greater surface run-off due to the proposed hardstanding and increased recharge projected during winter months may increase groundwater levels and potentially cause localised groundwater flooding on a seasonal basis (as a short-term event), particularly in topographically low areas of the site. 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 the underlying groundwater quality and future resource potential. However, the increase in upgradient groundwater recharge will increase groundwater flow beneath the site and thereby the potential for dilution of leaching contaminants. Near surface contamination could be mobilised from unsealed surfaces due to source zone erosion, with overland flow resulting in contaminants entering into drainage and/or migrating off-site.</i></p> <p><i>Extreme cold weather may result in additional recharge following ice/snow melt resulting in mobilising of near surface contaminants via increased leaching and potential overland flow pathways.</i></p> <p><i>Extreme heat and drought events may lead to reduction in the groundwater table, decrease in soil moisture content and desiccation and cracking of near-surface soils, particularly if cohesive. This could make the ground more susceptible for rainfall to infiltrate into made ground soils increasing leaching. However, this is likely to be limited to areas not covered by hardstanding or buildings.</i></p>

Potential Sources	Potential Pathways	Potential Receptors	Comments
<ul style="list-style-type: none"> Made Ground of unknown provenance / demolition of previous structures. Chemical releases associated with former site uses including abattoir, mills and chemical works. 	<ul style="list-style-type: none"> Migration of groundwater through preferential pathways associated with services 	<ul style="list-style-type: none"> Groundwater within the Raised Marine Deposits Groundwater within the Scottish Lower Coal Measures 	<p><i>Groundwater has been reported within 0.5m 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. In addition there is a low lying area of ground which is boggy and has the potential for groundwater flooding. Therefore, subsurface utilities and sewers have the potential to be inundated by groundwater and act as preferential pathways for contaminants affecting off-site water environment receptors, including the River Clyde (via sewers and surface water discharge).</i></p> <p>Under RCP8.5 Climate Change Projections</p> <p><i>Climate change is unlikely to significantly change long-term average groundwater levels underlying the site and as such is unlikely to significantly change this pollutant linkage.</i></p> <p>Extreme weather events</p> <p><i>Increased winter recharge coupled with extreme rainfall events (including ice/snow melt associated with extreme cold) could potentially cause localised groundwater flooding and increase the frequency and likelihood of inundation of utility service trenches, foul sewers or site drainage systems.</i></p> <p><i>Extreme heat and drought events are not considered to influence this contaminant linkage due to the depth of groundwater at the site. A drought will temporarily reduce the infiltration of rainwater to the ground and thereby temporarily reduce leaching of contaminants to groundwater. However, the benefit is marginal and short-lived.</i></p>

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

Potential recommendations to take account of projected climate change conditions:

- Further ground investigation should include continuous groundwater monitoring to characterise the groundwater regime over at least 12 months , particularly in the near-surface deposits, as well as the aquifer response to extreme precipitation events. Specific monitoring should be undertaken within the footprint of the proposed basement.
- The potential for future groundwater flooding should be considered within the future design of the proposed development and drainage strategy.

Example 4: Proposed commercial development in former mining area, central Scotland

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

Site Setting

The site is proposed to be redeveloped as an industrial estate, comprising low rise commercial buildings, car parking and access roads surrounded by areas of soft landscaping.

The nearest surface water is a tributary of the North Calder Water. The watercourse is located adjacent to the site boundary.

The ground conditions comprise made ground over glacial till over strata of the Scottish Middle Coal Measures Formations. The till is typically 5 to 8m thick beneath the majority of the site but is locally thin to absent along the adjacent watercourse. There are also localised thin alluvial deposits along the base of the watercourse.

The area has been previously mined for coal and ironstone. There are known and probable shallow underground mine workings as well as several known mine entries on and near the site.

The made ground ranges in thickness from absent to more than 10m thick, including a former raised deposit (bing) of mining spoil in part of the site. Historical mapping shows a mineral railway and a foundry on the site. Previous ground investigation has shown that the Made Ground comprises reworked natural soils, mining spoil, foundry wastes and slag, and anthropogenic materials relating to former buildings and other structures, including demolition wastes, timber, and metal. The site is currently used for grazing.

The groundwater body is the Glasgow and Motherwell groundwater body (150677). This is classified as having 'poor' status by SEPA. The bedrock aquifer is mapped as a moderately productive aquifer dominated by intergranular and fracture flow. There are also preferential paths through the subsurface associated with the former mine workings.

There are no groundwater abstractions within 1km of the site.

Hydrogeological Model

Made ground is known to be present across most of the site as a result of former mining and historical development. Previous ground investigation has reported areas of shallow, possibly perched, groundwater within the made ground. The shallow groundwater is potentially in hydraulic continuity with the nearby alluvial deposits and the adjacent watercourse.

Run-off across the made ground, particularly the bing, enters the adjacent watercourse directly and indirectly via the shallow groundwater. Run-off causes erosion and transport of particulate matter into the watercourse, where it can be transported downstream and redeposited further down the catchment.

The bedrock aquifer is predominantly capped by glacial till. However, there are preferential flow paths through the till associated with former mine workings. The till is also locally thin or absent beside the watercourse. The groundwater flow direction is towards the watercourse. Post-mining rebound of groundwater levels is understood to have already occurred. There is a mine water

discharge from a mine adit into the nearby watercourse. Changes in redox conditions once the mine water enters the watercourse result in ochreous deposits locally forming on the streambed.

Future Climate Change Under A RCP8.5 Scenario

Sea Level Rise / Coastal Erosion

The site is not near the coast and thus sea level rise is considered unlikely to be a significant factor.

Projected Changes in Flood Risk

The SEPA Flood Risk and Future Flood Mapping⁴⁶ indicates that the lowest part of the site (<10% of total site area) immediately adjacent to the watercourse is classed as being likely to be at low to medium risk from river flooding. Additionally, several parts of the wider site (c.20% of site area) are classed as being likely to be at low to high risk from surface water and small watercourse flooding.

The extent of the site classed as being potentially at risk of flooding is projected to increase marginally (<5%).

Projected Changes in River Flows

The closest river station modelled by the eFLaG⁴⁷ project is on the River Clyde, around 10km west of the site. The modelled far-future (2050-2079) projections for this station suggest that Q30 flows are likely to increase by up to 10% but the Q90 flows are likely to decrease by 40 to 60%. The duration of droughts is expected to double.

Projected Changes in Rainfall

The CRI⁴⁸ projections for annual rainfall suggest there will be a negligible change in annual rainfall (median -0.9%, with a range of -10 to 17%). However, rainfall seasonality is projected to increase, with projected median %change for winter, spring, summer and autumn being 14, 8, -31, and 1% respectively. The frequency and intensity of rainfall events are also expected to increase

Projected Changes to Groundwater Recharge

The eFLaG project far-future (2050-2079) projections for groundwater recharge to this groundwater body are for a 0.3mm per day increase in the winter months. No change from current recharge is indicated for spring, however, a reduction of summer and autumn recharge of 0.1mm per day is projected.

Seasonal changes in recharge, extreme rainfall events, and/or infiltration associated with fluvial and surface flooding are likely to result in temporary increases in shallow groundwater levels.

Increased recharge and any changes in shallow groundwater levels may also increase rates of leaching from the made ground.

⁴⁶ <https://map.sepa.org.uk/floodmaps/FloodRisk/FutureFloodMaps/>

⁴⁷ <https://eip.ceh.ac.uk/hydrology/eflag/>

⁴⁸ <https://uk-cri.org/>

Extreme weather event considerations

Extreme weather has the potential to occur at any site with extremes of precipitation and cold weather more likely to occur in the winter months and extreme heat and drought more likely to occur in the summer months.

Met Office UKCP18 regional projections for a high emissions scenario (RCP8.5) available on the UK CRI website indicate that median extreme weather event indicators for the site area projected to change as follows:

- Extreme precipitation: the wettest month is projected to quadruple from 0.093 months per year (2011-2040) to 0.415 months per year (2071 – 2100). It is therefore considered that there will be an increased likelihood of extreme precipitation, particularly in the winter months, which should be considered further in the CSM.
- Extreme cold weather: Met Office cold weather alerts are projected to decrease from a median of 2.774 events/year (2011-2040) to 0.767 events per year (2071 – 2100). The frequency of frost days ($T_{min} < 0^{\circ}C$) are projected to decrease from 43.194 days/year (2011-2040) to 14.043 days/year (2071 – 2100). This suggests that the site is unlikely to be at an increased risk from extreme cold weather events and as such this has not been considered further in the assessment.
- Extreme heat: the hottest month is projected to increase by an order of magnitude from 0.3 months per year (2011-2040) to 3 months per year by 2100. Met Office heat waves for West Scotland are projected to increase ~5-fold from 0.844 events per year (2011-2040) to 4.344 events per year (2071-2100). The number of very hot days ($T_{max} > 25^{\circ}C$) is projected to increase slightly from 0 days per year (2011-2040) to 0.122 days per year (2071-2100) but this is considered unlikely to significantly influence the CSM.
- Drought: the proportion of time rivers will experience a 2-year drought in West Scotland is projected to decrease overall from 0.014 (2011-2040) to 0.003 (2071-2100) but is projected to increase slightly in the short-term 2021-2050. However, note that the 2-year low river flows are projected to halve by 2100 compared with the baseline (1981-2010). Soil moisture content at the end of the century versus the baseline (1981 – 2010) is projected to increase by 1.151% in winter but decrease by -24.583% in summer. Although the projected change in drought risk may not be significant for the CSM, there is expected to be increased seasonality in water resources in the area.

Potential Sources

Potential sources of contamination include:

On-site

- Made Ground, including mining spoil, foundry wastes and demolition materials
- Historical coal and ironstone mining

Off-site

- Historical coal and ironstone mining

Potential Pathways*

Potential pathways include:

- Leaching of contamination into groundwater followed by lateral migration into surface water as baseflow
- Migration of groundwater through preferential pathways associated with former mine workings
- Erosion of particulate matter by run-off, followed by in-stream transport and downstream redeposition
- Mine water discharges into surface waters

Potential Receptors*

- Shallow groundwater in the Made Ground and Alluvial Deposits
- Groundwater within the bedrock aquifer
- Surface waters, including streambed sediments

* Water Environment pathways and receptors only

Preliminary Conceptual Site Model

Table 1 – Preliminary CSM

Potential Sources	Potential Pathways	Potential Receptors	Comments
Made ground, including mining spoil, foundry wastes and demolition materials	<ul style="list-style-type: none"> Vertical leaching of contaminants within made ground Lateral migration of impacted shallow groundwater, entering surface waters via baseflow 	<ul style="list-style-type: none"> Shallow groundwater Surface waters 	<p>The site has been impacted by former mining (coal and ironstone) and by former foundry and mineral railways. There is made ground across most of the site including a raised bing for mining spoil. The majority of the site will comprise hardstanding cover or buildings once redeveloped which will limit leaching pathways, although leaching may locally occur in areas designated for landscaping.</p> <p>Shallow groundwater is likely to be present within the made ground.</p> <p>There is potential for hydraulic connection between the made ground and the alluvial deposits in the adjacent watercourse.</p> <p>Under RCP8.5 Climate Change Projections</p> <p><i>Future annual mean precipitation is not projected to significantly increase from baseline conditions (0.9% change projected). In addition, change in winter recharge is considered to be minimal (14% from baseline for the far future, equating to a 0.3 mm increase per day over winter months). It is therefore considered that future climate change is unlikely to significantly change the rates of leaching across the majority of the site.</i></p> <p><i>However, the extent of fluvial and surface flooding may increase slightly (<5%) which could locally result in increased leaching and direct discharge of contaminants from made ground to surface water in previously unflooded areas.</i></p> <p><i>Decreases in flows during low flow conditions will reduce the potential for dilution of contaminants via baseflow in surface waters.</i></p> <p>Extreme weather events</p> <p><i>Additional recharge during storm events, coupled with higher winter recharge, and localised infiltration associated with fluvial and surface flooding is likely to temporarily increase shallow groundwater levels. The increased recharge and increase in groundwater levels over winter associated with extreme precipitation may increase leaching and mobility of any contaminant, although this is considered to be on a short term temporary basis. In addition, the effect of this will be tempered by the corresponding increase in upgradient groundwater recharge which will increase groundwater flow beneath the site and thereby the potential for dilution of leaching contaminants.</i></p> <p><i>It is considered unlikely that changes to the frequency and severity of extreme cold events will influence this pollutant linkage</i></p> <p><i>Increased duration of droughts, coupled with decreases in flows during low flow conditions, will reduce the potential for dilution of contaminants via baseflow in surface waters.</i></p> <p><i>Extreme heat is considered unlikely to influence this linkage significantly.</i></p>

Potential Sources	Potential Pathways	Potential Receptors	Comments
Made ground, including mining spoil, foundry wastes and demolition materials	<ul style="list-style-type: none"> Erosion and transport of particulate matter by run-off entering surface waters Transport and redeposition of particulate matter downstream Subsequent Leaching from redeposited materials 	<ul style="list-style-type: none"> Surface waters Shallow groundwater in flood plain downstream 	<p>Run-off across the made ground, particularly the raised bing, causes erosion and transport of contaminants in particulate form.</p> <p>Run-off enters surface waters and then the particulate contaminants are transported downstream.</p> <p>Under RCP8.5 Climate Change Projections</p> <p><i>Increases in flood risk may locally result in increased run-off, erosion and transport of particulate contaminants.</i></p> <p><i>The projected decrease rainfall and increase in temperatures in summer may increase the risk of surface soils and bing drying out seasonally, making them more susceptible to erosion.</i></p> <p>Extreme weather events</p> <p><i>During storm events, run-off increases. Increasing frequency and intensity of storm events is likely to enhance the rates of erosion and transport of particulate matter. Flooding events could also erode and transport particulate matter. Extreme weather or flood events could also result in slope instability of the former bing which could expose and further mobilise contaminants in the event of slumping.</i></p> <p><i>The increased risk of heat waves may increase the risk of surface soils drying out, including those in the bing, making them more susceptible to erosion, particularly in the event of heavy rainfall immediately following a prolonged spell of dry and hot weather.</i></p> <p><i>It is considered unlikely that changes to the frequency and severity of extreme cold events will influence this pollutant linkage.</i></p>
Shallow groundwater impacted by made ground contaminants	<ul style="list-style-type: none"> Vertical migration of contaminants through the till to bedrock aquifer via mine workings Lateral migration of contaminants within the bedrock aquifer 	<ul style="list-style-type: none"> Groundwater within the bedrock aquifer 	<p>Although the till is likely to be low permeability, the presence of mine workings is likely to create preferential pathways through the till.</p> <p>There are preferential pathways within the bedrock aquifer associated with the former mine workings.</p> <p>There is an existing mine water discharge into the adjacent watercourse.</p> <p>Under RCP8.5 Climate Change Projections</p> <p><i>Future annual mean precipitation is not projected to significantly increase from baseline conditions (0.9% change projected). In addition, change in winter recharge is considered to be minimal (14% from baseline for the far future, equating to a 0.3 mm increase per day over winter months). It is therefore considered that future climate change is unlikely to significantly change the risk associated with this pollutant linkage.</i></p> <p>Extreme weather events</p> <p><i>Additional recharge during storm events or localised infiltration associated with fluvial and surface flooding is likely to temporarily increase shallow groundwater levels. The increased recharge and increase in groundwater levels may increase the flow of shallow groundwater to the deeper bedrock aquifer, including via the shallow mine workings.</i></p> <p><i>It is considered unlikely that changes to the frequency and severity of extreme cold, extreme heat or drought events will influence this pollutant linkage.</i></p>

Potential Sources	Potential Pathways	Potential Receptors	Comments
Underground mining (coal and ironstone)	<ul style="list-style-type: none"> • Reaction of minerals within the mine workings coming into contact with groundwater • Lateral migration of mine waters within the bedrock aquifer • Contaminants entering surface water via baseflow where till is thin or absent • Contaminants entering surface waters via existing mine water discharge • Transport and deposition of contaminants downstream 	<ul style="list-style-type: none"> • Groundwater within the bedrock aquifer • Shallow groundwater in alluvial deposits • Surface waters 	<p>Rock-water interactions within the former mine workings mobilises salts and metals.</p> <p>Groundwater flow within the bedrock aquifer is inferred to be towards the watercourse, but may locally be via the shallow groundwater in the alluvial deposits.</p> <p>There are preferential pathways within the bedrock aquifer associated with the former mine workings.</p> <p>There is an existing mine water discharge into the adjacent watercourse.</p> <p>The solubility of the contaminants present in the mine water varies on entry into surface waters owing to change in redox conditions, resulting in ochreous deposits on the streambed.</p> <p>Under RCP8.5 Climate Change Projections</p> <p><i>Future annual mean precipitation is not projected to significantly increase from baseline conditions (0.9% change projected). In addition, change in winter recharge is considered to be minimal (14% from baseline for the far future, equating to a 0.3 mm increase per day over winter months). It is therefore considered that future climate change is unlikely to significantly change the risk to groundwater associated with this pollutant linkage.</i></p> <p><i>Decreases in flows during low flow conditions will reduce the potential for dilution of contaminants via baseflow in surface waters.</i></p> <p>Extreme weather events</p> <p><i>Additional recharge during storm events or due to fluvial flooding, including via preferential flow paths through mine workings, may result in increases in mine water levels and increased flows from the existing mine water discharge. There is also the possibility of the emergence of additional mine water discharges following extreme precipitation events.</i></p> <p><i>The projected decrease in low flows and the increased duration of droughts will mean there is the potential for periods of reduced dilution of baseflow and point source discharges into surface water more often and for longer.</i></p>

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

Potential recommendations to take account for projected climate change conditions:

- Monitoring of groundwater levels, mine water levels and mine water discharge rates on a semi-continuous basis to better characterise the influence of rainfall events and seasonal trends in recharge.
- Potential for increased flooding and temporary increases in shallow groundwater should be taken into account during the construction period as well as in the proposed development design and drainage strategy. This should be accounted for in the design of any infiltration-based SUDS.
- The potential for increased variability in groundwater levels should be taken into account during sensitivity analysis when undertaking DQRA to assess risks to the water environment.
- Potential for increased erosion and transport of particulate matter from the made ground, including the potential for slope instability after extreme weather events, should be taken into account during the construction period for the proposed development, as well as in the landscaping and drainage strategy.
- Potential increases in mine water levels and discharge rates, including the potential emergence of additional mine water discharges, after prolonged or extreme rainfall events, should be accounted for if any subsurface stabilisation of the former mine workings (e.g. grouting) is required.
- Include the projected future reduction in Q90 flows during sensitivity analysis when undertaking DQRA to assess risks to surface waters.