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Coastal impacts of rising groundwater levels scoping study: An Executive Summary

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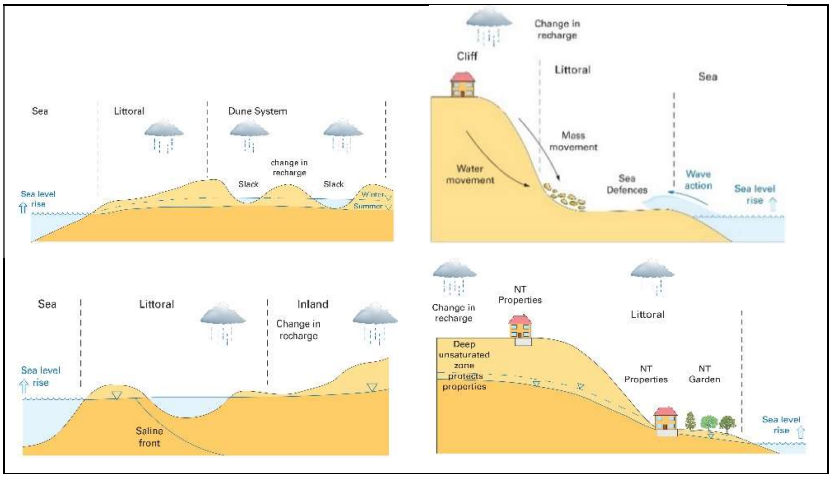

BRITISH GEOLOGICAL SURVEY

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Coastal impacts of rising groundwater levels scoping study: An Executive Summary

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Foreword

This report is the Executive Summary of a study by the British Geological Survey (BGS) in collaboration with the National Trust (NT). This jointly funded scoping project assessed the natural processes of rising groundwater levels and associated impacts within the coastal zone of Great Britain. It was instigated by the NT due to increasing evidence that changes in groundwater levels were having detrimental effects at their properties, gardens, and infrastructure near the coast, such as the demise of flora in coastal gardens due to changes in soil salinity, and flooding of underground structures. The study is also aligned closely with BGS's groundwater, coastal and climate change research.

Important objectives of the project were to enable the establishment of partnerships and identification of funding streams, to be able to carry out the work identified and ultimately produce decision support tools for stakeholders, both within NT and partner organisations. The project provided suggested plans, input datasets and time scales to undertake a full study on the impacts of rising groundwater at the coast, and to construct the recommended tools. This Executive Summary has been produced to support dissemination of the findings and recommendations of the scoping project by summarising them in an accessible and condensed format. Further details and explanations of the projects analysis and conclusions can be found in the main project report CR/20/017 (Harrison *et al*., 2020).

Acknowledgements

A large number of individuals in BGS, National Trust and within partner organisations have contributed to the project, freely giving their knowledge, advice, and providing the local knowledge so important to this study. Of the many individuals who have contributed to the project we would particularly like to thank those that attended the stakeholder workshop at Wallingford in November 2019, and National Trust staff that provided information on site impacts via telephone conversations during autumn 2019.

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Summary

This report provides a summary of the natural processes of rising groundwater within the coastal zone of Great Britain (GB), and associated impacts that potentially may be relevant to the NT.

This study had 3 key objectives:

1. Enhance the ability to understand where and to what extent rising Groundwater and changes in salinity will impact on NT coastal properties (built and natural), and inform management plans.
2. Demonstrate the Trust's ability to show leadership on flood and coastal erosion risk management.
3. Lead to establishing a collaborative partnership to undertake a full study on the impacts of rising groundwater at the coast.

The study met these objectives by providing:

1. A summary of factors and processes effecting groundwater at the coast.
2. An assessment of the impacts of these factors and processes.
3. Suggesting a potential strategic scale product interpreting complex research and modelling to provide GIS datasets and a range of options for delivery of these datasets, including costings and timelines.

Based on the project findings, stakeholder feedback and data accessibility, it is proposed that future work priorities are Options 1 and 2, as detailed in Section 5. Further options are also identified to build upon and strengthen these initial 2.

Based on this, the next stage should be building collaborations and identifying funding opportunities, as detailed in the report.

1 Project aims

The project was a collaborative BGS and National Trust scoping project, which assessed the controlling processes of rising groundwater levels within the coastal zone of Great Britain, and the associated impacts. In the project report, Harrison *et al*. (2020), presented methodologies to identify areas that are susceptible to future changes in groundwater, and proposed tools to provide data in usable formats, enabling informed decision-making for management practices and policies.

This Executive Summary has been written to support dissemination of the main findings and recommendations of the scoping project by summarising them in an accessible and condensed format. It highlights the influencing factors and processes on groundwater movement near the coast, the potential impacts of these and introduces the four Conceptual Impact Models developed. Lastly, it provides an outline of the recommended decision support tools, priorities within these and suggests next steps towards collaboration and identifying funding streams.

2 Influencing factors, processes, and potential impacts

A holistic understanding of the processes and controlling factors of groundwater movement in the coastal zone, and consequently salinity, is essential before an understanding of the impacts of variations in these, due to a changing climate, can be developed. Figure 1 illustrates the key mechanisms identified.

Groundwater flooding in coastal aquifers is caused by increased recharge values, such as rainfall, leading to the rise of the water table and the emergence of groundwater on the ground surface. The flow regime is the dominant factor that controls groundwater flooding. For saline intrusion, in addition to the flow regime in the aquifer, additional factors controlling the mechanisms that govern seawater intrusion are the variable density between the freshwater and seawater, and hydrodynamic dispersion, driven by changes in sea-level.

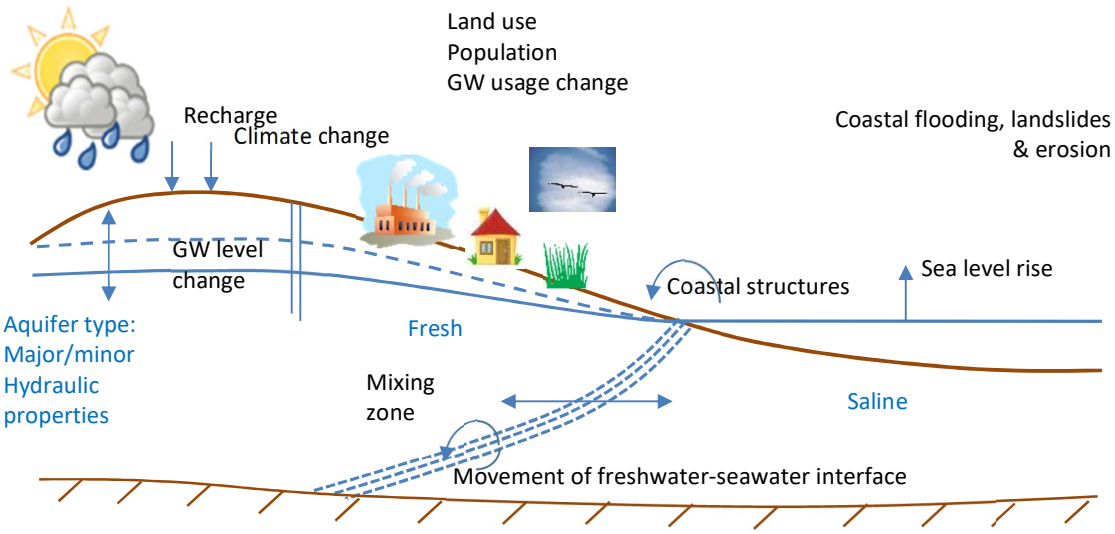

Figure 1 Illustration of the different mechanisms controlling groundwater flooding and saline intrusion.

In order to understand the likely impacts of variations in coastal groundwater levels, there is a need to consider quantity (flow related to groundwater head) as well as quality (increasing salinity) and how the two processes operating at the coast, could combine. Sea-levels are anticipated to rise in the coming century (Lowe *et al.,* 2018). In contrast, a projected increased chance of hotter drier summers and milder wetter winters, with an increase in the frequency and intensity of extremes, and variations in groundwater abstraction, could result in increased fluctuations in groundwater recharge, leading to increased variations in groundwater outflow. It is therefore likely, that salinity will move inland, combining with rising groundwater levels to impact shallow sub-surface and structures in a greater way.

If these expected processes occur, impacts could be seen in the natural and built environment. For example, in the natural environment, flora & fauna (water logging, soil salinity, soil structure, and shift in plant species and / or habitat types); wetlands and lagoons (displacement of freshwater, modification of habitats soil structure) and dune slacks: (groundwater recharge and land cover change). In the built environment, impacts may be seen in agriculture & land drainage (irrigation salinity), public water supply (salinity), landfill & industrial sites (mobilise contaminants), people and transport (access, infrastructure issues), utilities & infrastructure (power, telephone gas supply and water treatment works) and historic buildings, landscapes and gardens (degradation).

3 Conceptual Impact Models

To support development of a succinct understanding of the impacts of changing groundwater levels near the coast, the project developed conceptual impact models. Together they highlight the key physical processes and future climate variations to be considered. They identify the main dynamic components of a system (groundwater, geological, ecological) and model their response to a range of variables, such as rainfall and temperature. Four conceptual impact models have been developed and are outlined below.

3.1 CONCEPTUAL IMPACT MODEL 1: GROUNDWATER CHANGE: IMPACT ON ANTHROPOGENIC DEVELOPMENT

Historic houses and their gardens plus Scheduled Ancient Monuments can be vulnerable to saline intrusion and groundwater flooding, particularly in low-lying areas close to the sea, as seen at Alfriston Clergy House. The groundwater table can be located at or close to the surface and impact sub-surface structures, resulting in the salinization and/or water logging of soils (e.g. Mount Stewart, NI). The former can impact basements or other underground structures, such as weakening of certain foundations, such as concrete, due to Physical Salt Attack (PSA). The latter can affect gardens, particularly highly-managed ones, for example the Sea Plantation, Mount Stewart.

Changes in groundwater outflow resulting from variations in recharge could result in movement of the freshwater-saltwater interface; a decrease in outflow can lead it encroaching further inland, increasing the salinity of the local groundwater. Alternatively, increasing recharge and groundwater throughflow will reduce salinity. However, rising sea-levels combined with increased recharge can raise the water table, causing problems to both underground structures and ornamental gardens.

Place in the landscape, and elevation, can offer protection from groundwater flooding (Figure 2). For example, historic houses on hillsides, despite being close to the coast, can be protected from groundwater issues due to the depth to the groundwater table and thickness of the unsaturated zone.

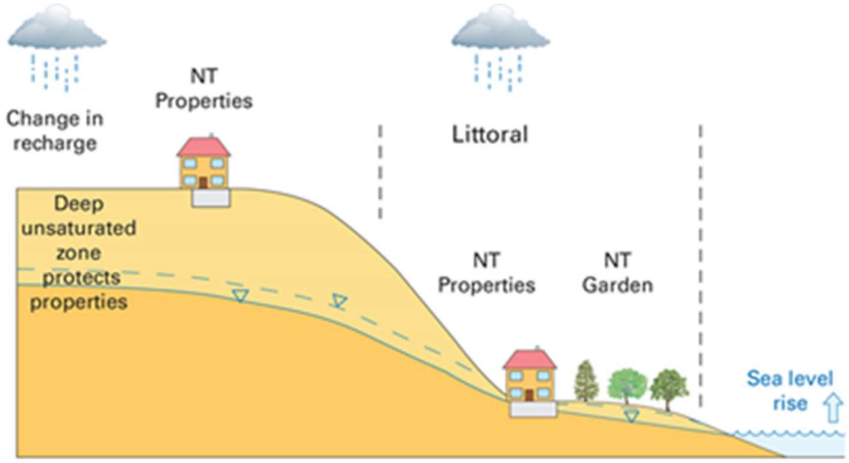

Figure 2 Conceptual Impact Model 1

3.2 CONCEPTUAL IMPACT MODEL 2: GROUNDWATER CHANGE: IMPACT ON NATURAL ECOSYSTEMS

Natural coastal ecosystems are reliant on the seasonal changes to groundwater levels. For example, dune slacks are formed due to variations in groundwater levels which lead to the formation of ephemeral ponds or slacks (Figure 3). These slacks provide important habitats, such as breeding locations for Natterjack toads, a European Protected Species (EPS). Their transient nature means their occurrence is highly-dependent on the response of the water table to seasonal recharge, and changes in climate.

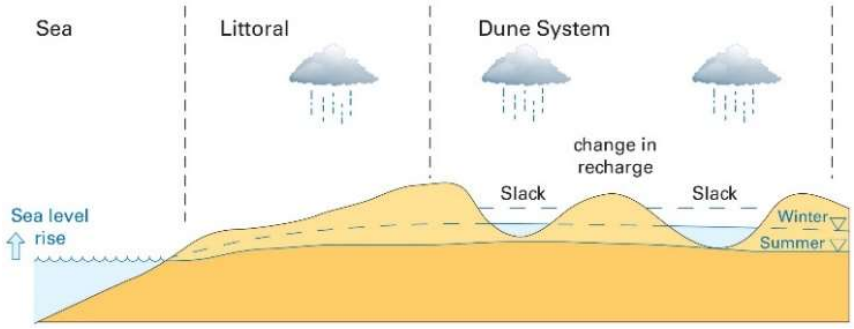

Figure 3 Conceptual Impact Model 2

3.3 CONCEPTUAL IMPACT MODEL 3: GROUNDWATER CHANGE: IMPACT ON COASTAL CHANGE

Coastal cliffs can become unstable and instability can be exacerbated by two processes (Figure 4): Increased rainfall leading to greater through-flow of water (within permeable deposits) and increased pore pressures, increases the likelihood of mass movement (particularly if the cliffs are multi layered and heterogeneous) and slope instability. Examples of this behaviour can be found at Porth y Swnt. Additionally, wave action at the base of cliffs can remove material causing over-steepening of the slope and exacerbate instability. Sea Level Rise combined with increased wave energy could result in greater likelihood for this to occur.

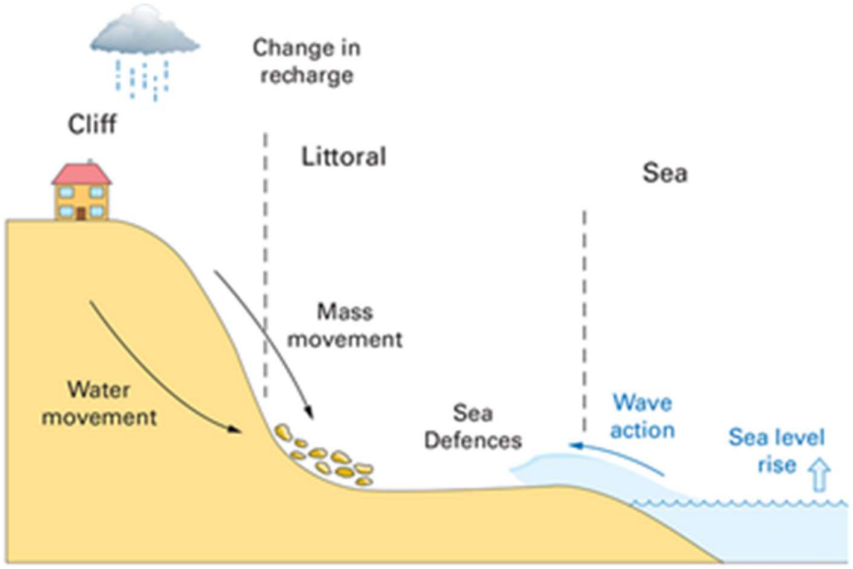

Figure 4 Conceptual Impact Model 3

3.4 CONCEPTUAL IMPACT MODEL 4: SALINE INTRUSION: IMPACT ON NATURAL ECOSYSTEMS

The ecological important brackish or saline ponds close to the sea are small-scale features and are typically fed by groundwater recharge or saline waters. The chemical quality of the lagoons is vitally important, with different flora and fauna sensitive to different water qualities. These ponds are typically fed by groundwater recharge or by tidal saline incursion. They depend on the balance of groundwater recharge and sea water intrusion to generate the correct chemistry (e.g. Stackpole Lakes). Sea-level rise, or a reduction of groundwater outflow resulting from lower recharge could increase the salinity of the lagoon. Alternatively, increasing recharge and groundwater through-flow may reduce the salinity of the pond.

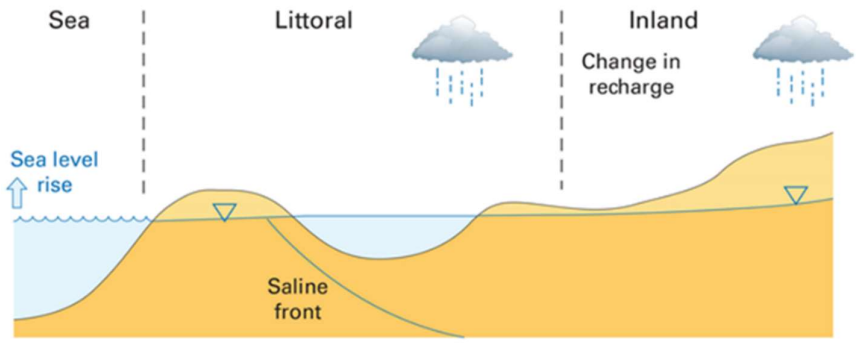

Figure 5 Conceptual Impact Model 4

4 Stakeholder consultation

Stakeholder consultation was undertaken throughout the project to understand current information available, levels of knowledge and concerns, issues seen on site, and user requirements. A project stakeholder event was held in November 2019, and stakeholders from industry, government and academia attended. To meet the various stakeholder's needs, 2 decision support tools are proposed, as well as supporting research and tasks.

5 Decision Support tools

5.1 OPTION 1: A GIS FOR INTERNAL ORGANISATIONAL USE (NATIONAL TRUST AND PARTNER ORGANISATIONS)

The aim at all scales will be to provide a “traffic light” (red/amber/green or high/medium/low susceptibility) screening that can be used to inform users of the potential for impacts to an asset, highlighting a requirement for additional site assessment or management to establish the potential risk.

It will incorporate climate change projections, including sea level rise projections, coastal vulnerability data and information on anthropogenic activities. It will provide groundwater quantity model projections (groundwater flooding) and groundwater quality model projections (changes in salinity). An example of a similar dataset, incorporating climate change scenarios, is BGS GeoClimateUKCP09 clay shrink-swell (https://www.bgs.ac.uk/geoindex/).

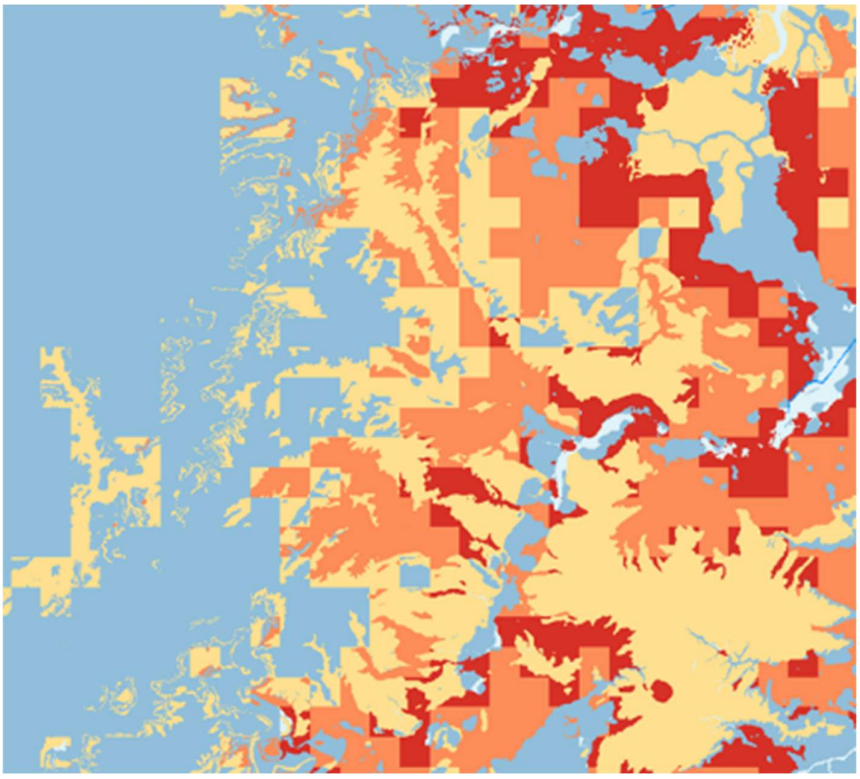

Figure 6 The BGS GeoClimate Open product: An example of a dataset integrating climate change scenarios

5.2 OPTION 2: DECISION SUPPORT TOOL 2: PUBLIC FACING (ONLINE PLATFORM)

This is an online, public-facing solution that will collate and make accessible a large range of open data from various organisations, as well as temporal streamed data. This platform would support data sharing and integration, stakeholder’s engagement actions and ease communication with the public.

Functionality features should include the ability to view a range of map layers. It should also be possible to obtain details of data sources that can be accessed/downloaded and brought into other environments to undertake further analysis e.g. downloaded or accessed via a web service into a GIS or statistical package. It should also include a slider bar to view different timescales or different climate scenarios.

5.3 OPTION 3: CROWDSOURCING AND APP DEVELOPMENT

This option would utilise citizen science functionality to submit observations such as hazards, flora, fauna, and interact with submissions provided by other users. It would allow members of the public or other organisations to collect and input large amounts of data, providing valuable results if used appropriately. Its targeted users would be the National Trust and partner organisation staff who collect data as part of their day-to day tasks and maintenance regimes, as well as external users such as the general public, NT visitors or local authorities. An example of similar crowdsourcing is the BGS My Soil app (https://www.bgs.ac.uk/mySoil/).

Additionally, an app could be developed to support fieldwork and site management allowing access to data and maps whilst on-site, similar to iGeology (https://www.bgs.ac.uk/iGeology/).

5.4 OPTION 4: CASE STUDY SITE MONITORING

This monitoring, of a number of key case study sites (4 – 8 sites), would refine scientific understanding and interpretation. The instrumentation and data collection could include installation of boreholes, monitoring of water chemistry/salinity and laboratory analysis. New data and knowledge resulting from this work would ground-truth conceptual models and ultimately feed into the groundwater modelling methodologies, enabling refinement and update.

5.5 OPTION 5: META MODELLING

Four conceptual models have been developed, each representing a site type. These could be encapsulated into generic, site-based models and scenarios and developed to understand how changes to sea level and recharge affect groundwater level and salinity.

6 Conclusions and Recommendations

This collaborative project enabled a first-of-its-kind holistic study of the main factors and processes controlling groundwater movement in the coastal zone, to develop an understanding of the impacts of changes in climate on surface and sub-surface infrastructure near the coast. It proposes GIS based tools to support decision making in the coastal zone, that enables the most relevant and up-to-date research and projections to be taken into consideration.

The scoping study provided valuable insight into the range of stakeholders and highlighted their broad scope of requirements, as well as how they would like to view and access hazard susceptibility data within the proposed tools. This has informed the identification of priority datasets and decision support tool design, as detailed below.

The study proposes that future work should have the following priorities:

Priority 1: *Options 1 & 2*: The provision of initial summary datasets in GIS format for both internal NT users and partner organisations, alongside the public-facing web-based GIS.

Priority 2: *Option 3*: Building on Options 1 & 2 to provide crowdsourcing functionality and appropriate apps to improve usability. This work can run in parallel to Options 1 & 2.

Priority 3: *Options 4 & 5*: Monitoring of NT sites and data collection to provide evidence of the impacts of climate change, and meta-modelling to refine understanding of processes and impacts at type sites.

Priorities 2 and 3 could run in parallel to the higher priority tasks, or at a later date to enable output refinement.

6.1 NEXT STEPS TOWARDS A COLLABORATIVE MULTI-PARTNER PROJECT

6.1.1 Build collaborations

A broad range of research and datasets have been identified from academia, government organisations and commercial industries. The key partners emerging that could bring valuable input are identified.

6.1.2 Monitor potential funding streams identified and scan for new opportunities to take this work forward.

Potential funding streams were identified during the project and during the stakeholder workshop, where the wider implications of this research to so many sectors previously unconsidered was discussed. Those recognised during the workshop included farming, communities and commercial. New opportunities will arise over time, key existing streams include:

- UKRI Landscape Decisions
- Arts and Humanities Research Council (AHRC)
- Flood and Coastal Erosion Risk Management Research and Development Programme (FCERM)

Glossary

Aquifer A rock formation that is sufficiently porous and permeable to yield a significant quantity of water to a borehole, well or spring. The aquifer may be unconfined beneath a standing water table, or confined by an impermeable or weakly permeable horizon.

Clearwater flooding A form of groundwater flooding caused by the water table in an unconfined aquifer rising above the land surface in response to extreme rainfall.

Geological model A geological model is a spatial representation of the distribution of sediments and rocks in the subsurface.

Groundwater flooding Groundwater flooding is the emergence of groundwater at the ground surface or the rising of groundwater into man-made ground, through natural processes, under conditions where the 'normal' range of groundwater levels and groundwater flows are exceeded.

Permeability The ability of a fluid, like water or oil, to pass from one pore space to another. Substances that allow water to pass through them are called 'permeable'.

Recharge The quantity of water that is added to a groundwater reservoir from areally distributed sources such as the direct infiltration of rainfall or leakage from an adjacent formation or from a watercourse crossing the aquifer.

Saline intrusion The entry of sea water into a coastal aquifer. It may be caused by over pumping fresh water from the aquifer or insufficient natural head on the fresh water aquifer. Sea water is denser than fresh water and it may form a wedge beneath the fresh water adjacent to the coast.

Shoreline Management Plans A large-scale assessment of the risks associated with coastal processes and helps reduce these risks to people and the developed, historic and natural environments.

UKCP09 UK Climate Projections 2009 allow users to access information on plausible changes in 21st century climate for the United Kingdom. It provided future climate projections for land and marine regions as well as observed (past) climate data for the UK. It was superseded by UKCP18 in 2018.

UKCP18 UK Climate Projections 2018 provides probabilistic projections over land and provides a set of high-resolution spatially-coherent future climate projections for the globe at 60km scale and for the UK at 12 km scale. It uses cutting-edge climate science to provide updated observations and climate change projections out to 2100 in the UK and globally. The project builds upon UKCP09 to provide the most up-to-date assessment of how the climate of the UK may change over the 21st century.

Water Table The surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere. The static water level in a well in an unconfined aquifer.

References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: https://envirolib.apps.nerc.ac.uk/olibcgi.

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