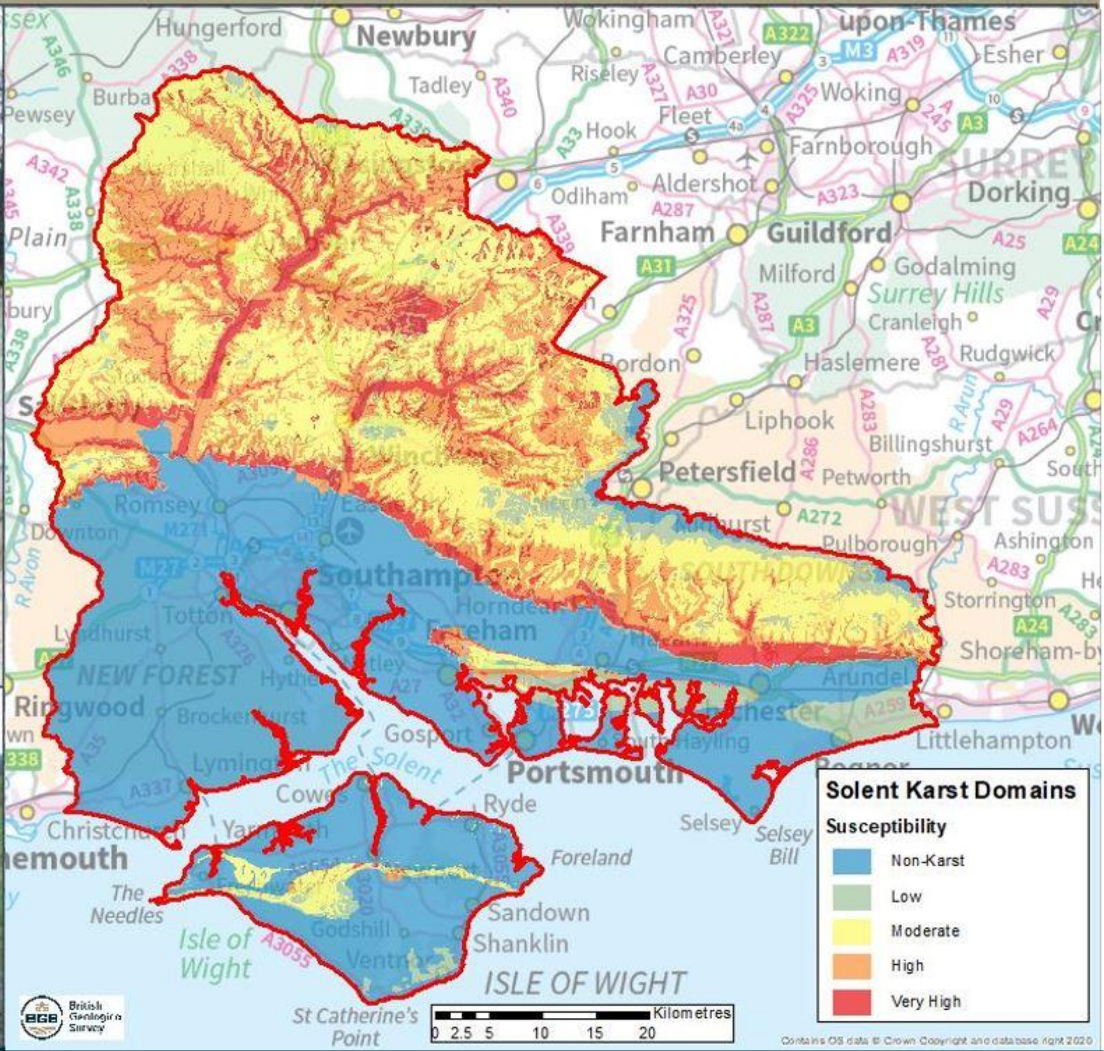

NATIONAL PROGRAMME

User Guide: BGS Conceptual Domains for Rapid Karstic Groundwater Flow in the Unsaturated Zone Dataset

Open report OR/22/031

British Geological Survey

BRITISH GEOLOGICAL SURVEY

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Keywords

Karst, groundwater, Chalk, unsaturated zone, recharge, bypass flow, catchment management, Solent, GIS, domains..

Front cover

Top left – Solution pipe in chalk, Marlborough.

Bottom left – Stream sink in chalk, Pang Catchment, Berkshire

Right – Map showing the Conceptual Domains for Rapid Karstic Groundwater Flow in the Unsaturated Zone Dataset

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1 Introduction

There is now substantial evidence that the Chalk aquifer is impacted by karst (Maurice et al., 2021; Foley and Worthington, 2021; Farrant et al. 2021a,b). It is well known that in karst aquifers solutional development results in high vulnerability to pollution with the potential for rapid groundwater flow and long-distance pollutant transport. Karstic solutional development in the Chalk can lead to rapid groundwater flow through the unsaturated zone enabling the transport of pollutants from the surface to the saturated zone. In 2022 the British Geological Survey were commissioned by the Environment Agency to develop spatial domains using Geographical Information System (GIS) polygons that reflect the likelihood of rapid flow pathways within the unsaturated zone. This project was part of the wider Solent Shared Outcome Fund Project led by DEFRA to develop and test a land use change trading platform to help farmers and landowners manage their land better to reduce the potential for groundwater contamination. The Environment Agency are leading the mapping and modelling work stream of this project, which includes developing understanding of groundwater pathways and nitrate transport within the Solent catchment. The BGS part of the project led to the creation of four karst domains that range from a low to a very high likelihood that some fully connected rapid flowpaths are present in the unsaturated zone. The detailed methodology developed by BGS to create these domains is reported in Cullen-Gow et al. (2021), held by the Environment Agency. The aim of the current report is to provide some background on these domains and the factors used to create them, and further information on how they should be used and interpreted.

2 Project Area

The study area (Figure 1) comprises the Solent catchment with extension eastwards to include the groundwater bodies of the Itchen, Chichester Chalk, Littlehampton anticline and the Sussex Lambeth group, finishing at the Arun in the East. Further information on karst in this area can be found in the BGS karst knowledge exchange reports for the Chalk of the Isle of Wight (Maurice et al., 2022a) and the South Downs (Maurice et al., 2022b), and in the paper on caves and karst of East Sussex by Farrant et al., (2021a), with additional information on caves in Reeve (2021).

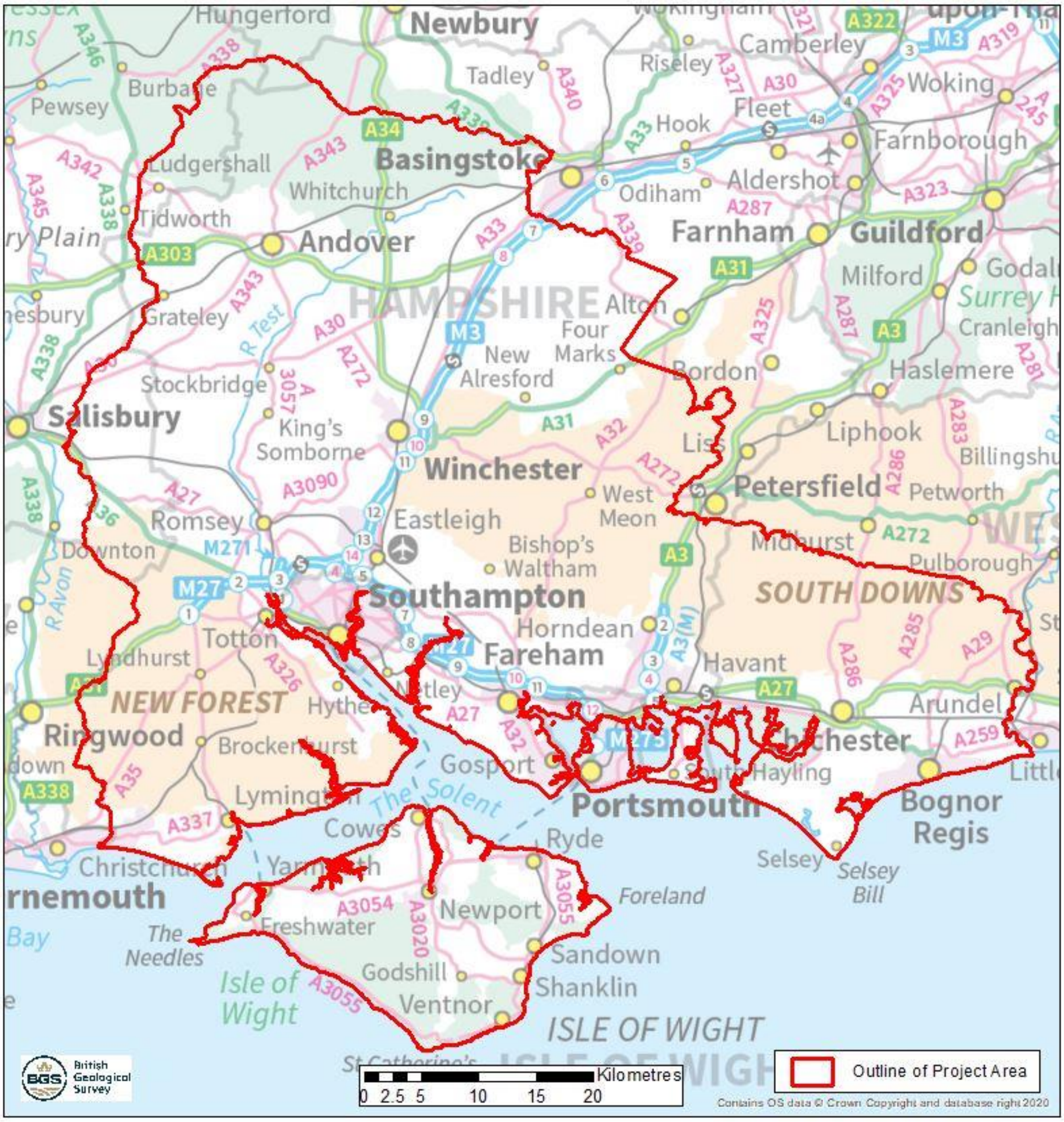

Figure 1 - Solent Karst Project Area

3 Background

It is well established that there are different mechanisms of recharge to the Chalk aquifer with much of the flow in the unsaturated zone thought to be via a piston flow mechanism through the Chalk matrix, taking place over many decades (Smith, 1970; Price 1987; Price et al., 1993). There are multiple strands of evidence to suggest that these unsaturated zone flowrates are about 1 metre per year, and the different types of studies that have shown this are outlined in Maurice et al. (2021). It has also long been known that a proportion of recharge to the Chalk occurs via “bypass flow” through solutional features in the Chalk that enable rapid flow through the unsaturated zone (Smith, 1970; Price et al., 1993). This rapid unsaturated zone flow is thought to be activated following heavy or persistent rainfall (Price et al., 1993; Ireson and Butler, 2011), with the solutional features likely to be unsaturated during dry periods. The study by Smith et al. (1970) suggested that about 15% of recharge to the Chalk is via bypass flow based on studies of tritium. However, the proportion of bypass recharge is likely to be quite variable (Maurice et al., 2021), and is generally poorly known at local/catchment scales. Early discussions on bypass recharge in the Chalk did not consider the karstic mechanisms that produce the solutional voids that enable it, and hence the likely spatial variability in bypass flow.

Where karst stream sinks are present there is likely to be a higher proportion of bypass flow because there is a large volume of water directly recharging the Chalk, and because karst stream sinks are likely to be feeding into well-developed conduit networks (Maurice et al., 2021;2022b). Such well-developed karstic cavities are also likely where stream sinks occurred in the geological past (Maurice et al., 2006). However solutional fissure pathways through the unsaturated zone also occur away from surface karst stream sinks, as observed in quarries and coastal cliffs (Farrant et al., 2021a,b); and as shown by tracer tests from arbitrary points on the surface demonstrating rapid unsaturated zone flow (e.g. Allshorn et al., 2007). The locations of these solutional fissures are usually unknown, although where anthropogenic drainage has a high infiltration rate into the Chalk these may be indicative of karstic solutional fissures in the unsaturated zone, as it is unlikely that the unmodified fracture network would have the capacity to take such flows, although the threshold infiltration rate for unmodified fractures versus solutional fissures is not known (Maurice et al., 2022).

As in all karst aquifers, contaminant transport in the unsaturated zone of the Chalk is rapid where bypass flow is occurring, but there appears to be a considerably higher degree of attenuation than in more classic karst (Maurice et al., 2021). This may be due to both diffusion between solutional voids and the matrix/unmodified fracture network; and also, through dispersion where the solutional networks are less well developed. However, there still remain considerable uncertainties about the proportions of unsaturated zone flow in the different types of voids within the Chalk (the bedrock matrix, the unmodified fracture network, solutionally enlarge fissures, and the larger cavities and conduits), and how this varies spatially (Maurice et al., 2021). The unsaturated zone karst domains developed for this project reflect the current understanding of where bypass flow is more or less likely to occur based on our current conceptual understanding of karst in the Chalk.

4 Methodology

The Conceptual Domains for Rapid Karstic Groundwater Flow in the Unsaturated Zone Dataset have been developed in GIS using BGS datasets. Six factors were used in the development of the domains. These factors are (1) the location of karstic stream sinks; (2) areas of Palaeogene runoff from Palaeogene strata; (3) the BGS GeoSure (soluble rocks) dataset; (4) designated 'Karst Zones'; (5) unsaturated zone thickness; and (6) geological strata with tendency for vertical fissure development. The 6 input layers were analysed, processed and combined using a Geographical Information System (GIS) to produce the final dataset. The GIS methodology was carried out using ESRI ArcMap 10.7.1 with the Spatial Analyst extension.

Datasets on dolines and dissolution pipes have not been used to determine the karst domains. Over time it has become apparent that many surface depressions that were initially thought to be karst dolines are more likely to be pits of anthropogenic origin (Farrant et al., 2021a,b). It is also often very difficult to determine whether a surface depression is karstic or anthropogenic in origin, and therefore surface depression datasets are not necessarily a reliable indicator of karst. The spatial distribution and density of dissolution pipes noted in the various datasets often reflect the areas where there is good exposure or ground investigations have been undertaken, rather than the true spatial distribution. Where they are well exposed, the data suggests that in certain geological settings they are dense and ubiquitous. It was considered best to use the karst zones and the GeoSure datasets as the inputs into the karst domains rather than the data on dolines and dissolution pipes in order to avoid biases based on data availability and difficulties in identifying dolines. Consequently, surface depressions and dissolution pipes were not used in the development of the karst domains in this project.

Four karst domains were created to reflect areas that ranged from low to very high likelihood of the presence of some rapid flowpaths in the unsaturated zone, and these domains are described in Section 5.2. The following factors were used in the creation of the domains:

4.1 STREAM SINKS AND CATCHMENTS

Where there is direct point recharge to the Chalk with a reasonable flow of water entering the ground over a sustained period of time, then this water is likely to be feeding into karstic solutional features in the unsaturated zone. There are three main types of point recharge.

The first is karst stream sinks associated with runoff from low permeability cover adjacent to the Chalk, typically Palaeogene sand and clay (e.g. Figure 2). This type of point recharge is associated with well-developed karst, and there will be significant cavities and conduits in the unsaturated zone associated with these surface karst features. Therefore, the locations of stream sinks and their catchment areas were an important input factor to the domains.

Point recharge into karstic solutional fissures and conduits can also occur where rivers crossing outcrop Chalk have substantial losses through their riverbed. The third type of point recharge is via anthropogenic drainage (e.g. soakaways); and these may be indicative of karstic solutional fissures in the unsaturated zone where they have high infiltration rates to the Chalk, as discussed above. Good datasets on point recharge through chalk riverbeds or from anthropogenic drainage are not currently available and therefore these factors could not be used in the domains model. However, where there is local evidence of such features they and their catchments should be considered as falling within the “very high likelihood of rapid unsaturated zone flow category” even if they fall within a lower scoring domain in the current model.

Figure 2 - Examples of karst stream sinks in the Chalk (Pang catchment, Berkshire)

4.2 PALAEOGENE RUNOFF

Along the edge of the chalk outcrop, there are areas where runoff from adjacent, topographically higher, low permeability Palaeogene deposits is likely to enter the Chalk. In some areas, as discussed above, the runoff will be via well-defined stream sinks. However, there are other areas outside the calculated stream sink catchment areas where surface runoff is still likely to enter the chalk. This may be where the stream sink dataset is incomplete, for example where the sinks are obscured or not visible, or where recharge is through the thin feather edge of the Palaeogene deposits, which may be locally more permeable, without generating streams. In these areas, the recharge may not be via discrete sinks but seeping through the basal Palaeogene, and then feeding into solutionally widened fractures and conduits in the underlying Chalk. There are also areas where the Palaeogene is not likely to contribute recharge to the Chalk, for example where the edge of the Palaeogene is topographically lower than the adjacent chalk.

A manually digitised set of polygons, clipped to the Chalk-Palaeogene margin, was used to identify those areas of the Palaeogene outcrop that are likely to drain onto the Chalk away from discrete stream sinks. This also includes a small area of the Lower Greensand on the Isle of Wight. These were based on topographical and geological maps and expert knowledge.

4.3 GEOSURE

The GeoSure dataset is a GIS layer of subsidence risk due to karst, that was developed by the BGS for assessing surface engineering hazards (Farrant and Cooper, 2008). This layer gives a useful indication of where surface karst is likely to occur, and hence where there are more likely to be karstic solutional networks in the unsaturated zone.

4.4 KARST ZONES

The concept of “Karst Zones” was originally developed by Maurice et al. (2006) for the Pang and Lambourn catchments in Berkshire, using the BGS karst database as a guide. Three broad zones were defined (Figure 3). Karst Zone 1 was the area around the Chalk-Palaeogene margin where stream sinks are common. Karst Zone 2 was the area associated with the Clay-with-Flints which is the area from which the Palaeogene has most recently been eroded. This area is associated with many buried dolines. These are sediment filled dissolution pipes with no surface expression. Surface depressions are common, but it is important to note that many surface depressions may be of anthropogenic rather than karstic origin, and hence it is likely that many of the point localities identified on Figure 3 may not actually be dolines. Stream sinks are absent. Karst Zone 3 is the area furthest from the Chalk-Palaeogene margin where stream sinks are absent and dolines are rare. It was postulated that the prevalence of subsurface karst would reflect these patterns, with the most subsurface karst development in Karst Zone 1 and the least in Karst Zone 3. More recent work has demonstrated that although there is more evidence for karst in association with the Chalk-Palaeogene margin, and it is likely that there is more karstic development in Karst Zone 2, there is also considerable evidence for karst, especially in the saturated zone, in areas more than 5 km away from the Chalk-Palaeogene margin (Maurice et al., 2021), in areas classed as Karst Zone 3. Areas away from the Chalk or the Bembridge Limestone were deemed as non-karstic.

The concept of karst zones was modified in a project undertaken at BGS for South East Water in 2021. For this project, karst zones were identified to provide a more detailed assessment of where near surface karst dissolution features (stream sinks and dolines/dissolution pipes) are most likely to occur. Figure 4 shows an example of this from the Eastbourne and Seaford area of the South Downs from Farrant et al. (2021a). In this example, the karst zones were digitised manually using topography, geomorphology and geology as a guide. In the current project the karst zones have been used in this way to reflect specific areas where surface karst features are likely to be present.

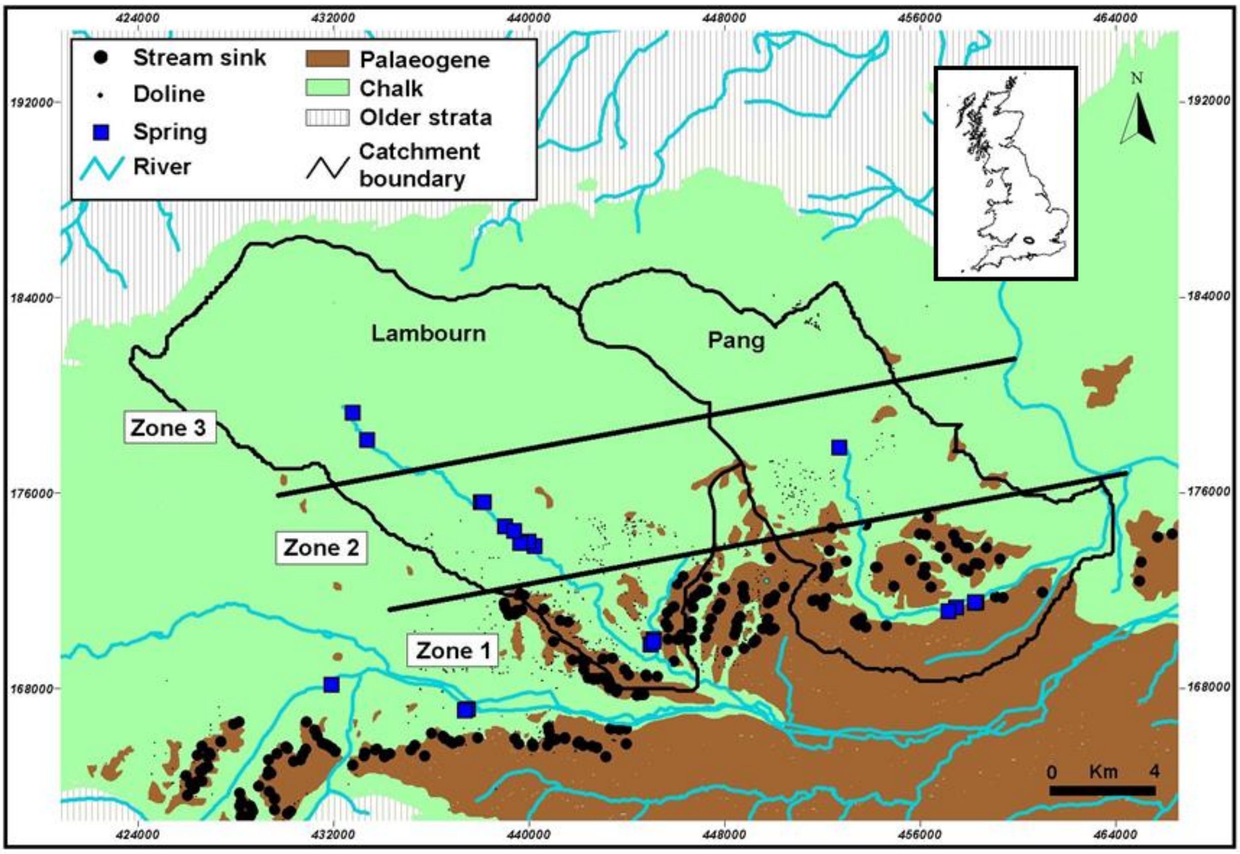

Figure 3 - Karst Zones from Maurice et al. (2006)

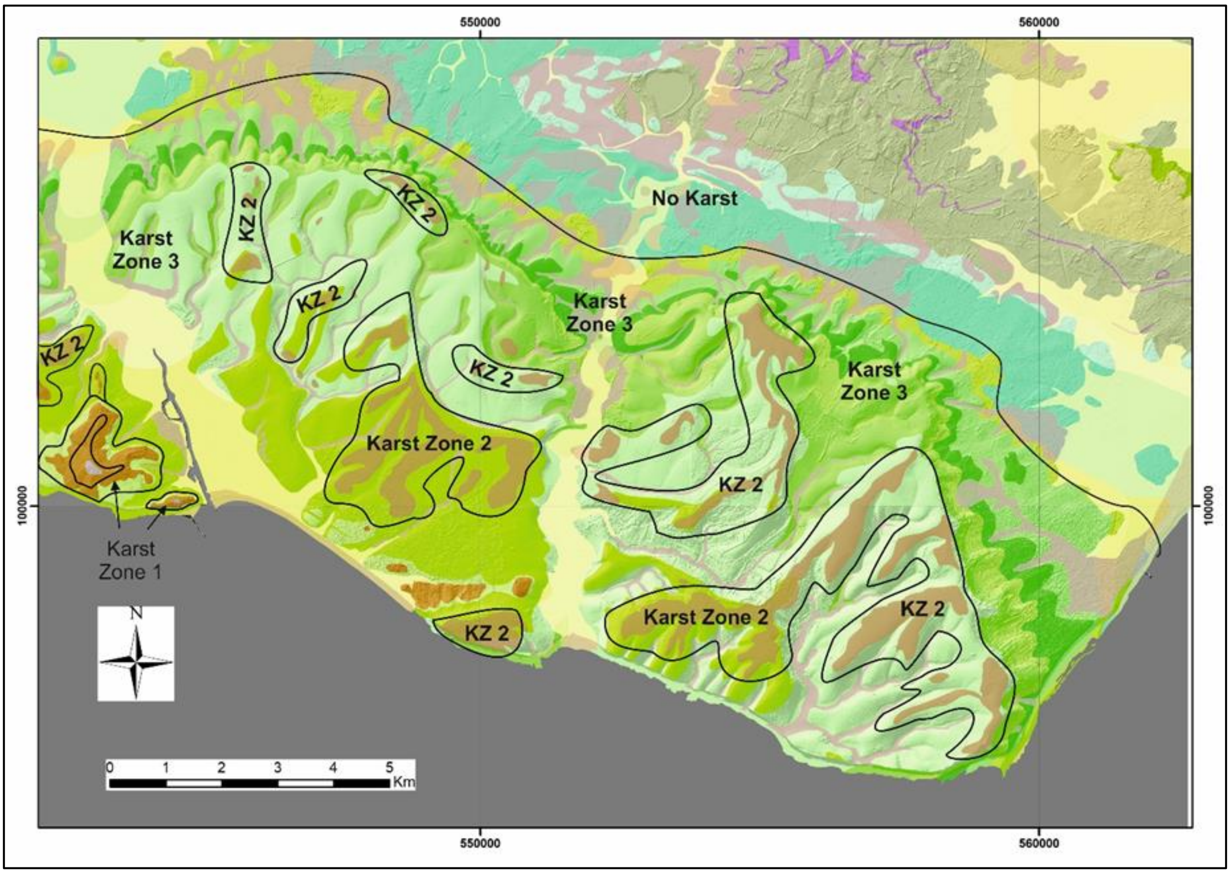

Figure 4 - Karst Zones in the Eastbourne area from Farrant et al (2021a)

4.5 UNSATURATED ZONE THICKNESS

The thickness of the unsaturated zone is an important factor in determining the likelihood of pollutants at the surface reaching the saturated zone. Where there is a thick unsaturated zone it is less likely that there will be fully connected networks of solutional fissures and conduits between the surface and the saturated zone. Unsaturated zone thickness was therefore used as a factor in the development of the unsaturated zone karst domains. It should be noted that the BGS Depth to Groundwater dataset was used as a proxy for unsaturated zone thickness, and this dataset generally represents low groundwater levels (and hence indicates thicker unsaturated zones than occur under high water level conditions). There may be some areas that have large water level fluctuations, where there may be a much thinner unsaturated zone under high water table conditions, and this is not captured in the domain's methodology.

4.6 CHALK LITHOSTRATIGRAPHY

The Chalk lithology has an influence on the propensity for karst features, with some units being more prone to karstic conduit development than others. In general, the lower Grey Chalk Subgroup (West Melbury Marly Chalk and Zig Zag Chalk formations) has fewer karst features due to the more clay-rich marly nature of the deposit. The White Chalk subgroup is less marly and contain particular stratigraphical horizons that are conducive to conduit formation, in particular sheet flints, marl seams and hardgrounds. The harder nodular chalks (Lewes Nodular Chalk and Holywell Nodular Chalk formations) are likely to have more open fractures. Fracture style is also important. Those parts of the sequence with common marl seams (New Pit Chalk, Lewes Nodular Chalk and Newhaven Chalk formations) are characterised by conjugate fracture sets, whilst the Seaford Chalk has more vertical joint sets.

Coastal surveys (e.g. Farrant et al., 2021a) have revealed that some Chalk stratigraphical units have a greater propensity for vertical solutional development than others. For example, vertical fissures are common in the Seaford Chalk and in the upper Lewes Nodular Chalk. These can extend vertically over 95 m (Figure 5) and often have evidence of dissolution and sediment infill. These fractures link up quasi-horizontal conduits developed along stratigraphical inception horizons. The geological strata present were therefore considered in the karst domains, to reflect the tendency for vertical solution fissures and open conjugate fractures that facilitate rapid bypass flow from the surface to the saturated zone.

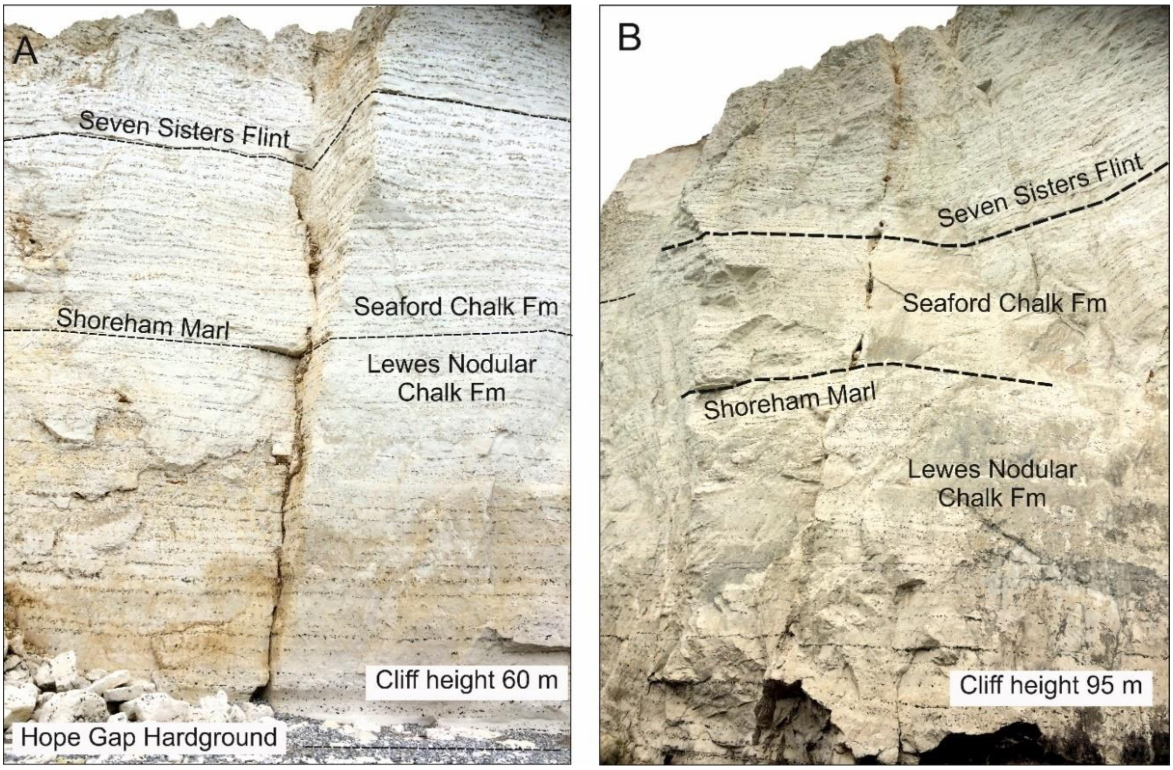

Figure 5 - Vertical fractures in the Seaford Chalk. A Seaford Head. B. Beachy Head. From Farrant et al., 2021.

5 Interpretation and Use of Unsaturated Zone Karst Domains

The karst domains (Figure 6) provide an indication of the likelihood of rapid flow in the Chalk unsaturated zone (or that drainage from the land surface is likely to feed into rapid flowpaths in the Chalk unsaturated zone). They are based on the probability that there are networks of solutional fissures and conduits that connect the surface to the saturated zone. These could be from a surface karst feature such as a stream sink or a subsurface feature such as a buried doline (dissolution pipe) with no surface expression, or simply focussed recharge through a superficial cover, focussing flow onto a particular fracture. Rapid bypass recharge can also occur following heavy or sustained rainfall through normally unsaturated vertical solution fissures on outcrop Chalk, which have no surface expression. These domains do not reflect the likelihood of rapid flow in the saturated zone which can occur in the absence of surface karst and without connectivity with the surface. For an assessment of saturated zone karst, it is recommended that additional factors are considered, including: locations of larger springs, transmissivity, borehole images, indicators of rapid flows at abstractions, and tracer test connections.

The unsaturated zone karst domains are primarily based on geological data and the current conceptual understanding of karst in the Chalk. Whilst the principles used in the development of the domains are quite robust and well established, there are other datasets which are not currently well developed or available for this project which would provide additional evidence of rapid groundwater flow in the unsaturated zone, and could be used to refine the domains if these datasets are developed in the future. For example, data on point recharge through riverbeds, anthropogenic drainage features with high infiltration rates, and evidence of rapid flow at abstractions (e.g. coliforms). In addition, there has been very little tracer testing conducted in the Solent Karst area, and future tracer tests may result in a new understanding of karst at some localities. The domains are based on the currently available knowledge and data on karst, and are not a substitute for local/catchment scale studies to consider the local evidence for karst.

There remain some uncertainties/caveats in the factors used to define the domains, and the scoring system applied. For the GeoSure dataset, although it is likely to give a very good indication of where surface karst features (dolines and dissolution pipes) are likely to occur, there is uncertainty about how frequently these features are associated with a fully connected flow path through the unsaturated zone. For the unsaturated zone thickness, the dataset of depth to water table that was used for this project is likely to represent low water levels, and the unsaturated zone thickness will be less under high water level conditions (substantially less in areas with large water table fluctuations). In addition, although it is known that thick unsaturated zones in the Chalk offer a high level of protection, there is considerable uncertainty about the depths of vertical solutional fissures. It is therefore uncertain what thickness of unsaturated zone is needed to offer protection, and what the most appropriate scores should be to reflect the relationship between the unsaturated zone thickness, and vertical solution pathways. Although there is some evidence from coastal surveys about where vertical solution fissures occur in the Chalk, the frequency and distribution of such features is still poorly known, and therefore there is also some uncertainty in the scoring of the factor that considers the geological propensity for vertical fissures.

The difficulties in determining where karst flow paths occur in the Chalk mean that the domains methodology has to be strongly dependent on well-established geological principles and expert judgement, and the domains should be considered as representing the current conceptual understanding of controls on karst in the Chalk based on extensive geological field mapping experience.

5.1 USE OF THE UNSATURATED ZONE KARST DOMAINS

The karst domains are intended to assist with catchment management and groundwater protection. However, they should be used with caution as the actual location of most karst features are unknown and karst features can occur anywhere within the Chalk. These domains should not be used for development or land use decisions without a full local assessment of the evidence for rapid flow in the unsaturated and saturated zones. The domains are based on fairly basic scoring estimates, and therefore small-scale variability in domains should be interpreted with caution. Whilst they give a broad indication of where there are more or less likely to be some unsaturated zone karst pathways, they cannot be used to determine the precise location of karst features in the unsaturated zone. The main use of the domains should be to assist with prioritising catchment management and input into decisions about where more or less groundwater protection might be appropriate, but with consideration of the caveats outlined in this report.

The boundaries between domains do not represent real world boundaries, and are a product of the GIS methodology and scoring system. Local scale variability in the domains should be interpreted very cautiously, and in lower scoring domains where there are nearby domains with a high or very high likelihood of rapid unsaturated zone flow then recommendations related to that higher domain may be more appropriate.

5.2 INTERPRETATION

In this section, further detail is provided on what the different domains represent, and what the implications might be for groundwater management and protection.

5.2.1 Domain 1 "Very high likelihood of rapid groundwater flow in the unsaturated zone"

These are areas where there is direct evidence of karstic flow paths in the unsaturated zone (principally the presence of stream sinks), or where there are a very high numbers of factors indicating that karstic flow paths are likely. This domain mostly covers areas close to the Palaeogene margin and in Karst Zone 1 where stream sinks and other karstic features are present. It also includes some river valleys where there is likely to be extensive groundwater flow in dissolutionally enlarged fractures at shallow depth beneath the valley floor. These areas commonly have high transmissivity values. This domain also includes some areas where there is a very thin unsaturated zone combined with geology conducive to vertical solutional fissure development. Note that for this project, only data on Chalk-Palaeogene margin stream sinks are available. Areas where there is point recharge via losing Chalk rivers or major soakaways are not well characterised and so could not be incorporated into the stream sink database. These should be in the very high category. It should be noted that most of the losing chalk rivers are by definition within the river valleys, and so are generally in the 'high' or 'very high' domains anyway.

In Domain 1 areas, karstic pathways comprising fissures and or conduits that connect the surface to the saturated zone are likely to be common. Maximum protection is recommended when considering surface land use; and these are important areas for catchment management work. Domain 1 covers both areas of the Chalk where karstic pathways through the unsaturated zone are likely, and also areas of the Palaeogene where surface runoff is likely to feed into chalk unsaturated zone karstic pathways.

5.2.2 Domain 2 "High likelihood of rapid groundwater flow in the unsaturated zone"

This covers areas where the geological setting suggests that there are likely to be fairly frequent rapid flow pathways in the unsaturated zone, and therefore maximum protection is also recommended for these areas; and these are important target areas for catchment management, especially where there are water quality problems at springs or abstractions.

This domain incorporates areas close to the Chalk-Palaeogene margin where subsurface karst development is highly likely, areas in Karst Zone 2 where there is a thin unsaturated zone or chalk with a higher tendency for vertical solution features; and areas of Karst Zone 3 where there is a thin unsaturated zone and chalk with a higher tendency for vertical solution features. Domain 2 does also include some areas with Palaeogene/other cover where surface runoff and interflow may travel some distance before reaching the Chalk. These are included in this domain because pollutants from these areas are likely to feed into chalk unsaturated zone karstic pathways.

5.2.3 Domain 3 "Medium likelihood of rapid groundwater flow in the unsaturated zone"

In these areas there are several factors suggesting that some rapid groundwater flow in the unsaturated zone is likely, and therefore high levels of protection are still recommended; and these are areas where catchment management measures may be useful. This could be especially important in areas close to, or surrounded by, domains 1 and 2. However, it is generally anticipated that unsaturated zone rapid groundwater flowpaths will be considerably less common than in Domains 1 and 2, and that there is greater potential for attenuation of contaminants in the unsaturated zone in this domain. This domain might include areas in Karst Zone 2 where there is a thicker unsaturated zone that mitigates against the higher propensity for karst; and areas in Karst Zone 3 where there is a thin unsaturated zone which makes it more likely that there could be karstic fissures extending the full depth of the unsaturated zone.

5.2.4 Domain 4 "Low likelihood of rapid groundwater flow in the unsaturated zone"

In these areas there is little evidence to suggest that rapid groundwater flowpaths connecting the surface to the saturated zone occur, for example in parts of Karst Zone 3 where there is no surface karst and a thick unsaturated zone. In these areas, although some karstic features may still be present, we would expect fully connected karstic pathways between the surface and the saturated zone to be rare. However, some protection is still recommended as the Chalk is a vulnerable aquifer, and there may still be a small number of rapid flow-paths through the unsaturated zone in this domain, and it is impossible to know exactly where they are. With this caveat, and others discussed elsewhere in this report, these areas are likely to be lower priority areas for catchment management strategies.

5.2.5 Domain 5 "Non-Karst".

Areas within the Solent Karst project area which are underlain by non-karst rocks are mapped as a separate domain. Where these comprises older non-karstic strata that underlie the Chalk (e.g. the Lower Greensand Group on the Isle of Wight) then karst is obviously not an issue, (except in localised areas where they form catchment areas for stream sinks which are included within the karstic domains). The non-karst domain does also include areas where the Chalk is confined beneath a thick low permeability cover, for example beneath the Palaeogene outcrop where the London Clay is present at the surface. In these areas there will not be rapid karstic flow-paths through the unsaturated zone, and therefore protection for surface activities and catchment management will not be of benefit to the Chalk aquifer.

Areas on the Palaeogene where there is surface runoff that later reaches the Chalk will not be included in this domain as they will have high scores for stream sink catchments or areas with Palaeogene runoff (Sections 4.1 and 4.2). There may also be cases where recharge to the Palaeogene strata may discharge at springs that feed into streams that then sink into the Chalk some distance away. This has not been included in the domains model as there are insufficient data to do so. The Palaeogene runoff zone is determined by topographic catchment alone and not potential groundwater catchments within the more permeable parts of the Palaeogene succession. It is therefore recommended that further work is done locally to assess the groundwater catchments of springs within the Palaeogene succession that subsequently drain to stream sinks in the Chalk where appropriate.

In some areas, there is the potential for rapid saturated zone groundwater flow at depth within the Chalk beneath the Palaeogene cover. This is the case in the area around Bedhampton and Havant where there is good evidence for rapid flow pathways beneath the Palaeogene cover infilling the Chichester syncline. These link stream sinks in the Horndean area with large springs at Bedhampton. Similar conduit systems are likely to be present at depth elsewhere in the Solent karst project area. Although the Chalk beneath these areas of low permeability cover are unlikely to be impacted by surface activities, there may be karstic networks in the saturated zone which are vulnerable to saturated zone activities (e.g. borehole soakaways) where saturated zone karst pathways pass beneath these deposits. The present study does not address this.

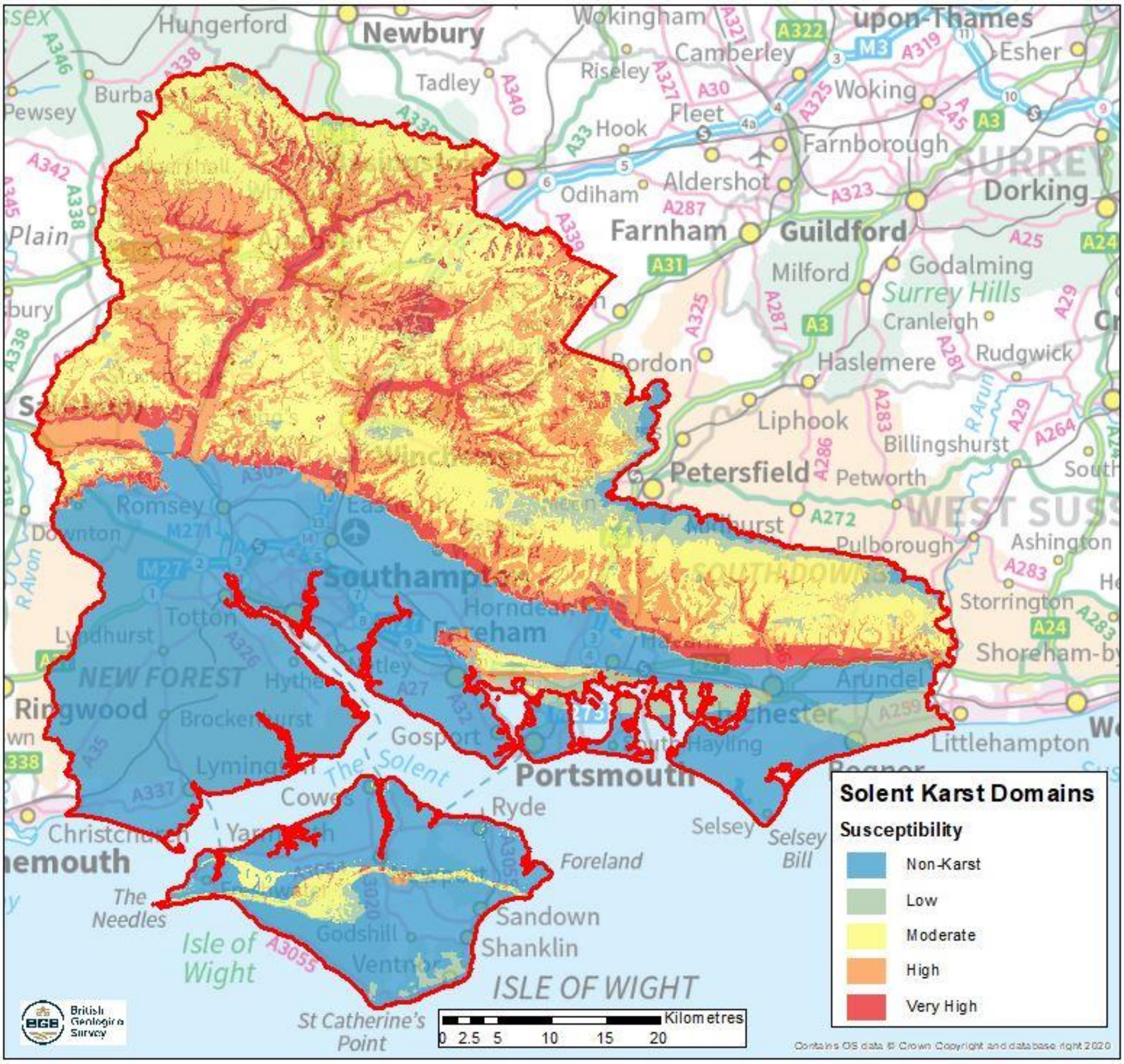

Figure 6 - Conceptual Domains for Rapid Karstic Groundwater Flow in the Unsaturated Zone Dataset

6 Technical Information

6.1 SCALE

This dataset has been developed at 1:50 000 scale and is not suitable for use at larger (i.e. more detailed) scales, for example 1:50 000 scale data should not normally be enlarged and used at 1:10 000 scale. All spatial searches of the maps should be undertaken using a minimum 50 m buffer. This is because the smallest detectable feature at this scale is 50 m.

6.2 COVERAGE

This dataset covers the Solent Catchment but is also extended eastwards to include the groundwater bodies of the Itchen, Chichester Chalk, Littlehampton anticline and the Sussex Lambeth group finishing at the Arun in the East (Figure 7).

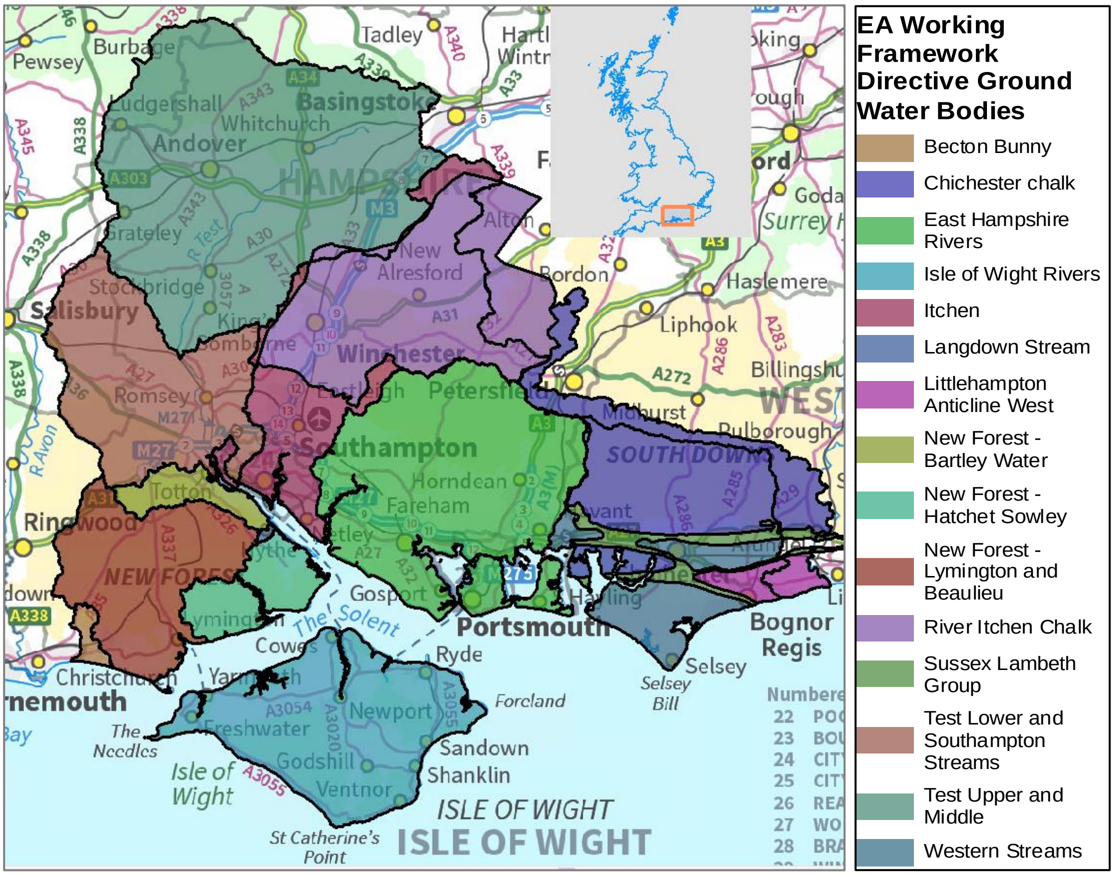

Figure 7 - Dataset Coverage and EA WFD Groundwater Bodies Cycle 2 - 2021. Contains public sector information licensed under the Open Government Licence v3.0. Contains OS data © Crown Copyright and database rights 2022.

6.3 ATTRIBUTE DESCRIPTION

Table 1 shows the attributes of the BGS Conceptual Domains for Rapid Karstic Groundwater Flow in the Unsaturated Zone Dataset (Karst Domains)

Table 1 - Attributes of the Conceptual Domains for Rapid Karstic Groundwater Flow in the Unsaturated Zone Dataset

Field name	Field description
Susceptibility	The likelihood of there being rapid unsaturated zone flow connecting the surface to the saturated zone given as a rating of either Very High, High, Moderate, Low or Non-Karst
Description	A brief description of the domain susceptibility rating
Dataset	Solent_Karst_Domains
Version	1
Created	30/03/2022

6.4 DATA FORMAT

The Solent Karst Domains dataset is available as a vector GIS dataset with attribute values relating to the susceptibility to rapid karstic groundwater flow in the unsaturated zone. The dataset is provided as polygon data within an ESRI ArcGIS file geodatabase (.gdb).

6.5 DISPLAYING THE DATA

The Solent Karst Domains dataset contains 5 attribute fields, but the key field to use for a general overview of the susceptibility to rapid karstic groundwater flow in the unsaturated zone is the Susceptibility field. The colours used for display are shown in the table below:

Susceptibility	RED	GREEN	BLUE	HEX	LOOKS LIKE
Very High	232	16	20	#E81014	
High	250	141	52	#FA8D34	
Moderate	250	250	100	#FAFA64	
Low	160	194	155	#A0C29B	
Non-Karst	40	146	199	#2892C7	

7 General Limitations

- Geological interpretations are made according to the prevailing understanding of the geology at the time. The quality of such interpretations may be affected by the availability of new data, by subsequent advances in geological knowledge, improved methods of interpretation, improved databases and GIS software, and better access to sampling locations.
- It is important to note that this dataset represents an interpretation of the data available; other interpretations may be valid. The full complexity of the geology may not be represented by the dataset due to the spatial distribution of the data at the time of data compilation and other limitations including those set out elsewhere in this report.
- Best endeavours (detailed quality checking procedures) are employed to minimise data entry errors but given the diversity and volume of data used, it is anticipated that occasional erroneous entries will still be present (e.g. locations, feature type etc.) Any raw data considered during integration may have been transcribed from analogue to digital format. Such processes are subjected to quality control to ensure reliability; however undetected errors may exist.
- Digital elevation models and digital terrain models (DEM or DTM) are sourced externally by BGS and are used to represent the ground surface in many products. These may have been processed to remove surface features including vegetation and buildings. However, some surface features or artefacts may remain, particularly those associated with hillside forests. The DTM may be sub-sampled to reduce its resolution and file size; therefore, some topographical detail may be lost.

7.1 DATA CONTENT

The domains dataset has been constructed by combining six layers of data as discussed in the Methodology section of this document. Consequently, the values within this dataset are limited by the components on which they are based. Given the methodology described within this document, the values provided here are to the best of our knowledge and current data holdings.

7.2 SCALE

The BGS Conceptual Domains for Rapid Karstic Groundwater Flow in the Unsaturated Zone Dataset is produced for use at 1:50 000 map scale providing 50 m ground resolution, and must not be used at larger scales. All spatial searches against the data should be done with a minimum 50 m buffer.

7.3 DISCLAIMER

The use of any information provided by the British Geological Survey (‘BGS’) is at your own risk. Neither BGS nor the Natural Environment Research Council (NERC) or UK Research and Innovation (UKRI) gives any warranty, condition or representation as to the quality, accuracy or completeness of the information or its suitability for any use or purpose. All implied conditions relating to the quality or suitability of the information, and all liabilities arising from the supply of the information (including any liability arising in negligence) are excluded to the fullest extent permitted by law. No advice or information given by BGS, NERC, UKRI or their respective employees or authorised agents shall create a warranty, condition or representation as to the quality, accuracy or completeness of the information or its suitability for any use or purpose.

8 Concluding Remarks

The karst domains that have been produced for this project show where it is more or less likely that solutional fissures and conduits in the Chalk connect the surface to the saturated zone (or that drainage from the land surface is likely to feed into rapid flowpaths in the Chalk unsaturated zone). These domains are based on current conceptual understanding of karst in the Chalk, and in particular the geological controls on karstic solutional development. Six factors were used in the development of the domains. These factors are (1) the location of karstic stream sinks; (2) areas of Palaeogene runoff from Palaeogene strata; (3) the BGS GeoSure (soluble rocks) dataset; (4) designated ‘Karst Zones’; (5) unsaturated zone thickness; and (6) geological strata with tendency for vertical fissure development.

Four domains are defined, ranging from domain 1 with a very high likelihood of some rapid unsaturated zone flow to domain 4 with a low likelihood of rapid unsaturated zone flow. It should be noted that the actual frequency of rapid unsaturated zone flowpaths is unknown, and that these domains represent the relative likelihood of rapid unsaturated zone flow. In other words, the expectation would be that such flowpaths occur most frequently in domain 1 and least frequently in domain 4.

The domains provide a broad indication of where rapid bypass flow in the unsaturated zone is more likely to occur, and therefore the domains could be used to inform land use choices and groundwater protection strategies. However, the actual locations of solutional fissures and conduits are not known, and they can occur anywhere within the Chalk. Therefore, the domains should not be used to make local development or land use decisions, for which a full local assessment of the evidence for karst should be undertaken. Boundaries between the domains do not reflect real world boundaries, and small-scale variations in the karst domains may reflect the GIS methodology. Areas adjacent to, or surrounded by, higher scoring domains should be interpreted with particular caution.

A future iteration of the domains could use GIS methods to even out some of the small-scale variability. GIS techniques could be used to aggregate data to regularly shaped grids (e.g. hex grids) in order to reduce the small-scale variability and issues that arise from using irregularly shaped polygon boundaries created arbitrarily through the nature of the GIS methodology.

The domains are based on current conceptual understanding of unsaturated chalk karst and could be revised if future research provides additional information. These domains are not intended to reflect the likelihood of saturated zone karst which may enable rapid flow.

9 Karst Glossary

Cave: A subsurface solutional conduit large enough for humans to enter.

Conduit: A subsurface solutional void which is usually circular or cylindrical in cross section. Sometimes used predominantly for conduits which are too small for humans to enter.

Doline: A surface depression formed by karst processes.

Dissolution pipe: A sediment filled solutional void in the subsurface, often with no surface expression.

Dissolution tubules: Networks of small cylindrical solutional voids ~ 0.5 cm in diameter found in chalk.

Estavelle: A karst feature in a stream or river which acts as a spring under high water levels and a sink under low water levels.

Fissure: An enlarged fracture with aperture of ~ 0.5 to > 2 cm, and a planar cross-sectional shape. Often used for fractures that are enlarged by dissolution. Those developed on bedding partings may extend laterally both along strike and down dip.

Inception horizon: Lithological horizon which favours dissolution and the development of fissures, conduits and caves.

Karst: Term applied to rocks which are soluble and in which rapid groundwater flow occurs over long distances. The development of subsurface solutional voids creates characteristic features including caves, dolines, stream sinks, and springs.

Scallop: Small-scale dissolution features on cave walls caused by the flow of water which indicate the direction and relative speed of groundwater flow.

Sinkhole: Term widely used for surface depressions. These may be karstic in origin and synonymous with dolines, but can also arise from surface collapse into anthropogenic voids such as mines and pits. The term has also been used for the actual hole into which water sinks into karstic voids in the subsurface through the base of a stream or river, and may be used in this context in these reports.

Stream sink: A stream which disappears into solutional voids in a karst rock. The stream may fully sink into a closed depression or blind valley or may partially sink through holes in the stream bed. The term is used in preference to sinkhole which can be confused with dolines or depressions caused by collapse into anthropogenic voids.

Surface depression: The term used in these reports for all surface depressions where it is unclear whether they are karstic or anthropogenic in origin.

Swallow hole: Another term for stream sink, although it has been used in the past for dry dolines that do not contribute surface runoff to the aquifer.

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