BGS Karst Report Series: C6. Karst in the Chalk of the North Downs

Environmental Change, Adaptation & Resilience Programme

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Executive Summary

This report documents the evidence for karst and rapid groundwater flow in the Chalk of the North Downs area in Southern England. It is part of the BGS karst report series 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". 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 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; geological mapping; and through knowledge exchange with the Environment Agency, universities, water companies and consultants.

The report shows that in the North Downs area of the Chalk, there is extensive evidence for karst with dry valleys and many stream sinks and springs recorded; and particular evidence for karst in the Farnham, River Mole, Faversham and Canterbury areas. Throughout the North Downs area, 21 short natural karst caves have been documented. Many stream sinks occur, particularly in association with the Chalk-Palaeogene boundary. Apart from the River Mole where significant karst swallow holes are prevalent, the contribution of major rivers to point recharge via river losses to the aquifer was not assessed in this report. Spring discharges are generally unknown, but some very large springs occur in the area. There has been very little tracer testing conducted, but tracer tests from a doline demonstrated very rapid groundwater flow of ~1000-2500 km/day over a distance of 3.2 km. There is also considerable evidence for karst and rapid groundwater flow at groundwater abstractions in the North Downs area. Consideration of karst and rapid groundwater flow will improve understanding of how the Chalk aquifer functions in this area, and this report provide a basis for further investigations of karst in this area to enable improved management and protection of groundwater resources.

Introduction to the BGS Karst Report Series

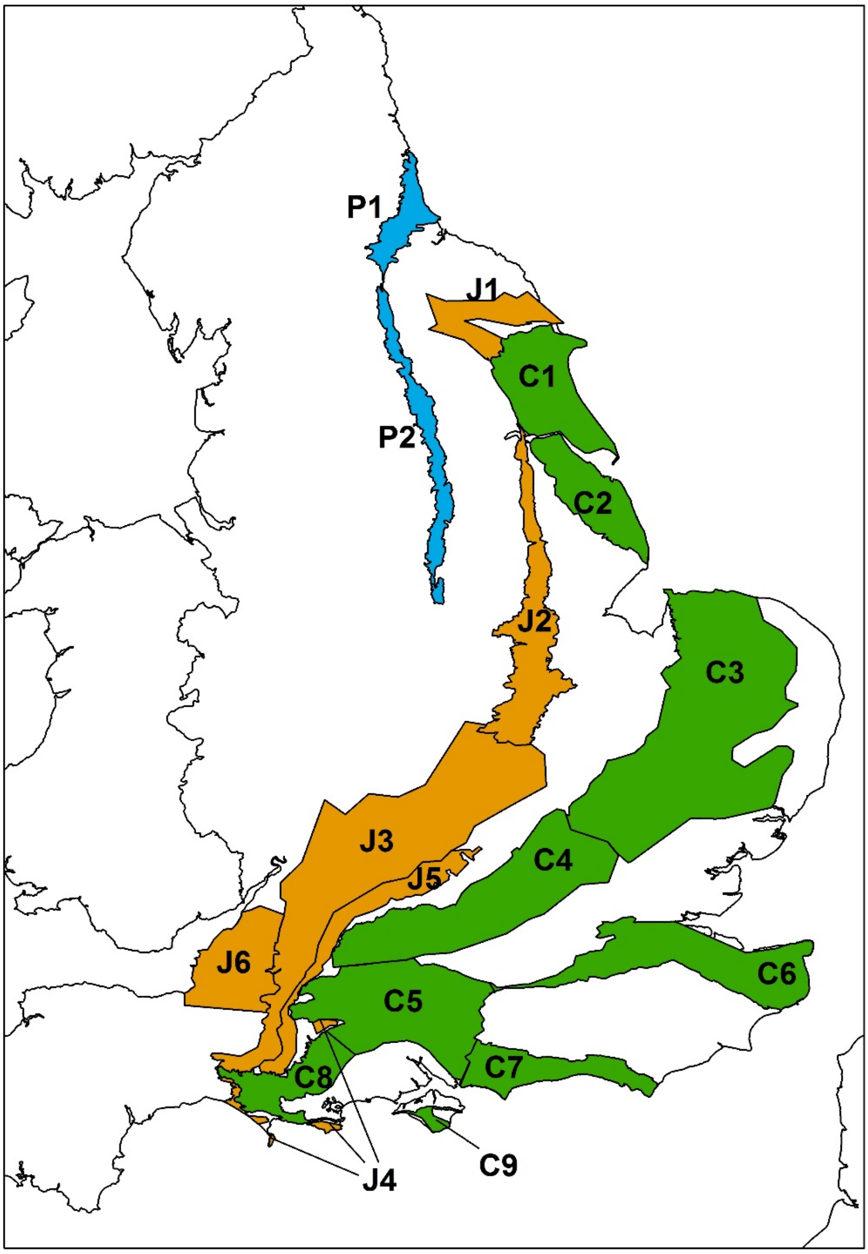
The BGS karst report series is focused on karst aquifers in England in which cave development is limited – The Chalk and the Jurassic and Permian limestones. The series is the main output of the NERC funded Knowledge Exchange fellowship "Karst knowledge exchange to improve protection of groundwater resources" undertaken between 2015 and 2021.

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 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 ~ 5-30 cm diameter and solutionally enlarged fractures (fissures) of ~0.5-15 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 comprises 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 and Inferior Group oolites 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 2021 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 fuller picture of karst development in these aquifers, and to investigate the detail of local catchments. The reports provide an initial overview of the 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 provide a basis 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 Chalk of the Wessex basin
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 Corallian Group limestones of Northern England
J2) Karst in the Jurassic limestones of Central England
J3) Karst in the Jurassic Great and Inferior Oolite groups 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. 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. 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, 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, and in images of borehole walls. Conduits (~5 to >30 cm in diameter) and larger solutional fissures (apertures of > 2 cm) are 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 are 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 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 is comprised of 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 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 that have not 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, and these have been recorded as “assumed large springs”. 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 flowpaths 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 flowpaths 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. 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 low residence time groundwater and/or connectivity with surface water; for example high coliforms, high turbidity, detection of rapidly degrading pesticides, evidence of connectivity with the sea or surface rivers over long distances. These data are not presented to protect site confidentiality, but a general overview is provided where possible.

Acknowledgements

We thank Terry Reeve for providing information, photos and surveys of caves. For their advice and input we thank: Debbie Wilkinson, Graham Earl and Steve Howe from South East Water; Simon Cook, Richard Gamble and Chris Woolhouse from Southern Water; Dawn O Neill, Simon Deakin and other staff from the Environment Agency; and Tim Atkinson from University College London. We also thank Timo Roth for his assistance compiling cave and tracer data. This work was 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 C6 North Downs Chalk area is south of London, extending from just west of Guildford to Ramsgate in the east (Figure 1). The major rivers include the River Mole in the west of the area; and the Darent and Medway in the centre. These two rivers are both tributaries of the Thames, which drain eastwards to the Thames Estuary to the north of the area (Figure 2). In the east, the Little Stour and Great Stour combine to form the River Stour, which drains eastward to the North Sea.

Figure 2 shows the simplified bedrock formations in the area, and the stratigraphical units present are listed in Table 1. The Chalk aquifer is underlain by the Selborne Group mudstones, siltstones and sandstones, which outcrop to the south of the area. The thickness of the Chalk aquifer ranges from approximately 160 to 260 m. To the north, the Chalk is overlain by the clays, silts, sands and gravels of the Thanet Formation, Lambeth Group and Thames Group (Figure 2; Table 1).

The Chalk in the North Downs generally dips gently to the north or north east at up to 5°. Towards the Hogs Back, near Guildford, at the western end of the North Downs, the dip steepens to reach up to 55°, associated with faulting on the northern margin of the Weald Basin. In east London, the Greenwich Fault zone and folding around Cliffe and Purfleet brings the Chalk back up to the surface.

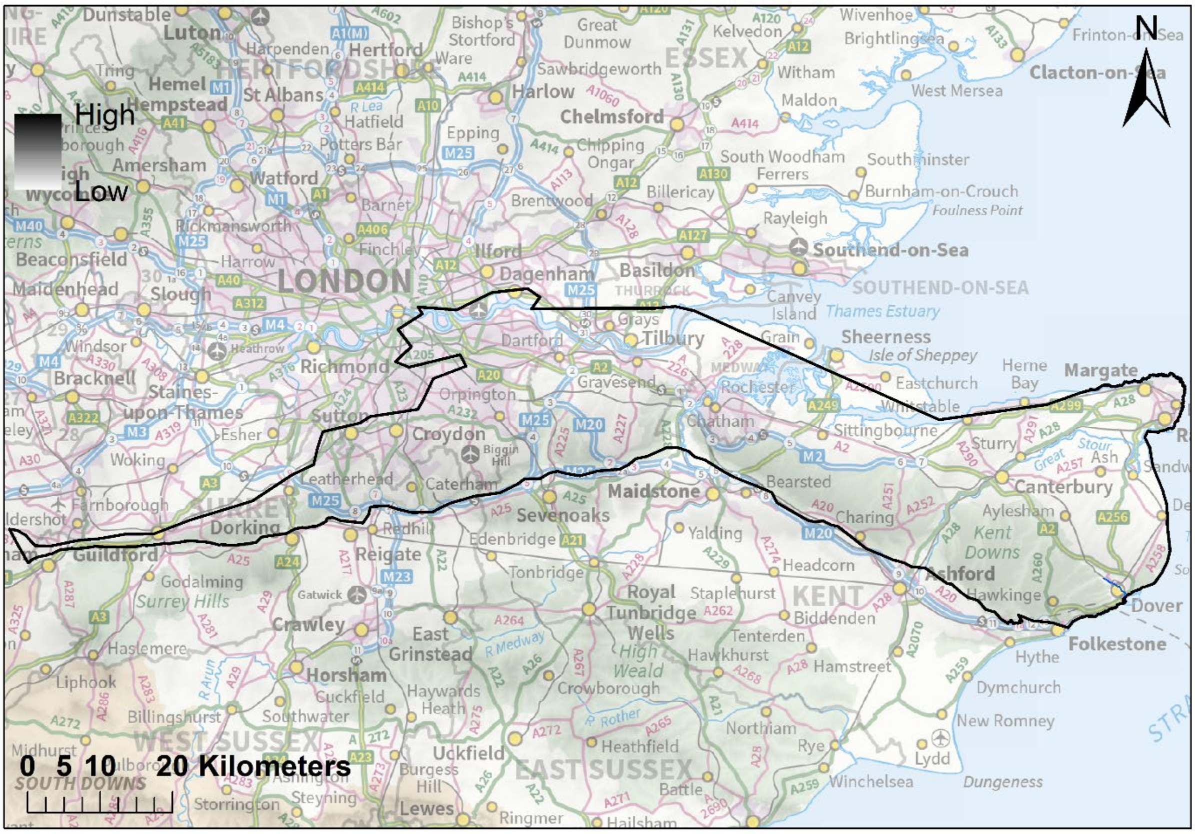

Figure 1. The C6 North Downs Chalk area.

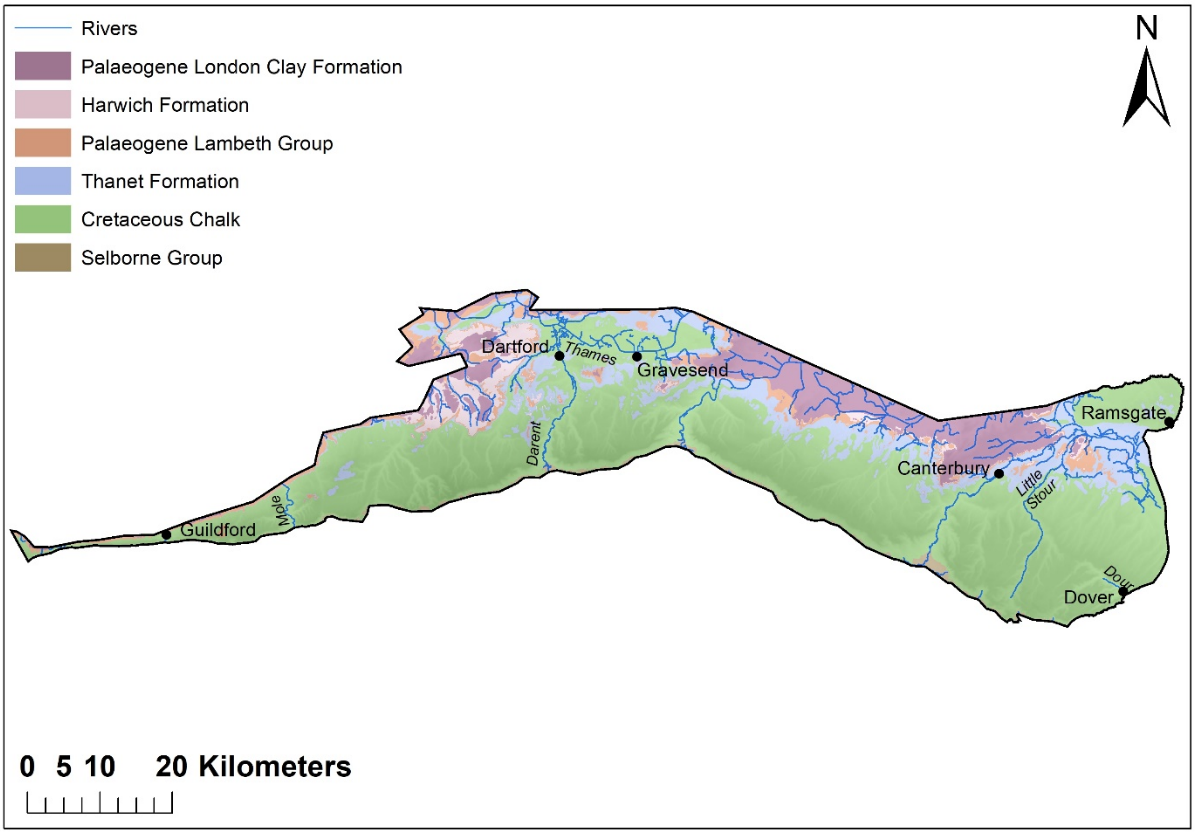

Figure 2. Bedrock geology and rivers in the C6 North Downs Chalk area.

Table 1. Basic stratigraphy in the C6 North Downs Chalk area (Powell, 1998; Allen et al., 1997; Adams, 2008)

Group	Subgroup	Formation	Lithology	Thickness
Thames Group		London Clay Formation	Clay and silt	0-150 m
		Harwich Formation	Sand and gravel	0-24 m
Lambeth Group			Clay, silt, sand and gravel	0-39 m
		Thanet Formation	Sand	0-30 m
Chalk Group	Upper Chalk	Newhaven Chalk Formation	Chalk	0-24 m
		Seaford Chalk Formation		55-60 m
		Lewes Nodular Chalk Formation		35-60 m
	Middle Chalk	New Pit Chalk Formation		10-25 m
		Holywell Nodular Chalk Formation		10-15 m
	Lower Chalk	Zig Zag Chalk Formation		35-50 m
		West Melbury Marly Chalk Formation		15-25 m
Selborne Group		Upper Greensand Formation	Siltstone and sandstone	0-75 m
		Gault Formation	Mudstone	90-110 m

There are extensive superficial deposits in the C6 area (Figure 3). Clay-with-flints deposits are widespread across the higher elevations in the south. River terrace deposits are present in the northwest; alluvium is present around the larger tidal rivers in the north and northeast; and brickearth deposits occur in the east. There are small amounts of Crag Group sand and gravel in the southwest.

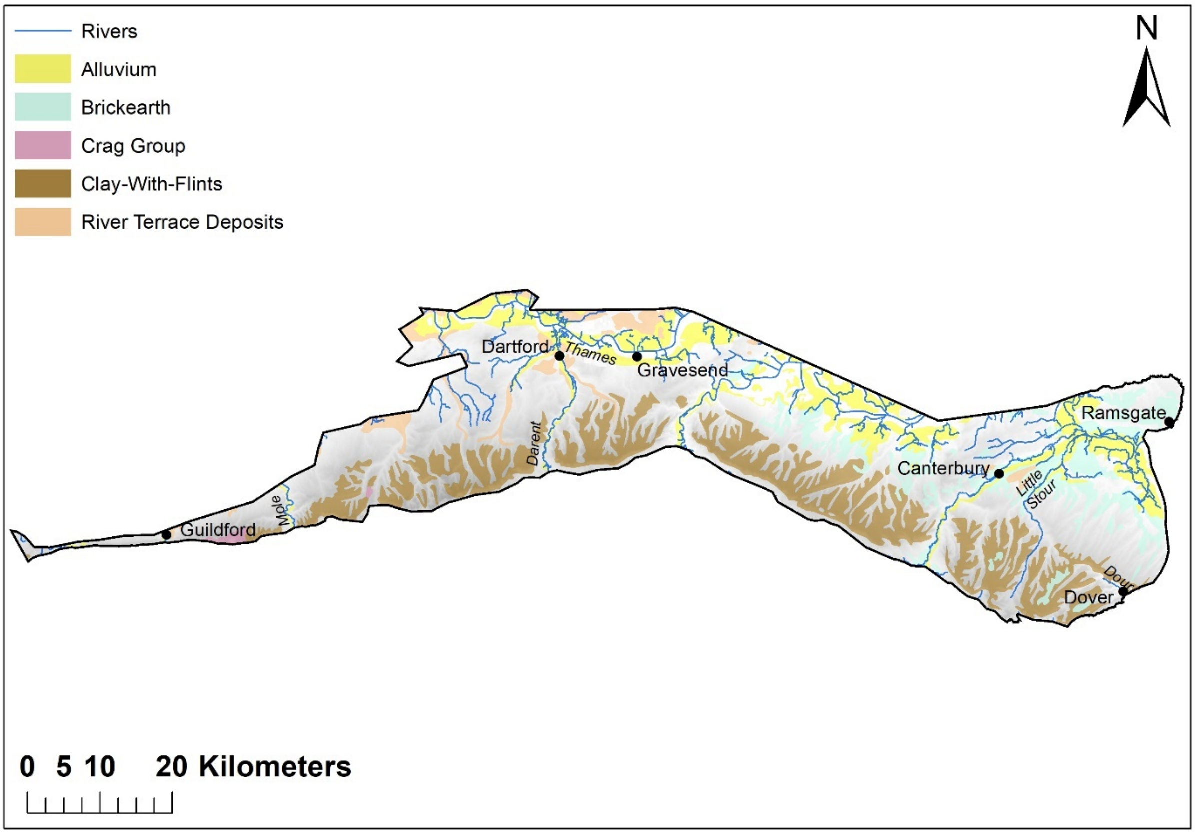

Figure 3. Superficial geology and rivers in the C6 North Downs Chalk area.

1.2 WATER PROVIDERS AND REGULATORS

The water providers for the C6 area are Affinity Water, Southern Water and South East Water in the east; Essex & Suffolk Water in the north; and Thames Water and Sutton & East Surrey Water in the west. There are also two small areas in the west which are supplied by Affinity Water and South East Water (Figure 4).

Most of C6 is within the Kent and South London Environment Agency area (Figure 5). Some northern parts of the area are in the Hertfordshire and North London, and Essex, Norfolk and Suffolk areas, and the west is within the Thames area.

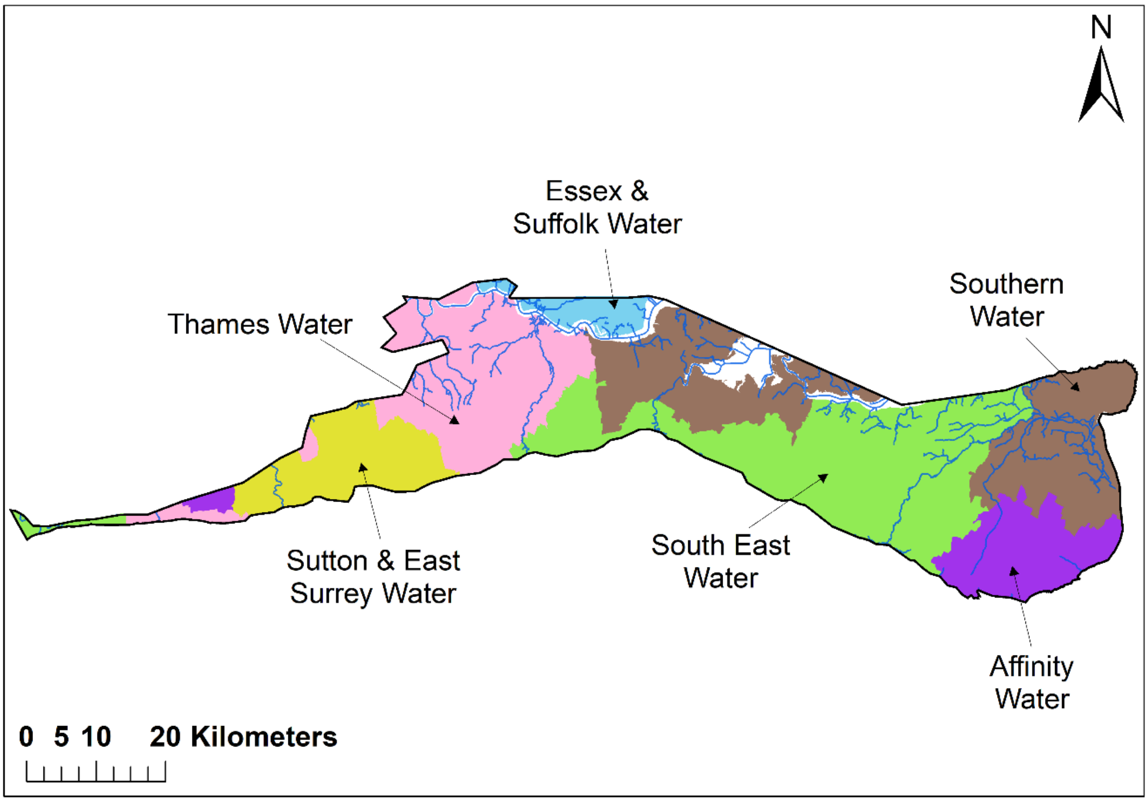

Figure 4. Water providers in the C6 North Downs Chalk area.

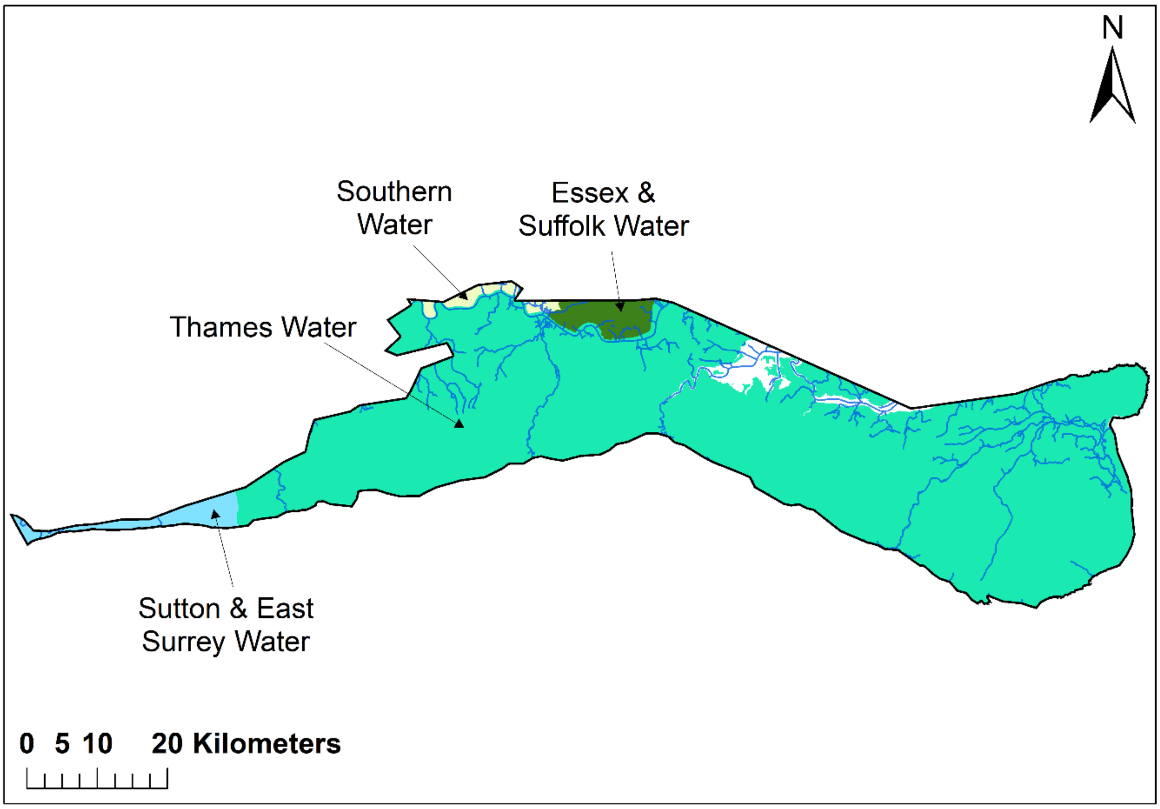

Figure 5. Environment Agency areas in the C6 North Downs Chalk area.

2 Karst geomorphology

2.1 CAVES AND CONDUITS

Small karstic conduits and fissures are likely to be common, especially associated with hardgrounds and flint layers in the Lewes Nodular Chalk and the Seaford Chalk formations, and have been observed in a Chalk Pit near Doddington [TQ 721 567] (Farrant and Aldiss, 2002). A flowing karstic conduit ~15 to 20 cm in diameter was intersected at Swanscombe Quarry (photograph on page 83 of Maurice, 2009). Borehole records also provide some indication of karstic cavities. For example, Bull et al. (1932) note that sand at about 30 m below the surface in a borehole near Leatherhead in the area of the River Mole swallow holes was likely to be a subterranean channel. Farrant et al. (2021) also report that a significant karst feature was intersected in a borehole sunk at Hale Farm [SU 8490 4830]. The borehole penetrates around 2 m of sand and gravel overlying 23 m of Palaeogene strata before entering the Chalk. At around 8-10 m down into the Chalk (at c. 60 m OD, approximately the elevation of the River Wey) “a spring was reached which was supposed to be the Bourne Mill stream and the instrument went down rapidly many fathoms through a chalk mud”.

Solutional conduits and fissures, associated with karstic inception horizons and with apertures of very approximately ~ 1-10 cm, are observed in many abstraction boreholes in the area (Knowledge exchange meetings; Farrant et al., 2018; Farrant et al., 2021; Mathewson et al., 2021; Bunting et al., 2021). They occur at depths of up to ~110 m below the surface, and some contain sediment suggesting connectivity with the surface through solutional networks (Figure 6 and Figure 7).

Figure 6. Solutional conduits with sediment at 102 and 107 m below the surface (image from borehole in the North Downs area). Images provided by South East Water.

Figure 7. Solutional conduits at depths of ~40-45 m below the surface (images from boreholes in the North Downs area). Images provided by South East Water.

There are 20 recorded caves in the C6 area (Figure 8; Table 2). Most caves are less than 25 m in length, but one is 60 m and one is over 100 m. The grid references of the caves are approximate. Most of the caves are described by Terry Reeve (personal communication, 2017) with some details in the Chelsea Speleological Society journals (CSS, 1968; 1973; 1979; 1990). Other caves are described in Bradshaw et al. (1991) and Reeve (1976). An overview of chalk caves observed over 50 years by Terry Reeve is now available in Reeve (2021).

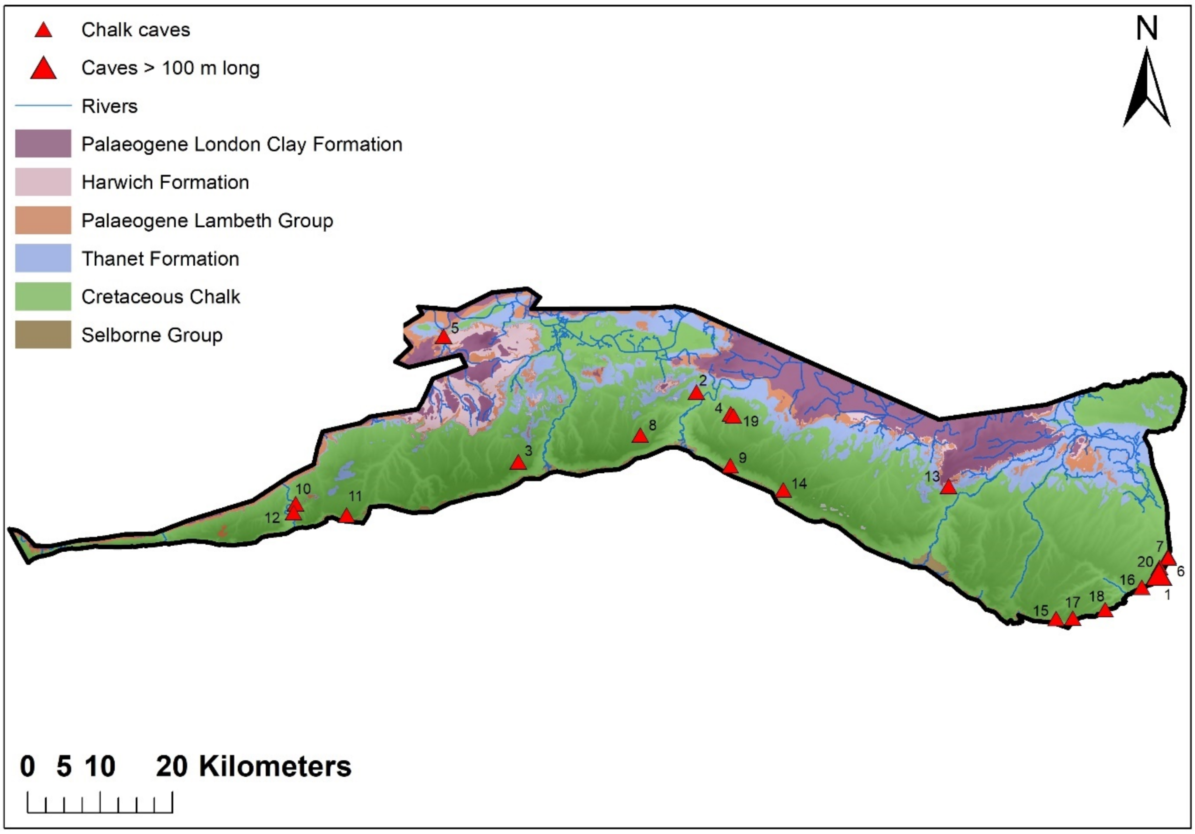

Figure 8. Caves in the C6 North Downs Chalk area. Numbers refer to Table 2 and the cave descriptions.

Table 2. Recorded caves in the C6 North Downs Chalk area (grid references are approximate).

No.	Name	East	North	Length	Bedrock geology	Sources
1	Canterbury Cave	636800	144200	110 m	Lewes Nodular Chalk Formation	BCRA (1976); CSS (1979)
2	Strood cave	572900	169300	60 m	Lewes Nodular Chalk Formation	Bradshaw et al. (1991); CSS (1973)
3	Knockholt borehole cave	548300	159700	10 m	Lewes Nodular Chalk Formation or Seaford Chalk Formation	Bradshaw et al. (1991)
4	Chatham borehole cave	577600	166300	N/A	Lewes Nodular Chalk Formation	Bradshaw et al. (1991)
5	Blackheath sewer tunnel caves	538000	177000	N/A	Lewes Nodular Chalk Formation or Seaford Chalk Formation	Bradshaw et al. (1991)
6	Cave at Kingsdown	637900	146500	20 m	Seaford Chalk Formation	Reeve (1979)
7	Hope Point Cave	637900	146500	25 m	Seaford Chalk Formation	Reeve (personal communication 2017); CSS (1979)
8	Flittermouse Hole	566100	161800	6 m	Lewes Nodular Chalk Formation	Reeve (personal communication 2017); CSS (1973)
9	Boxley Quarry Cave	577400	159800	10 m	Unknown	Reeve (personal communication 2017); CSS (1990)
10	Headley Nature Reserve	517500	153800	N/A	Lewes Nodular Chalk Formation, Seaford Chalk Formation and Newhaven Chalk Formation (undifferentiated)	Reeve (personal communication 2017)
11	Colley Hill	524600	152300	9 m	Holywell Nodular Chalk Formation and New Pit Chalk Formation (undifferentiated)	Reeve (1979); CSS (1968); CSS (1979)
12	Policeman's Hole	517000	153000	N/A	Holywell Nodular Chalk Formation and New Pit Chalk Formation (undifferentiated)	Reeve (personal communication 2017); CSS (1979)
13	Canterbury swallow holes caves	608000	156200	N/A	Seaford Chalk Formation	Reeve (personal communication 2017); CSS (1979)
14	Hollingbourne Quarry cave	584880	155820	N/A	New Pit Chalk Formation	Reeve (personal communication 2017)
15	Folkestone Quarry cave	622500	138000	N/A	Zig Zag Chalk Formation	Reeve (personal communication 2017); CSS (1979)
16	Langdon Bay	635000	142000	20 m	Lewes Nodular Chalk Formation	Reeve (personal communication 2017); CSS (1979)
17	Folkestone Warren cave	624100	137600	N/A	Zig Zag Chalk Formation	Reeve (personal communication 2017); CSS (1979)
18	Samphire Hoe cave	629000	139000	N/A	Holywell Nodular Chalk Formation	Reeve (personal communication 2017); CSS (1979)
19	Luton	578000	166000	N/A	Lewes Nodular Chalk Formation	Reeve (personal communication 2017); CSS (1979)
20	Cave at St Margarets Bay	636800	144300	8 m	Lewes Nodular Chalk Formation	Reeve (personal communication 2017); CSS (1979)

2.1.1 Canterbury Cave, St. Margaret's Bay, Kent

Canterbury Cave is the longest Chalk cave in the area with a mapped length of 110 m. The cave is described by Reeve (1976) and also by Reeve in CSS (1979) and Reeve (personal communication, 2017) who suggests that: "It appears to be a fossil cave system formed under phreatic conditions and the explored passages are joint orientated. Behind the entrance at the cliff face, the 2 m wide and 1 m high passage leads into a 10 m long, 4 m wide and 1.5 m high chamber. After further crawls and larger passages the end of the cave is choked with rubble and boulders". The cave is developed on top of a sheet flint layer within the Lewes Nodular Chalk Formation, that can be observed on the cave floor. This may have formed an effective water barrier and enabled the development of the cave cavity above (Bradshaw et al. 1991). Many other smaller karstic cavities and tubes are present at the same stratigraphical horizon in the area.

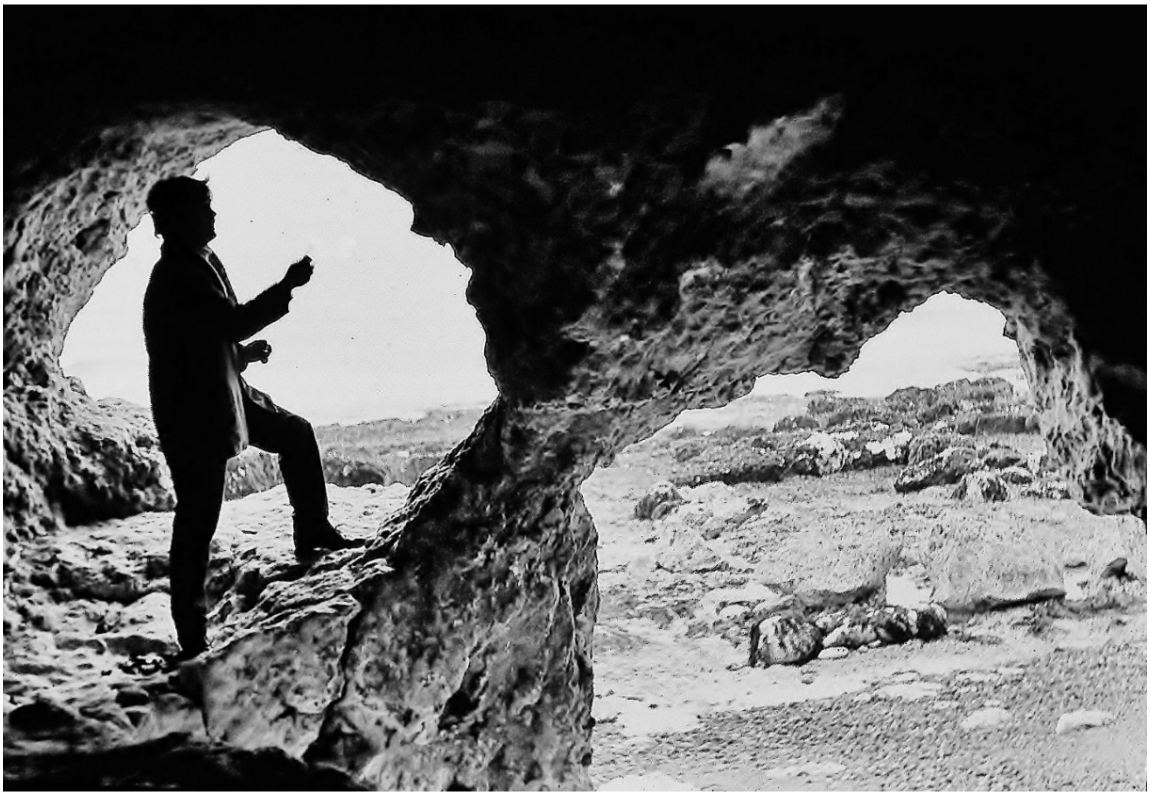

Plate 1. Entrance of the Canterbury Cave in 1968 before the dividing pillar was eroded away (photo courtesy of Terry Reeve).

Plate 2. Main passage of the Canterbury Cave (photo courtesy of Terry Reeve).

Plate 3. One of the side passages of the Canterbury Cave (photo courtesy of Terry Reeve).

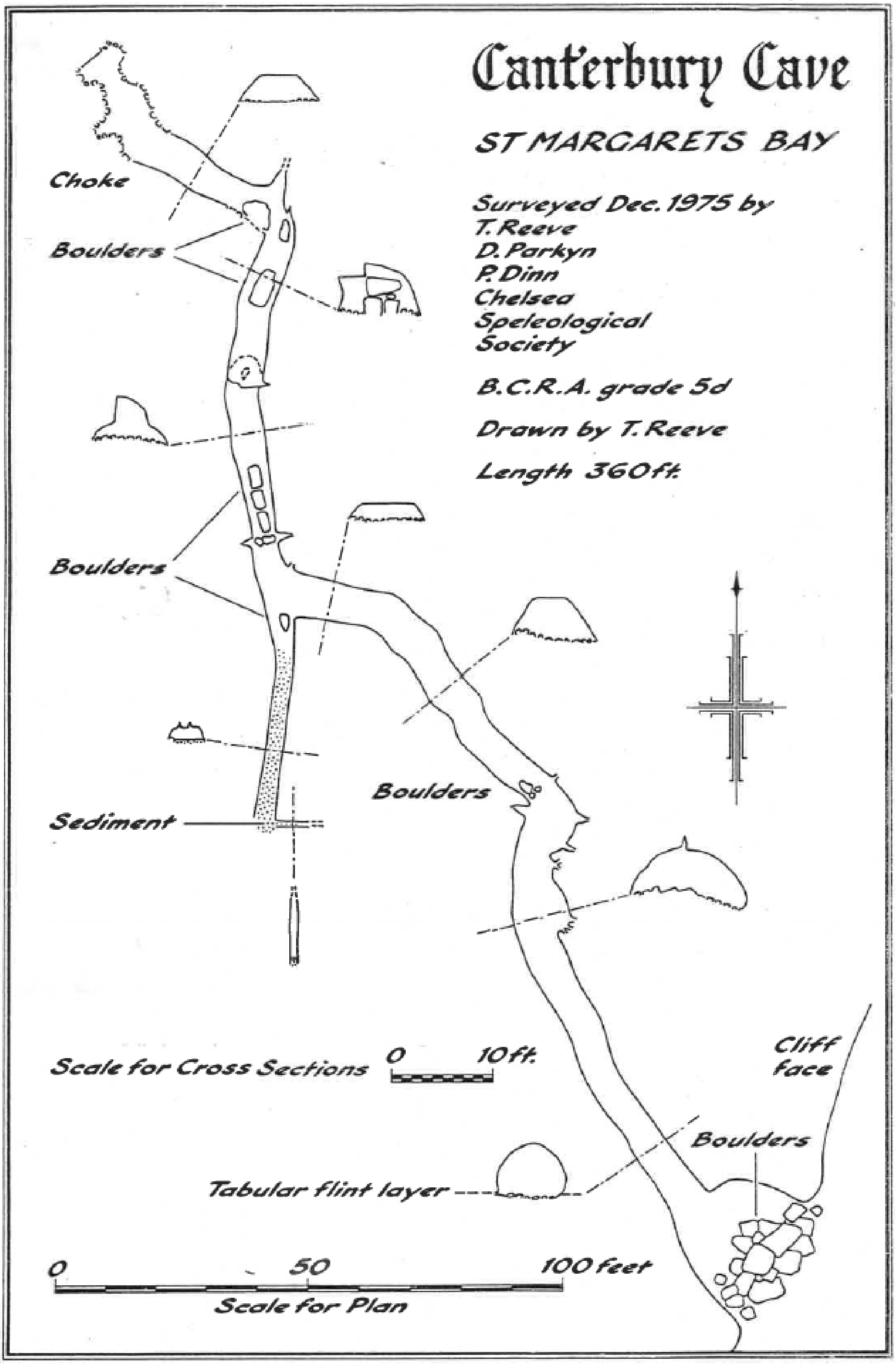

Figure 9. Survey of the Canterbury Cave in St Margarets Bay, provided by Terry Reeve.

2.1.2 Strood cave, Strood, Kent

This large natural cavern is described in CSS (1973). It was discovered during the construction of an adit tunnel from a well at Strood. The cave passage was explored for 60 m and contained an active streamway but is no longer accessible (Bradshaw et al. 1991). Passages in the cave reach up to 3 m wide and up to 5 m high. The stream enters the cave from the west and flows along flint layers in the chalk, and may be aligned along faults and joints. The direction of stream flow is towards the River Medway to the east of Strood cave (CSS, 1973). There are also good descriptions of the cave in Coles-Finch (1908).

Plate 4. Passage in Strood Cave, from Coles-Finch (1908).

Plate 5. Large chamber inside Strood Cave, from Coles-Finch (1908).

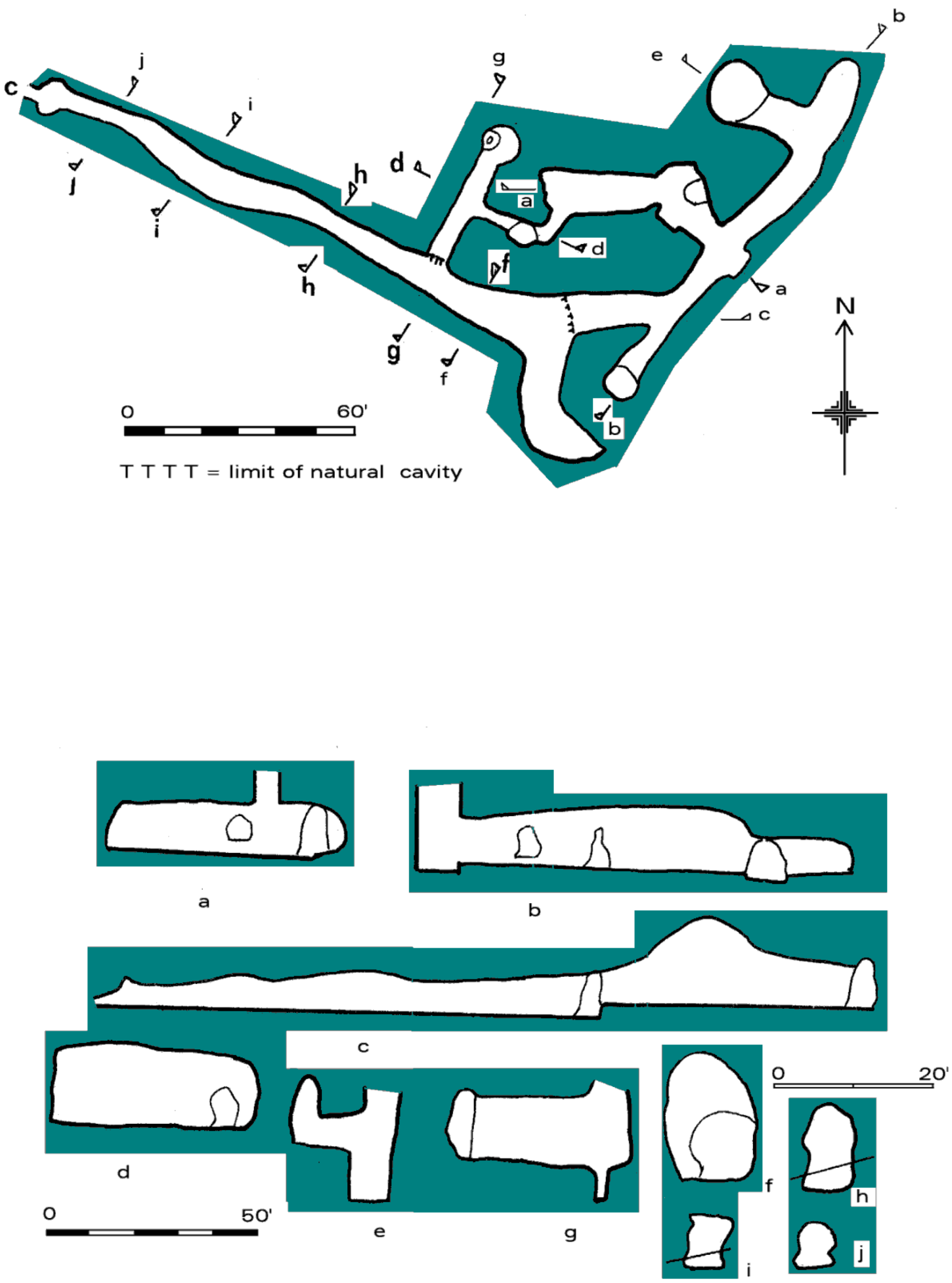

Figure 10. Survey of Strood cave from CSS (1973).

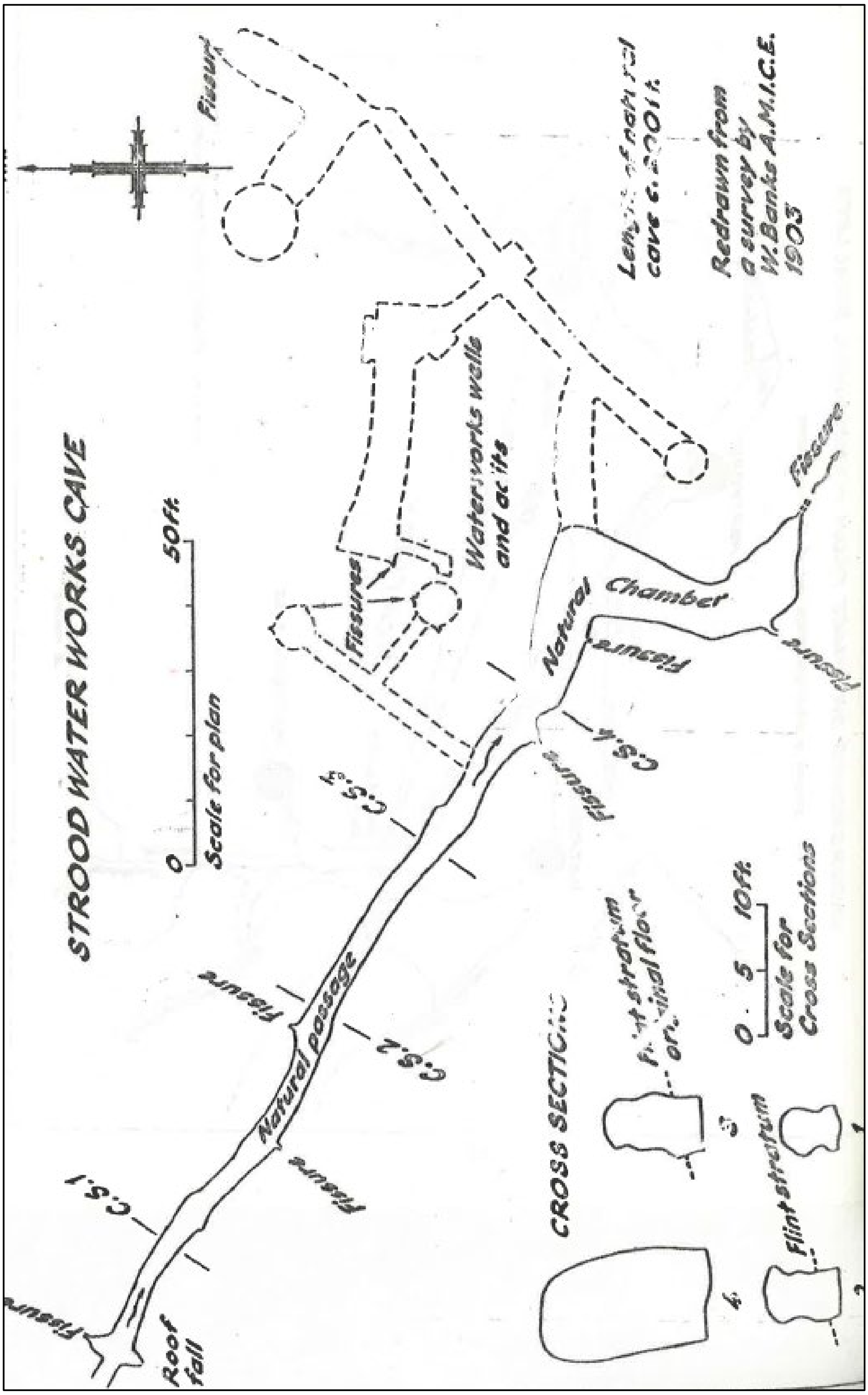

Figure 11. Survey of Strood cave from CSS (1979).

2.1.3 Knockholt Borehole Cave, Knockholt, Kent

This cave was also discovered during construction of a well, and is no longer accessible. The cave is described as 10 m long, 5.5 m high and 3.5 m wide with a stream flowing through it (CSS, 1973; Bradshaw et al. 1991). There are no photos or surveys of this cave.

2.1.4 Chatham Borehole Cave, Chatham, Kent

This cave is similar to the Knockholt Cave and no longer accessible (Bradshaw et al. 1991). There are no photos or surveys of this cave.

2.1.5 Blackheath sewer tunnel caves, Blackheath, Kent

These caves were discovered during the construction of a sewer tunnel (Bradshaw et al. 1991). Three separate caves are described in CSS (1973): The full length of the first cave has not been explored, but at the entrance to the cave the passage is 5 m long and 3.5 m wide (CSS, 1973). The second cave is enterable up to 3.5 m and is 3.5 m wide, but it narrows and continues up to an unknown length (CSS, 1973). A small amount of water was observed flowing in both the first and second caves. The third cave is just 2 m deep and no running water was observed (CSS, 1973). There are no photos or surveys of these caves.

2.1.6 Cave at Kingsdown, Kent

Caves were initially observed in the sea cliffs at Kingsdown in 1976 (Reeve, personal communication, 2017). They may have been of marine origin, but a fissure infilled with Palaeogene sediment was observed, as well as solutional features, suggesting a karstic origin. These caves could not be located on subsequent visits, probably due to cliff falls.

An additional cave was later observed about 20 m above the beach which was about 0.8 m wide and 1 m high. Plates 6-8 show an upper and lower cave entrance, and anastomosis which can be observed in the roof of another cave. The lower cave is now buried and there are also some changes to the upper cave due to cliff fall (Reeve, personal communication, 2017; Reeve 2021). There is no survey available for these caves.

Plate 6. Entrance of the Cave at Kingsdown, the lower cave is now buried after cliff fall (photo courtesy of Terry Reeve).

Plate 7. Entrance of the upper Cave at Kingsdown (photo courtesy of Terry Reeve).

Plate 8. Anastomosis at the roof top of a cave at Kingsdown (photo courtesy of Terry Reeve).

2.1.7 Hope Point Cave, Kingsdown, Kent

This large sea level cave was exposed by cliff retreat, and had not been not visible during an earlier visit (Reeve, personal communication, 2017). It seems to be a chamber that was exposed by cliff falls at some time during the last 15 years. It has an 18 m wide entrance, a length of 25 m, and is up to 10 m high. Plates 9-13 show the inward and seaward view of the cave, well developed rounded cavities in the roof (suggesting a phreatic karstic origin), and typical erosion features (Reeve, personal communication, 2017; Reeve, 2021). Given that it was exposed by cliff retreat, and it has a karstic morphology it is clear that parts of it are of karstic rather than of marine origin.

Plate 9. Hope Point Cave, View looking inward showing karstic cavities in the roof (photo courtesy of Terry Reeve).

Plate 10. Hope Point cave, looking inwards (photo courtesy of Terry Reeve).

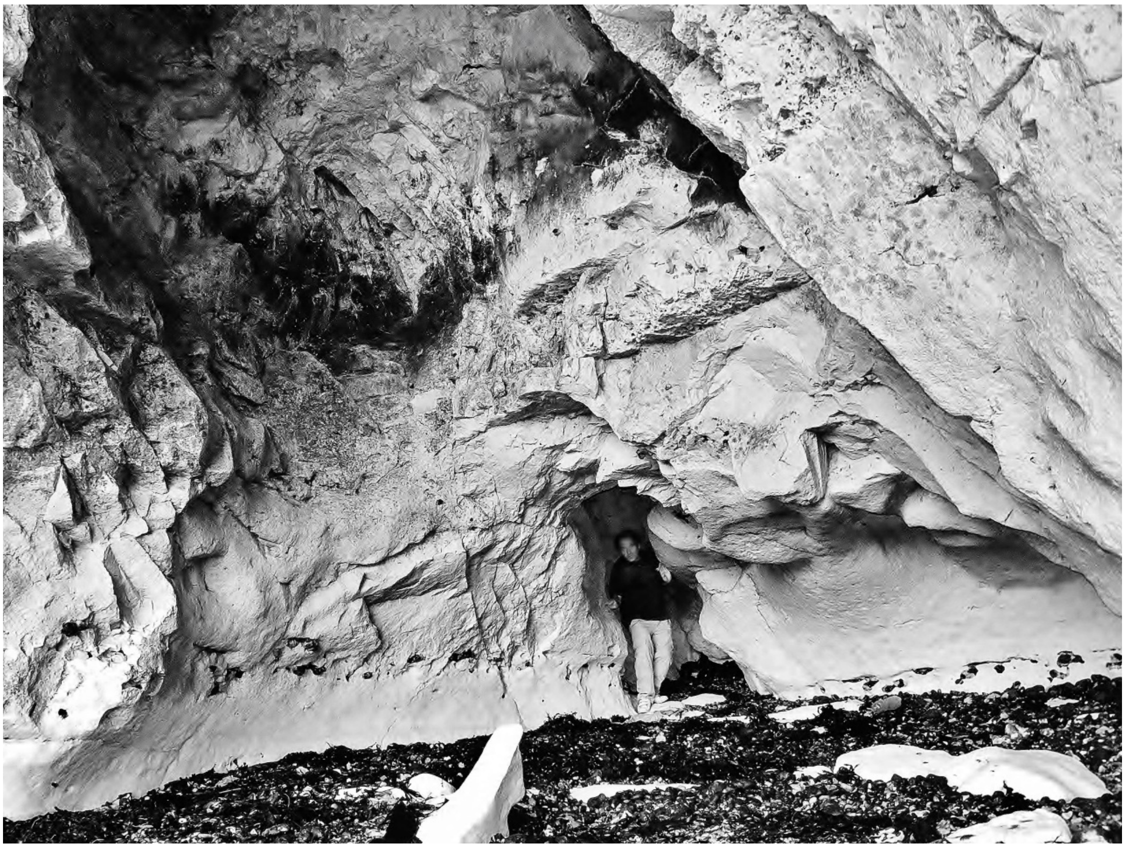

Plate 11. The back of Hope Point cave (photo courtesy of Terry Reeve).

Plate 12. Seaward view through the Hope point cave (photo courtesy of Terry Reeve).

Plate 13. Erosion of the walls and roof of the Hope Point Cave (photo courtesy of Terry Reeve).

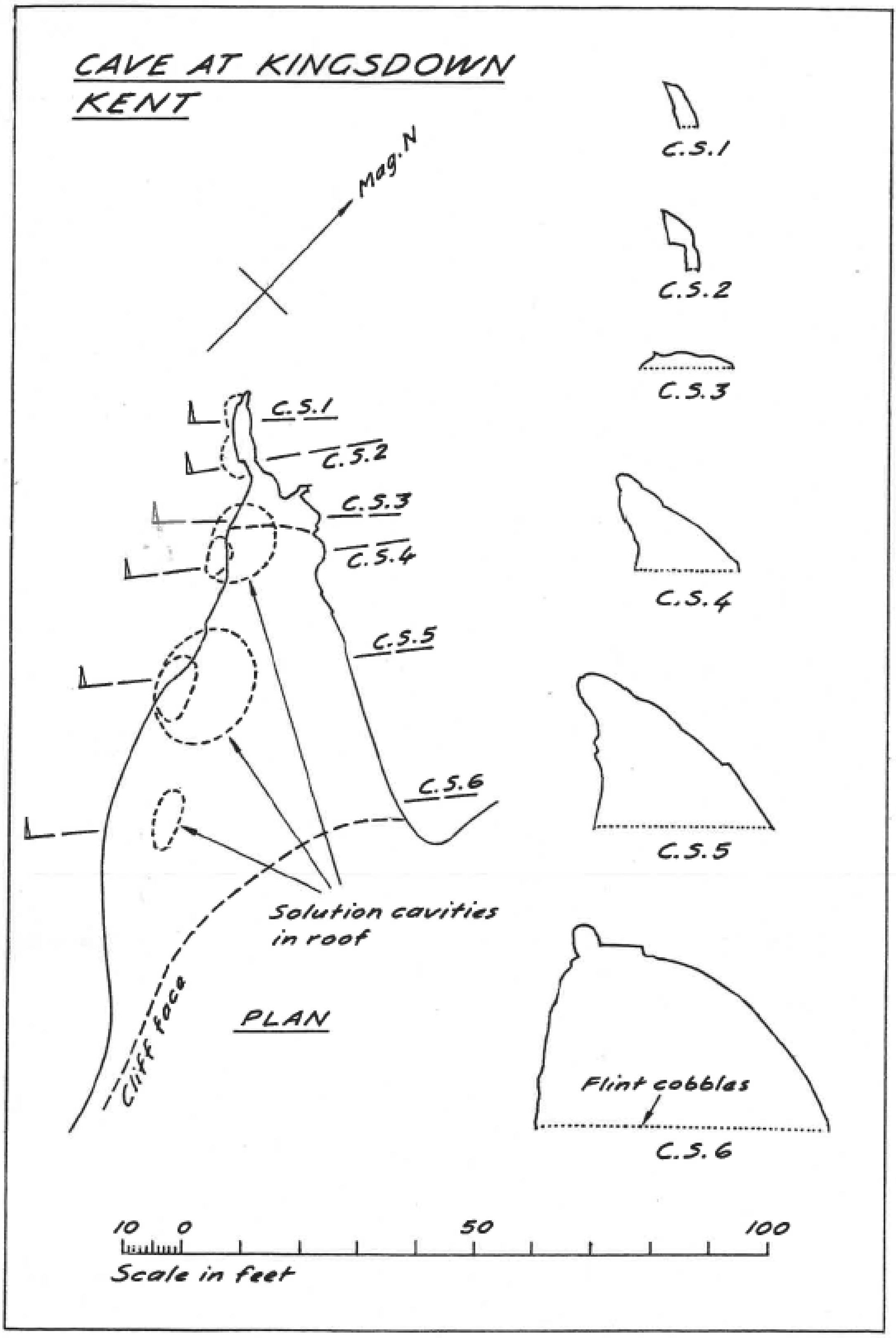

Figure 12. Plan Survey of Hope Point Cave at Kingsdown, provided by Terry Reeve.

2.1.8 Flittermouse Hole, Harvel, Kent

This is a short cave in an old chalk pit with a length of 6 m in the scarp face of the North Downs. It is described in CSS (1973). The entrance is about 3 m high and 2 m wide. The passage quickly narrows and ends in a fissure about 15 to 20 cm wide. On the right side of the cave a flint layer can be seen. In addition, a small phreatic tube with a diameter of about 0.2 m was found below the main cave.

There is also a cavity in Whitehorse wood nearby which could be a collapsed denehole. However, it is only a few metres from the edge of the hillside and therefore could have been easily quarried, suggesting that it may be a natural cavity (CSS, 1973).

Plate 14. Entrance of the Flittermouse Hole (photo courtesy of Terry Reeve).

Plate 15. Entrance of the Flittermouse Hole and the flint layer (photo courtesy of Terry Reeve).

Plate 16. Phreatic tube next to the entrance of the Flittermouse Hole (photo courtesy of Terry Reeve).

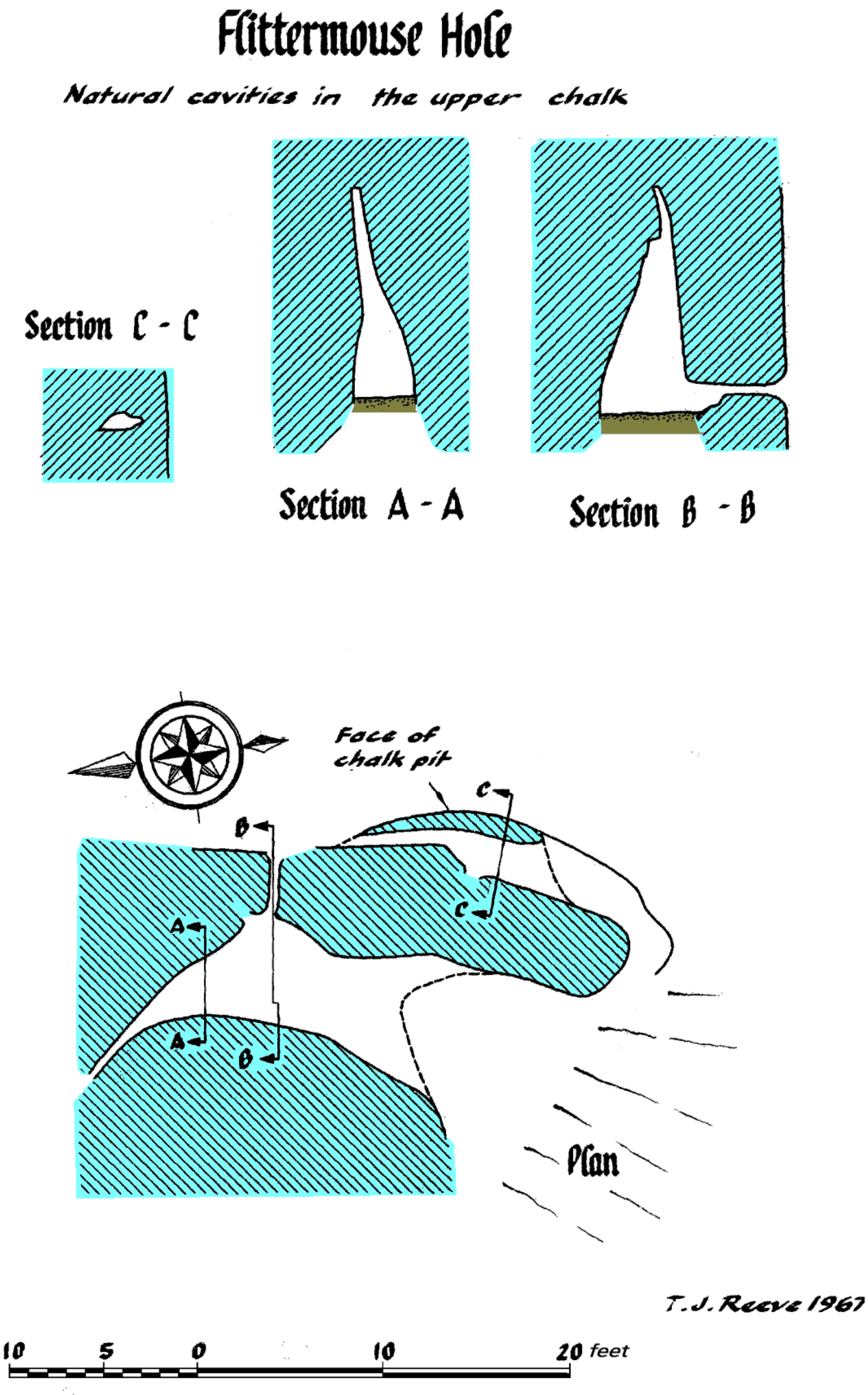

Figure 13. Survey of Flittermouse Hole by Terry Reeve from CSS (1973).

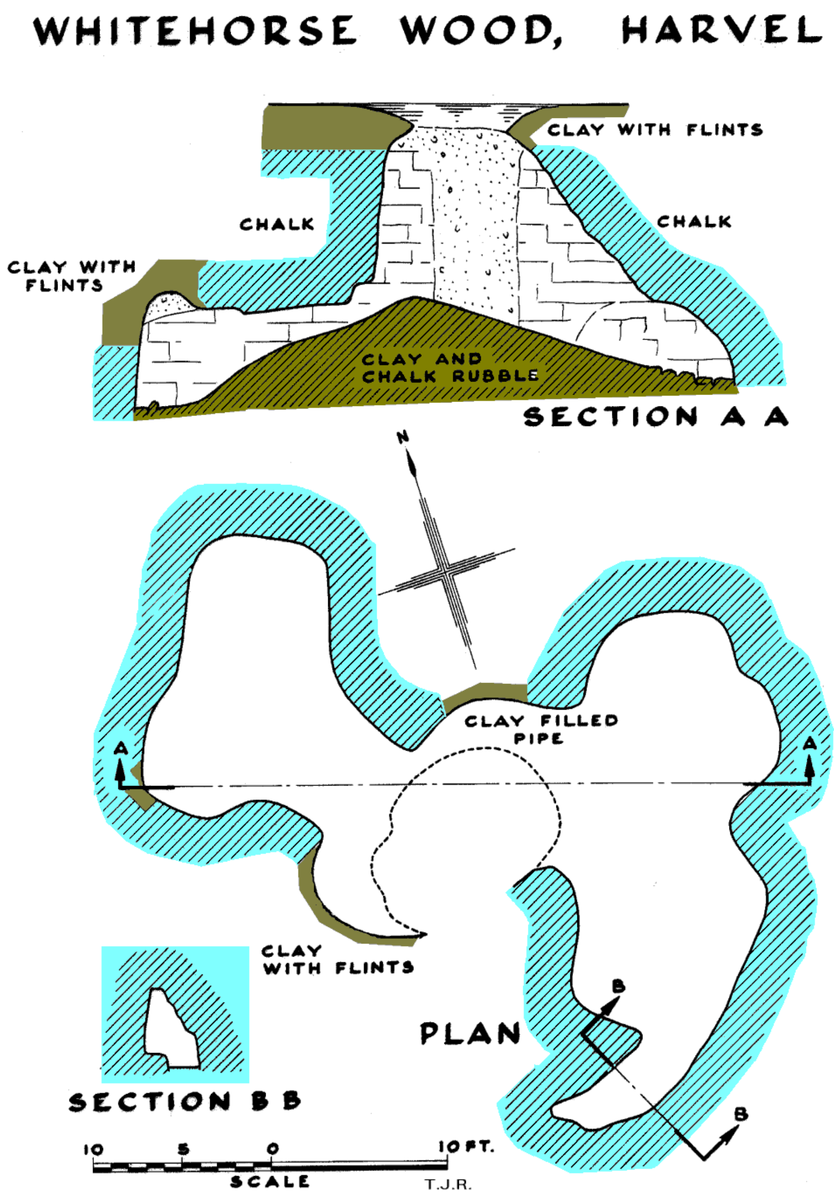

Figure 14. Survey of cavity in Whitehorse Wood which may be a collapsed denehole or a natural karst cave (Terry Reeve, personal communication, 2017).

2.1.9 Boxley Quarry Caves, Maidstone, Kent

There is a walking-sized cave passage intercepted by quarrying at Boxley which consists of a chamber 10 m long, 3 m high and up to 3 m wide (grid reference uncertain). This, and another cave at Boxley quarry, are briefly described by CSS (1990). The first cave is 8.5 m long, 3 m wide and 4.5 m high. The second cave is more hazardous to explore due to a low and friable roof, but the total explored length of both caves (explored by Terry Reeve) is approximately 85 m (CSS, 1990).

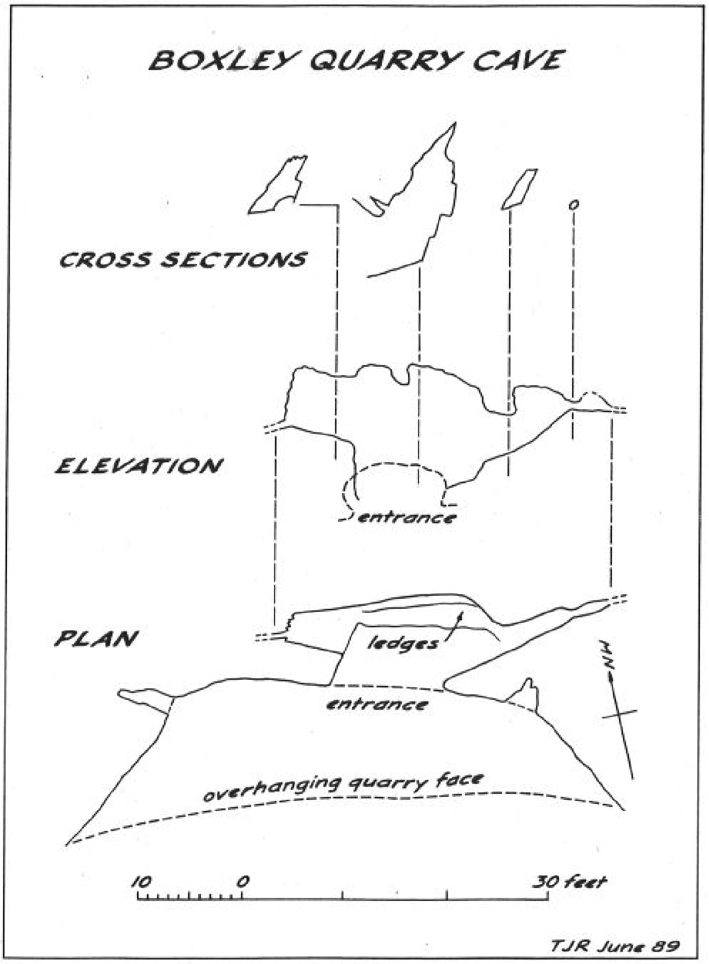

Figure 15. Survey of Boxley Quarry Cave, provided by Terry Reeve.

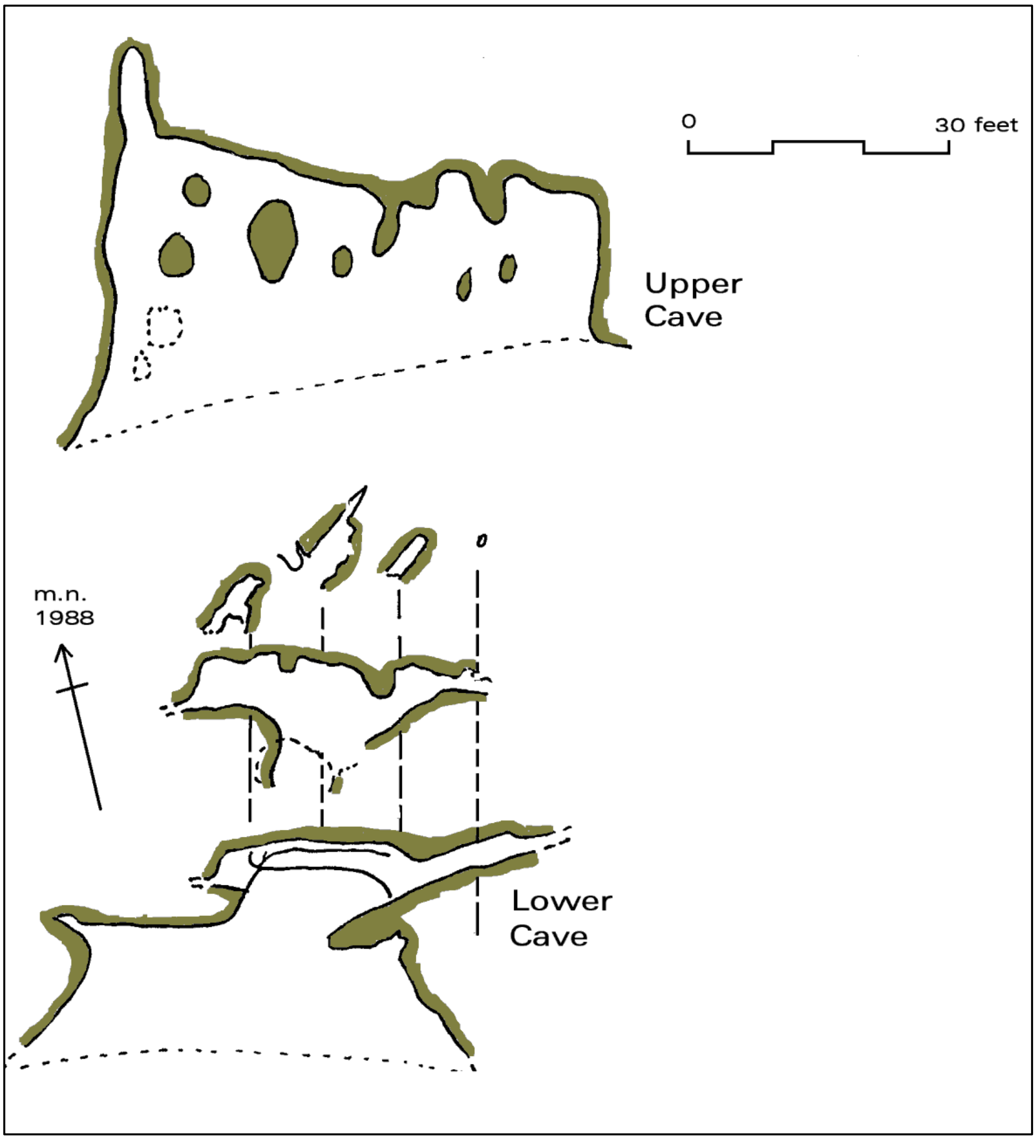

Figure 16. Survey of Boxley Quarry caves by T Reeve (in CSS, 1990).

2.1.10 Cave in Headley Nature Reserve, Surrey

Cavities within the Chalk of up to 1 m can be seen in depressions near an active stream sink (Reeve, personal communication, 2017). There is no survey available for this cave.

Plate 17. Top of cavities in depression, near active swallow hole, Headly nature reserve (photo courtesy of Terry Reeve).

2.1.11 Colley Hill cave, Reigate, Surrey

This cave is described originally in CSS (1966) and later by Terry Reeve in CSS (1976). It is a chamber which extends around 9 m in length and is 3 m wide by up to 1.5 m high. The cave was exposed due to subsidence in 1966 (CSS, 1976).

There has been considerable deterioration in the state of the cave since it was first found, and some observations are provided here (Reeve, personal communication, 2017): To one side of the cave, rainwater has worn a shallow gully in the hillside, exposing the chalk surface beneath the turf. A similar, but deeper gully drains the cave from the collapsed area and merges with the first gully further down the slope. The cave and gully system only becomes active at times of heavy rain, but the flow at such times is considerable.

There are traces of another cave near the top of the escarpment, where there are two small cavities in a bank at the side of a depression.

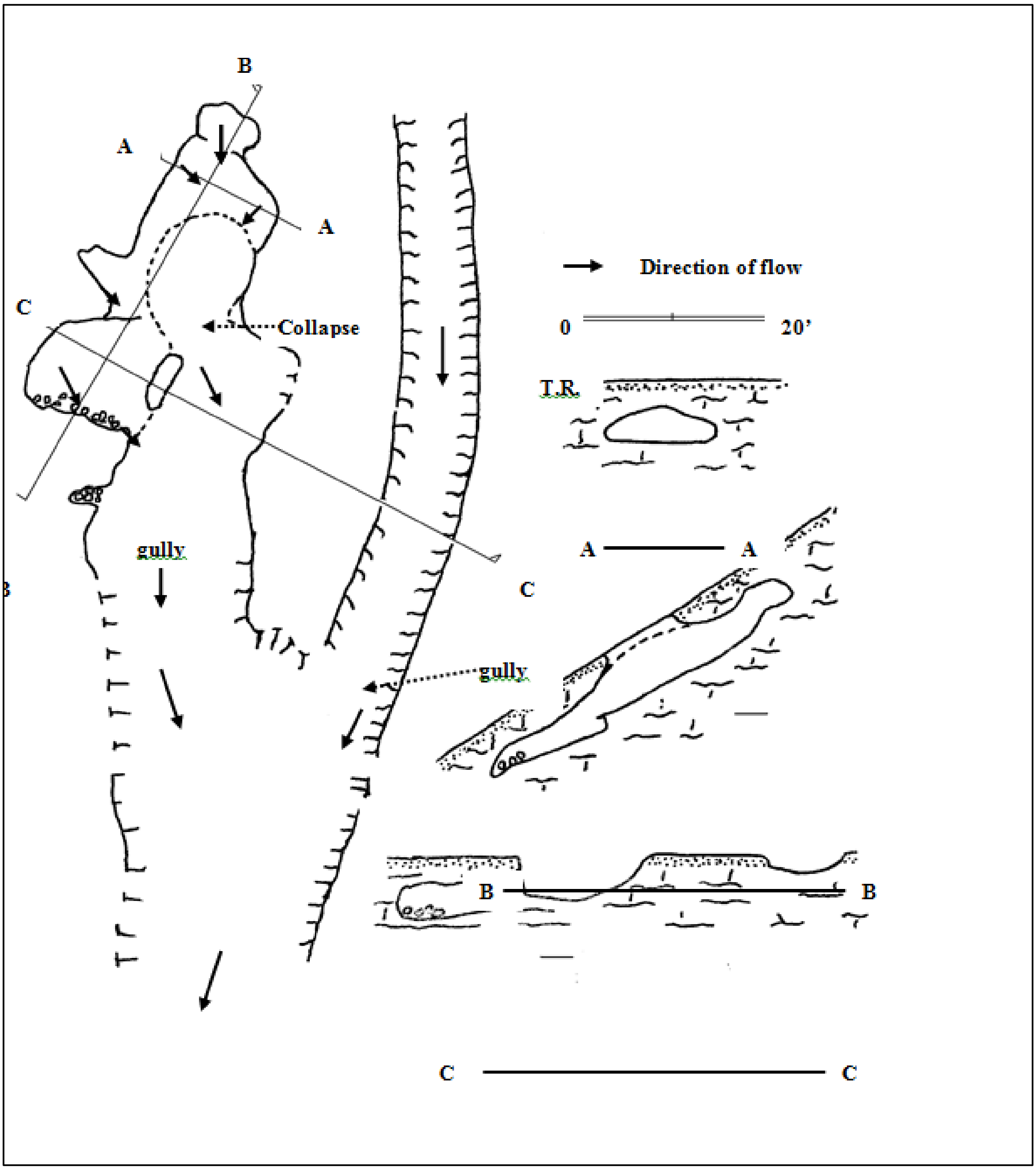

Figure 17. Survey of Colley Hill Cave by Terry Reeve (From CSS, 1976).

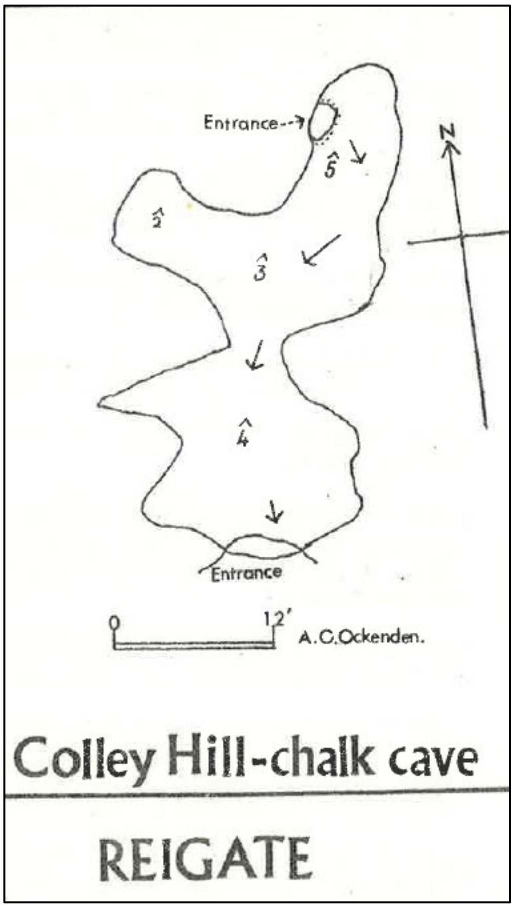

Figure 18. Survey of Colley Hill Chalk cave made by A.C. Ockenden and reported in CSS (1966).

2.1.12 Policeman's Hole, Mickleham, Surrey

A sudden collapse occurred in February 1947, and an entire tree sank into the ground (Crawford, 1960). The cavity gradually filled with water from below. It is probable that the cavity is a natural karst feature as it is close to the River Mole swallow holes.

Many other karst collapses and features have been observed in the Mole Valley. For example, exposed Chalk fissures were observed at the top of the river cliff at the edge of Box Woods (CSS, 1987).

There are no photos or surveys of this cave.

2.1.13 Canterbury swallow holes caves/Lower Ensden Swallets, Kent

Six stream sinks were found near Canterbury, of which three were well developed with Chalk cavities large enough to enter in their bases (CSS, 1979). The streams drain off the clay and sink into large sink holes, up to 20 m wide and 13 m deep (Reeve, personal communication, 2017). Digging through the overlying sediment led to the discovery of cave passages below. The cave passages discovered beneath the stream sink named “Lower Ensden Swallet No. 1 and No. 3” are each about 6 m in length.

Plate 18. Lower Ensden stream sink #1 (photo courtesy of Terry Reeve).

Plate 19. Cave exposed by digging in Lower Ensden stream sink #1 (photo courtesy of Terry Reeve).

Plate 20. Entrance to cave in Lower Ensden stream sink #3 before digging (photo courtesy of Terry Reeve).

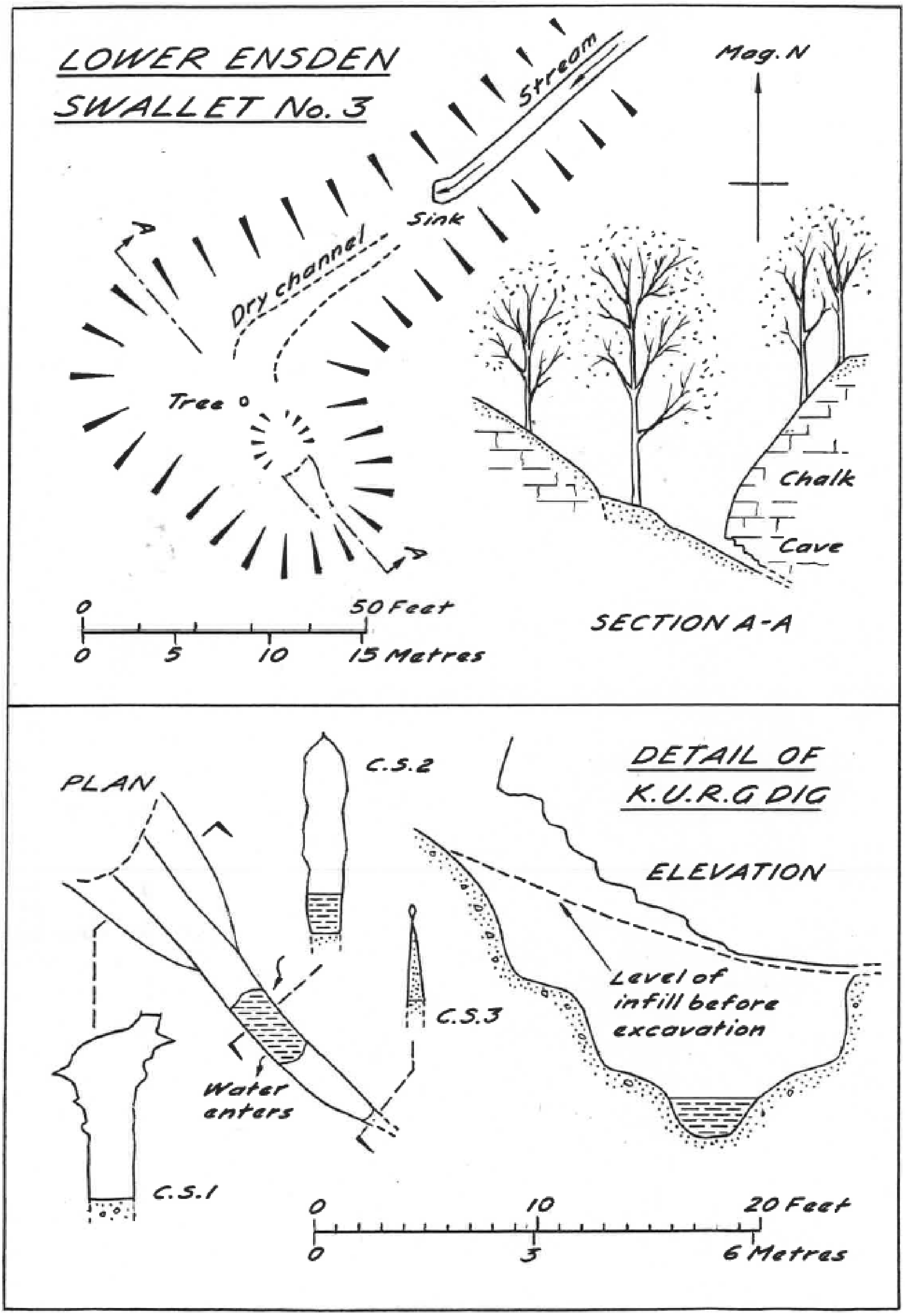

Figure 19. Survey of Lower Ensden Swallet No. 3 (courtesy of Terry Reeve).

2.1.14 Hollingbourne Quarry Cave, Kent

A small cave in a quarry in the scarp face of the Chalk could be followed for a short distance (Reeve, personal communication, 2017).

There are no photos or surveys of this cave.

2.1.15 Folkestone Quarry cave, Kent

There is a small cave in a quarry near Folkstone (Reeve, personal communication, 2017). The location of this cave is uncertain. The NGR used is for a quarry near Folkestone, but it is not certain that this is the quarry in which the cave was discovered. There are no photos or surveys of this cave.

2.1.16 Langdon Bay, Dover, Kent

Quite large passages at sea level appeared suddenly due to cliff collapse. One was an oval tube about 2 m wide which continued for about 20 m. The sudden appearance of these caves suggests a karstic origin, although some of them may have existed prior to the collapse and have a marine origin. The caves are now buried beneath cliff fall debris. There are no photos or surveys of these caves.

2.1.17 Folkestone Warren cave, Kent

A small cave was observed high up in the cliff in a nodular band of Chalk (Reeve, personal communication, 2017; CSS, 1979). There are no photos or surveys of this cave.

2.1.18 Samphire Hoe cave, Kent

A small cave was observed high up in the cliff and accessed by abseil. The cave was blocked by rubble (Reeve, personal communication, 2017). There are no photos or surveys of this cave. However, there is a photo of a cave at Samphire Hoe which may be the same site:

https://www.alamy.com/cave-in-the-chalk-cliff-samphire-hoe-kent-uk-image226819330.html

2.1.19 Cave at Luton

A small natural chamber with a watercourse was discovered during the sinking of a well at Luton, near Chatham (CSS, 1968). There are no photos or surveys of this cave.

2.1.20 Cave at St Margaret's Bay, Kent

There is a phreatic tube about 2 m above the base of the cliff, north of St Margaret's Bay (Reeve, personal communication, 2017). The cave extends for about 8 m, ending in a blockage comprised of flints, shingle and storm debris. The grid reference is approximate. There are no surveys of this cave.

Plate 21. Entrance to St Margaret's Bay cave (photo courtesy of Terry Reeve).

Plate 22. Close up of entrance to St Margaret's Bay cave (photo courtesy of Terry Reeve).

Plate 23. Blockage at the end of St Margaret's Bay cave (photo courtesy of Terry Reeve).

2.2 STREAM SINKS

There are 84 recorded stream sinks in the C6 area (Figure 20). Fifty-four of these are from the BGS karst database, which includes records from a study by Fagg (1958) on the River Mole, BGS memoirs (Dines et al., 1933; Whitaker & Mill, 1912; Whitaker et al., 1908; Dewey & Bromehead, 1921), and Ordnance Survey maps. 12 stream sinks in the Farnham area were visited and described in a report by Farrant et al. (2018). 10 stream sinks in the Faversham area were visited and described by Farrant et al. (2021). Five caves associated with stream sinks are described by Terry Reeve and in CSS (1979) in three areas: Headley nature reserve; in Cockham Wood; and in the Canterbury area.

The areas with stream sink records are described in more detail below.

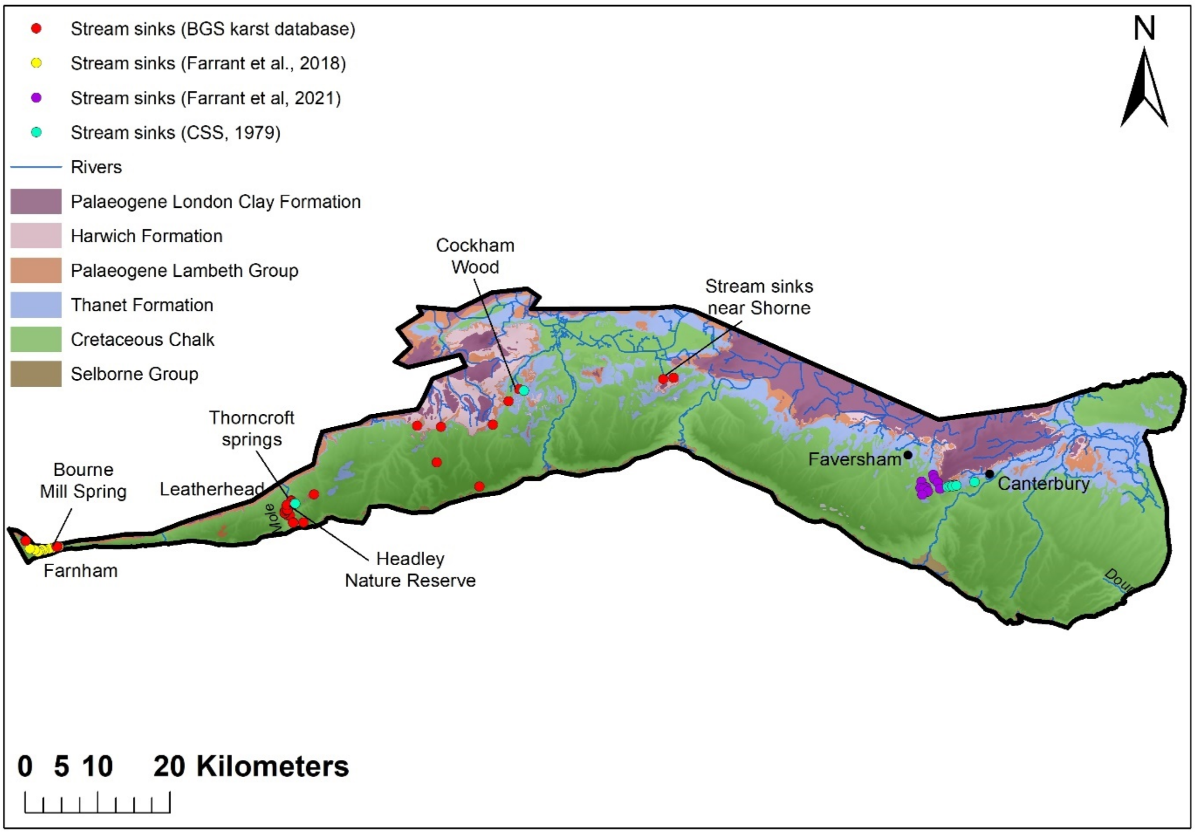

Figure 20. Stream sinks in the C6 North Downs Chalk area.

Stream sinks in the Farnham area are described in some detail in Young (1908). Recently, Farrant et al. (2018) conducted a field survey of stream sinks in the Farnham area (Figure 21), which is in the far west of the C6 karst knowledge exchange area (Figure 20). Many of the stream sinks in the Farnham area appear to be fairly significant features associated with small collapse sinkholes (Farrant et al., 2018; Figure 22). There are no flow data for the stream sinks, and visual estimates are extremely uncertain but Farrant et al. (2018) suggested that they might take flows of very approximately 1-10 $l.s^{-1}$ during wet periods. Long (1842) and Young (1906) suggested that stream sinks in the Farnham Park area may resurge at Bourne Mill spring [SU 8524 4791] at around 72 m OD. A nearby borehole record suggests that a substantial karst cavity (probably with water flow) was intersected during drilling in this area (Farrant et al., 2018; Section 2.4). Farrant et al. (2018) identify four other areas to the west of Farnham where springs occur which may be natural outlets for stream sinks (Section 2.3).

Farrant et al. (2018) also noted that several other streams drain the Palaeogene outcrop, but were either very small, ephemeral or lacked any identifiable sink point. They also report several places where natural stream sinks may have been present, but where the drainage has now been captured by field drains and roadside ditches: near Park Corner Farm at [SU 7680 4870], in the valley north of Horsedown Farm [around SU 7670 4760], north of Swanthorpe Farm [SU 7740 4800], and near Well [SU 7600 4564]. These are just to the west of the C6 area (Figure 23).

Near Leatherhead, the Mole valley is a particularly important area for stream sinks (Figure 24). Significant stream sinks occur along the bed of the River Mole between Leatherhead and Dorking, and are discussed in Fagg (1958), Allen et al. (1997), and Adams (2008). 25 sinks in the Mole valley were identified during a dry period (Fagg, 1958) and new ones can be very quick to develop (Adams, 2008). Fagg (1958) separated active stream sinks into four groups depending on whether they were at the very bottom of the river bed, towards the edges of the river bed, on the river valley edges, or in the flood plains of the river. Flows into the sinks of up to 120 $l.s^{-1}$ have been measured (Fagg, 1958). Tracer tests have not been conducted to determine groundwater flow pathways, but it has been suggested that the stream sinks may be connected to springs at Thorncroft, near Leatherhead, but not to springs at Fetcham Pond (Ruby, 1988-89). The geology and geomorphology of the Mole valley is described in detail in Bull et al. (1933) who also suggest that in the dry season water that disappears in swallow holes at Fredley and in Norbury Park, reappears near Leatherhead. The stream sinks along the River Mole appear to be developed where the river passes onto the Holywell Nodular Chalk Formation, with sinks occurring at intervals further downstream at successively higher stratigraphical levels. Hydrogeological and geomorphological information, including details of steam sinks in the Mole valley can also be found in the Mole Valley Geological Society publications:

http://www.mvgs.org.uk/MVGS%20Files/Geomorphology.pdf

http://www.mvgs.org.uk/index.htm.

Adams (2008) notes that the River Dour (in the far east of the North Downs karst knowledge exchange area) also has “swallow holes” and is associated with karst, and also report that Docherty (1971) suggested that such karst features may be common in chalk valleys but obscured by superficial deposits.

There are two stream sinks near Shorne, Kent (near Strood) which drain a Palaeogene outlier and are recorded in the BGS karst database (Figure 25). The easterly of the two is a stream that sinks into an old chalk pit.

Farrant et al. (2021) conducted a field survey of 10 stream sinks in the Selling area, south of Faversham (Figure 26). They concluded that these were generally small features; with 5 of the 10 streams sinking into small karst depressions, whilst the others fed culverts or ponds. No discharge measurements were made, but flows were very roughly estimated based on visual observations and the size and characteristics of the stream channels. Most were considered likely to have small flows of up to 1 $l.s^{-1}$ following sustained rainfall, although the Oversland Sink was thought to be larger, with flows of up to 10 $l.s^{-1}$.

Reeve (personal communication, 2021) describes a stream sink with a perennial flow on the edge of Howfield Wood, near Bigbury Camp hillfort [TR 1000 5770] and another one that was dry when visited, but which was about 15 m diameter and about 4 m deep at [TR 1070 5750]. Reeve notes that there are about 7 large closed depressions in this area, and there have been historical reports of subterranean streams flowing in the base of depressions. Reeve (personal communication, 2021) also describes three stream sinks near Woodnesborough (in the east of the C6 area). These stream sinks near Bigbury Camp Hillfort and Woodnesborough are not included on Figure 20.

The C6 area is not fully covered by the BGS karst database. There may be more stream sinks in the Chalk, especially associated with the Cretaceous Chalk/Paleogene margin. There are old records of stream sink development to the east, although the precise locations of these stream sinks are not known. Prestwich (1854) and Whitaker et al. (1908) describe several stream sinks southwest of Canterbury, including swallow holes up to 12 m across and 9 m deep into which streams disappear. Prestwich (1854) describes 6-7 streams that sink into swallow holes “within a mile between Nickhill Farm and Lower Elmsdon”, and suggests that they may resurge at major springs on the River Stour at Shalmford Street which is about 60-90 m lower. Prestwich (1854) also describes several stream sinks "on the other side of the hill from Hatchgreen to Dinstead and Fish Pond Farm". Whitaker et al. (1908) state that most of these stream sinks are in the Chalk near the boundary with the overlying Thanet Formation. It is possible that the stream sinks described by Prestwich (1854) and Whitaker et al. (1908) are the same stream sinks as those described by Reeve (personal communication, 2017) in the Canterbury area, which are included on Figure 20.

River losses were not considered in this data compilation (other than the River Mole) and therefore there may be additional point recharge via riverbeds.

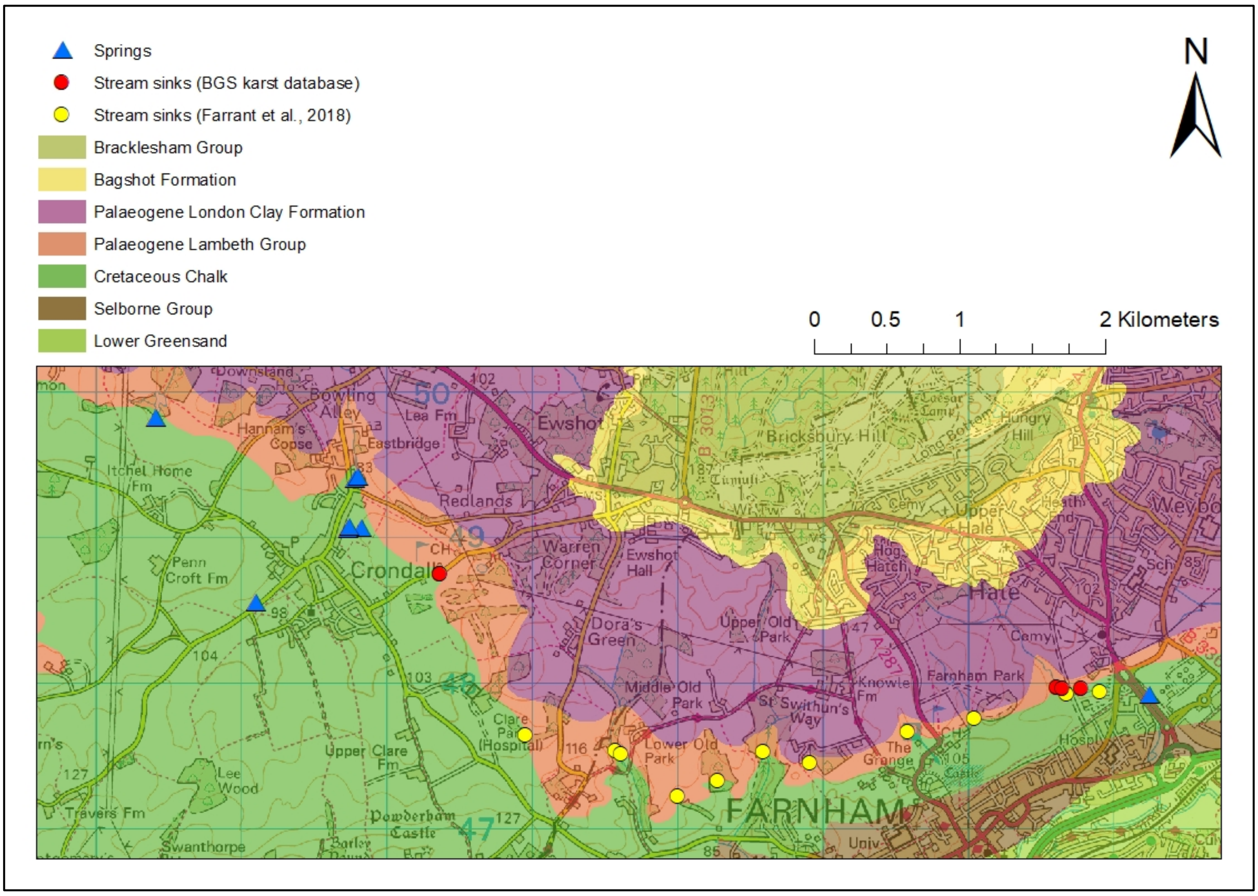

Figure 21. Stream sinks in the Farnham area.

Figure 22. Sink point collapse in streambed in the Farnham area during dry conditions.

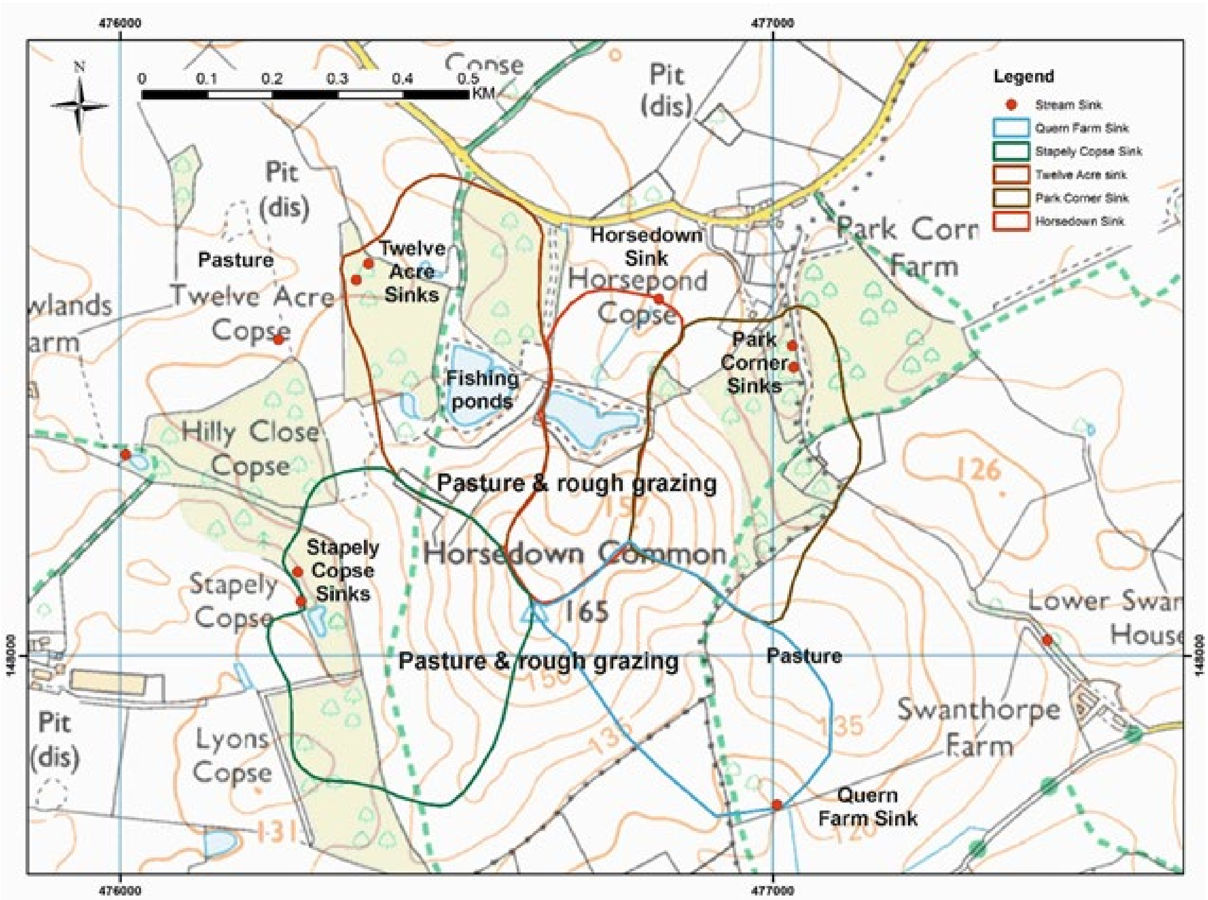

Figure 23. Stream sinks in the Horsedown Common area (west of Farnham). Figure produced by BGS on behalf of South East Water.

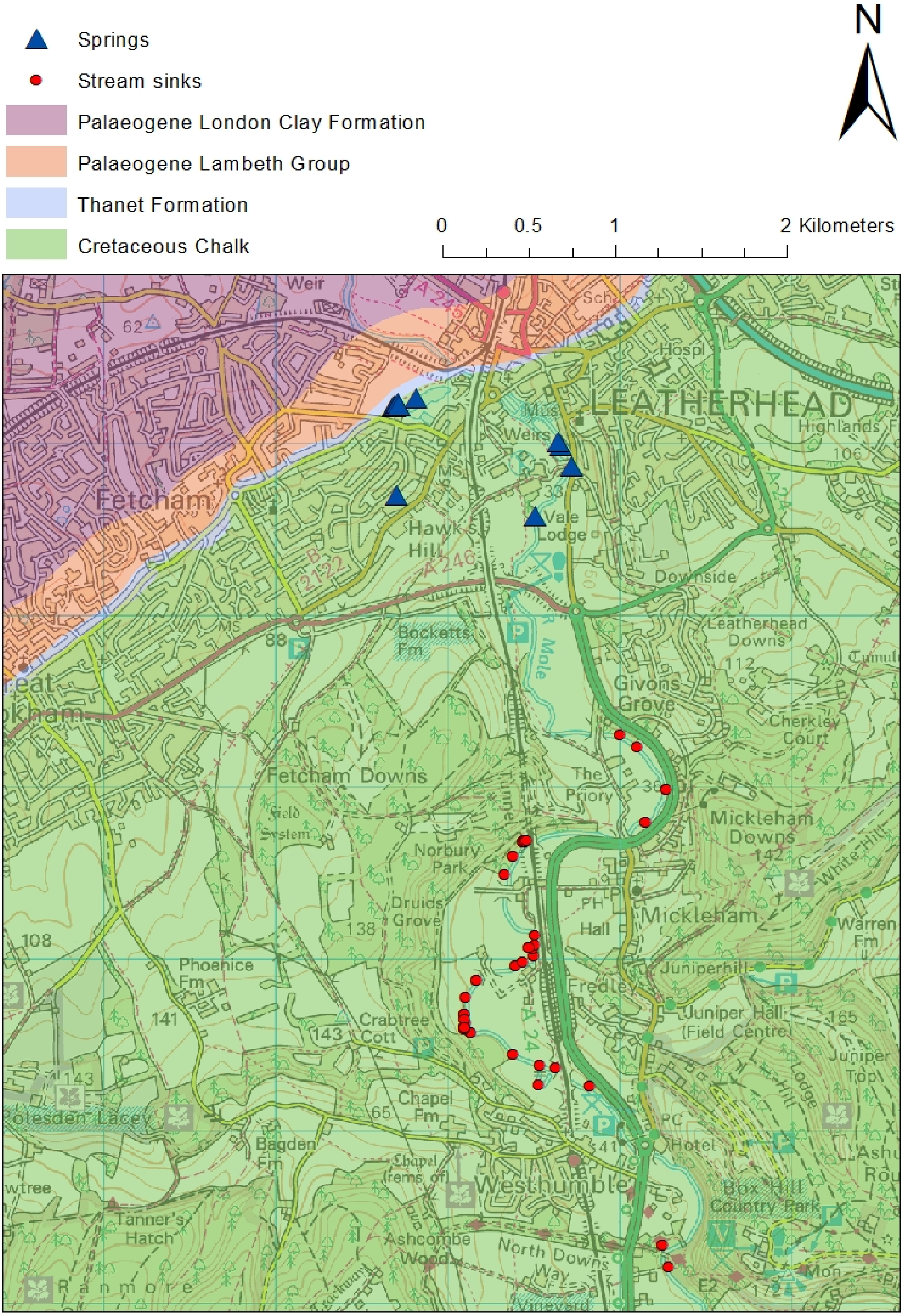

Figure 24. Stream sinks in the Mole River valley.

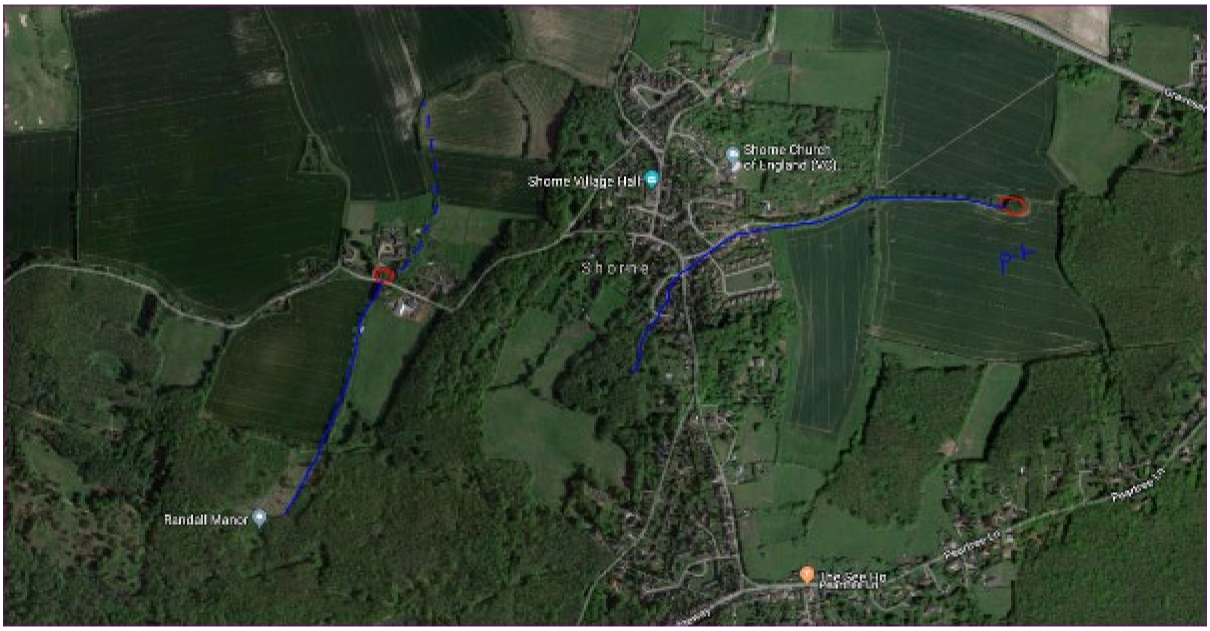

Figure 25. Satellite image of stream sinks near Shorne, Kent.

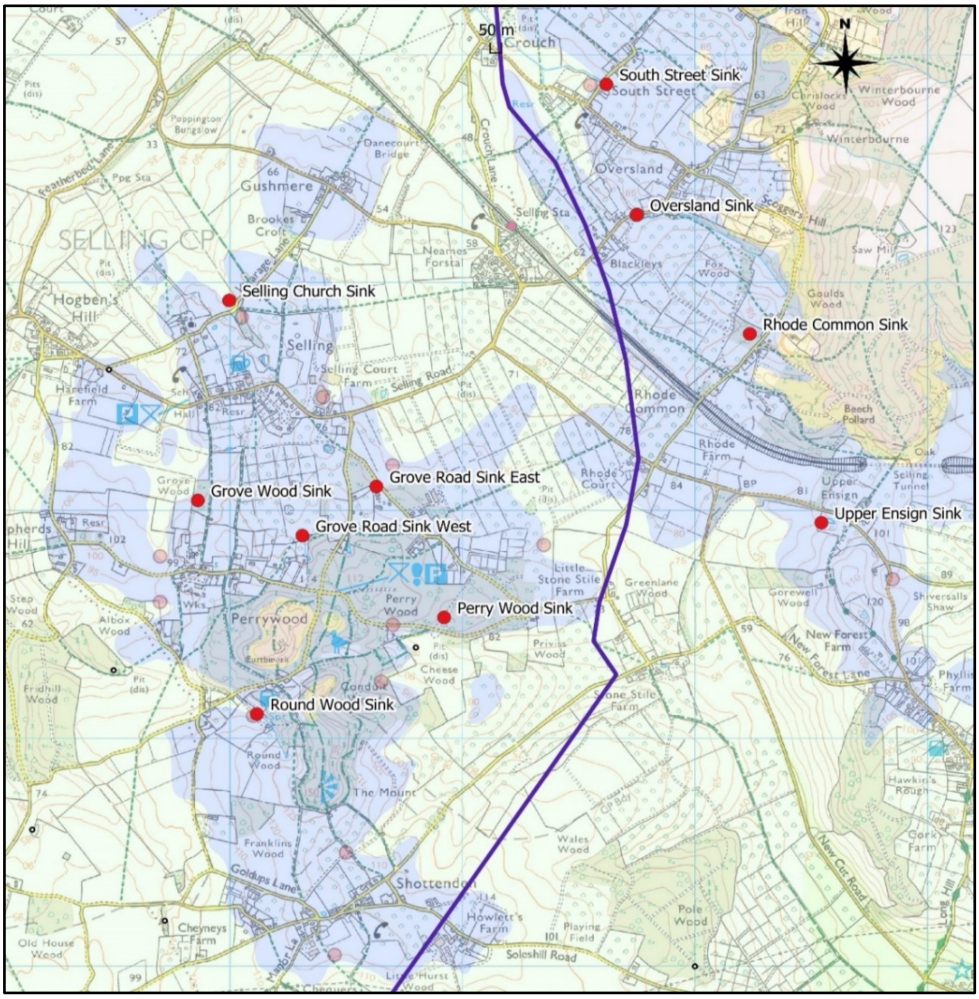

Figure 26. Stream sinks in the Selling area, from Farrant et al. (2021). Figure produced by BGS on behalf of South East Water.

2.3 SPRINGS

The North Downs area is characterised by many dry valleys reflecting the solutional development of karstic permeability in the subsurface (MacDonald et al., 1998; Adams, 2008). Valley patterns form orthogonal rather than classic dendritic drainage networks; and many valleys have classic bourne behaviour, with ephemeral springs activated under high water level conditions (MacDonald et al., 1998; Adams, 2008). Springs can also form in normally dry valleys under exceptional flood conditions; for example in the Ravensbourne catchment dry valley network during the floods of 2000/2001 (Adams, 2008). Baseflow in the rivers in the area is sustained by springs which discharge groundwater from networks of karstic solutional fissures and conduits. The discharge of most of these springs is unknown and has been heavily impacted by the extensive abstraction in the area, which has been mitigated by compensation schemes to maintain river flows (Adams, 2008).

There are 244 records of Chalk springs in the C6 North Downs Chalk area (Figure 27). These include records from the BGS springs dataset and records of springs within the BGS karst database; Environment Agency springs used for water quality monitoring; and springs reported in Irving (2004). Of these springs, most have unknown discharge, but there are 15 with reported discharges of greater than 10 $l.s^{-1}$, including six with discharges > 100 $l.s^{-1}$ (Table 3; Figure 28). The recorded discharges range from 11 to 1150 $l.s^{-1}$ (Table 3). Many of these springs are described by Whitaker et al. (1908), who also describe two other large springs in East London with discharges of 15 $l.s^{-1}$ and 19 $l.s^{-1}$, but their exact locations are unclear. Chalk spring discharge information in this area is very limited. Where there are any discharge measurements, generally there is just a single value for the spring, and the range of flows is unknown.

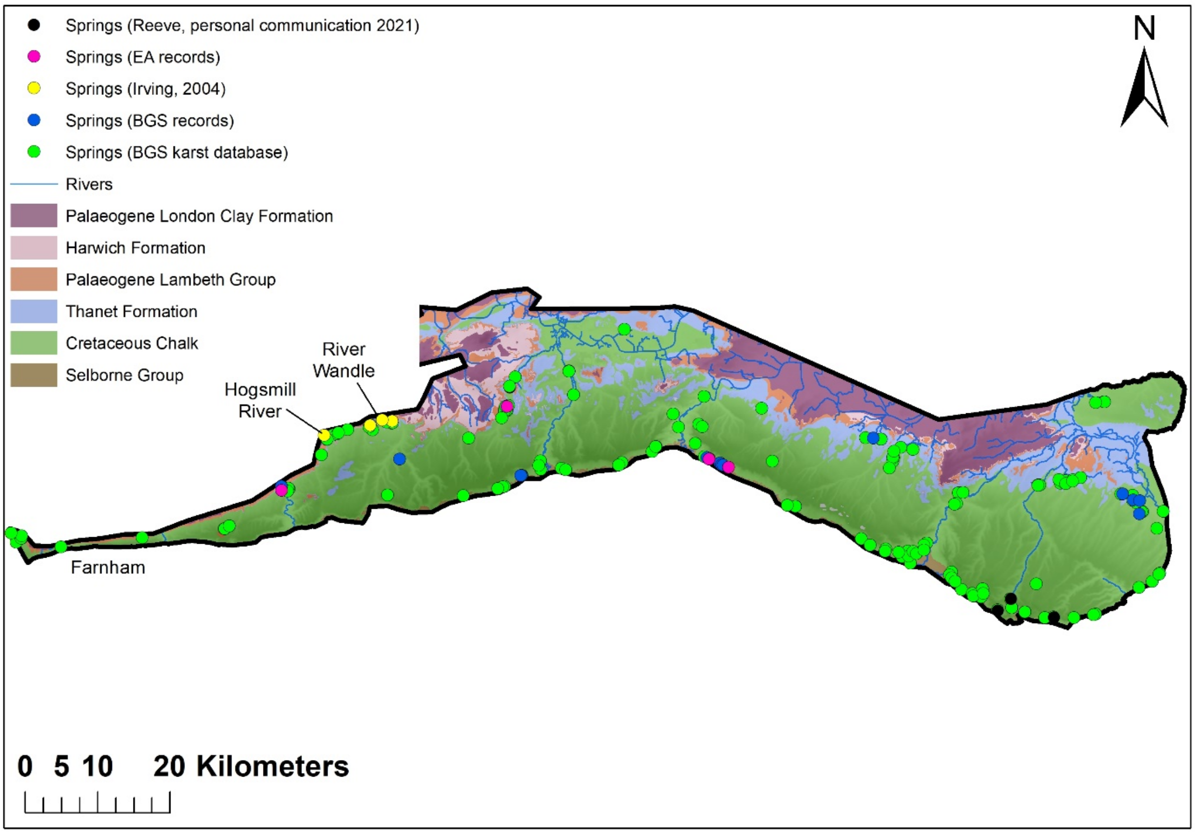

Figure 27. Recorded chalk springs of known and unknown discharge in the C6 area.

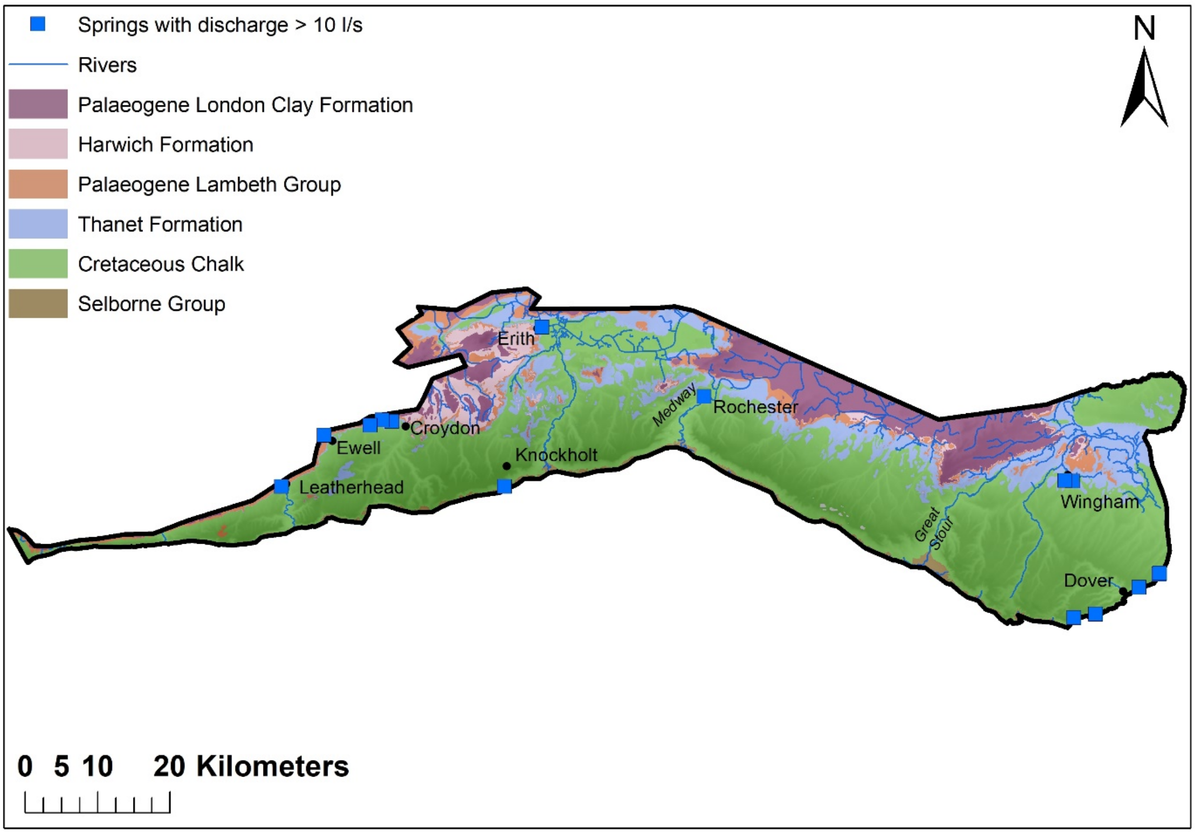

Figure 28. Large springs in the C6 area.

Table 3. Large springs recorded in the C6 North Downs Chalk area.

Spring	Location	East	North	Discharge ($l.s^{-1}$)	Chalk formation	Source
Watercress Farm Spring	Leatherhead	515710	156220	105 to 536	Lewes Nodular Chalk, Seaford Chalk and Newhaven Chalk formations (undifferentiated)	BGS WellMaster
Langdon Convict Prison Spring	Dover	634045	142281	11.5	Seaford Chalk Formation	Whittaker et al. (1908)
Canterbury Cave Spring		636794	144103	12.7	Lewes Nodular Chalk Formation	Whittaker et al. (1908)
Ness Point Spring		636884	144287	13.9	Lewes Nodular Chalk Formation	Whittaker et al. (1908)
Lydden Spout		628072	138624	157.9	Zig Zag Chalk Formation	Whittaker et al. (1908)
Frenchman's Fall Spring		625036	138111	25.2	Zig Zag Chalk Formation	Whittaker et al. (1908)
Wetherden Hall Spring	Wingham	624858	156992	16.1	Newhaven Chalk Formation	Whittaker et al. (1908)
Wingham Springs		623832	157053	43.7	Newhaven Chalk Formation	Whittaker et al. (1908)
Strood Springs	Rochester	574006	168677	22.7	Lewes Nodular Chalk Formation	Whittaker et al. (1908)
Court Lodge Spring	Knockholt	546492	156245	60.4	West Melbury Marly Chalk and Zig Zag formations (undifferentiated)	Whittaker et al. (1908)
Erith Pier Springs	Erith	551620	178221	78.9	Seaford Chalk Formations	Whittaker et al. (1908)
Waddon Ponds	Croydon	530900	165200	0 to 350	Lewes Nodular Chalk, Seaford Chalk and Newhaven Chalk formations (undifferentiated)	Irving (2004)
Beddington Park springs		529600	165400	0 to 1150		Irving (2004)
Carshalton spring		527900	164700	0 to 850		Irving (2004)
Ewell springs	Ewell	521600	163300	0 to 200		Irving (2004)

Further details of large springs in the area are described from west to east:

In the west of the C6 area, there are large springs in the Farnham area (Figure 21). Farrant et al. (2018) report that there is a major spring on the Bourne Mill stream close to the sewage works at Hale [SU 8524 4791] at an elevation of 69-70 m OD, which is reported to have a flow of several $l.s^{-1}$ even when the stream sinks were dry, and which Long (1840) and Young (1906) suggested might be the outlet for stream sinks in the Farnham Park area. Farrant et al. (2018) also identify four other places west of Farnham where springs occur which may be the natural outlets for the stream sinks in the Farnham area (Figure 21). However, no tracer testing has been carried out in the Farnham area to determine the stream sink outlets. The four places with natural springs are:

(1) Two springs near Crondall. The largest is the Ashley Head spring [SU 7975 4906] (c. 83 m OD). This spring, with an estimated discharge of c. 1-2 $l.s^{-1}$ under very low flow conditions rises up through gravel at the base of a bluff on the Chalk-Palaeogene contact. The spring discharges into a large artificial culvert, but the discharge of the spring under high flow conditions was not observed. A second spring is marked on OS maps downstream at [SU 7979 4941], but was not visited. Farrant et al. (2018) suggest that it is likely that other springs (winterbournes) occur in this area, rising up through the valley bottom superficial deposits to feed the stream that runs through the village of Crondall.

(2) A possible spring emerges from a culvert adjacent to Crondall Lane, 800 m ENE of Dippenhall [SU 8224 4693] at an elevation of c. 85 m OD.

(3) Itchell Mill springs near Crondall.

(4) Springs at Greywell [SU 7180 5067].

Adams (2008) report dip slope springs at Clandon (a few kilometres NE of Guildford, see Figure 2) with flows varying from 0 to ~20-25 $l.s^{-1}$; and a large perennial scarp slope spring "Silent Pool spring" to the south with flows from ~ 10 to ~115 $l.s^{-1}$. Adams (2008) notes that this is the only major scarp slope spring for 17 km.

Moving east, there are very large springs at Leatherhead on the River Mole (Figure 28) which are thought to be the resurgence for the River Mole stream sinks (Ruby, 1988-1989), although this has not been proven by tracer testing. "Substantial" springs also occur at Fetcham (Adams, 2008), just southwest of Leatherhead.

Springs at Ewell (Figure 28) feed the Hogsmill River, and a spring discharge graph in Irving (2004) suggests flows ranging from ~ 0-200 $l.s^{-1}$ between 1990 and 2002. Near Croydon (Figure 28), the baseflow of the River Wandle is maintained by large springs at Carshalton, Waddon and Beddington (Beloe, 2003; Irving, 2004; Adam, 2008). The spring discharge graph in Irving (2004) suggests flows ranging from 0-350 $l.s^{-1}$ for Waddon springs (between 1969 and 2002); with ~0-850 $l.s^{-1}$ for Carshalton springs, and with ~0 to >1150 $l.s^{-1}$ for Beddington springs (between 1965 and 2002).

Farrant and Aldiss (2002) describe six large springs in the area between the River Medway and the Great Stour river, which occur at the foot of the downs close to the boundary with the overlying Thanet formation, and suggest that there may be others in this geological setting. They also suggest that there may be some structural control on this spring line where there is fracturing associated with gentle folding.

Farrant et al. (2021) provide an overview of springs in the area between Charing and Faversham and these are shown in Figure 29. They note that Whitaker (1908) records several springs in Faversham, and several at Ospringe; one just east of the Church, one near the Vicarage, two others in the stream above the Vicarage and the spring-head southeast of Painters Forstal, and on a tributary near the old workhouse. No details on their size, seasonality or flow are given. It is not known how many of these are still functioning. The natural (pre-groundwater abstraction) and current discharge of these springs is also unknown. Farrant et al. (2021) also note that springs are mentioned by Whitaker (1908) in the Great Stour valley. No details are given except for a spring marked on OS maps near Chartham at [TL 0913 5534]. It has been suggested that this spring is the resurgence for the Lower Ensden stream sinks (Prestwich, 1854). It is possible that stream sinks in the Selling area may resurge here (Figure 29). No details are known and no tracer tests have been carried out.

Mathewson et al. (2021) note two springs issuing from the West Melbury Marly Chalk Formation at the base of the Chalk in the Stockbury area (Figure 31), but with no information on their size.

In the east of the area, there are also large springs on the River Stour at Shalmford Street, southwest of Canterbury. Prestwich (1854) notes that "on the river bank near that village (Shalmford Street) a large and perennial spring bursts out" and suggests that this may be the resurgence for the stream sinks to the northwest. He also reports that there are several other springs in the River Stour. Also in the east of the area, Watson (2005) reports that in groundwater models, Acer (1991) use a flow of 4000 to 27000 m^3/day (46-312 $l.s^{-1}$) for the Well Chapel Springs which flow into the Wingham River, a tributary of the Little Stour river.

Reeve (personal communication, 2021) notes that there are a number of substantial springs in the Folkestone area: (1) A "very powerful" scarp slope springs near Pent Farm, Postling at [TR 1410 3940] (2) Another spring near Postling at [TR 1440 3920] that feeds the East Stour river (3) Springs near Lyminge, to the east of the church at [TR 1620 4080] which feed the Nailbourne Stream. Reeve (personal communication (2021) also reports that (1) there are springs at Newington which feed a fairly large stream. (2) Although there is not much flow coming out of the Holywell springs near the channel tunnel entrance [TR 2230 3830], they emerge from a cavity in the Chalk. (3) springs about half a mile east of the village of Alkham emerge from solutional fissures. The discharges of these springs are unknown, but their locations are shown in Figure 27.

Many of the springs on the south side of the Downs occur near the base of the Chalk, close to the boundary with the underlying Selborne Group. The 'Cast-Bed', at the base of the Zig Zag Chalk Formation, forms a spring line in Kent. The large spring Lydden Spout between Dover and Folkestone issues from this spring line (Figure 28; Table 3). Homersham (1850) describes Lyddon Spout "which discharges a body of water at an elevation of about 20 feet above high-water, through a fissure in the chalk cliff……the water discharged from it being conducted for a long distance through fissures or openings in this rock". Homersham (1850) also describes springs that emerge at low tide at a place called "Cobblers Rock" which were used to supply the Cornwell coastguard station, east of Dover Castle; and other freshwater springs exposed at low tide in St Margaret's Bay. Springs occur throughout the Chalk sequence, and can be common in the upper parts of the Chalk (Whitaker et al., 1908). There are likely to be many more springs in addition to those shown on Figure 27.

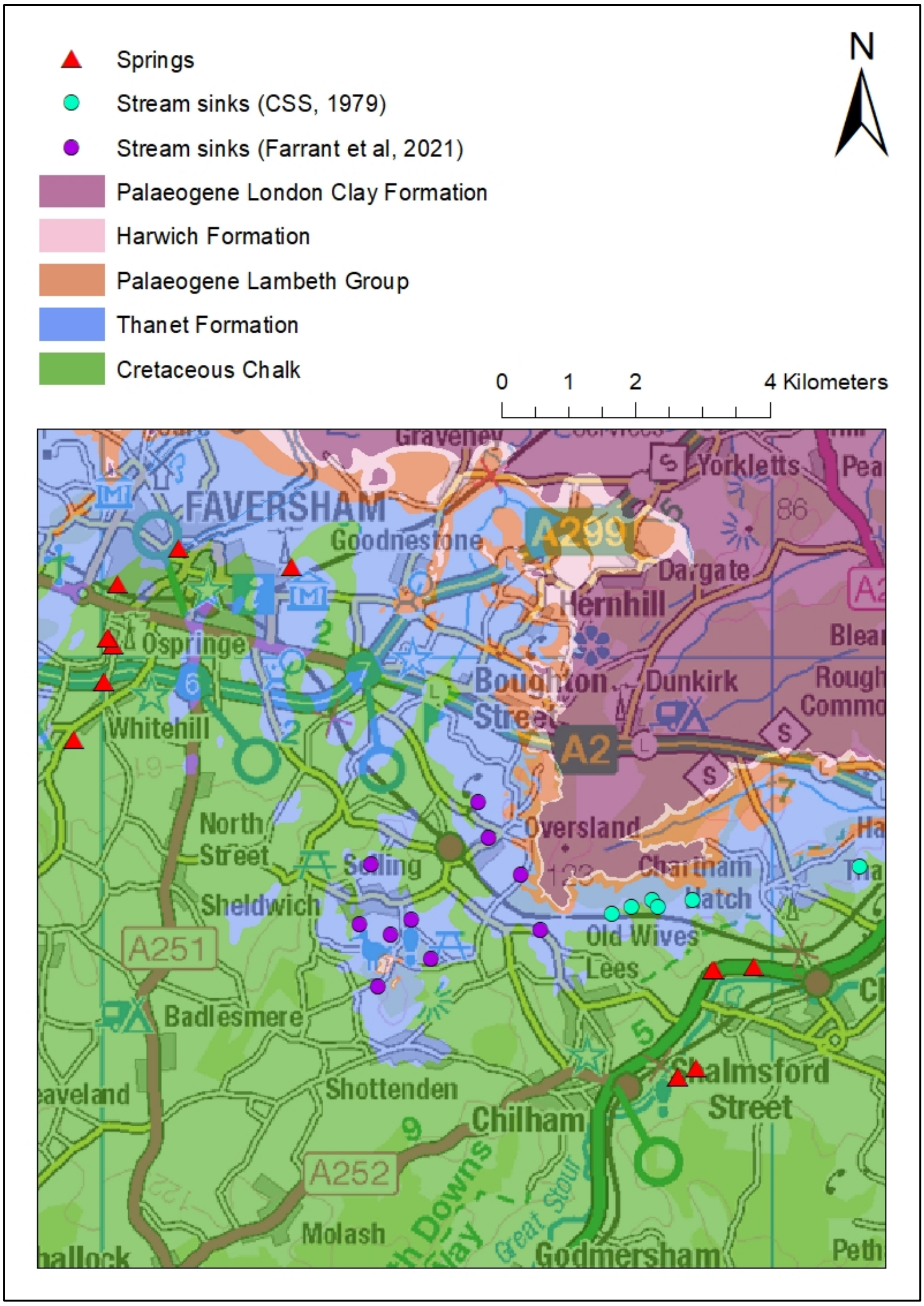

Figure 29. Springs in the Faversham area, modified from Farrant et al. (2021).

2.4 DOLINES AND DISSOLUTION PIPES

Records of dolines and dissolution pipes have not been compiled in the BGS karst database in the C6 Chalk area. There are 154 dolines and 411 dissolution pipes recorded in the Natural Cavities database in the area (Figure 30). The Natural Cavities database is a legacy dataset held by The British Geological Survey and Peter Brett Associates. It is comprised of data from a range of sources originally commissioned by the Department of the Environment and by Applied Geology Limited (1993). As in all areas of the Chalk, it is unclear whether all these dolines are natural karst depressions or whether they are manmade pits. They are therefore listed as surface depressions on Figure 30. Dissolution pipes are recorded throughout the area, but records of surface depressions appear to be concentrated in the western parts of C6.

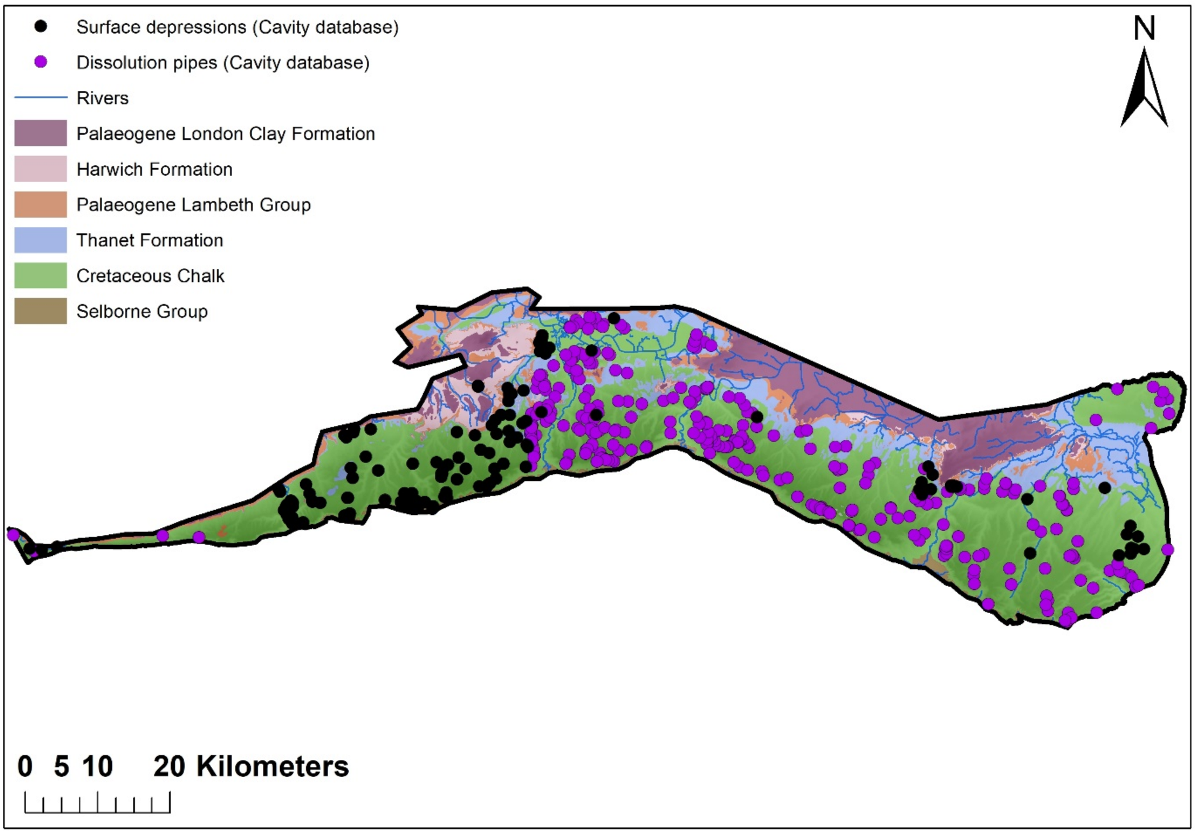

Figure 30. Surface depressions and dissolution pipes in the C6 North Downs Chalk area.

High densities of solution features have been recorded in the North Downs area (Edmonds, 1983; Adams, 2008). Frequencies of solution features were observed to be higher in the eastern part of the North Downs, with 51 to 70 features per 100 km^2, compared to the west, where densities were reported to be 31 to 50 features per 100 km^2 (Edmonds, 1983).

Farrant et al. (2021) review the evidence for dissolution features in the area between Charing and Faversham, which is in the centre of the North Downs karst knowledge exchange area. They suggest that dissolution pipes are most likely to occur around the margins of the Thanet Formation outcrop; and are likely particularly around Lees Court [TQ 0200 5600] and Owens Court [TQ 0280 5770], where Smart et al. (1966) state 'the margin of the outlier is extensively piped'; and along the northern margin of the area between Rushett and Oversland close to the contact with the Thanet Sand. In these areas, dissolution pipes are likely to be numerous, and in some areas, may merge to create a highly irregular Chalk-Thanet Formation contact, with isolated pinnacles of chalk left between them. Farrant et al. (2021) report that many of the 26 dissolution pipes in this area in the Natural Cavities database are old historical records derived from BGS memoirs (Whitaker, 1872; Smart et al., 1966). For many, little is known about their size or form, but they are probably sediment-filled dissolution pipes identified in old pits and quarries. Their distribution reflects more where they have been exposed rather than their true distribution, as the vast majority are unrecorded. Whitaker (1872) noted extensive dissolution pipes in the railway cutting just south of the M2 at Brenley Farm [TL 0380 5870], and Smart et al. (1966) record pipes 3-4 m deep in a pit at [TL 0440 5870]. Other pipes were noted in a chalk pit at [TL 0480 5540], in a trench at [TQ 9840 5170], and at [TQ 9980 5330].

In a study of karst in the Stockbury area, Mathewson et al. (2021) report that there were no karst stream sinks. They also report that there are few records of dolines or dissolution pipes. There are a number of surface depressions (Figure 31), which were considered likely to be dug pits and not natural karst features, although dug pits could be sited on natural karst depressions. Four dissolution pipes recorded in the Natural Cavities database (Figure 30), were located within the Clay-with-Flints cover. These were originally reported in the BGS geological memoir for the region (Worssam et al., 1963), and could not be observed in a 2020 field survey as they were in overgrown pits and quarries. Mathewson et al. (2021) suggest that it is likely there are many more dissolution pipes, which have no surface expression, where the Clay-with-Flints is present. They also note that Worssam et al. (1963) describe an area “riddled with solution pipes” up to “15 or 20 feet in diameter” on the escarpment above East Lenham.

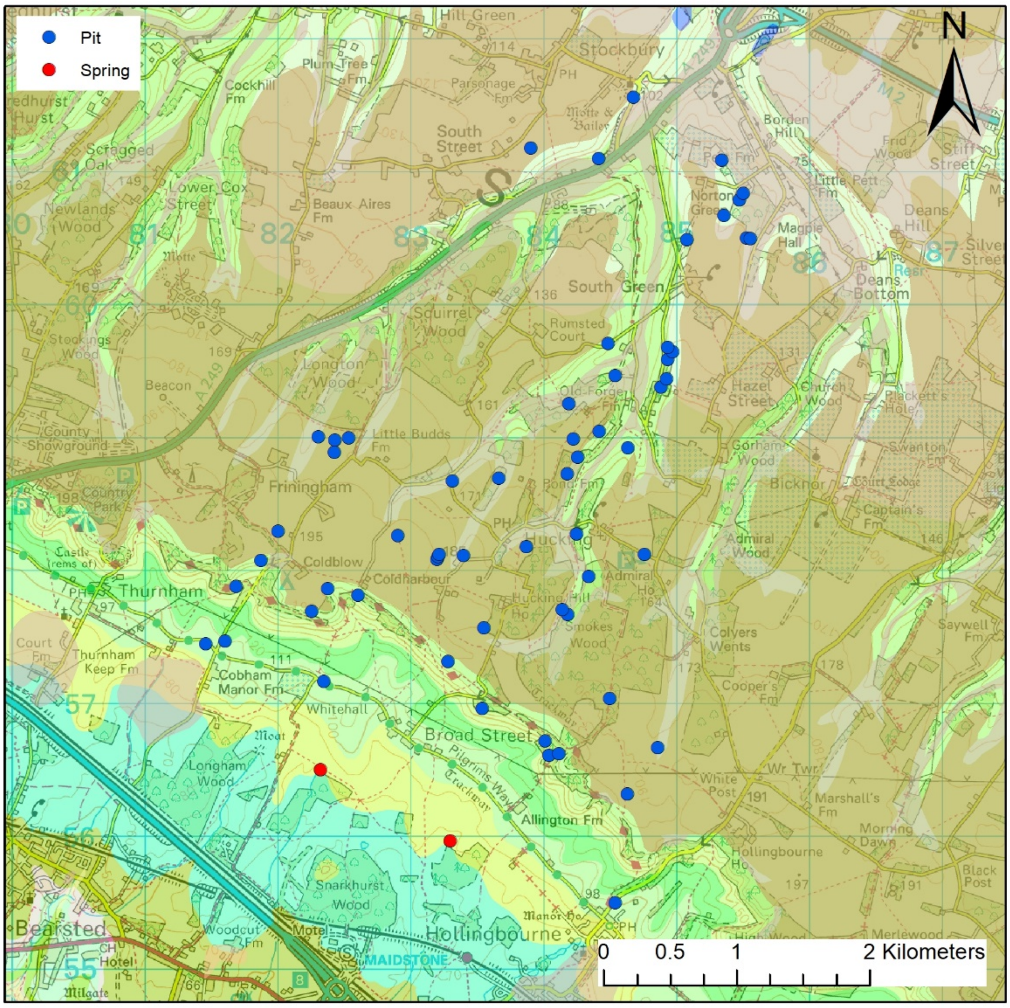

Figure 31. Surface depressions in the Stockbury area, modified from Mathewson et al. (2021).

In a study of karst in the Hartley area, Bunting et al. (2021) discuss dissolution pipes recorded in the Natural Cavities database, mostly from old pits, road and railway cuttings, and again located within the Clay-with-Flints cover. Many of these were identified from BGS memoirs (Whitaker, 1872, Dewey et al., 1921). Specifically pipes of Thanet Sand are recorded in the cutting at Longfield Green, some of which come down to rail level, and at Nursted, including a ‘very pipey patch’ of the Thanet Sand basal bed by Meopham station. These are no longer visible. Bunting et al. (2021) also identified numerous pits and surface depressions from historic maps and BGS field slips (Figure 32), generally clustered around the Chalk/Clay-with-Flints outcrop. However, field visits and aerial photographs suggested many may be dug Chalk pits of anthropogenic origin.

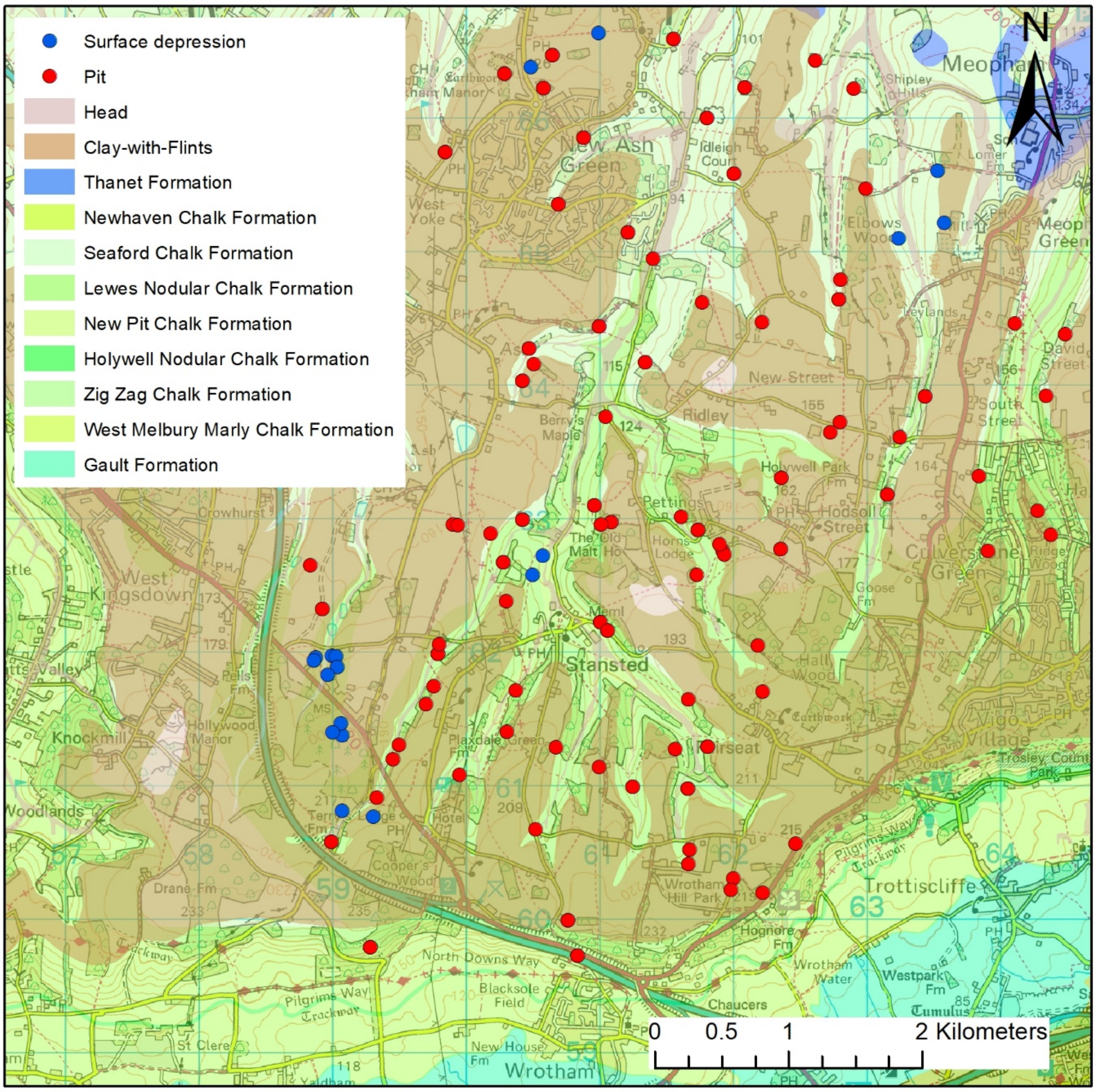

Figure 32. Surface depressions in the Hartley area, adapted from Bunting et al. (2021).

A short field survey in September 2020 found no stream sinks or springs in the Hartley area (Bunting et al., 2021). Many of the features identified in the Natural Cavities database were no longer visible or had no surface expression. A possible doline or old pit was observed on the ridge 650 m northeast of Stansted church. There was little remaining trace of features revealed during construction of the M20 cutting on the Chalk escarpment. Similarly, features recorded in the old pits at White Hill [TQ 5925 5965] and Platt Hill [TQ 6160 5969] are no longer visible. Several additional karst features were identified (Figure 33) including a chalk pit in Baker’s Wood

[TQ 6042 6300] with a small dissolutional cavity > 1 m long and 40 cm high, and a possible small doline 10 m across and 1 m deep in Viney Wood, near Ridley at [TQ 6179 6459].

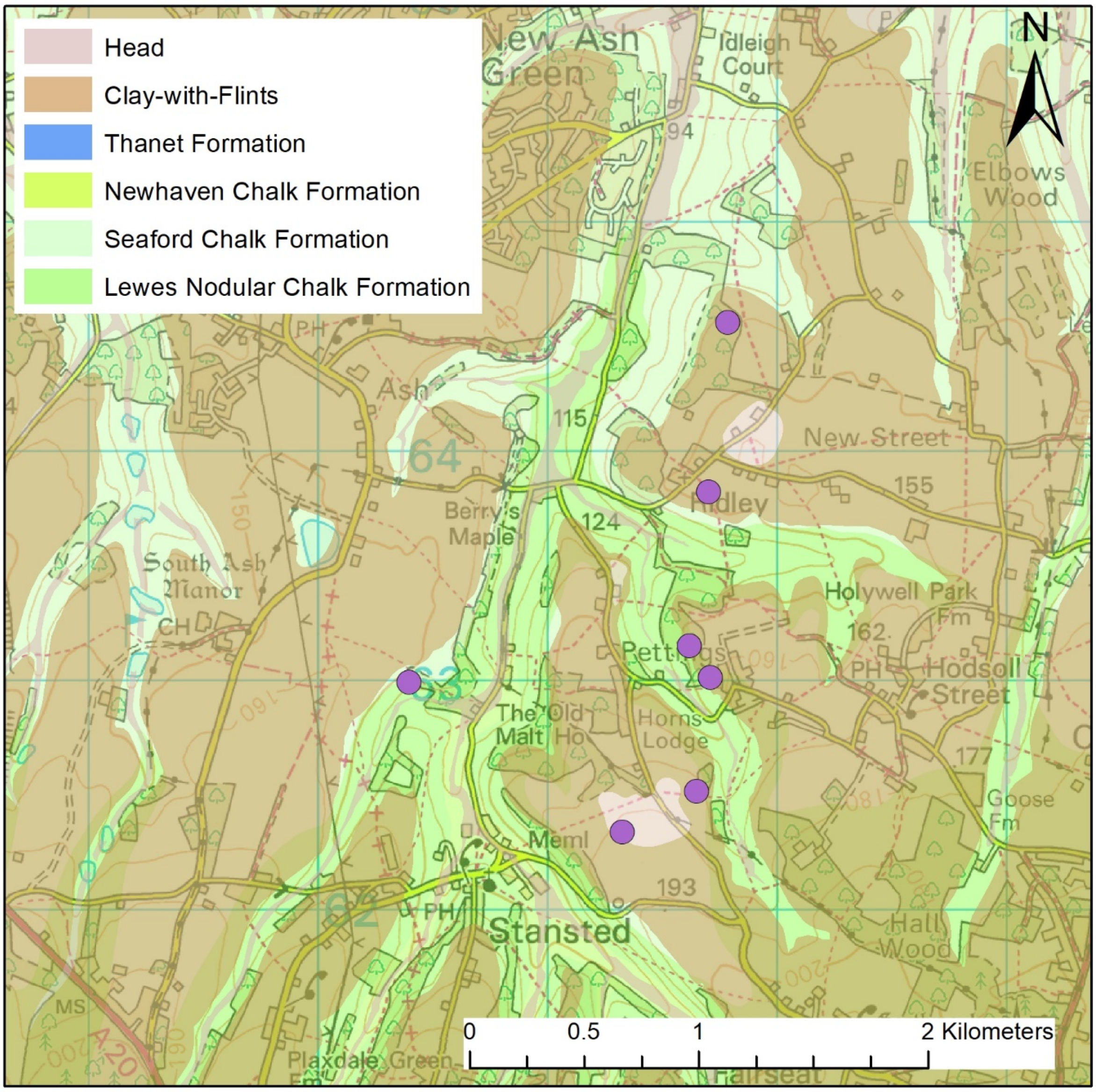

Figure 33. Solution features identified in a 2020 field survey of the Hartley/Stansted area.

Dissolution pipes are also discussed by Irving (2004) who reports that they have been observed in the Lewes Nodular Chalk Formation in the North Downs Tunnel in the centre of the C6 area. Reports of dissolution pipes and cavities identified during construction of the Channel Tunnel Rail Link and North Downs Tunnel are recorded in Warren & Mortimore (2003), who note that “the scale of the pipes on parts of the route were spectacular”. Dissolution pipes were especially prominent at the northern portal of the North down tunnel and in the cuttings just west of the Medway viaduct. They also noted solution features more than 80 m below the surface in the Holywell Nodular Chalk. Dissolution pipes are also noted in the north of C6 in East London, where Thanet Sand or overlying superficial deposits have infilled solution cavities in the Chalk below (Walsh et al., 1973). Overall, it is likely that dissolution pipes are primarily associated with the contact between the Clay-with-Flints or the Palaeogene sediments and the underlying Chalk (Farrant et al., 2017).

3 Tracer tests

Tracer tests have been conducted at two locations in the C6 Chalk area (Figure 34).

The first involved four injections of salt or bacteria into one doline in the Croydon area (Richards and Brinker, 1908). A connection to a pumping borehole 3200 m away was demonstrated (Richards & Brincker, 1908; MacDonald et al., 1998). The tracer test demonstrated rapid groundwater flow with velocities based on time to peak tracer concentration of between 985 and 2648 m/day. Tracer recovery was not estimated.

Tracer testing has also been conducted in the east of the area (near Tilmanstone) and is reported in the PhD by Watson (2005). Watson (2005) describes a tracer test reported by Bibby (1979) in which alcohol was injected into a monitoring borehole and detected at a pumping borehole 25 m away, with a recovery of 60%. A breakthrough curve from this test is presented in Watson (2005) and shows tracer breakthrough about 30 minutes after injection (indicating a groundwater velocity of 1200 $m.d^{-1}$), and a peak about 90 minutes after injection. There are very limited details about this test, or two others which were reported by Bibby (1979) which were unsuccessful.

Watson (2005) gives details of a series of tracer tests and borehole dilution tests that were conducted with MSc. Students Hazell (1998), Quinn (2000) and Patel (2001) under the supervision of Tim Atkinson. A first test was conducted in winter 1999/2000 from borehole BGSLVV with monitoring at BH2, 3 and 4. Tracer was conclusively detected in BH3 which is 28 m from the injection borehole, with a possible positive at BH2. Subsequent tracer testing was undertaken between borehole BGSLVV and BH3 in 2000 (when approximately 1% of tracer was recovered in BH3) and summer 2001. In the 2001 test, tracer concentrations were measured at 10 depths of between 20 and 46 m below ground level in BH3. Tracer breakthrough was fairly rapid with tracer arriving at three horizons in 9.25 hours indicating a groundwater velocity of about 73 $m.d^{-1}$ (Watson, 2005). An example tracer breakthrough curve is shown in Figure 35. Tracer appears to peak about 30 hours after injection, and continued to be discharged at around these peak concentrations until monitoring ceased 673 hours after injection.

Watson (2005) also provides details of 8 single borehole dilution tests undertaken in the Tilmanstone area. These indicated variable and quite rapid dilution rates, with two boreholes diluting most of the tracer within 6 hours, whilst others took 24 to 48 hours for most of the tracer to be diluted. Watson (2005) calculated hydraulic conductivities of ~10-100 $m.d^{-1}$ based on the dilution test results, with similar hydraulic conductivities estimated from packer testing.

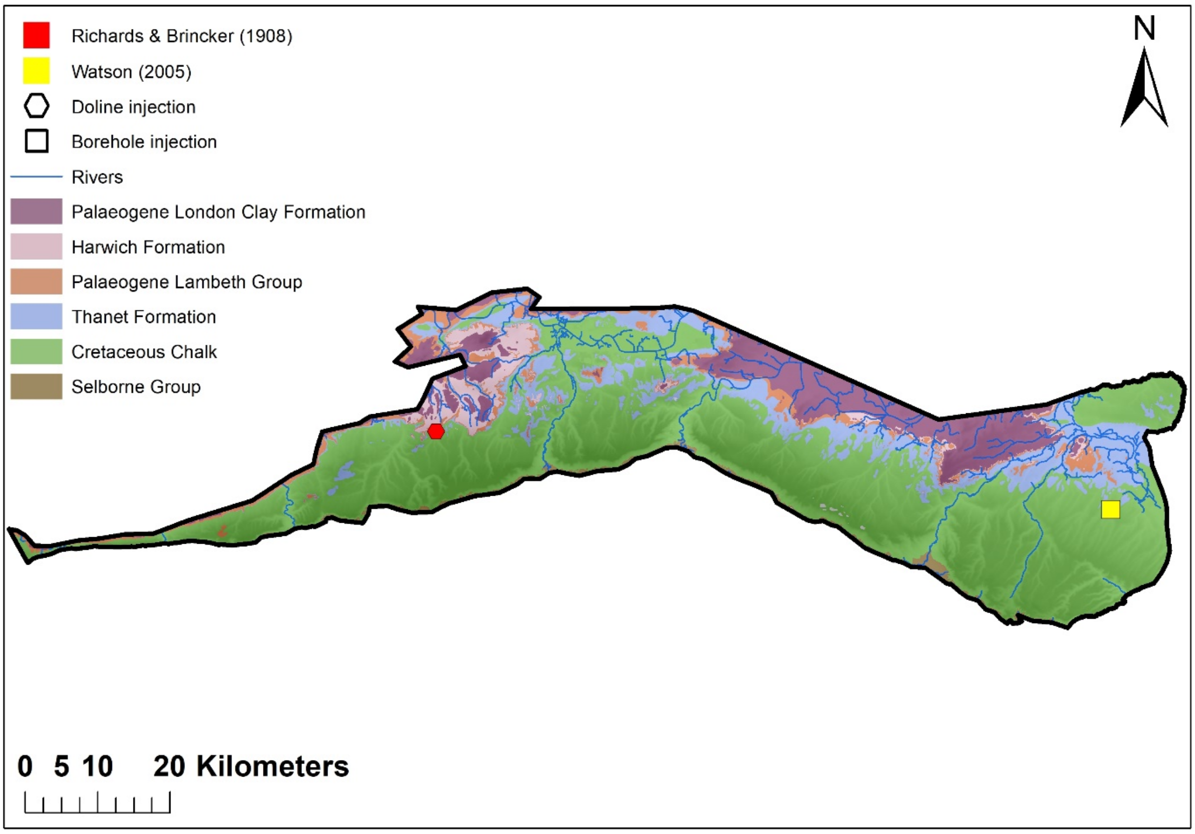

Figure 34. Location of tracer tests in the C6 North Downs Chalk area.

Figure 35. Example breakthrough curve from tracer testing at Tilmanstone (Tim Atkinson, personal communication, 2019; from work carried out by Patel, 2001 and Watson, 2005).

4 Other hydrogeological evidence of karst and rapid flow

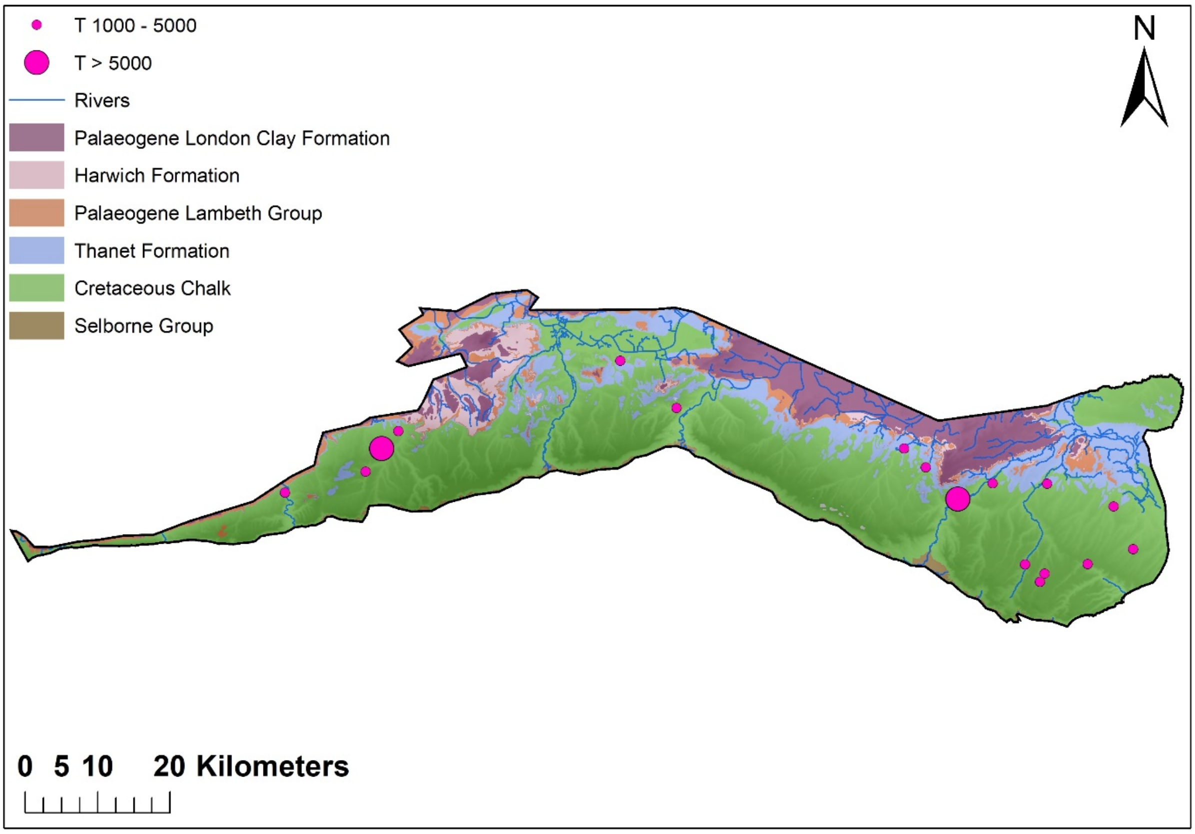

Figure 36. Transmissivities ($m^2.d^{-1}$) in the C6 area.

There are many boreholes in the C6 area where pumping tests have indicated high transmissivities of > 1000 $m^2.d^{-1}$, and a small number of sites with transmissivity of > 5000 $m^2.d^{-1}$ (Figure 36). It is widely recognised that the high transmissivity observed in the chalk boreholes in the North Downs area is due to a small number of solutionally enlarged fissures/small conduits which enable rapid flow (Reynolds, 1970; Allen et al., 1997; Adams, 2008). Groundwater abstraction in the area is often from boreholes located in dry valleys and/or close to springs (Adam, 2008; Farrant et al., 2021; Mathewson et al., 2021; Bunting et al., 2021) which form the natural outlets to the karstic solutional networks.

There is evidence of karst at some abstraction boreholes in the area (knowledge exchange meetings with water companies; Farrant et al., 2017; Farrant et al., 2018; Farrant et al., 2021; Mathewson et al., 2021; Bunting et al., 2021). Evidence includes conduits observed in borehole images and/or the presence of water quality indicators of rapid flow (which might include the presence of coliforms, detection of rapidly degrading pesticides, turbidity, salinity from road applications, or indicators of connectivity with the sea or surface water rivers).

There is further evidence of focused karstic flow from the types of inflows that were encountered during the drilling of adits for water supply. For example, Homersham (1850) reports that during the drilling of an adit near Dover "a workman observed a small stream of water to follow the withdrawal of his pick-axe; on the next blow this stream was very much increased; and on the third there issued such a rush that the workmen escaped from the well with great difficulty, for the water filled the shaft nearly as fast as they could be drawn up".

Rapid responses of groundwater levels to rainfall events in the east of the C6 area may also be indicative of rapid subsurface flow. Results of a study correlating rainfall and water levels (Lee et al., 2006) show two responses over time; an initial increase in water-levels within two days of a rainfall event, followed by a much later response. This first response was interpreted as indicating the presence of fissure flow (Lee et al., 2006).

A study by Beloe (2003) suggests focused karstic groundwater flow in the Chalk of the Wandle Catchment (in the Croydon area). Unusually constant water levels in observation boreholes were thought to be due to a high permeability layer, which corresponded with the elevations of "wide fissures" observed in a borehole caliper log, and spring elevations. Once this thin high permeability layer was incorporated in the groundwater model, borehole water level and spring discharge simulations were improved.

5 Summary

- There is strong evidence of karst in the C6 North Downs Chalk area.
- There are records of 21 natural caves with evidence of karstification. Most are less than 25 m long, but the longest, Canterbury Cave, is 110 m in length.
- Dissolution pipes occur very commonly throughout the area, particularly in association with thin superficial/Palaeogene cover. There are likely to be many more dissolution pipes that are not currently recorded.
- Surface depressions are also common, although it is unclear whether many of these are natural karst features, as they are difficult to distinguish from manmade pits.
- 84 stream sinks are recorded in the area. There may be more stream sinks, particularly in association with the Chalk/Palaeogene boundary.
- Apart from the river Mole where swallow holes are well developed, river losses were not considered in this data compilation and there may be river losses within the North Downs area enabling point recharge to the Chalk.
- There are 244 records of springs in the Chalk in this area. There is very little information on the discharge or characteristics of these springs and there may be more unrecorded springs.
- 15 of the recorded springs are known to have discharges > 10 $l.s^{-1}$ with six having records of > 100 $l.s^{-1}$ including one which has a discharge that can exceed 1100 $l.s^{-1}$.
- Karst stream sinks and springs have been particularly documented in the Farnham area, the River Mole, the Faversham area and the Canterbury area.
- There has been very little tracer testing in the North Downs Chalk, with only two tracer studies conducted.
- Natural gradient borehole to borehole tests demonstrated moderately rapid flow of ~ 70 $m.d^{-1}$ over 28 m.
- Very rapid groundwater flow of ~ 1000 to 2650 $m.d^{-1}$ was demonstrated over a distance of 3.2 km following tracer injections into a doline.

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.

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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