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BGS Karst Report Series: C5. Karst in the Wessex Chalk (Hampshire and Wiltshire)

Environmental Change, Adaptation and Resilience Programme

Open Report OR/22/053

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Maurice, L.D., Mathewson, E., and Farrant A.R.

Keywords

Chalk, Karst, Groundwater, Wessex Basin.

Front cover

Dissolution pipe in a quarry at Quidhampton near Salisbury. BGS image P598768.

Bibliographical reference

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Executive Summary

This report documents the evidence for karst and rapid groundwater flow in the Chalk of the Wessex Basin area in Southern England which comprises parts of Hampshire and Wiltshire. It is part of the BGS karst report series on those karst aquifers in England in which cave development is limited – principally the Upper Cretaceous Chalk and the Jurassic and Permian limestones. The series is the main output of the NERC funded Knowledge Exchange fellowship "Karst knowledge exchange to improve protection of groundwater resources". The term "karst" applies to rocks that are soluble. In classical karst there are extensive caves and large scale surface karst landforms such as dolines, shafts, river sinks, and springs. In the past, the Chalk and the Jurassic and Permian limestones of England were not considered karstic because they have limited cave development, and because karst features are usually small and have not been well documented. However, permeability in these aquifers is determined by their soluble nature and groundwater flow is predominantly through small-scale karstic solutional features. These reports provide data and information on karst in each area. Karst data are compiled from the British Geological Survey databases on karst, springs, and transmissivity; reports and peer reviewed papers; from geological mapping, and through knowledge exchange with the Environment Agency, universities, water companies and consultants.

There is clear evidence for karst in the Chalk of the Wessex basin area, with stream sinks, losing rivers, springs, dolines, dissolution pipes, dry valleys and conduits present. There are no documented enterable caves, but conduits are observed in borehole images and in road cuttings and quarries; and it is likely that they are quite common. There are high densities of stream sinks associated with the Chalk-Paleogene margin, and evidence of recharge from losing streams and rivers away from this margin. Dissolution pipes are common where there is a thin Paleogene or superficial cover over the Chalk, and although many of the numerous surface depressions in the area may be anthropogenic pits rather than karst dolines, some of them are likely to be dolines in this setting of thin cover. There are many springs in the area, with these spring sites representing the natural outlets for the karstic solutional networks of fissures and conduits. While there are very few data on spring discharge, it is likely that there are many large springs, as well as springs that were large prior to the development of chalk groundwater resources. High transmissivities of 1000s m^2/day are indicative of extensive karstic networks in the saturated zone, which has also been demonstrated by the single tracer test reported in the C5 area. This tracer test from a monitoring borehole demonstrated very rapid groundwater flow of up to 4750 m/day to three abstractions over distances of many kilometres, with tracer recoveries of ~1-2% at each of the three outlets.

There have been few studies of karst in this area, and karst data are fairly limited. Hence further work is recommended to develop karst datasets, and to conduct investigations to improve understanding of the karst to assist with groundwater protection and management.

Introduction to the BGS Karst Report Series

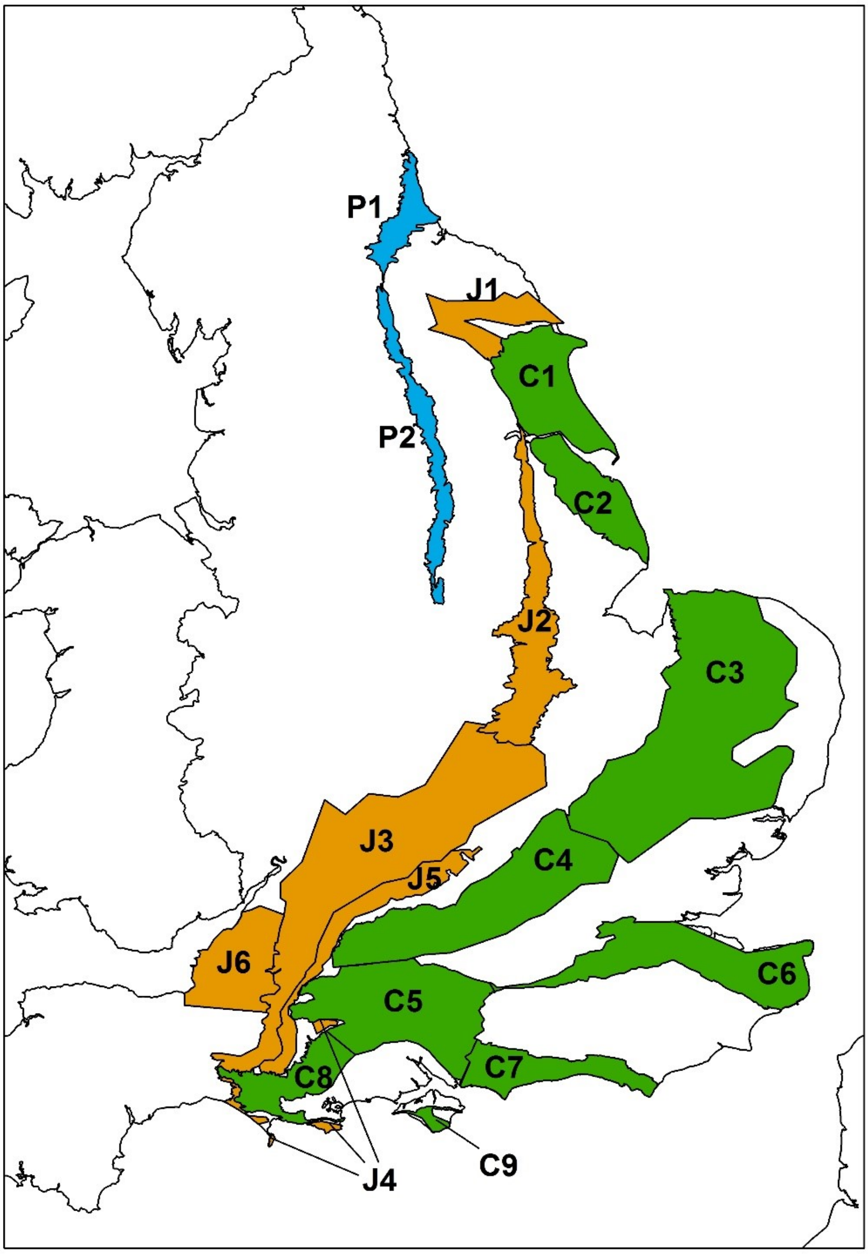
The BGS karst report series is focused on karst aquifers in England in which cave development is limited – the Chalk and the Jurassic and Permian limestones. The series is the main output of the NERC funded Knowledge Exchange fellowship "Karst knowledge exchange to improve protection of groundwater resources" undertaken between 2015 and 2022. This series is the first systematic review of karst features across these aquifers and provides a useful basis for future karst and hydrogeological studies.

The term "karst" applies to rocks that are soluble. In classical karst regions there are extensive caves; and there are large scale surface karst landforms such as dolines, shafts, river sinks, and springs. In the past the Chalk and the Jurassic and Permian limestones of England were not considered karstic because they have limited cave development, and because karst features are usually small and have not been well documented. However, permeability in these aquifers is determined by their soluble nature and groundwater flow is predominantly through small-scale karstic solutional features comprising small conduits ~ 5 to >30 cm diameter and solutionally enlarged fractures (fissures) of ~0.5 to >2 cm aperture. There are some short caves in all three aquifers; they all have dolines, stream sinks and large springs; and rapid flow can occur over long distances. Karst is therefore an important feature of these aquifers.

The series will comprise 17 reports which provide an overview of the evidence for karst in different areas of England. The Chalk is divided into nine regions, primarily based on geomorphology and geography. The Permian limestones are divided into two areas, comprising a northern and southern outcrop. The Jurassic limestones have more variable geology and are divided into six areas. J1 covers the Corallian Group of Northern England. J2 covers the Lincolnshire Limestone Formation of central England. J3 covers the Great Oolite Group and Inferior Oolite Group of Southern England. J4 covers three small areas of the Portland and Purbeck limestones in Southern England. J5 covers the Corallian Group limestones of Southern England. J6 covers the Blue Lias limestones of Southwest England and comprises several small outcrops within a large area.

Karst data are compiled from the British Geological Survey databases on karst, springs, and transmissivity; peer reviewed papers and reports; geological mapping; and through knowledge exchange between 2015 and 2022 with the Environment Agency, universities, water companies and consultants. The data are not complete and further research and knowledge exchange is needed to obtain a full picture of karst development in these aquifers, and to investigate the detail of local catchments. The reports nonetheless provide an overview of the currently available evidence for karst and demonstrate that surface karst features are much more widespread in these aquifers than previously thought, and that rapid groundwater flow is common. Consideration of karst and rapid groundwater flow in these aquifers will improve understanding of how these aquifers function, and these reports highlight the need for further investigations of karst to enable improved management and protection of groundwater resources.

The reports are structured to provide an introduction to the area and geology, evidence of karst geomorphological features in the area (caves, conduits, stream sinks, dolines and springs); evidence of rapid flow from tracer testing, and other hydrogeological evidence of karst. Maps of the area show the distributions of karst features, and there is a quick reference bullet point summary.



Map of the locations of the Karst reports

C1) Karst in the Chalk of the Yorkshire Wolds
C2) Karst in the Chalk of Lincolnshire
C3) Karst in the Chalk of East Anglia
C4) Karst in the Chalk of the Chilterns and the Berkshire and Marlborough Downs
C5) Karst in the Wessex Chalk (Hampshire and Wiltshire)
C6) Karst in the Chalk of the North Downs
C7) Karst in the Chalk of the South Downs
C8) Karst in the Chalk of Dorset
C9) Karst in the Chalk of the Isle of Wight
J1) Karst in the Jurassic Limestone Corallian Group of Northern England
J2) Karst in the Jurassic limestones of Central England
J3) Karst in the Jurassic Great and Inferior Oolites of Southern England
J4) Karst in the Jurassic Portland and Purbeck limestones in Southern England
J5) Karst in the Jurassic Corallian Group limestones of Southern England.
J6) Karst in the Jurassic Blue Lias limestones of Southwest England.
P1) Karst in the northern outcrop of the Permian limestones
P2) Karst in the southern outcrop of the Permian limestones

Introduction to Karst Data

This section provides background on each type of evidence for karst, the data sources used, and any limitations in the data. This introduction is general to all the BGS karst reports and further specific information on data sources is provided within the individual reports where applicable. A glossary is provided at the end of the report.

Stream sinks

Stream sinks provide direct evidence of subsurface karst and rapid groundwater flow because they are indicative of a network of solutional voids of sufficient size to transport the water away through the aquifer. Most stream sinks occur near to the boundary between the carbonate aquifer and adjacent lower permeability geologies, with surface runoff from the lower permeability geologies sinking into karstic voids in the carbonate aquifer at the boundary or through more permeable overlying deposits close to the boundary.

Data on stream sink locations in the Chalk and Jurassic and Permian limestones are variable and although there are many records, the dataset is incomplete, and further surveys are likely to identify additional stream sinks. Many sites have not been verified in the field. Stream sink records are predominantly from the BGS Karst database in which many were identified by desk study and geological mapping. Several stream sink field surveys have also been carried out, predominantly in areas of the Chalk in Southern England. Some additional records were obtained through knowledge exchange.

Most streams that sink have multiple sink points over distances of 10s to 1000s of metres. The sink point varies depending on flow conditions and also as some holes become blocked with detritus and others open up. Each individual sink point provides recharge into a solutional void in the underlying carbonate aquifer, and their locations therefore provide direct evidence of the locations of subsurface solutional features enabling rapid recharge. The sink points range from seepages through alluvial sediments in the stream bed and small holes in stream beds, to sink points located in karstic depressions of more than 10 m in depth and/or diameter. Some data sources report many/all individual sink points associated with a stream; whilst others report a single point for an individual stream irrespective of whether there are multiple sink points. The data presented here comprise all the sink point records that the studies report, but there are likely to be many more sink points in streambeds which have not yet been identified. Further information on the discharge and nature of the stream sinks is generally sparse, but where available, information from reports and papers are summarised.

Some streams and rivers flowing over carbonate geologies have sections with substantial losses or which dry up in the middle of their course. These are also a type of karst stream sink providing recharge to solutional voids in the subsurface. Whilst some that sink into obvious holes in the riverbed have been identified, and there are some studies that provide evidence of river losses/drying, there has been no systematic study of the occurrence of karstic recharge through riverbeds in the Chalk, or Jurassic or Permian limestones. River flow data were not reviewed for these reports. The data presented are from a brief literature review, and there may be many other streams and rivers that provide point recharge into subsurface karstic features.

Caves and smaller conduits

Karstic caves (conduits large enough for humans to enter) occur in the Chalk and Jurassic and Permian limestones, providing clear evidence of the importance of karst in these aquifers. Caves were identified from literature review, predominantly from publications of the British Cave Research Association, and local and regional caving societies. Many chalk caves were identified by Terry Reeves of the Chelsea Spelaeological Society, who provided pictures and information about the caves, many of which are documented in the Chelsea Spelaeological Society Records.

Smaller conduits are observed in quarry walls and natural cliff outcrops. Conduits (~5 to >30 cm in diameter) and larger solutional fissures (apertures of > 2 cm) are also commonly observed in images of abstraction and monitoring boreholes. However, there is no dataset on conduits, and they have generally not been studied or investigated, so it is not possible to assess their frequency or patterns in their distributions. Information on conduits from knowledge exchange and literature review is included, but the data are very limited in extent.

Dolines

Dolines provide direct evidence of karst, and may be indicative of rapid groundwater flow in the subsurface. They occur in the Chalk and Jurassic and Permian limestones. However, their identification can be challenging as surface depressions of anthropogenic origin (e.g. dug pits, subsidence features associated with the collapse of old mines, dewponds) can appear similar to karst dolines. This is especially the case in the Chalk. The reports review the evidence for surface depressions in the area, and discuss whether these are likely to be karstic or anthropogenic in origin.

Data on surface depression locations come from the BGS Karst database in which they were identified by either desk study or during geological mapping. Other records of surface depressions were obtained through knowledge exchange and literature review, and studies of dolines in the area are summarised. In some areas there may be surface depressions/dolines that have not yet been identified.

Dissolution pipes

Dissolution pipes (a form of buried doline) only occur in karstic soluble rocks, and their presence is therefore evidence of karst. Their role in providing recharge into subsurface karstic features is poorly understood. Many of them appear to contain low permeability material and may be formed by in-situ bedrock dissolution and therefore may not be linked to larger dissolutional voids in the subsurface, but some may be associated with open solutional fissures.

Dissolution pipes occur at very high spatial densities in some areas, and are commonly encountered in civil engineering projects. Some data on dissolution pipes come from the Natural Cavities database. This is a legacy dataset held by the British Geological Survey and Peter Brett Associates. It comprises data from a range of sources originally commissioned by the Department of the Environment and reported by Applied Geology Limited (1993). In some areas dolines and dissolution pipes are not distinguished in the Natural Cavities database. Information from reports and papers with information on dissolution pipes in the area are summarised.

Springs

Large springs are indicative of connected networks of karstic voids that provide flow to sustain their discharges. Data on spring locations were collated from the BGS karst and springs databases, and Environment Agency spring datasets. Further information on springs was obtained through knowledge exchange and literature review. The springs dataset presented in this report series is not complete, and there are likely to be more springs than have been identified. In England there are very few data on spring discharges and most springs are recorded as of unknown discharge. However, in most areas some springs with known discharges of > 10 or > 100 $l.s^{-1}$, have been identified. There are also some springs with no discharge data but which have been observed during field visits to be large (likely to be > 10 $l.s^{-1}$), or were used as monitoring outlets in tracer studies. There remains much work to be done to develop a useful dataset on the discharges and characteristics of springs in the Chalk and Jurassic and Permian limestones, but the data presented here provide an initial overview, and suggest that large springs are common in these aquifers.

Tracer tests

Tracer tests provide direct evidence of subsurface karstic flow paths in which groundwater flow is rapid. The development of cave-sized conduits is not a pre-requisite for rapid groundwater flow, and in these aquifers where cave development is limited, the karstic flow paths may comprise connected networks of smaller conduits and solutional fissures. Tracer test data were compiled from literature review and knowledge exchange. It is probable that most of the successful tests that have been carried out in these aquifers have been identified.

Other evidence of karst and rapid groundwater flow

This section provides an overview of other evidence of karst from literature review and knowledge exchange; and includes evidence from borehole monitoring or other hydrogeological studies.

There is substantial evidence of karst from groundwater abstractions from these aquifers. Whilst all successful abstractions are likely to be supplied by connected networks of solutional voids, the higher the transmissivity, the more widespread and well developed the karstic networks are likely to be (Foley and Worthington, 2021; Maurice et al., 2021). Transmissivity data from the national aquifer properties manual (Allen et al., 1997; MacDonald et al., 2001) are presented.

Knowledge exchange with water companies highlighted that in many areas water supply abstractions and springs have some characteristics that are indicative of karst. In some areas abstractions have indicators of groundwater with low residence time and/or connectivity with surface water; for example coliforms, turbidity, detection of rapidly degrading pesticides, evidence of connectivity with the sea or surface rivers over long distances. To protect site confidentiality these data are not presented specifically, but a general overview is provided where appropriate.

Acknowledgements

For discussions on karst we thank James Bucknall and Simon Deacon from Portsmouth Water; Debbie Wilkinson, Graham Earl and Steve Howe from South East Water; Simon Cook, Richard Gamble and Chris Woolhouse from Southern Water; Dawn O'Neill, Ally Thomas, Tom Wickens, Polly Wallace and other staff from the Environment Agency; and Vanessa Banks at BGS who led much of the work on the BGS Karst database. We thank Emily Crane at BGS for reviewing the report and providing useful input. We also thank Carole Sharratt at BGS for assistance with report formatting. This work was predominantly carried out under the Natural Environmental Research Council (NERC) Knowledge Exchange Fellowship Scheme, grant ref NE/N005635/1.

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1 Introduction

1.1 AREA/GEOLOGY

The C5 Wessex Basin Chalk area is in southern England and comprises parts of Wiltshire and Hampshire (Figure 1). The west of the area includes Salisbury Plain and is drained by the River Avon and its major tributaries: the Ebble, the Wylie and the Bourne rivers, which flow south to the sea at Christchurch (Figure 1; Figure 2). To the east, in Hampshire, the area extends from Basingstoke in the north to just north of Portsmouth and Southampton. The Test and Itchen rivers drain towards the south where they converge at the Southampton Water estuary and the River Meon drains into the Solent. General information on the geology of the area can be found in Allen and Crane (2017), with local information in BGS geology reports, for example: Aldiss (2000), Farrant (2001), Farrant et al. (2001), Hopson (2001), and Hopson et al. (2006).

Most of the C5 area is underlain by the Late Cretaceous Chalk Group. This is underlain by the older Selborne Group (the low permeability Gault Formation and overlying permeable Upper Greensand Formation), which crops out to the northwest, west and east of the C5 area (Figure 2; Table 1). The eastern part of the outcrop marks the western closure of the Weald anticline, which swings round into the South Downs. Here, the Chalk continues into the C7 South Downs area (Maurice et al., 2022). In the northeast, the Chalk dip swings to the north, steepening up into the Hog's Back structure around Farnham, where it continues into the C6 (North Downs) karst report area (Mathewson et al., 2021[a]). The northern boundary is marked by the Vale of Pewsey, floored by the outcrop of Upper Greensand Formation in the core of the Pewsey Anticline. The area of chalk to the north of the Vale of Pewsey is covered by the C4 karst report for the Chilterns and Berkshire and Marlborough Downs (Maurice et al., 2020).

Across much of Salisbury Plain, the Chalk dips generally to the south, locally interrupted by some gentle east-west fold structures. A more intense series of en-echelon anticlines and corresponding synclines extend between Petersfield, Winchester, Kings Somborne, Dean Hill and Alderbury. In the west, the Mere Fault Zone runs between Mere, Wilton and Salisbury, forming the northern edge of the Vale of Wardour. To the southwest, the Chalk continues into Cranborne Chase, forming a south-easterly dipping cuesta, which is covered by the Dorset Chalk area report (C8, in preparation). In the south of the area, the Chalk is overlain by the younger Paleogene Lambeth Group, London Clay and Bracklesham Group sands, silts and clays. These crop out where the Chalk dips into the broad syncline that underlies the Solent. Paleogene rocks also occur in the northeast between Crondall and Hungerford, in the core of a syncline between Mottisfont and Alderbury between the Avon and Test valleys, and as small outliers near Mickledever.

Superficial deposits in the C5 area (Figure 3) are less extensive than in some other Chalk areas in the south-east of England, but are locally important. Around the major rivers there are alluvium and river terrace deposits and there are small amounts of sand and gravel and brickearth in the south. Clay-with-Flints is present on higher ground, particularly in the northeast around Alresford.

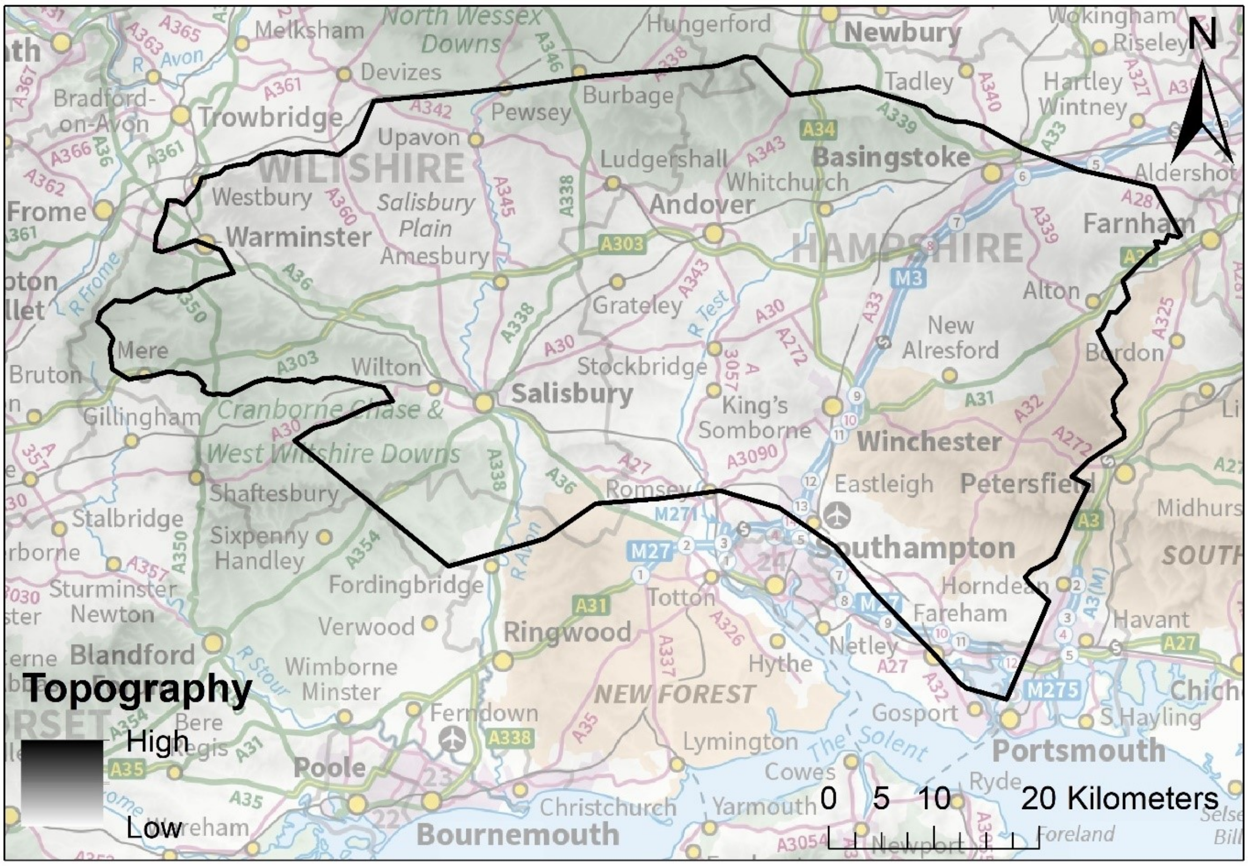

Figure 1. The C5 Wessex Basin Chalk area

Table 1. Stratigraphy in the C5 Wessex Basin Chalk area (Powell, 1998; Allen et al., 1997)

Group	Formation	Lithology	Thickness
Bracklesham Group	Selsey Sand Formation	Sand, silt and clay	25 - 27 m
	Marsh Farm Formation		12 - 13.5 m
	Earnley Sand Formation		22 - 25 m
	Wittering Formation		40 - 53 m
Thames Group	London Clay Formation	Sand, silt and clay	0 - 150 m
Lambeth Group	Reading Formation	Sand	12 - 27 m
Chalk Group	Portsdown Chalk Formation	Chalk	62 m
	Culver Chalk Formation		65 - 75 m
	Newhaven Chalk Formation		45 - 75 m
	Seaford Chalk Formation		50 - 80 m
	Lewes Nodular Chalk Formation		35 - 80 m
	New Pit Chalk Formation		10 - 25 m
	Holywell Nodular Chalk Formation		10 - 15 m
	Zig Zag Chalk Formation		35 - 75 m
	West Melbury Marly Chalk Formation		15 - 25 m
Selborne Group	Upper Greensand Formation	Sandstone	0 - 75 m
	Gault Formation	Mudstone	90 - 110 m

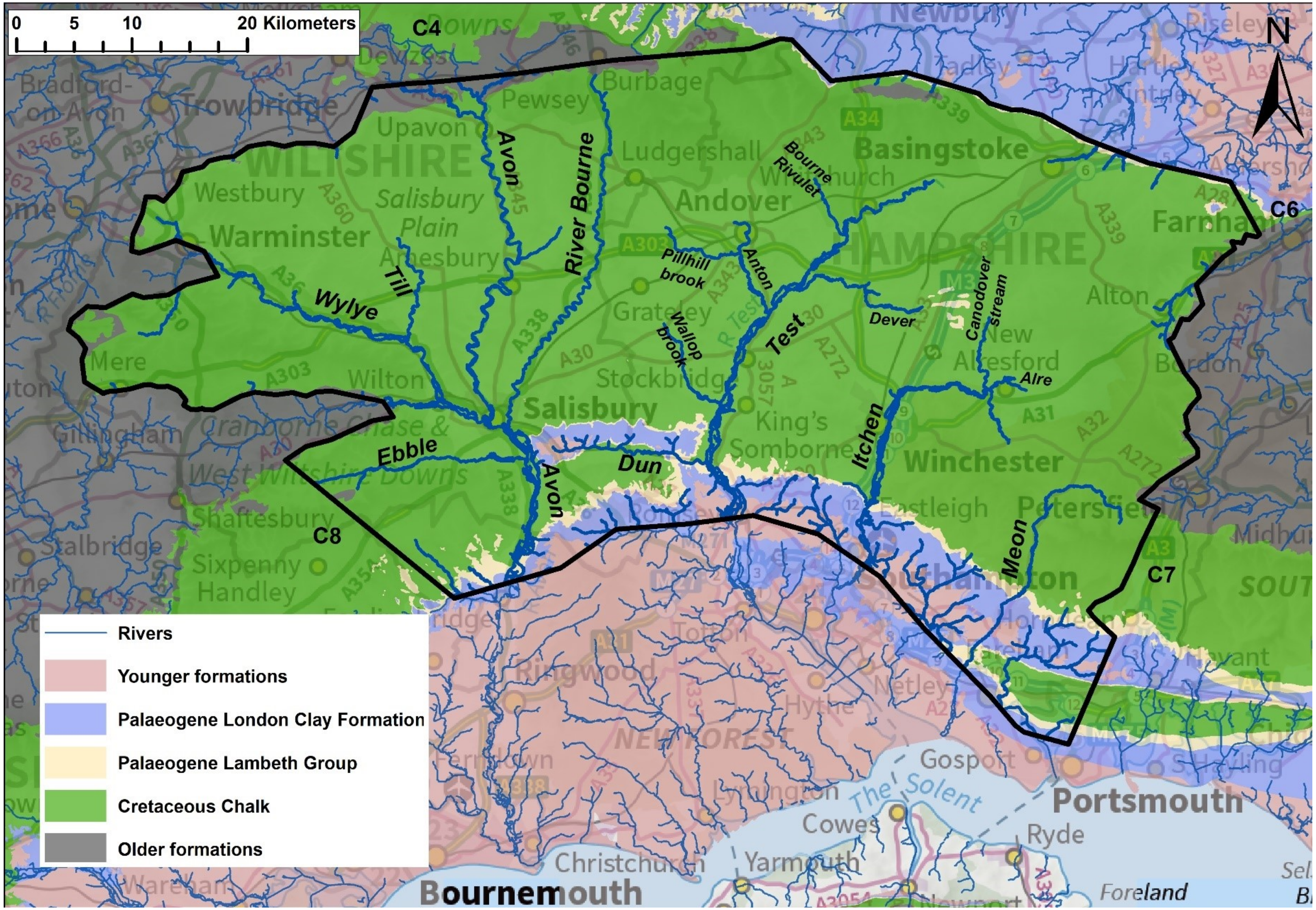

Figure 2. Bedrock geology and rivers in the C5 Wessex Basin Chalk area

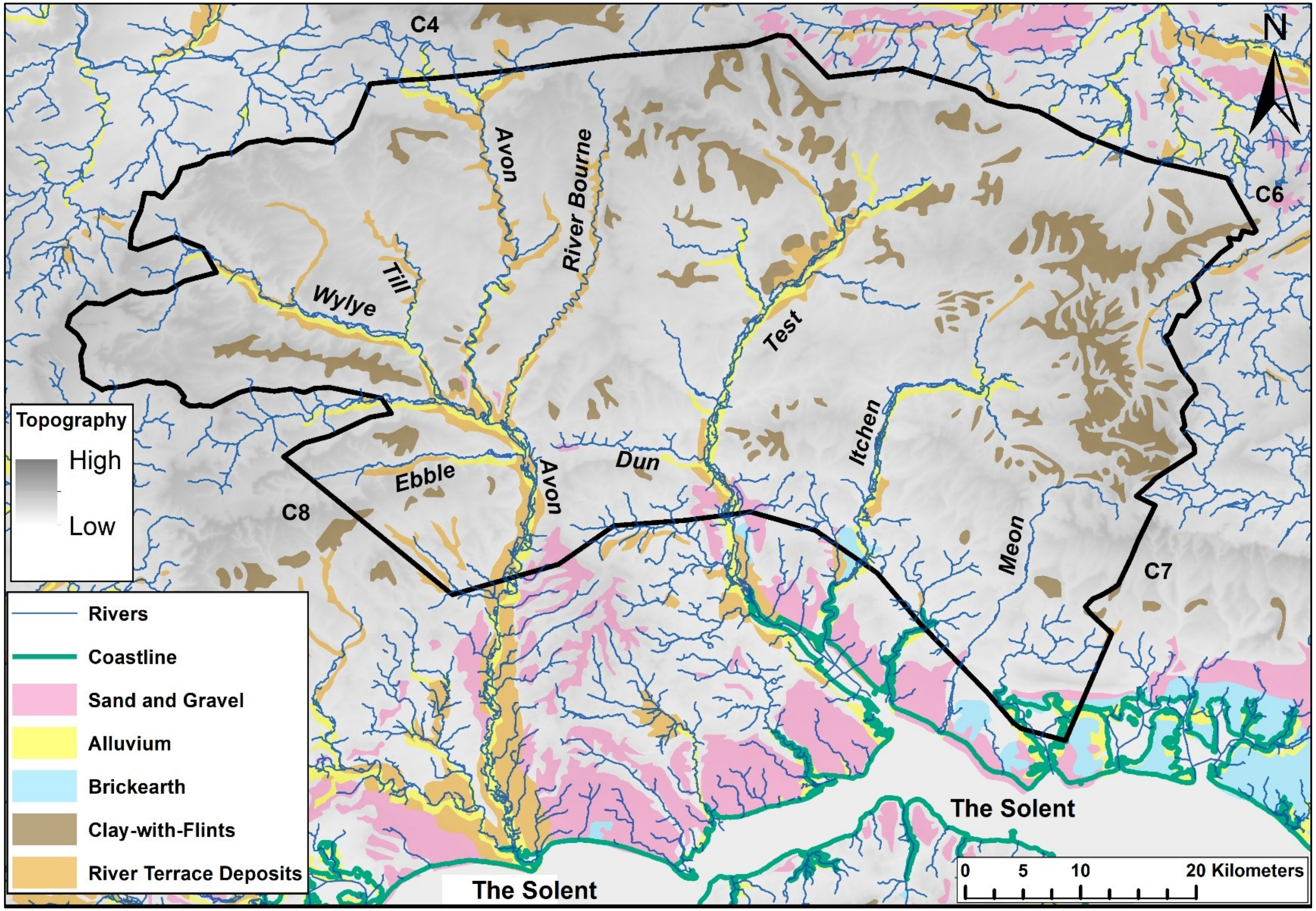

Figure 3. Superficial geology and rivers

1.2 WATER PROVIDERS AND REGULATORS

The major water providers in the C5 area are Wessex Water, Southern Water and South East Water (Figure 4). The C5 area is in the Wessex, West Thames, and Solent and South Downs Environment Agency areas (Figure 5).

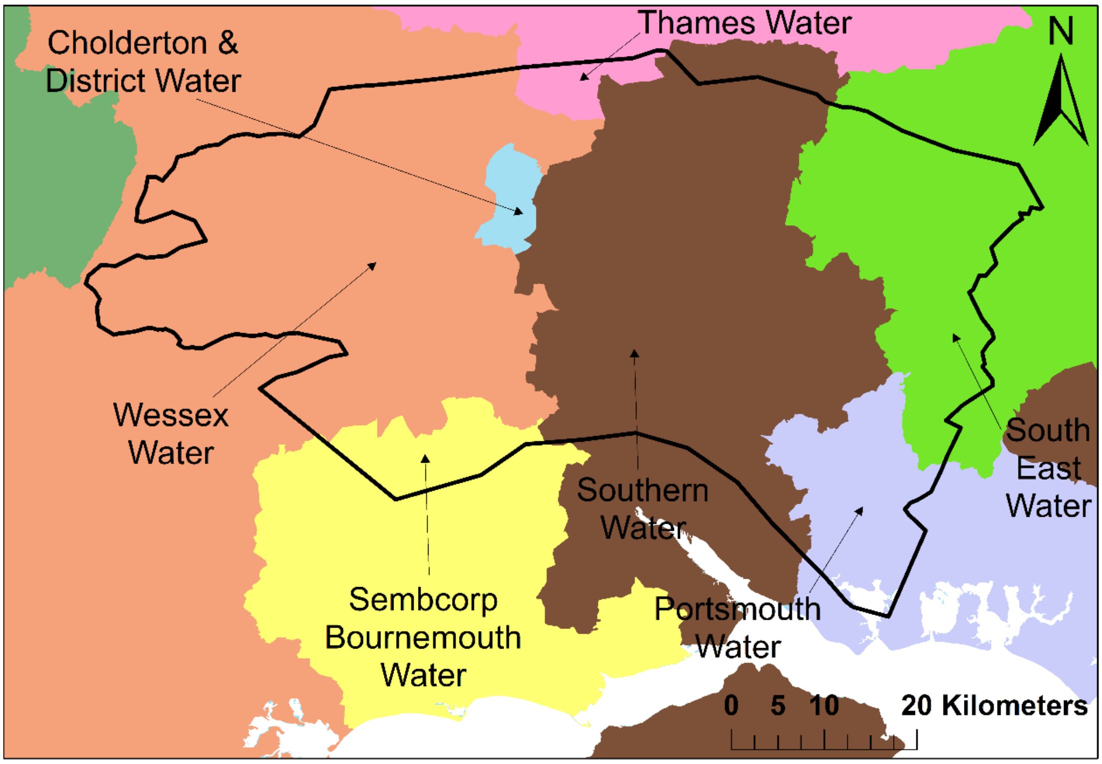

Figure 4. Water providers in the C5 Wessex Basin Chalk area

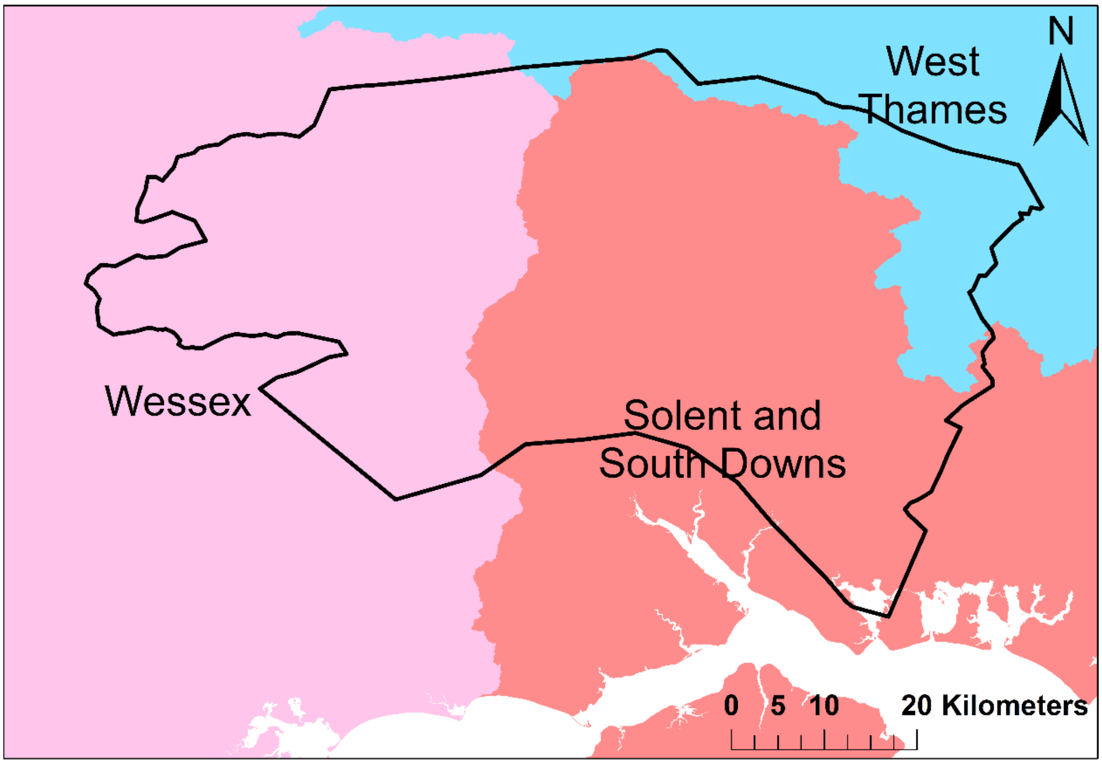

Figure 5. Environment Agency areas in the C5 Wessex Basin Chalk area

2 Karst Geomorphology

2.1 CAVES AND CONDUITS

While there are no recorded enterable caves in the C5 area, there is evidence of conduit development, including some sediment filled cavities with dimensions of small caves. Some locations where conduits have been observed are shown in Figure 6, and although there are few records, they are distributed throughout the C5 area.

Some karst cavities have been exposed in road cuttings. Mortimore (2012) discusses karst features in the area around the Twyford cutting for the M3 motorway (Figure 6). In the centre of the cutting a palaeo-cave system was identified, partially filled with sediment, and solution features were observed at the southern end along the main fractures and along the surfaces of hardgrounds and marls. Mortimore (2012) notes that the Bar End Hardground (at the junction between the Lewis Nodular Chalk Formation and the Seaford Chalk Formation) is heavily calcreted and associated with karst. Mortimore (2012) also reports that tubular karst and sediment filled cave systems were associated with faults, with tubular karst particularly apparent at the intersection of faults and bedding planes. In Figure 22 of his paper, Mortimore (2012) provides a geological cross section through the Twyford cutting, including the main karst features.

Aldiss (2000) discusses two karst cavities exposed in a road cutting east of Snoddington Manor, (NGR: SU 245 447, which is the point just east of the River Bourne on Figure 6). These were recorded on geological field slips made by Bennett in 1889 and 1892. Aldiss (2000) notes that the cross bedding that was observed in the sediment fill in the solution features indicates that these cavities once carried water.

Conduits have also been observed in quarries. Small sediment filled caves were observed in two quarries (Whiteparish Quarry and Worthy Hassocks Copse) to the south of the River Dun, during BGS geological field mapping. West of these, near Salisbury, Hopson et al. (2006) report a sediment filled solution feature at Britford Quarry (see photograph in Figure 7). A few kilometres to the north of this, in a quarry at Upper Woodford (SU 1235 3700), there are some small solution cavities on sheet flints in the upper Lewes Chalk Formation (Hopson et al., 2006). Many small sediment filled conduits are present in the Holywell Nodular Chalk in a limeworks pit at Lower Froyle between Alton and Farnham (Farrant, 1997). This is the point in the far northeast of the area in Figure 6, and an example of a sediment filled conduit is pictured in Figure 8.

Saturated and unsaturated solutional fissures and conduits are commonly observed in boreholes in the area (Allen and Crane, 2019). Giles and Lowings (1990) report that one of the production boreholes in the Alre catchment had “a large cavity about 4m deep observed at a depth of 75 m”. Giles and Lowings (1990) note that this borehole had the highest yield/drawdown relationship of all the boreholes drilled in the area. Pumping this borehole at a rate of ~ 160 l/s resulted in only about 0.7 m of drawdown. They also note that another borehole only 25 m away did not intersect the cavity and had one of the poorest yields.

Evidence of karst and conduits has been reported at boreholes in the east and north-east of the C5 area (Bunting et al., 2021[a]; Bunting et al., 2021[b]; Mathewson et al., 2021[b]; Mathewson et al., 2021[c], borehole locations not shown on Figure 6 for site confidentiality reasons). CCTV footage of boreholes shows some extensive fissuring in the Chalk, with both horizontal and vertical fissures. The types of features observed from the borehole logs include minor conduits which have developed on small-scale vertical fractures or faults (Bunting et al., 2021[a]), but also larger conduits associated with large-scale marl seams or known karst inception horizons such as the Chalk Rock hardground within the Lewes Nodular Chalk Formation (Bunting et al., 2021[b]) An example of a conduit observed in a borehole is shown in Figure 9. The dimensions are unknown but it is likely to be between 5 and 30 cm high. Borehole investigations discussed in these studies also show evidence of flow through some of these features. For example, particle movement observed from CCTV footage around conduits implying active flow. Similarly, flow logs of some of the boreholes showed flow coincident with features observed in CCTV (Mathewson et al., 2021[b]).

There is also some evidence of conduit development at depth in the confined Chalk. Sediment filled conduits (requiring plain casing) were encountered in the Chalk between 126 and 143 m below ground level, just below the boundary with the overlying Paleogene material in a borehole at Raglington Farm, east of Southampton (Allen and Crane, 2019). However, yields from this borehole were poor.

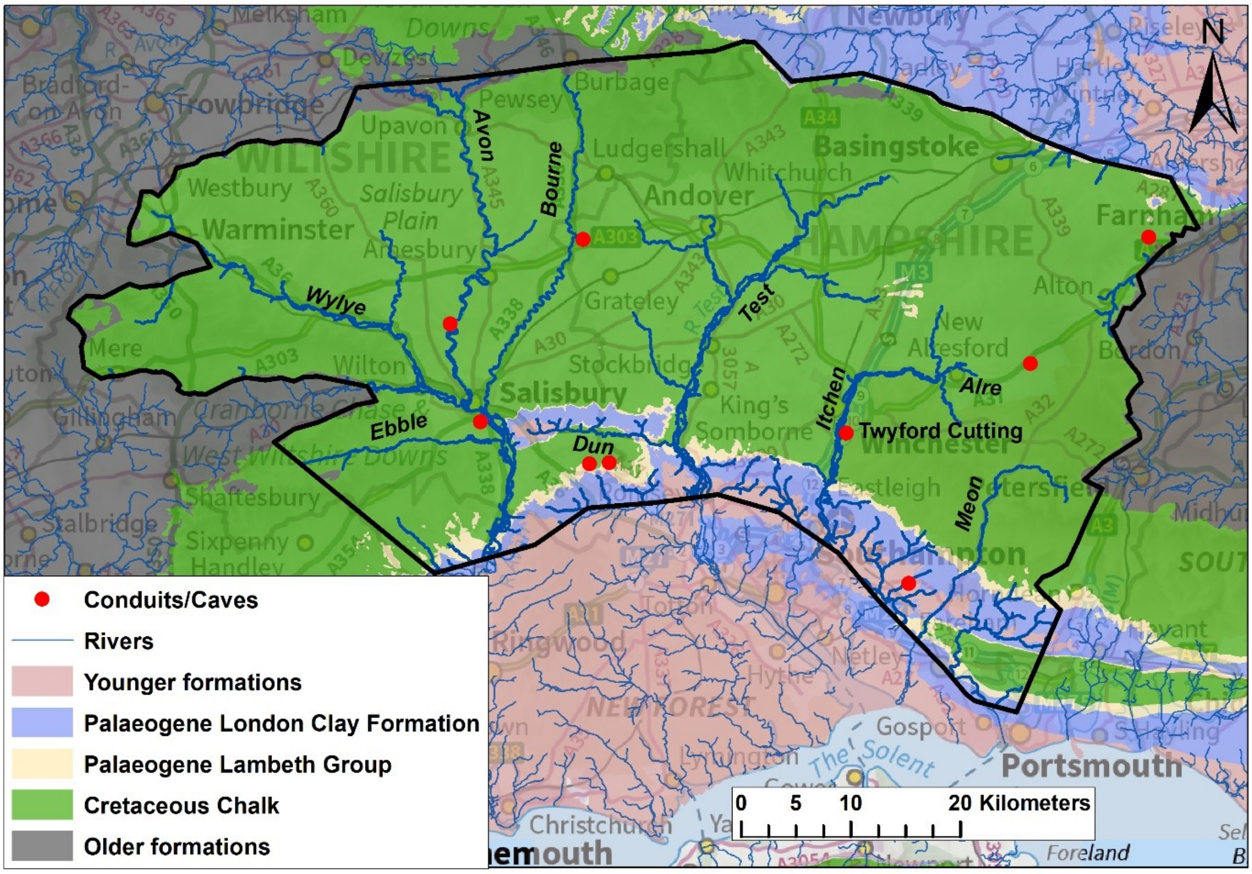

Figure 6. Some locations where conduits have been observed.

Figure 7. Large sediment filled karst conduit, Britford Quarry, Salisbury (from Hopson et al., 2006)

Figure 8. Sediment filled conduit in the Quarry at Lower Froyle.

Figure 9. Solutional conduit at 112 m depth in a borehole near Basingstoke (Photo courtesy of South East Water).

2.2 STREAM SINKS

There are many stream sinks recorded in the C5 area (Figure 10). Some of the stream sinks on Figure 10 that are away from the Chalk-Paleogene margin and the main rivers may be soakaways rather than natural karst features, and have generally not been verified in the field. Most records are from the BGS Karst database, which includes stream sinks identified from geological field slips, historic topographical maps, BGS memoirs, and Farrant (2001) and Farrant (2003). There are also many stream sinks recorded in the Natural Cavities database, which is a legacy dataset held by the British Geological Survey and Peter Brett Associates. It comprises data from a range of sources originally commissioned by the Department of the Environment and by Applied Geology Limited (1993); and many of these records have not been verified in the field. The other stream sink records shown on Figure 10 in the C5 area were not in either of these databases, and these were identified from Hopson et al. (2006) or Whitaker et al. (1910), or reported in Farrant et al. (2018). The stream sinks in the C6 (Mathewson et al., 2021[a]) and C7 (Maurice et al., 2022) karst areas have also been included on Figure 10 to show those that occur close to the C5 area. Farrant et al. (2001) also reports two "major soakaways" which recharge the Seaford Chalk near Boscombe Down airfield.

As in many areas of the Chalk, stream sinks are mostly concentrated in areas around the Chalk-Paleogene boundary (Maurice et al., 2021), and there may be some other stream sinks associated with this boundary in the C5 area. Streams sinking into the Chalk in this geological setting are usually fairly small features with flows of a few litres per second following rainfall (Maurice et al., 2021), although there is very little information on the amount of flow in most stream sinks, and this is especially the case in this area.

Examples of three areas with particular concentrations of stream sinks along the Chalk-Paleogene margin (the River Dun, Soberton, and the Farnham area) are discussed in more detail below, which is followed by a discussion of stream sinks/river losses associated with rivers on outcrop chalk. Groundwater contours used in the figures in these sections are from the BGS Chalk groundwater storage project by Lewis et al. (1992) who note that few datapoints were available in the Wessex area and therefore contours were constructed by hand. Therefore, these contours may only provide a rough approximation of groundwater flow directions.

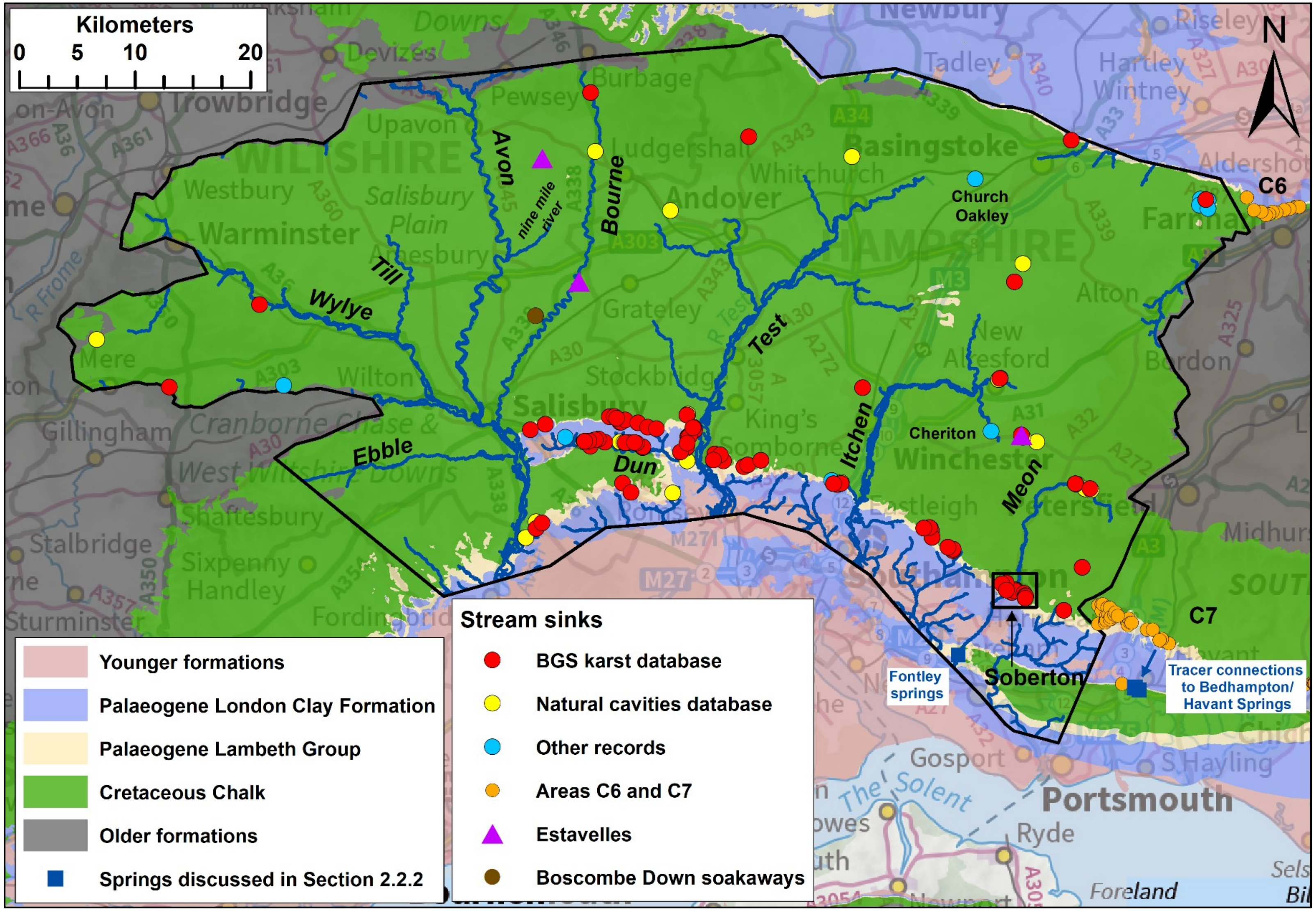

Figure 10. Stream sinks in the C5 Wessex Basin Chalk area

2.2.1 Stream sinks in the River Dun area

Most stream sinks recorded in the C5 area are associated with the Chalk-Paleogene margin near the River Dun and the Lower Test valley (Figure 10). Stream sinks and other karst features in this area are shown in more detail on Figure 11. It is likely that most surface runoff (and drainage from small springs) that occurs on the Paleogene deposits, recharges the Chalk at and around the geological boundary, and there may be other small stream seeks and seepages along this boundary that have not been recorded. There are no data on the flows in these stream sinks but some of them are described as significant features, for example the Devil's Hole (Figure 11). White (1912) notes that "While revising the geological mapping of the district…..Mr. W. Whitaker observed several well-marked swallow-holes at the boundary of the Reading Beds, but the only local example mentioned in his Water Supply of Hampshire is the Otterbourn swallow hole, half a mile east-south-east of Silkstead. Other good examples occur in the south-western part of the district, e.g., in the little chalk inlier south-west of Newtown; at a spot half a mile north-east of Bentley Farm (East) near East Tytherley; and at short intervals along the northern side of the Dean Valley. Among these last is Devil's Hole, half a mile due north of East Dean Church, and a big compound swallow-the largest sink in the district-at the south-eastern corner of Hawks Grove". The Devil's Hole site is now infilled with sediment.

The natural groundwater outlets for the stream sinks shown on Figure 11 are not known. It is possible that there are local outlets in the River Dun/River Test, and a number of springs are recorded along these rivers (Figure 11). In general, information on the discharge and characteristics of these springs has not been collated for this karst report, and further work is required to identify springs that may form the outlets to the karst networks. However, the Mottisfont Spring on the River Test is a large spring (see Section 2.4), and may be an outlet for stream sinks. The groundwater contours (during high groundwater levels when the stream sinks are likely to have been active), indicate groundwater flow from the stream sinks immediately to the west of the Test valley towards the Mottisfont spring. The groundwater contours suggest that the stream sinks further west (particularly those along the northern Chalk-Paleogene margin) may also supply groundwater flowing east towards the Mottisfont spring. However, there also appears to be a southerly component to the groundwater flow, and these stream sinks may be connected to other spring outlets within the valley of the River Dun, or possibly with springs associated with the Chalk-Paleogene margin to the south of the River Dun. It is likely that some of the stream sink recharge is captured by groundwater abstractions in the area, but no tracer testing has been done to investigate this, or to determine the stream sink to spring connections.

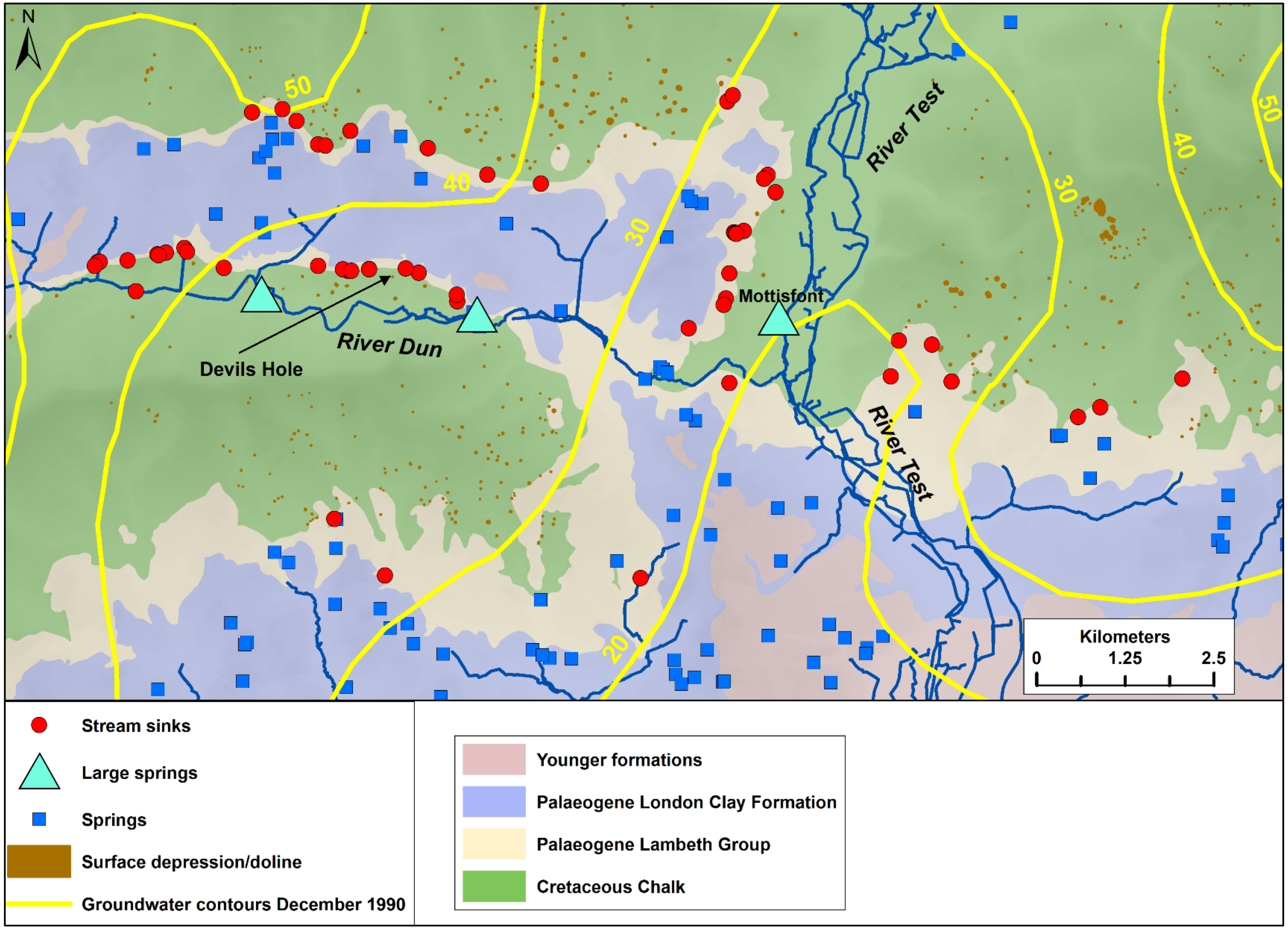

Figure 11. Stream sinks and other features in the River Dun/River Test area

2.2.2 Stream sinks in the Soberton/River Meon area

Another example of an area along the Chalk-Paleogene margin where stream sinks occur is the Soberton area (Figure 10). A karst survey was conducted here in February 2003 to identify stream sinks, dolines, old pits and soakaways which could provide point recharge to the Chalk aquifer (Farrant, 2003). Figure 12 shows the locations of karst features in the Soberton/River Meon area from this survey, along with other records from the BGS Karst database and the Natural Cavities database, and some stream sinks in the nearby C7 area (see Maurice et al., 2022). Fourteen karst stream sinks were identified in the survey by Farrant (2003). Two sinks were also identified in an artificial mill leat (SU 6009 14700 and 30 m upstream at SU 60109 14729), and Farrant (2003) suggests that there could also be leakage to the Chalk aquifer from the River Meon in the reaches near to the stream sinks. Farrant (2003) also identified 31 soakaways in the wider Soberton area (Figure 12) and noted that this was likely to be an underestimate of the true number. These soakaways took drainage from roads, tracks and farmyards, and Farrant (2003) suggested that the volume of water recharging the Chalk may be significant during heavy rainfall. Whilst these are not natural karst features, if substantial water volumes are infiltrating the Chalk, they may be feeding into solutional fissures in the unsaturated zone.

No tracer tests have been conducted in the area, and the outlets for the stream sinks to the south of Soberton (and the groundwater supplied by the soakaways in the Soberton area) are unknown. Although there are a number of springs recorded in the area (Figure 12), their discharges were not established during the survey by Farrant (2003) or during the current karst data compilation, and it is unclear if any of them are larger springs that could form the natural outlets for the stream sinks. The substantial springs at Bishops Waltham are unlikely to be an outlet for the Soberton stream sinks as they are not down gradient (Figure 12). The groundwater contours suggest flow towards the south from the Soberton stream sinks (Figure 12), and the Chalk outcrops again to the south of the Paleogene, where there are some chalk springs at Fontley (Figure 10). Although the discharge of these springs has not been established for this karst data compilation, Allen and Crane (2019) report that south of the Paleogene outcrop at "Funtley" where the River Meon again flows over the Chalk, there are minor springs, that were previously major. These may be the large springs described by Whittaker et al. (1910) at Great Fontley and Little Fontley farm (labelled "Fontley springs" on Figure 10). It is possible that groundwater recharging the Chalk at the northern Chalk-Paleogene margin near Soberton may flow beneath the Paleogene to re-emerge in chalk groundwater outlets to the south. This is the case nearby in the C7 area to the east (Figure 10) where the stream sinks feed groundwater that flows south beneath the Paleogene deposits to re-emerge at large springs at Bedhampton and Havant (Atkinson and Smith, 1974). The Bedhampton and Havant springs are extremely large (see Maurice et al., 2022 for more information on these springs), and it is even conceivable that they are a natural outlet for the Soberton sinks. Wherever the natural groundwater outlets are, it is quite likely that the stream sinks and soakaways in the Soberton area are connected to groundwater abstractions in the area, although no tracer testing has been done to investigate this.

Several sinks points have been recorded in the upper reaches of the River Meon (Figure 12). Whitaker et al. (1910) report some observations of Col. G Greenwood in 1864 who stated that "the stream which usually runs through West Meon has for many weeks entirely disappeared, so that there is no running water between Westbury Pond and Warnford Pond". Greenwood suggested that there was water flow upstream of West Meon supplying three mills, but that water sank into "swallow holes" below Drayton. Greenwood also observed two swallow holes below Westbury Ponds. There are large springs at Warnford (Figure 12), and it is possible that these may form the natural outlets for the stream sinks in the upper reaches of the River Meon (as suggested by Greenwood in 1864). Groundwater contours suggest that the springs at Warnford are broadly down gradient of the stream sinks (Figure 12). These contours are not based on many datapoints (Lewis et al., 1993), and it is also the case that these contours are for high groundwater levels, when the stream sinks around the Chalk-Paleogene margin are more likely to be active. Contours during low water levels (not shown in Figure 12), when the stream sinks in the upper reaches of the River Meon may be more likely to be active (according to the descriptions by Greenwood), indicate a stronger east to west flow component towards the Warnford springs. It seems quite likely that the stream sinks feed a short groundwater flow path beneath the River Meon to the Warnford springs, but no tracer tests have been done to demonstrate this, and it is also possible that the stream sinks feed flow paths that flow towards the east or south.

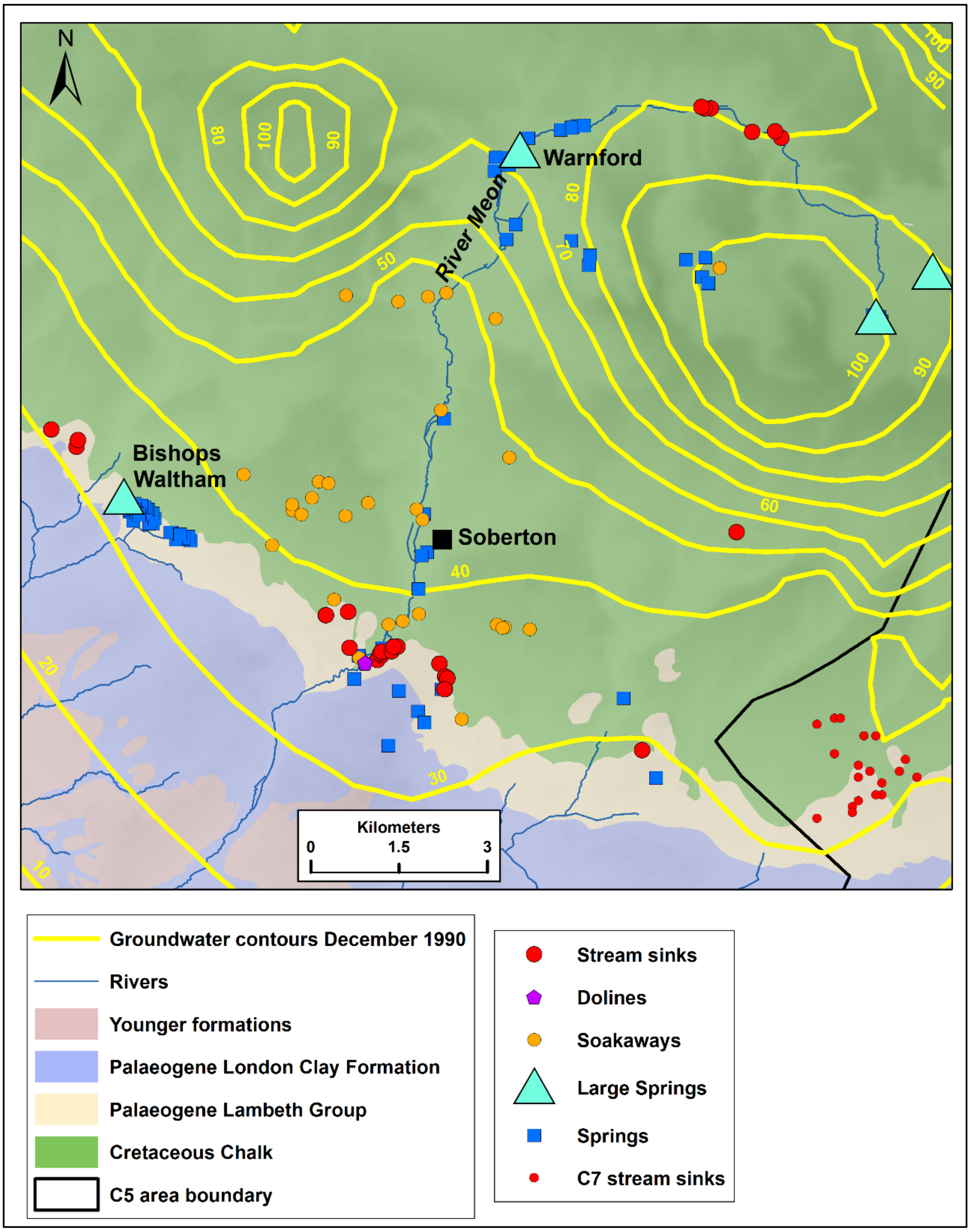

Figure 12. Karst features in the River Meon/Soberton area

2.2.3 Stream sinks in the Farnham area

Farrant et al. (2018) undertook a survey of some of the stream sinks in the Farnham area. Stream sinks were visited in the Horsedown common area in the far northeast of the C5 area, and in the area in the far west of the C6 area (Figure 13). This work was discussed in the karst report for the C6 area (Mathewson et al., 2021[a]), where detailed maps of the stream sinks in both the C6 and C5 area are provided. Photographs of some of the stream sinks are shown in Figure 14 to Figure 17. These pictures were taken in dry conditions. The size of the channels and the nature of the sink points suggest that they may take flows of a few l/s in wet periods. The locations of these sinks are shown in Figure 13 (site 1 = Horsedown sink, site 2 = Old Park sink, site 3 = Crondall Lane sink, site 4 = Clay Pit Gully sink).

The outlets for the stream sinks in Figure 13 are unknown and no tracer tests have been conducted. There are a number of springs in the area, associated with the Chalk-Paleogene margin, some of which may be the natural outlets for the stream sinks. Groundwater contours suggest flow from the Horsedown Common area stream sinks in the C5 area is broadly towards the north where there are several springs. Groundwater contours in the C6 area also indicate flow towards the north from the stream sinks, although the springs are mainly located to the northwest of the stream sinks. Groundwater abstractions in the area may also be connected to the stream sinks.

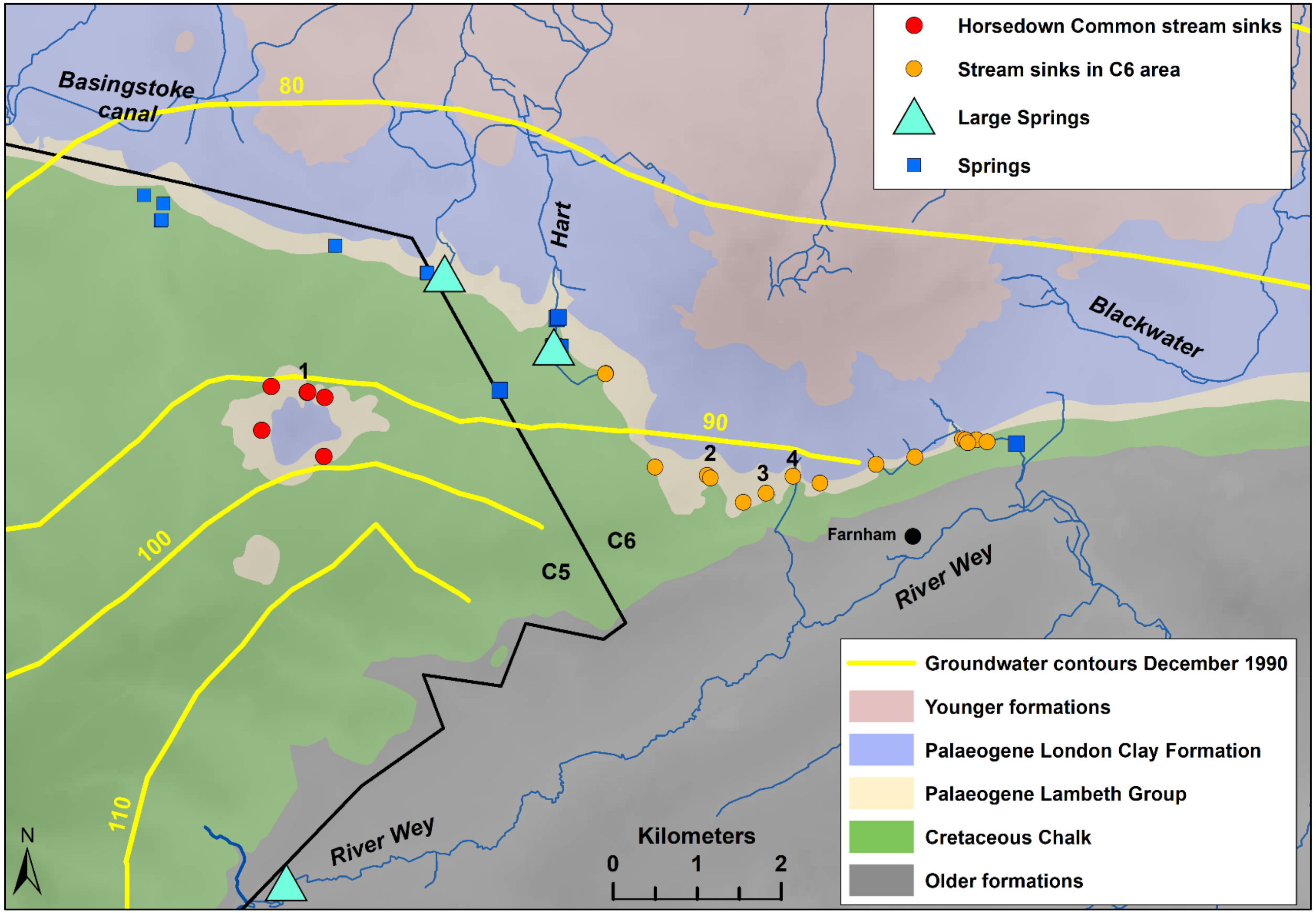

Figure 13. Stream sinks in the Farnham area (from Farrant et al., 2018). Contains Ordnance Survey data © Crown copyright and database right [2023], British Geological Survey © UKRI [2023]. Shaded relief derived from NEXTMap® Britain elevation data from Intermap Technologies.

Figure 14. Looking upstream at Horsedown sink. The stream sinks into the grassy area in the centre of the image. Photo by A. Farrant.

Figure 15. Old Park sink (flood sink). Photo by A. Farrant.

Figure 16. Crondall Lane sink. The stream sinks in a wooded depression in the top middle of the picture. Photo by A. Farrant.

Figure 17. Looking downstream at Claypit Gully Sink. Collapse feature just downstream of dry weather sink. Photo by A. Farrant.

2.2.4 Recharge through Chalk Riverbeds

Streams and rivers on the Chalk outcrop in the C5 area also display characteristics indicative of karstic subsurface flow (Whitaker et al., 1910; MacDonald et al., 1998; Allen and Crane, 2019). Discharge via springs, and recharge through the river bed are both indicative of solutional fissures and conduits in the aquifer below. Discharge via springs and winterbourne behaviour is discussed in Section 2.4, whilst here the focus is on river losses, which can provide a substantial contribution to recharge, and occurs in most catchments in the area. On some rivers there are “Bourne holes” reported, which can be either sinks recharging groundwater or spring discharge points depending on groundwater levels (Hopson et al., 2006). These are commonly known as estavelles in the karst literature, and some of these are shown on Figure 10. There are a few stream sink records along the major rivers in the area away from the Paleogene outcrop (Figure 10), and it is likely that there are many more sink points along rivers on outcrop chalk. Some of the recorded stream sinks in riverbeds may be estavelles. Losses along chalk rivers are discussed below for some of the main river catchments: The Wylye, the Bourne, and the Test and the Itchen. River losses in the Meon are discussed in Section 2.2.2. There are also bourne holes in the headwaters of the Nine Mile River (Farrant et al., 2001), which is a short tributary of the River Avon (Figure 10). Farrant et al. (2001) note that according to the Devizes geological memoir, one of these was up to 7 m deep.

The Wylye and tributaries

The River Wylye is in the west of the C5 area (Figure 10) and there are flow losses reported for the Wylye and two of its tributaries: the Chitterne Brook and the River Till (Allen and Crane, 2019). The Chitterne Brook is a short tributary not shown on Figure 10 but it joins the Wylye about 10 km upstream of the River Till. The complexities of flow losses and accretion in the Wylye and its tributaries are described in Allen and Crane (2019). They report that there are flow losses in the River Wylye in the stretch between Bishopstrow and Upper Lovell. They also show that there are sections in the Chitterne Brook and River Till tributaries of the Wylye that dry up due to leakage through the riverbed. This was apparent in the Chitterne Brook in April 1997 at around 5 km upstream (Figure 18), and in the River Till in May 1997 and January/February 1998 (Figure 19). Hopson et al. (2006) also report that there are "bourne holes" along the middle and upper reaches of the Till and Chitterne Brook where significant recharge into the aquifer can occur. The groundwater outlets for water recharged through the Wylye and its tributaries are not known for certain, although groundwater emerges downstream in these rivers.

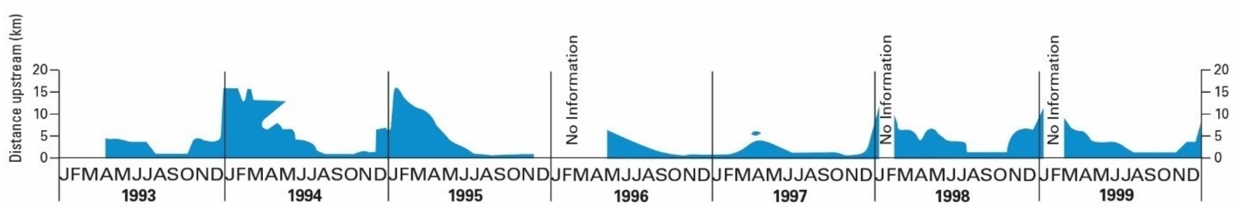

Figure 18. Flow patterns in the Chitterne Brook. From Allen and Crane (2019), original figure courtesy of the Environment Agency.

Figure 19. Flow patterns in the River Till. From Allen and Crane (2019), original figure courtesy of the Environment Agency.

The Bourne

Flow, accretion, and losses along the Bourne are very complex (Figure 20); and are discussed in Allen and Crane (2019), Farrant et al. (2001), Hopson et al. (2006), Whitaker et al. (1910) and Soley et al. (2012). Hopson et al. (2006) suggest that "bourne holes" occur in the Upper and Middle reaches of the Bourne, and Farrant et al. (2001) report that they occur between Collingbourne Kingston and North Tidworth. Figure 21 shows photographs of the Bourne at Cholderton, which is approximately 6 km downstream of North Tidworth, from Tyler-Whittle et al. (2000). In February 2000 the river channel was dry, whilst heavy rainfall in April resulted in considerable flow in early May, illustrating a relatively rapid change.

There appears to be some geological control on river flow patterns (Farrant et al., 2001; Allen and Crane, 2019; Soley et al., 2012). Farrant et al. (2001) suggest that significant recharge occurs as the Bourne crosses the base of the Holywell Chalk Formation around Collingbourne Kingston, and that recharge may also occur through the Lewes Chalk Formation between Collingbourne Ducis and Tidworth. Recharge may be associated with particular hardgrounds within the Chalk (Farrant et al., 2001; Allen and Crane 2019; Soley et al., 2012). The groundwater outlets for water recharged through the Bourne are not known with any certainty. Whilst the Bourne regains flow via springs at Idmiston (Section 2.4), it has been suggested that under low water table conditions, the flow lost from the Bourne goes to the River Avon to the west, or tributaries of the River Test in the east (Soley et al., 2012).

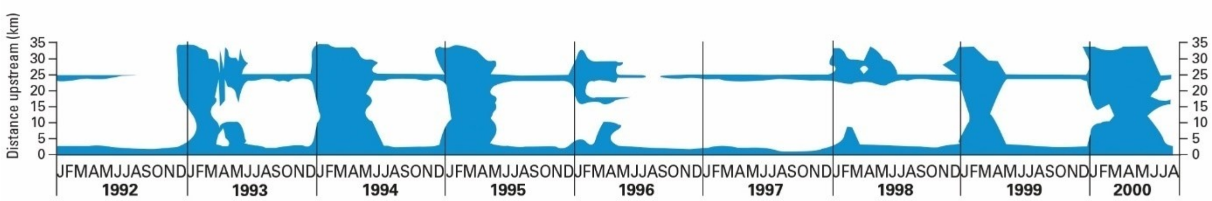

Figure 20. Flow patterns in the Bourne. From Allen and Crane (2019), original figure courtesy of the Environment Agency.

Figure 21. The River Bourne at Cholderton on 2nd February 2000 (left) and 6th May 2000 (right). From Tyler- Whittle et al. (2000).

The Test and the Itchen

Whitaker et al. (1910) report that in dry periods the water in the upper reaches of the Test sinks in the Church Oakley area (Figure 10, note that the headwaters of the river Test extend further than shown).

There is also some evidence of recharge in the upper reaches of the tributaries of the Itchen (Figure 22). Whitaker et al. (1910) discuss the work of Shore (1890) who reported that “the system of water drainage in the dry valleys near Cheriton is a system of soakage and swallow holes. In wet seasons, and particularly in rainy winters, plenty of water may be seen flowing down the little channels from the higher ground to the hollows where the porous chalk absorbs it”. The village of Cheriton lies on the River Itchen with many dry valleys in the surrounding area (Figure 22). Shore (1890) and Whitaker et al. (1910) also describe an estavelle at Bramdean to the east: “At rare intervals the water flowing beneath the surface down the Bramdean valley rises in a great spring a little west of the village (of Bramdean), and flows along the bourn channel. Some springs in very wet seasons have been known to burst out not far from Woodcote (just above Bramdean). The bourn spring west of Bramdean, is one of the most interesting of Hampshire springs. Only sometimes is it a spring; much more often it is a swallow hole. It is easy to understand that the underground channel from which the water rises when the chalk is saturated with water and the water level consequently high, is capable of forming a channel through which the water can sink when the chalk is dry and the water level is low.” Whitaker et al. (1910) also reports that Alresford pond, on the Alre tributary of the Itchen, is a swallow hole with substantial losses through the base of the pond.

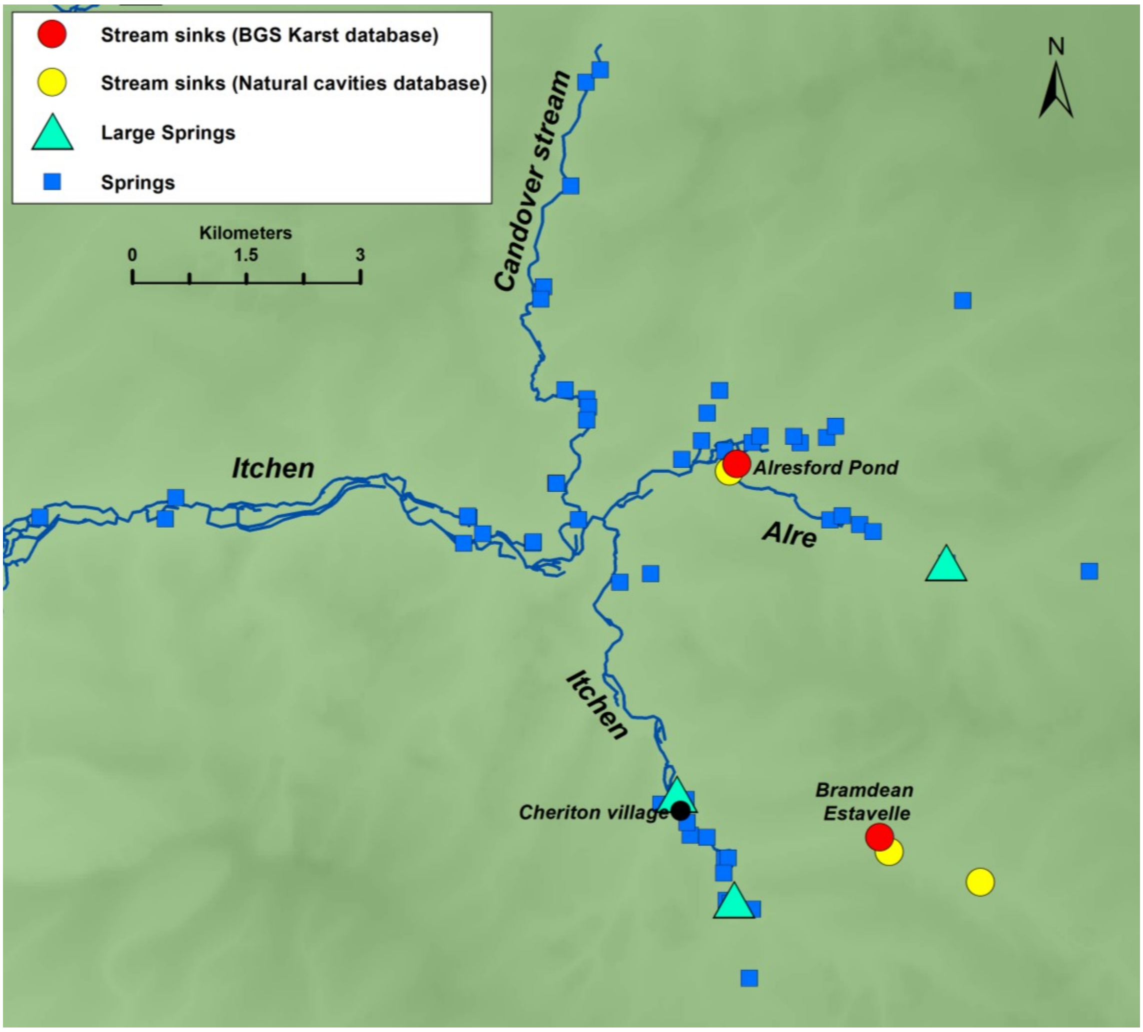

Figure 22. Stream sinks in the upper reaches of the Itchen

2.3 DOLINES AND DISSOLUTION PIPES

Surface depressions and dissolution pipes are common in the C5 area (Figure 23). The surface depression data include both point and footprint data from the BGS Karst database. The footprint data are outline areas of surface depressions and hence of variable sizes. The surface depressions were identified from geological field slips, BGS memoirs and aerial photographs. Although these sites were originally recorded as dolines in the BGS Karst database, as in all areas of the Chalk it is often uncertain whether surface depressions are karst dolines or pits of anthropogenic origin, and hence the data are reported here as surface depressions. It is likely that many of the surface depressions from the BGS Karst database are of anthropogenic origin, as discussed below. Figure 23 also shows the locations of surface depressions from Environment Agency records, and surface depressions and dissolution pipes recorded in the Natural Cavities database (Applied Geology Ltd., 1993).

The data are biased to where and how studies have been undertaken, and do not reflect the natural distribution of karst features. For example, in the east of the area between Basingstoke and Winchester there is a line of dissolution pipes trending roughly NNW to SSE. These are located along the M3 motorway, and are features encountered during the site investigations for the motorway. There is also a very dense cluster of surface depressions in the east of the area. This is because these include old chalk pits which were not recorded in other areas. Nevertheless there are some patterns that may be related to karst. The surface depressions recorded by the Environment Agency appear to be related to the Chalk-Paleogene margin and may therefore reflect the karst development that commonly occurs along this boundary. There is also a pattern of higher densities of surface depressions and dissolution pipes associated with areas where the Chalk is overlain by the Clay-with-Flints, which would be expected as solutional karstic development is known to be common in this geological setting. It is likely that dissolution pipes will be ubiquitous in areas where Clay-with-Flints and some other superficial deposits occur.

Edmonds (1983) suggests densities of solution features in the Chalk in the Salisbury Plain and Hampshire Downs (western and eastern parts of the C5 area) of <5 and 5-10 features per 100 m^2 respectively, with densities of 21-30 features per 100 km^2 in the very north of the area. However, as shown in Figure 23 and discussed in this section, the density of solution features in the area is likely to be much higher than suggested by Edmonds (1983). Hopson et al. (2006) suggest that solution feature densities in the Hampshire area are likely to be between 10 and 50 per km^2, with the main control on the distribution of these features being the presence or absence of a low permeability cover, such as Clay-with-Flints deposits. Hopson et al. (2006) also suggest that there are likely to be many solution features around the headwaters of the Bourne, Till, and Chitterne Brook, where a large amount of recharge to the Chalk occurs. A survey of surface karst features in the area, using both desk based methods and field mapping, was conducted by Wood Consultants in 2021 for Southern Water.

Dolines and dissolution pipes in the area are discussed in several reports and papers, and an overview of the information from these is provided below, described broadly from west to east, with the locations of the places described in the text shown in Figure 23, and summarised in Table 2.

Table 2. Sites discussed in the text where surface karst/dissolution pipes are recorded.

No.	Site	Description	Source
1	Clay Pit Hill	Large solution feature	Hopson et al. (2006); Kellaway (1996)
2	Quidhampton Quarry	Solution pipes	Hopson et al. (2006)
3	Everleigh	Solution features	Farrant et al. (2001)
4	Sidbury Hill	Solution features	Farrant et al. (2001)
5	South Tidworth	Solution features	Farrant et al. (2001)
6	Collingbourne Wood	Solution features	Farrant et al. (2001)
7	Quarley Hill	Solution pipe	Aldiss (2000)
8	Upper Enham	Solution pipes and surface depressions	McDowell et al. (1975)
9	Hannington to Woodgarston area	BGS report on karst	Bunting et al. (2021[b])
10	West of Basingstoke	BGS report on karst	Mathewson et al. (2021[c])
11	Preston Candover to Alton	BGS report on karst	Bunting et al. (2021[a])
12	Basingstoke	Solution pipes	Chartres and Whalley (1975)
13	Soberton	BGS Karst Study	Farrant (2003)
14	Lower Froyle Pit	Clay-with-Flints infilling solution pipes	Farrant (1997)

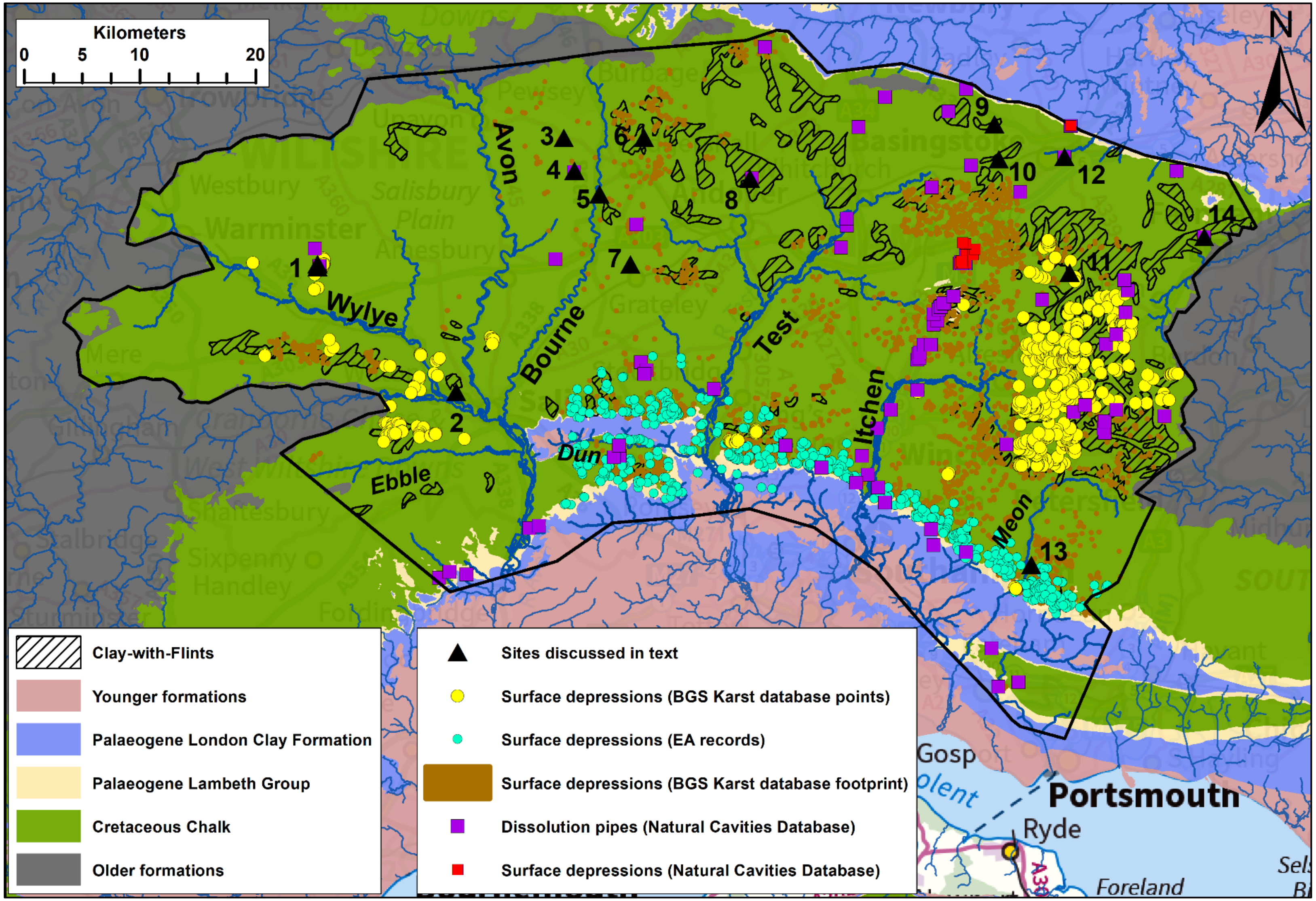

Figure 23. Surface depressions/dolines and dissolution pipes in the C5 Chalk area

Although there are fewer records of solution features in the west of the C5 area than in the east, there are some distinctive features. Above the upper reaches of the Wylye, there is a significant solution feature at Clay Pit Hill near Chitterne (Site 1 on Figure 23). This feature is in the BGS Karst and Natural Cavities databases and discussed by Kellaway (1996), who notes that the infill material has been excavated for centuries. The feature is significant due to the thickness of the clay and sand infilling, which has been demonstrated in boreholes that were drilled at the site in 1972 (Hopson et al., 2006). Hopson et al. (2006) report that the borehole data suggested that the feature is a bowl-shaped solution feature which has deeper and narrower solution pipes within it which extend to a great depth (more than 20 m), and perhaps to the local water table at the time that it was formed. Hopson et al. (2006) also note that there are other karst dolines in the Clay Pit Hill area.

At Quidhampton (near the confluence of the River Wylye with the River Nadder; site 2 on Figure 23), there is a large chalk quarry where several solution pipes have been observed (Hopson et al., 2006). An example of one of these solution pipes is shown in Figure 24.

To the west of the upper reaches of the Bourne, Farrant et al. (2001) report that there are high densities of solution features in the area between Everleigh and Sidbury Hill (Sites 3 and 4 on Figure 23). There are also high densities of solution features on the scarp crest to the east of South Tidworth, and at Collingbourne Wood near Ludgershall, associated with the Clay-with-Flints (sites 5 and 6 on Figure 23). Further south, site 7 is a solution pipe reported on Quarley Hill (Aldiss, 2000).

McDowell et al. (1975) undertook a geophysical survey at Upper Enham near Andover and identified some subsurface dissolution pipes which had no surface expression. The precise location of this site is not recorded, but the location of Upper Enham village is shown as site 8 on Figure 23. McDowell et al. (1975) also noted that there were several large depressions about 300 metres north of the site which were thought to be "swallow holes", they may be referring to dry dolines, rather than active stream sinks.

Figure 24. Solution pipe in a quarry at Quidhampton near Salisbury (from Hopson et al., 2006). BGS image P598768

In 2021, the British Geological Survey conducted three desk based karst studies in the northeast of the C5 area. In the Hannington to Woodgarston area (Site 9 on Figure 23) Bunting et al. (2021[b]) identified 20 surface depressions from historic maps and BGS geological field slips, but suggested that most of them were likely to be of anthropogenic origin. They did note that there is a dissolution pipe at NGR (SU 54055584), and suggested that there are likely to be many more in this area, associated with the Clay-with-Flints. A similar desk-based study was undertaken in an area just to the west of Basingstoke (Mathewson et al., 2021[c]; site 10 on Figure 23). A number of surface depressions were identified (Figure 25). Based on LiDAR and aerial photographs some were thought to be natural karst dolines (labelled as "Surface depressions" in Figure 25), but may be worked chalk pits which resemble natural depressions. The third desk-based assessment of karst features was conducted for the area around Alton (Bunting et al., 2021[a], site 11 in Figure 23). Many surface depressions and dolines are recorded in this area (Figure 26). Bunting et al. (2021[a]) considered information from historic BGS geological field slips and OS maps and concluded that many of these may be anthropogenically formed surface depressions rather than karst dolines, due to their large size. Many of the features identified in Bunting et al. (2021[a]) are focussed around the Clay-with-Flints deposits, often at the boundary with the underlying Newhaven, Seaford and Lewes Nodular Chalk formations. It is unclear how many are natural or anthropogenic. Bunting et al. (2021[a]) also suggested that there are likely to be many more dissolution pipes associated with the Clay-with-Flints.

Dissolution pipes have been identified in the northeast of the C5 area, including some that were revealed in the Chalk at a building construction site in Basingstoke (Chartres and Whalley, 1975; site 12 on Figure 23). Multiple pipes were recorded at this site which were infilled with overlying clay and gravel deposits. Chartres & Whalley (1975) provide some photographs of these features.

In the southeast of the C5 area, Farrant (2003) identified 269 surface depressions in the Soberton area, north of Fareham, with most located on Clay-with-Flints (Site 13 on Figure 23). This was part of the field survey discussed in Section 2.2.2, with features shown on Figure 12. Farrant (2003) noted that some are likely to be karst dolines and some are likely to be anthropogenic pits, and this study illustrates the difficulties in determining whether surface depressions are of karstic or anthropogenic origin (e.g. Figure 27).

In the Lower Froyle area (site 14 in Figure 23), Clay-with-Flints deposits are mostly the remnants of dissolution pipes (Farrant, 1997). Examples can be seen in the Renoun Limeworks Pit (Figure 28), with pipes up to 6 m below the surface (Farrant, 1997).

Overall, sediment infilled dissolution pipes are likely to occur ubiquitously and at high densities where the Chalk is overlain by Clay-with-Flints or other superficial deposits. There are also likely to be many karst dolines, especially associated with the Chalk-Paleogene margin and perhaps also with the margins of the Clay-with-Flints deposits. However, many of the surface depressions recorded in the area are likely to be of anthropogenic origin. Due to the difficulties of distinguishing between karstic dolines and anthropogenic pits, in a recent study which used multiple strands of evidence to describe different spatial karst domains in the Solent area (which includes the C5 area of this report), dolines/dissolution pipes were not used as a factor in defining the domains (Cullen-Gow et al., 2022). Instead, the geological setting was used, as it was considered a more reliable factor in determining the likely distributions of surface karst features.

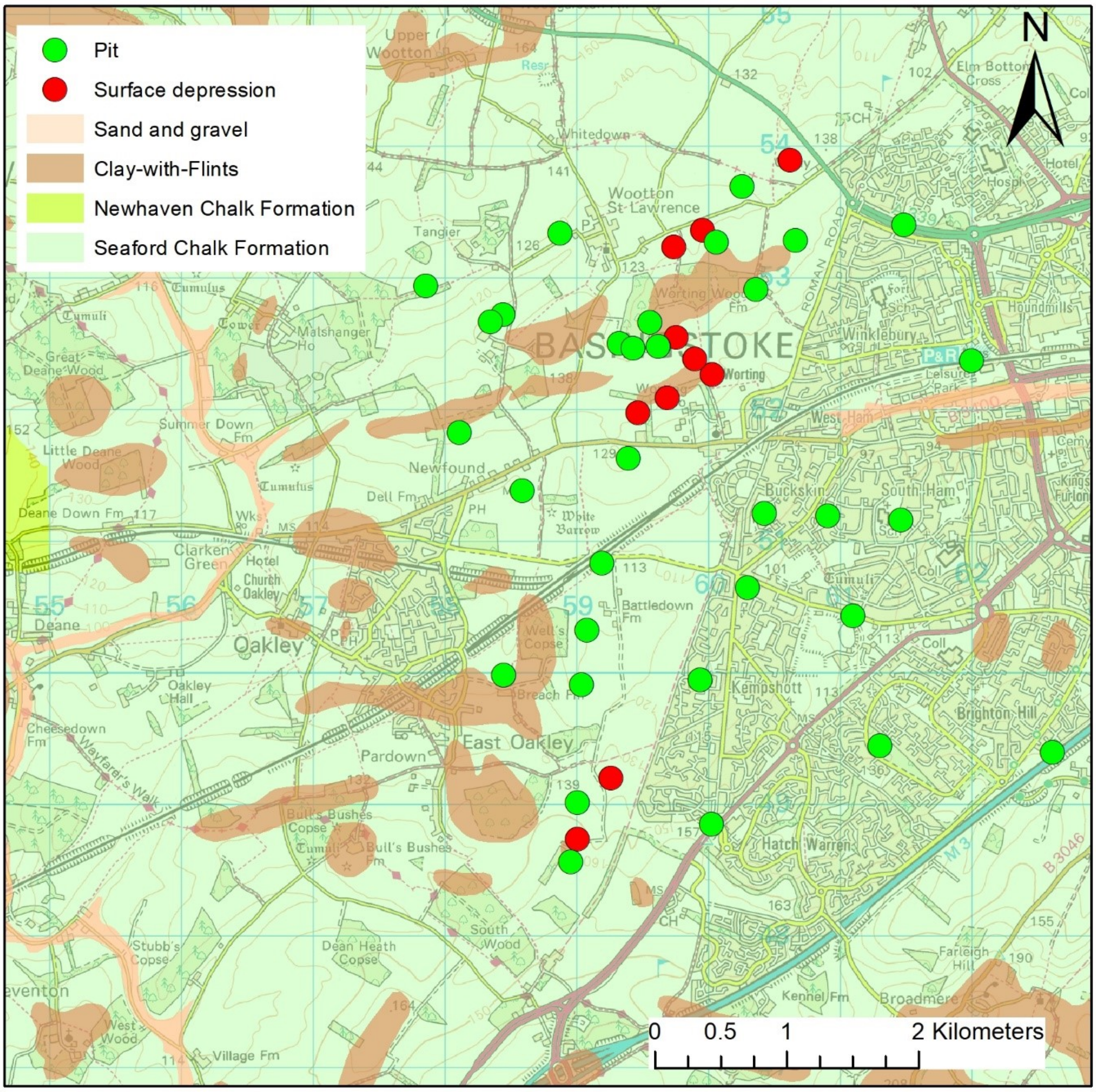

Figure 25. Surface features around Basingstoke from Mathewson et al. (2021[c]).

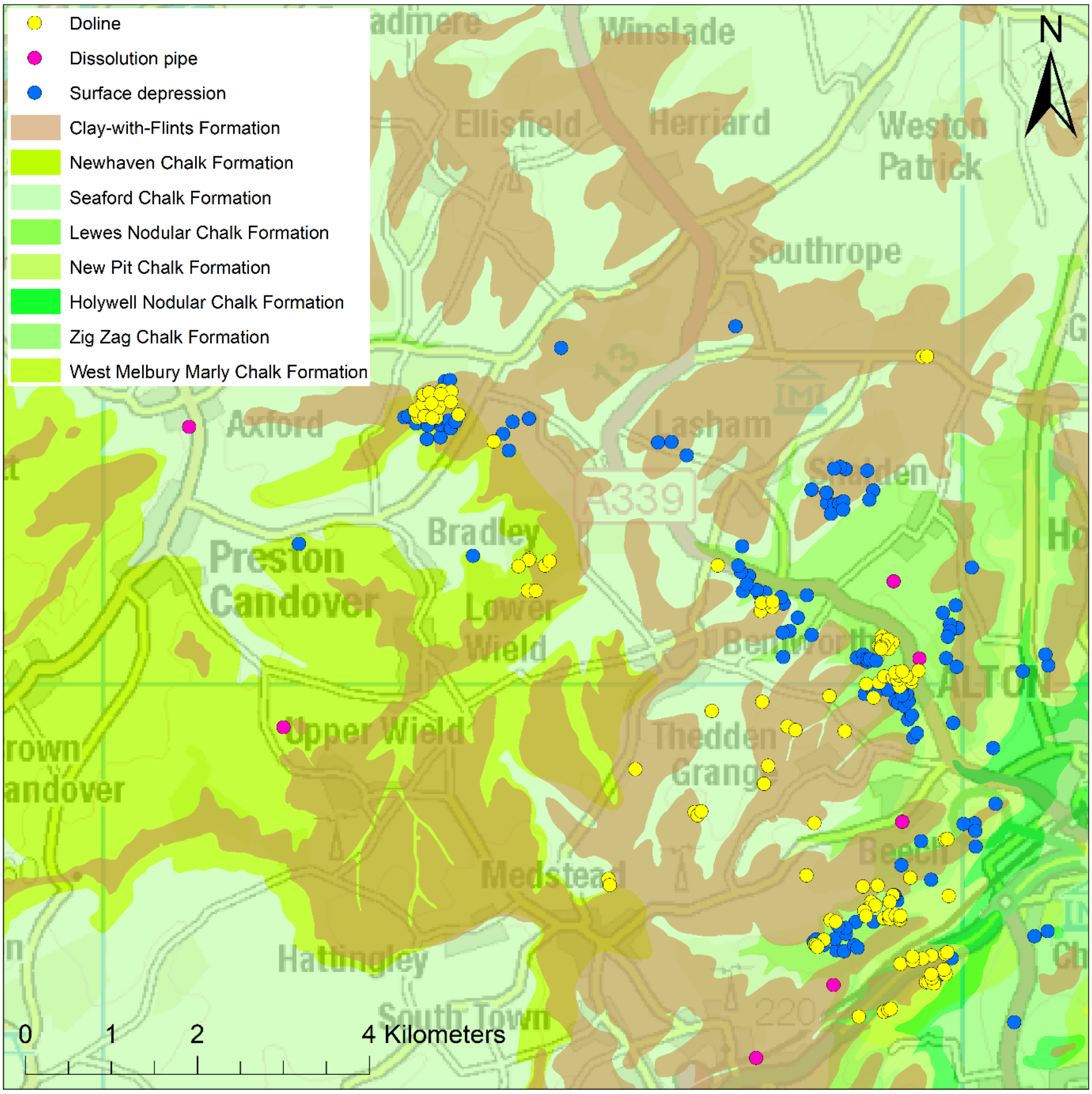

Figure 26. Possible karst features in the Preston Candover to Alton area from Bunting et al. (2021[a]).

Figure 27. Shallow depression in a dry valley in the Soberton area (SU 9260 1565) that may be a karst doline or a shallow pit that has been ploughed in (from Farrant, 2003)

Figure 28. Clay-with-Flints infilling dissolution pipes at Renoun Limeworks pit, Lower Froyle. Photo by A. Farrant.

2.4 SPRINGS

There are hundreds of records of spring locations in the C5 area which are likely to be springs which discharge chalk groundwater (Figure 29). The records are mainly from the BGS Karst database which includes some springs identified from OS maps, BGS geological field slips and BGS memoirs. Spring data have not been systematically collated, and there are many more springs on old Ordnance Survey maps that are not included on Figure 29. Three sites that are estavelles (also known as bourne holes) are also shown (reported by Aldiss, 2000; Farrant et al. 2001; and Whitaker et al., 1910), and some of the other springs in the C5 area may also act as estavelles.

2.4.1 Spring flows

Large springs are indicative of karstic networks, and in general the higher the flow the more extensive the solutional networks (Worthington and Ford, 2009; Maurice et al., 2021). Identifying springs with large flows is useful for understanding the karstic development in the Chalk and improving conceptual models of groundwater flow. However, there are very little data on spring flows in the C5 area. Some springs with reported discharges of more than 100 l/s are shown in Table 3 (with numbers indicating locations on Figure 29). For most sites recorded in the BGS spring datasets, the discharge is unknown. It is also likely that the flows from many springs have substantially reduced since the development of water resources for supply. Indeed, many water supply abstraction boreholes in the area are sited near to springs (Hopson et al., 2006; Allen and Crane, 2019). It may be a very long time since many springs had their natural flow volumes. Whitaker et al. (1910) report that Col. G. Greenwood had written a letter to the Hampshire Chronicle in 1886 noting that "springs about Bishops Sutton, Bighton and Hinton which are among the earliest sources of the Itchen, have been for some time dying off".

The "large springs" shown on Figure 29 are all likely to have (or have had prior to groundwater development) substantial flows of 10s or in some cases 100s of litres per second. Although there are no discharge data for most of these sites, there are references that indicate that they are or were large. Many of these were identified from descriptions in Shore (1890), Whitaker et al. (1910), or Whitaker and Edmunds (1925). Although many more springs were discussed in these references, only those that were described as having a "great" flow, or similar were classified as "large" in Figure 29. Hopson et al. (2006) provide a list of "significant springs" and these are also classed as large; and other large springs are identified from a report on Wiltshire springs by Buglife (2014). It is very likely that there are many more large springs in the C5 area that have (or once had) flows of 10s or 100s l/s, and further work to develop a better dataset on large springs would be useful.

2.4.2 Spring geological setting

There are broadly four groups of springs apparent in Figure 29:

(1) *Springs that emerge from the base of the Chalk or the top of the underlying Upper Greensand Formation, many of which feed the headwaters of chalk rivers.*

There are many examples around Alton and Selbourne in the east; and also in the northwest, for example at Bratton and Westbury. In many places the Chalk and Upper Greensand Formation are in hydraulic continuity and hence chalk groundwaters are discharged through Upper Greensand springs (Allen and Crane, 2019). One example where this occurs is the springs which feed the headwaters of the River Wey near Alton, where springs emerge from the Upper Greensand at Froyle Mill (Bunting et al., 2021[a]).

(2) *Springs in the Seaford/Newhaven Chalk Formations that form the headwaters of chalk rivers.*

Examples include the very large springs in the Basingstoke area (Greywell, Mapledurwell and Newram, Table 3; sites 2 to 4 on Figure 29) which form the headwaters of the River Lodden; the Polhampton springs at the head of the River Test; and springs in the headwaters of the Itchen and Alre (Figure 22).

(3) *Springs that emerge from the Chalk in the river valleys.*

These sometimes discharge through thin superficial deposits (predominantly river gravels) which may obscure the locations of the karstic chalk discharge points. Springs in this setting may be associated with particular karst inception horizons such as marls, hardgrounds and flint (Farrant, et al. 2001; Hopson et al., 2006; Soley et al., 2012; Allen and Crane, 2010). For example, Farrant et al. (2001) note that the large perennial springs at Idmiston occur in the lower Seaford Chalk Formation, about 20-30 m above the Lewes Chalk Formation, and may be associated with a major tabular flint band.

(4) *Springs that are concentrated along the Chalk-Paleogene margin.*

A significant example of a karst spring in this setting occurs at Bishops Waltham (Figure 12). This is a classic chalk karst spring which bubbles up through sand and is the source of the River Hamble. Hampshire County Council provide a good video of this spring at: https://www.facebook.com/CountrysideHCC/videos/806551703187095/. Another example of a large karstic spring associated with the Paleogene margin occurs at Mottisfont in the lower reaches of the River Test. This spring is pictured during drought conditions in Figure 30. In wetter times this spring has flows of more than 100 l/s (Whitaker et al., 1910), and may be the outlet for stream sinks in the area (Section 2.2.1). It is likely that there are other large karstic springs associated with the Chalk-Paleogene margin. Many of them may have substantially reduced flows as large groundwater abstractions have been sited on some of these large former springs, such as the major springs at Otterbourne in the lower reaches of the Itchen, as well as those in the Test and Meon valleys.

2.4.3 Karstic characteristics of springs

The complex bourne behaviour observed in streams in the C5 area is indicative of the presence of karstic springs. Riverheads migrate downstream in dry periods with sudden reactivation of upstream springs (sometimes long distances upstream) as the water table rises. This type of riverhead migration is typical of karst aquifers where the capacity of the conduit system feeding the perennial spring is exceeded resulting in sudden activation of previously unsaturated conduits feeding ephemeral upgradient springs (Maurice et al., 2021). Some examples of this occur in the headwaters of the River Test, where a permanent spring around 10 km west of Basingstoke predominantly feeds the River Test, but in particularly wet seasons the river is fed by springs approximately 2 km further east (Whitaker et al., 1910). Whitaker et al. (1910) also discuss a similar occurrence in the “St Mary Bourne stream”, which is a tributary of the Test (now known as the Bourne Rivulet). Here, the source springs are further west during wet periods. To the west in Wiltshire, the Bourne, Till and Chitterne rivers show complex bourne behaviour as shown in Figure 18, Figure 19, and Figure 20. The flow patterns in the Bourne are particularly complex (Farrant et al., 2001; Allen and Crane, 2019). There are further details of the bourne behaviour of the major rivers in the C5 area in Allen and Crane (2019). This type of bourne behaviour results in groundwater flooding in the C5 area. Fissure/conduit networks that are usually unsaturated (observed in borehole image logs) become active during exceptionally wet periods resulting in the reactivation of springs at higher elevations (Allen and Crane, 2019).

Karstic springs that are fed by stream sinks are characterised by high turbidity and the presence of short residence time indicators such as coliforms (Maréchal et al., 2021). Whilst there are no data for the springs in the C5 area, it is likely that some of them have these characteristics, and especially those associated with the Paleogene margin, where spring discharges are likely to include some rapid flow derived from stream sinks.

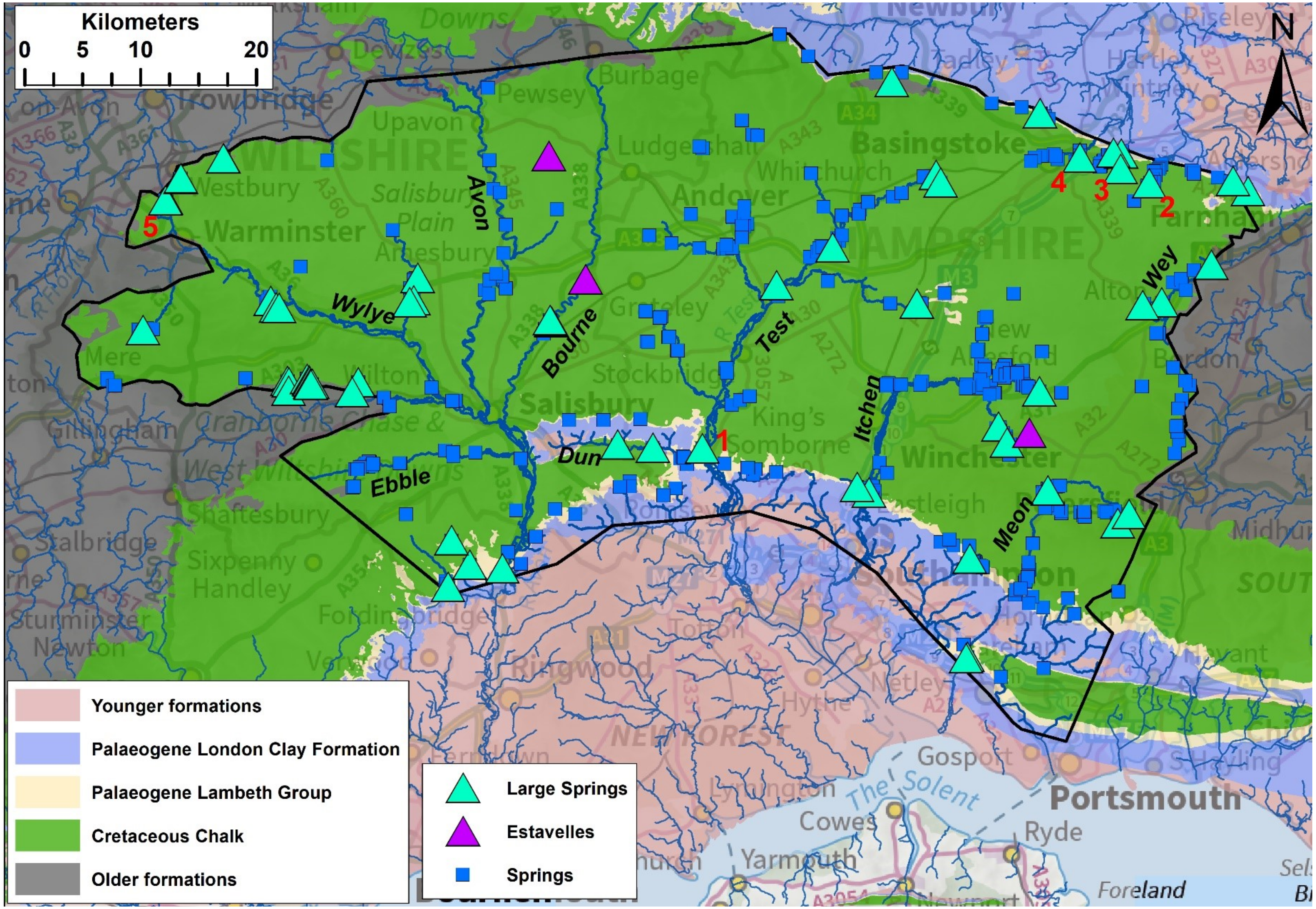

Figure 29. Springs likely to be discharging groundwater from the Chalk

Table 3. Some spring discharges in the C5 Wessex Basin Chalk area

Spring(s)	Easting	Northing	Discharge (l/s)	Source
(1) Mottisfont	432645	126888	105	Whitaker et al. (1910)
(2) Greywell	471202	149747	131.5	Hennell (in Whitaker et al. (1910)
(3) Mapledurwell	468757	150987	104.2	Hennell (in Whitaker et al. (1910)
(4) Newram (Basingstoke)	465233	151949	236.8	Hennell (in Whitaker et al. (1910)
(5) Biss Bottom, Upton Scudamore	386393	148306	21.5; 126	Whitaker and Edmunds (1925); BGS records

Figure 30. Dry streambed at Mottisfont spring during late summer drought in 2005. Photo by A. Farrant.

3 Tracer tests

Tracer testing was conducted in 1976 in the Candover catchment (an upper tributary of the River Itchen) in Hampshire (Collisch, 1976; Ward et al., 1998). Rhodamine WT was injected into an observation borehole and detected at three abstraction boreholes between 1800 and 3500 m away. Velocities based on time to first arrival were 163, 4750 and 229 m/day, with tracer recoveries of 0.8, 1.8 and 1.7 % respectively (Table 4). These tests demonstrate rapid groundwater flow in the saturated zone over distances of several kilometres indicating the presence of extensive karstic solutional networks. Tracer recoveries are fairly significant (~1-2 % at each outlet), given the distance involved and the fact that the tracer was not injected directly into a karst feature. Tracer losses are likely to reflect dilution, dispersion and diffusion along the flow paths.

Table 4. Tracer pathways defined by Collisch (1976).

Injection site	Outlet	Distance (m)	Velocity based on time to first arrival (m/day)	Tracer recovery (%)
OB4	Axford	1800	163	0.77
	Bradley	3500	4750	1.77
	Wield	3500	229	1.73

4 Other hydrogeological evidence of karst

4.1 HIGH TRANSMISSIVITY

High transmissivities of more than 1000 m^2/day occur widely across the C5 area (Allen et al., 1997; Figure 31). The data presented in Figure 31 are the best “locality” estimate of transmissivity from the BGS Aquifer Properties database (Allen et al., 1997). From the 40 reported estimates, the mean transmissivity is 2400 m^2/day, the median is 1600 m^2/day, and the maximum is 9000 m^2/day. These high transmissivities are indicative of well-connected networks of solutional fissures and conduits in the saturated zone. The pumping test data tend to be biased to successful abstractions, where these networks have been intercepted. At many sites there are multiple estimates of transmissivity, either because pumping tests were carried out on different boreholes, or because multiple tests were carried out on the same borehole. For each borehole, the best estimate of transmissivity was determined based on factors such as the length of the test, and then a site “best locality” value (incorporating all tests within 100 m) was determined by selecting the most reliable test result (Allen et al., 1997). The maximum and minimum transmissivity values for each site are also available. Many sites in the C5 area had higher maximum values, with 6 having a maximum value of more than 10,000 m^2/day, and the highest being 37 000 m^2/day. Whilst the “locality” values may generally be the most useful, in considering karst, the maximum values may also be of interest where within site variation is due to karstic heterogeneity.

Most of the highest transmissivities are in the east of the C5 area, measured as part of several groundwater investigations of the headwaters of the River Itchen and tributaries (Giles and Lowings, 1991; Southern Water Authority, 1984; Southern Science, 1991; Irving, 1993; see Section 4.2). A very high transmissivity of 23 000 m^2/day is also recorded for the Chalk at a site along the Test, in the south of the C5 area. Transmissivities are discussed in more detail in Allen et al. (1997) and Allen and Crane (2019) who suggest that the general trend in the area is high transmissivities in boreholes in young Chalk formations in the valleys, which decrease towards the interfluves. They also note that high transmissivity occurs along the axes of synclines and faults.

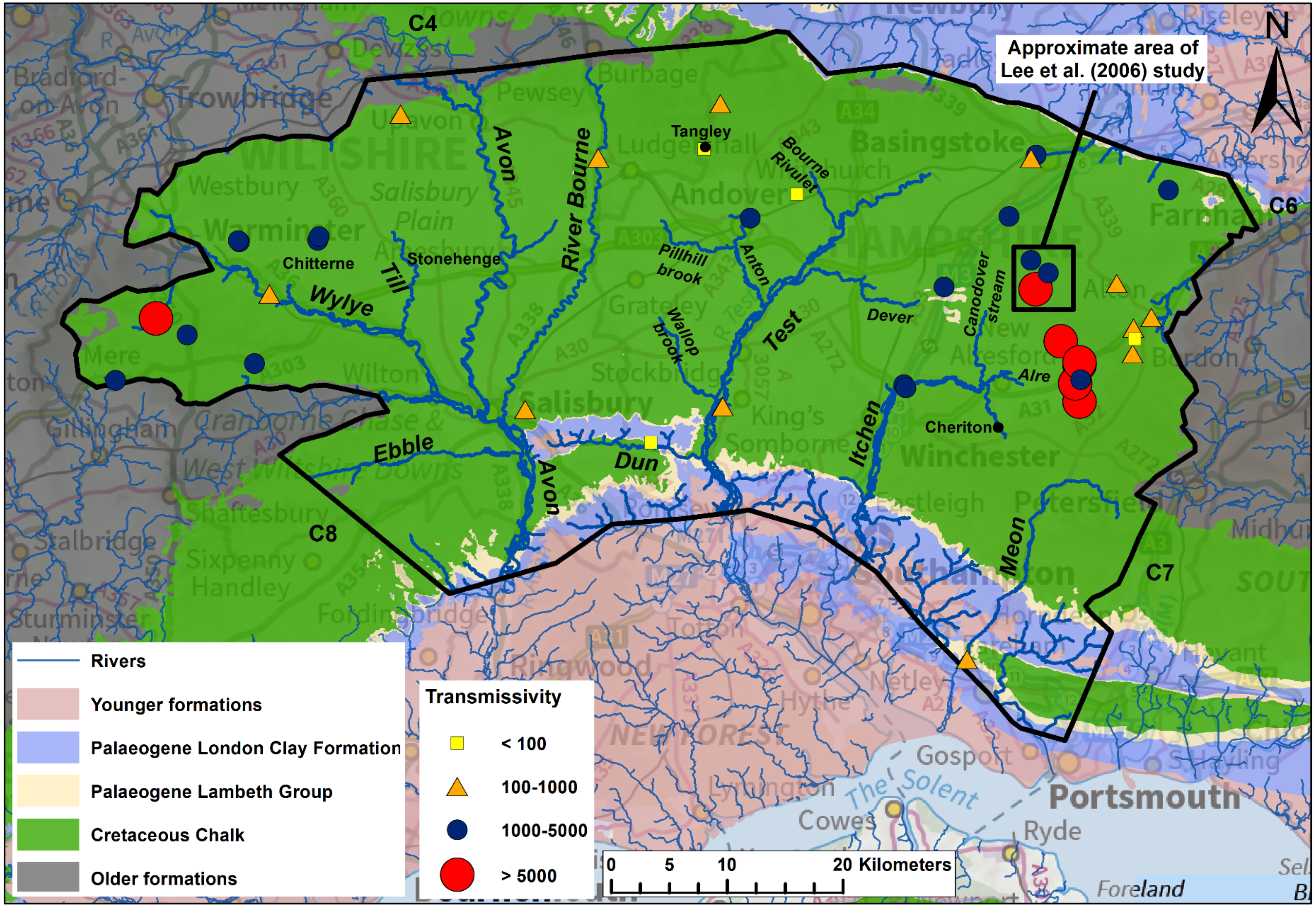

Figure 31. Best locality values of transmissivity (T) in m^2/day from the BGS aquifer properties database (Allen et al.,1997).

4.2 INDICATIONS OF KARST FROM BOREHOLE WATER LEVEL DATA

Borehole studies can provide evidence of karstic solutional networks where hydraulic gradients are low, where cones of depression during pumping tests are large or irregular in shape, where groundwater catchments extend into different topographical catchments, or where borehole water levels respond rapidly to rainfall. There are examples in the C5 area, and particularly from studies in the catchments of the Candover, Alre and Cheriton tributaries of the River Itchen which have been extensively investigated and discussed (Headworth et al., 1982; Giles and Lowings, 1990; Allen et al., 1997; Lee et al., 2006; Allen and Crane, 2019). Hydraulic gradients are generally low in this area (Allen at al., 1997), and the groundwater catchments of the Candover and Alre rivers do not coincide with the surface water catchments (Giles and Lowings, 1990).

The Candover and Alre catchments were the focus of a river augmentation investigation in the 1970s, and the results from the Candover catchment are discussed by Headworth et al. (1982): Six boreholes linked by a pipeline to the perennial head of the Candover stream had individual yields of ~17-73 l/s, and high transmissivities of 1500 to 8500 m^2/day when tested in 1975. Pumping produced a circular, shallow, but extensive cone of depression; with drawdown extending well beyond the topographical and groundwater catchment of the Candover stream. Specific capacities measured during the drought of 1976 were between 29 and 85% lower. Headworth et al (1982) noted that seasonal groundwater level fluctuations were only about 3-5 m (and unusually, even less on the groundwater divide) and were one third lower than normally observed in unconfined chalk. They also observed that the hydraulic gradient in the area (1 in 500) was particularly low (about half that normally observed in unconfined chalk). The conclusion of the study was that there is a thin highly permeable layer just below the water table, which acts as an important conduit feeding the stream flows. Tracer testing in the Candover catchment also demonstrated extensive karstic networks connecting observation boreholes to abstractions (Section 3); and borehole water level responses to recharge are also consistent with these findings. Lee et al. (2006) investigated borehole water level responses to rainfall at six sites in the Chalk of Southern England, including a site at Preston Candover in the Candover catchment. They found that at this site water levels usually responded within a day of rainfall and attributed this to fissure flow.

The work in the Candover and Alre tributaries of the River Itchen is also reported by Giles and Lowings (1990). They note several unusual characteristics in the groundwater contours, and also suggest that there are perched groundwater levels in the Alre Catchment. They report that during pumping tests the cone of depression in the Alre catchment was shallower but much more extensive than that in the Candover catchment, and note that the groundwater catchment of the River Alre extends 8 km to the east of the surface water catchment. Giles and Lowings (1990) also reported a large cavity in one of the pumping boreholes (see Section 2.1). It appears that transmissivity in the Alre catchment is controlled by "large diameter conduits", with boreholes that intersect these having very high transmissivity whilst others that do not intercept them have much lower yields (Giles and Lowings, 1990; Allen et al., 1997). This illustrates the high heterogeneity created by karst processes.

Also in the Alre catchment, flows from several artesian boreholes around Alresford, that were used for watercress farm irrigation, were assessed between 1972 and 1975 (Headworth, 1978). The data showed large average flows of approximately 11 l/s, with some flows of more than 40 l/s. Flow logging showed that most of the flow into the boreholes was associated with solutionally-enlarged fissures, generally in the top 30 m (Headworth, 1978).

There are some other examples away from the Upper Itchen where borehole data have indicated karstic processes. An example of the extensive connectivity of a karstic fissure and conduit network is reported by Mortimore (2012). During site investigations for the proposed A303 tunnel at Stonehenge, high permeability fissure zones were identified in investigation boreholes; and pumping trials to investigate dewatering potential indicated widespread interconnectivity in the Chalk aquifer with drawdown of only 1 mm in all of the monitoring boreholes over a very wide area (Mortimore, 2012). Another example occurs at Chitterne, where pumping results in rapid drawdown 6 km away to the SE (Soley et al., 2012). Soley et al. (2012) discuss movement of groundwater between topographical catchments. For example, in groundwater models high transmissivity areas were needed in the River Till catchment to represent flows across catchments in the Chalk Rock and around the top of the Lewes Chalk Formation to the River Avon (Soley et al. 2012).

4.3 WATER QUALITY INDICATORS OF KARST IN BOREHOLES

Some contaminants are indicative of rapid groundwater flow and connectivity between abstraction boreholes and the surface (e.g. coliforms, turbidity, pesticides that degrade rapidly in the subsurface). This has not been systematically investigated in the C5 area, but there are many examples of abstractions where these contaminants are present (Stuart et al., 2016; Farrant et al., 2018; Bunting and Ascott, 2019; Mathewson et al., 2021[b], Mathewson et al., 2021[c], Bunting et al., 2021[a]). Turbidity has also been reported in adits at Otterbourne following rainfall (Allen et al., 1997). At many sites these indicators of short residence time groundwater are present at very low levels suggesting either that there are limited pollutant sources in the catchment, or that there is high dilution of the rapid flow component with longer residence time groundwater. At some abstraction sites these contaminants are present at higher levels suggesting less dilution and attenuation.

An investigation of the impacts of a septic tank discharge on chalk groundwater at Cheriton in the River Itchen catchment is reported by Environment Agency (2007). Variable levels of coliform contamination (2 to 170 cfu/100 mls) were present in all the monitoring boreholes despite very small sample numbers (samples taken during borehole drilling and on 4 subsequent occasions). Overall, Environment Agency (2007) conclude that there is fast vertical flow due to fissuring beneath the septic tank outflow pipes, with rapid transport to the water table where high dilution and dispersion occurs within a large volume fast flowing aquifer.

Edmonds (2008) discusses a pollution incident at Tangley in Hampshire (Figure 31), in which a village water supply was polluted by farm waste slurry. Edmonds (2008) reports that the slurry travelled 100 m through a solution pipe and solutional fissures in the karstic chalk beneath Clay-with-Flints, reaching the water table within 24 hours, and travelling down gradient for 200 m to the water supply well. This indicates rapid karstic flow within the Chalk at this location despite the low transmissivity of < 100 m^2/day reported nearby (Figure 31).

4.4 KARST INCEPTION HORIZONS

Geological mapping and hydrogeological studies have shown the strong lithological controls on groundwater flow in the area, reflecting the karstic inception horizons within the Chalk (flints, hardgrounds and marls) that provide the focus for solutional development. Allen and Crane (2019) provide an extensive overview of the lithological controls on groundwater flow in the area, providing information about geophysical logging studies which have identified solutional flow horizons. Many of these borehole logging studies have shown that flows come from a small number of solutionally enhanced fractures, and in some boreholes most of the flow comes from a single horizon (for example a borehole in the Bourne catchment where around 80% of the flow was found to come from the Stockbridge Rock Member (Ascott, 2015; Allen and Crane, 2019)). Allen and Crane (2019) also conclude that most of these flows occur within 60 m of the surface.

The strong stratigraphical control on the development of karst in this area is also discussed by Soley et al. (2012). They suggest that in the Wessex Basin chalk there are many places in the stratigraphical sequence where flints, marls and hardgrounds result in solutional development, but that there are three particularly important horizons that are associated with fissure flow to abstractions, river flow losses to the aquifer, and spring discharge. These horizons are the 'Melbourne Rock' and Plenus Marls at the base of the Holywell Nodular Chalk Formation, the Chalk Rock, and the Whitway Rock (usually known as the Stockbridge Rock Member). The Stockbridge Rock Member is an important flow horizon in the River Itchen and the River Test (Soley et al., 2012), and also influences the perennial head of the River Bourne, Wallop Brook, Pillhil Brook and River Anton (Farrant et al., 2001). Soley et al. (2012) suggest that to the west of the River Avon the Chalk Rock is an important flow horizon which is responsible for regional groundwater flows across surface water divides, inflows in abstractions, and spring discharges in the lower sections of the Chitterne and Till rivers. Soley et al. (2012) also note that in these areas the Whitway Rock (Stockbridge Rock Member) is above the water table but they suggest that it may facilitate down dip recharge through the unsaturated zone. The role of these inception horizons for unsaturated zone flow has not been widely investigated, although there do not appear to be many perched springs which might suggest that vertical development of permeability may transfer water from these horizons down through the unsaturated zone.

4.5 KARSTIC FLOWS IN THE UNSATURATED ZONE

Karst processes in the Chalk result in the development of connected solutional pathways through the unsaturated zone which enable rapid bypass recharge to reach the saturated zone, although there appears to be a higher degree of attenuation in the unsaturated zone than in more classic karst (Maurice et al., 2021). Rapid unsaturated zone flow paths occur where karst stream sinks have developed, but can also occur in the Chalk in the absence of surface karst (Farrant et al., 2021). These unsaturated zone flow paths can occur anywhere in the Chalk, their precise locations are difficult to identify, and the overall frequency with which they occur is unknown. However, the C5 area falls within the larger area of the BGS/EA Solent Karst Domains project reported by Cullen-Gow et al. (2022). This project aimed to identify domains where connected flow paths from the surface to the saturated zone enabling some rapid flow though the unsaturated zone are more or less likely to occur.

The karst domains were created in GIS based on six factors: (1) the location of karstic stream sinks; (2) areas of runoff from Paleogene 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. Further details can be found in Cullen-Gow et al. (2022). The resultant domains are shown in Figure 32. There are some areas within the C5 area in Domain 1 where there is a very high likelihood of some connected flow paths from the surface to the saturated zone – these mostly occur in the river valleys where the unsaturated zone is very thin, and in areas associated with the Chalk-Paleogene margin. There are also fairly extensive areas of C5 in Domain 2 with a high likelihood of some connected flow paths through the unsaturated zone, as well as extensive areas where rapid unsaturated zone flow paths are less likely to occur (the areas labelled Moderate and Low on Figure 32).

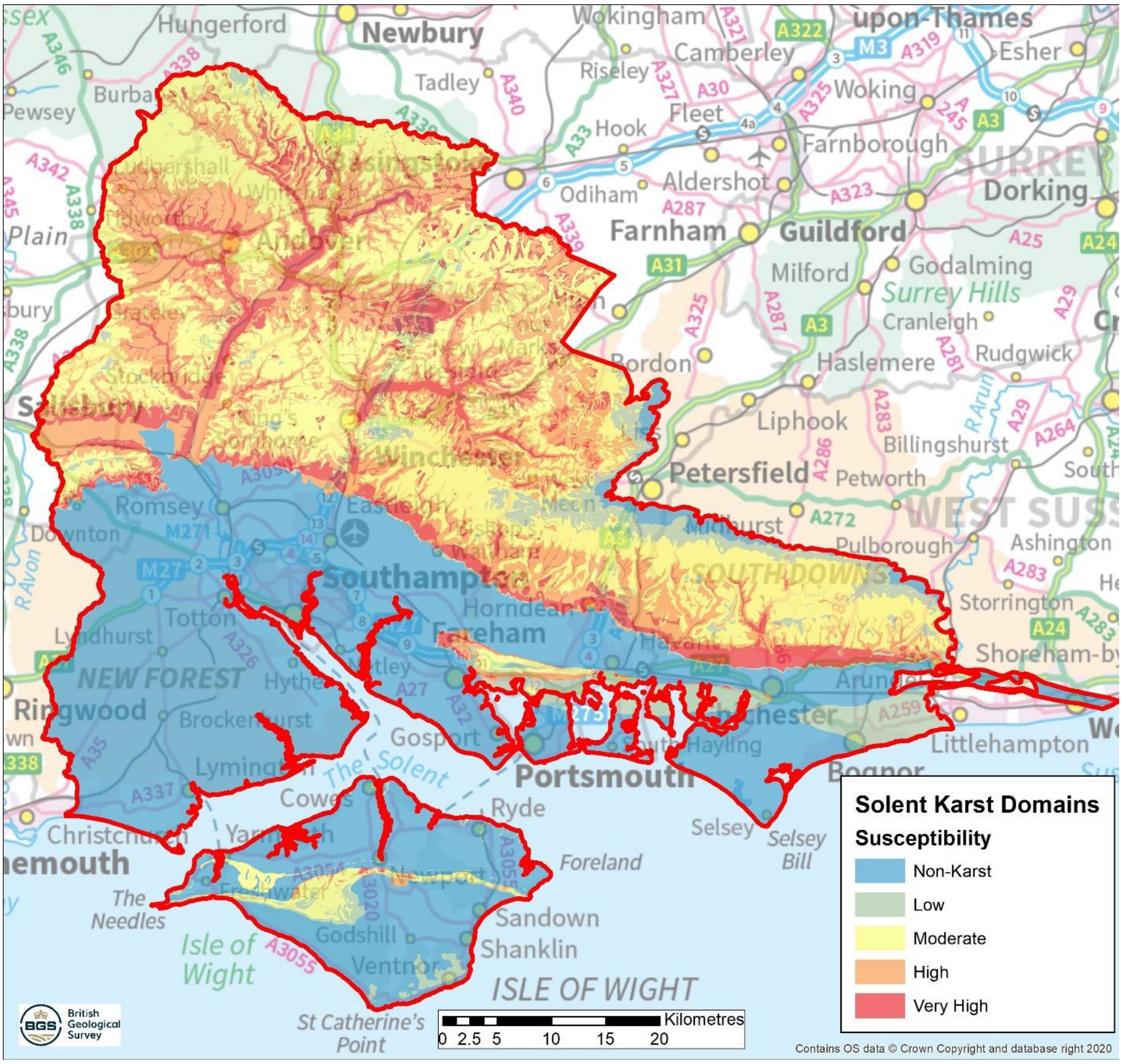

Figure 32. Unsaturated zone karst domains in the Solent area (from Cullen-Gow et al., 2022).

5 Summary

- There is clear evidence of karstification of the Chalk in the C5 Wessex Basin area, but there have been few studies of karst in this area, and karst data are thus quite limited.
- Whilst no enterable caves are recorded in the area, there is evidence of conduit development from borehole images and chalk exposures.
- There are many karst stream sinks in the area, most of which are associated with the Chalk-Paleogene boundary. There is also evidence of chalk streams contributing recharge via losing sections, including the Chitterne Brook, the River Till and the River Bourne. Some features are estavelles, acting as either stream sinks or springs depending upon water level conditions.
- Identification of karst dolines is difficult due to their similarities with surface depressions of anthropogenic origin. Surface depressions are very prevalent in the area, and although many may be anthropogenic features, dolines are likely to be present, especially in the area of the Chalk-Paleogene margin, and along the edges of Clay-with-Flints deposits.
- Dissolution pipes occur at high densities in some places, but the overall distribution reflects the areas where studies have been undertaken, and it is likely that they are very common where there is a thin Paleogene or superficial cover over the Chalk.
- Although there are records of hundreds of springs in the area, the dataset is incomplete. There are also very little data on spring discharges, and improved data on springs are needed.
- Discharge data for a small number of springs shows that they have large flows of more than 100 l/s. There are likely to be many more large springs with flows of 10s or 100s of l/s, that are the natural outlets for karstic solutional networks. There are also likely to be many other springs that would have had large discharges prior to the development of water resources (and may now be difficult to identify).
- Only one tracer test has been conducted in the C5 area. This demonstrated rapid groundwater flow of 163 to 4750 m/day over distances of several kilometres, reflecting the presence of extensive karstic networks of solutional conduits and fissures in the saturated zone. Tracer recoveries are significant (~1-2 % at each outlet), given the distance involved and the fact that the tracer was not injected directly into a karst feature.
- Pumping tests in the area have indicated high transmissivities of 1000s m^2/day, suggesting well connected karstic networks of solutional fissures and conduits in the saturated zone.
- Hydrogeological studies in the area also indicate the presence of karstic solutional networks with: low hydraulic gradients; extensive groundwater catchments that do not reflect topography; water quality indicators of rapid groundwater flow at abstraction sites; and borehole flow logging and geological studies indicating the importance of karst inception horizons in determining groundwater flow.
- Overall there is clear evidence for solutional karstic networks in the Chalk of the C5 area of Wiltshire and Hampshire, and further studies of karst would be useful to assist with groundwater protection and management.
- The impact of karst on recharge and the degree of connectivity between the surface and the saturated zone could be investigated through studies of point recharge via stream sinks, losing rivers, soakaways and SuDs (Sustainable Drainage Systems); and further work on indicators of short residence time groundwater. Further work on saturated zone karst could include consideration of the locations of larger chalk springs, imaging to identify conduits and fissures in abstraction boreholes, and tracer tests.

Glossary

Cave: A subsurface solutional conduit large enough for humans to enter (usually > ~ 0.5 m wide).

Conduit: A subsurface solutional void which is usually circular or cylindrical in cross section. In these reports the term is used predominantly for conduits which are too small for humans to enter (~0.05 to 0.5 m wide).

Doline: A surface depression formed by karst processes.

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

Dissolution tubules: Networks of small cylindrical solutional voids ~ 0.5 cm in diameter found in the 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 ~15 cm, and a planar cross-sectional shape. In these reports the term is 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. This term is not used for surface depressions in these reports due to the confusion arising from sinkholes of both karstic and anthropogenic origin. 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.

Soakaway: An anthropogenically created drainage feature that enables unwanted surface runoff to drain into the ground.

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 these reports 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. Therefore the term stream sink is generally used in these reports, as the presence of an active stream recharging the aquifer is directly inferred.

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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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