

9 UK: ESSE

9.1 Overview

ESSE Pumping Station is an example of a karstic chalk borehole abstraction. The pumping station is comprised of two operational boreholes located side-by-side approximately 50 m from the River Lea (Morrison, 2017). The water supply comes from boreholes and an adit system. Over the period April 1995 to January 2019 the average daily abstraction from the ESSE boreholes was 4.11 Ml/d, reaching a maximum of 10.80 Ml/d. The large yield and geophysical logging suggest the presence of solutionally enlarged fissures within the boreholes.

Karst features are prevalent in the ESSE area (Wooldrige and Kirkaldy, 1937; Harold, 1937; Cook, 2010), and include the Water End swallow holes which are the largest karst stream sink in the English Chalk. Tracer testing from the Water End swallow holes has demonstrated connections to a range of springs and boreholes over distances of up to 16.6 km with groundwater velocities of up to 3.36 km/day (Harold 1937; Cook 2010). Tracer injected at the Water End swallow holes has been detected at ESSE, with a groundwater velocity of 2.4 km/day over a distance of 6.8 km (Cook, 2010), demonstrating the extent of the ESSE catchment to the southwest.

Further insights into the hydrogeology of the area come from a detailed study of a bromate contamination event first detected in boreholes in May 2000 (Cook, 2010; Fitzpatrick, 2011; Cook et al., 2012; Wyke et al., 2013). The bromate originated from Sandridge and was widely mapped over an extensive area to the east of the source. It was detected at ESSE pumping station around 11km to the east, demonstrating that the ESSE catchment also extends to the west into an area of outcrop Chalk where surface karst features are generally absent.

9.2 Geology

Much of the ESSE catchment is overlain by superficial deposits, predominantly the Lambeth Group and London Clay Formation. The approximate thickness of superficial deposits in the ESSE region is 1-2 m. The Seaford Chalk Formation is exposed in the southern side of the Lea Valley (Farrant et al., 2017). There are also some thin layers of River terrace deposits and Alluvium, dominated by silts and sands associated with the former course of the River Thames (Farrant et al., 2017).

The Cretaceous Chalk dominates this area, and forms the principal aquifer in the south-east of England. The Cretaceous Chalk is a fine-grained and highly porous limestone comprised principally of coccolithic fragments. The boreholes at ESSE penetrate the Seaford Chalk Formation and Lewes Nodular Chalk Formation that form the upper part of the White Chalk Sub-Group. The Chalk Rock Member of the Lewes Nodular Chalk Formation is comprised of very hard Chalk with some nodular and mineralised hardgrounds and marls, and can be up to 4-5 m in the ESSE region. The average total thickness of the Chalk is approximately 200-215 m in the ESSE region, thinning to the north (Allen et al., 1997).

ESSE lies to the east of the Chilterns on the northern quarter of the London Basin. The London Basin that controls the regional structure is an asymmetrical syncline with a SW-NE-east axis that dips to the east beneath London (Shand et al., 2003). The regional dip of the Chalk is less than 2° down towards the Southeast (Cook et al., 2012).

Due to tectonic influences, a number of minor faults and folds exist on the main syncline of the London Basin (Shand et al., 2003). Walsh and Ockenden (1982) describe the fracture orientation at ESSE to be dominantly NE-SW striking, with a sub-ordinate NW-SE striking set. A number of N-S aligned fractures at ESSE suggests N-S faulting in the area (Cook, 2010).

9.3 Geomorphology

The ESSE boreholes are at an elevation of about 50 m above Ordnance Datum (OD) in a valley location, adjacent to the River Lea. From ESSE, the groundwater-fed River Lea flows towards the northeast and then the southeast. There are a number of substantial springs in the Lea valley. There are also dry valleys within the ESSE area.

Surface karst features are prevalent in the ESSE area. In the current ESSE Source Protection Zone 2, there were 5 stream sinks identified during a recent field survey (Farrant et al., 2017). A further three lie on the outskirts of the catchment and may be connected to the abstraction. (Figure 1) shows further stream sinks in the area, predominantly located on or near the Chalk-Paleogene boundary.

The Water End swallow holes are located approximately 6.8 km to the southwest of ESSE and form the largest stream sink complex in England (Farrant et al., 2017). Water from the Mimmshall Brook sinks into a series of over 15 karst sinkholes, the number and points vary in response to the amount of water flow from the Mimmshall Brook. Walsh and Ockendon (1982), report a mean flow of ~ 80 l/s, and suggest they have the capacity to take up to 1,000 l/s, before overflowing into the Upper Colne valley. Walsh and Ockendon (1982) describe the different sink points from observations between August 1969 and January 1970 and Wooldridge and Kirkaldy (1936) describe the swallow holes in 1936.

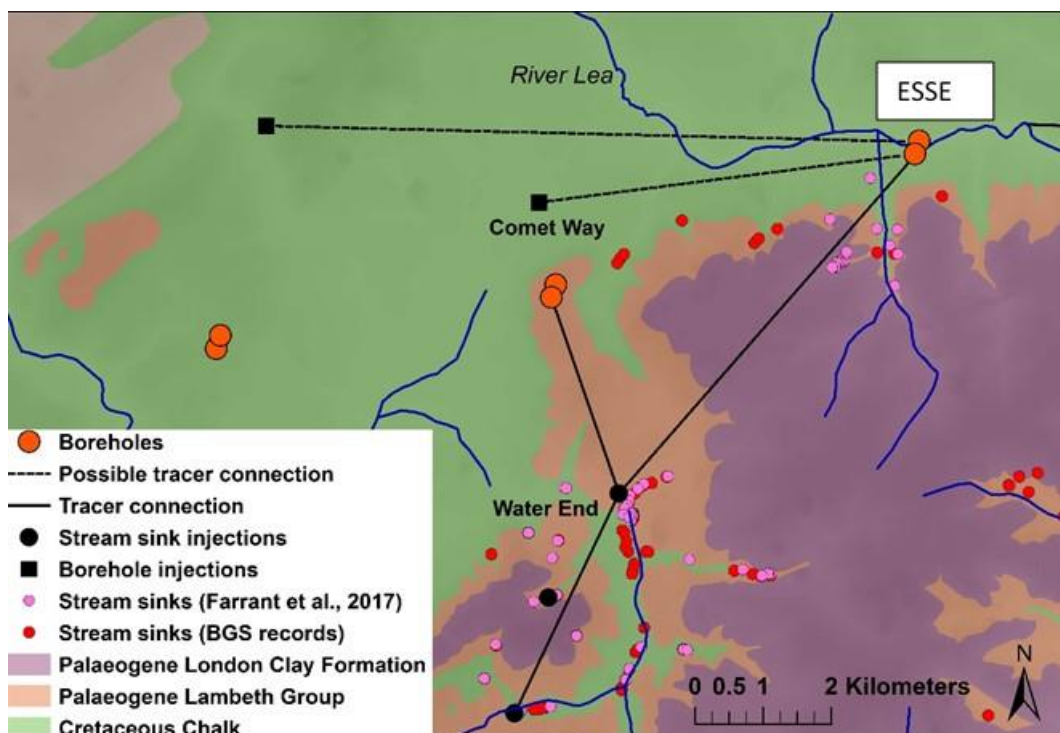


Figure 1: karstic features and tracer tests in the ESSE area. Geological material © NERC. All rights reserved. Topography © Crown Copyright reserved.

In the wider area, there are many other stream sinks which are generally associated with the Chalk-Palaeogene geological boundary (Whitaker, 1921; Farrant et al., 2017). Stream sinks represent a major point of recharge to the underlying Chalk aquifer in the ESSE region (Farrant et al., 2017). Farrant et al. (2017) identify 8 stream sinks within the SPZ 2 part of the catchment. Tracer testing has not been conducted from these stream sinks.

In the ESSE catchment few dissolution pipes have been recorded and little is known about their form. BGS hold records of two infilled dissolution pipes at ~ 1.2 km and ~ 1.8 km from the ESSE boreholes, sited on the boundary of the Chalk and Palaeogene deposits. A large number of dissolution pipes or surface depressions are recorded on the outskirts of Welwyn Garden City (~ 3 km to the north of ESSE), but little is known about their form. On the southern side of the River Lea, dissolution pipes with a length of less than 10 m are likely where river terrace deposits overlie the Chalk (Farrant et al., 2017). It is probable that karstic dissolution pipes are common in the area, particularly where the Chalk is overlain by thin Palaeogene or superficial deposits.

9.4 Climate

ESSE lies on the border between Southern and Eastern UK climate zones. In the Southern zone the mean annual temperatures vary between 11.5°C in central London and along the southern coast, to 9.5°C inland (Met Office, 2016). This is slightly higher than the UK average of between 7 and 11°C. ESSE lies close to the driest parts of eastern England which receive only 500 mm of rainfall per year (Met Office, 2016). The eastern region can be subject to dry periods and often requires water conservation measures such as hosepipe bans, particularly if recharge is low.

9.5 Hydrogeology

The ESSE boreholes and adits intercept the Cretaceous Chalk that forms the principal aquifer in the ESSE region. The abstracted water comes from a relatively small number of inflows to the adits and boreholes. The Cretaceous Chalk is a complex aquifer in which high matrix porosity and a dense network of unmodified fractures provides substantial storage, whilst flow occurs within solutionally enlarged fissures and conduits. The Chalk Rock Member of the Lewes Nodular Chalk Formation is thought to provide the main flows to the adits and headings at ESSE (Cook, 2010). Transmissivity values are also high along the nearby River Lea, suggesting the presence of solutionally enhanced fissures and conduits (Shand et al., 2003). The hydraulic gradient in the region is oriented towards the SE, following the regional dip of the chalk.

A tracer test using *Serratia Marcescens* bacteriophage demonstrated a connection between the Water End swallow holes and the ESSE boreholes over a distance of 6.8 km, with a calculated groundwater velocity of 2.4 km/day (Cook, 2010) (*Figure 1*). Tracer was also detected at two springs (Arkley Hole and Lynchmill) and four other abstractions (Amwell Marsh, Hatfield, Rye Common and Turnford), illustrating that there is a distributed network of conduits with flow down multiple flow-paths. These 6 connections had also been previously demonstrated with dyes (Harold, 1937), although ESSE was not monitored in these early tests. The tracer recovery of 4.53% at ESSE was higher than at the other sites, suggesting that the abstraction is well connected to one of the more significant conduits fed by the Water End swallow holes.

To date, there have been no tracer tests to demonstrate how the stream sinks in the ESSE catchment are related to this conduit system. Previous tracer testing from Water End has indicated a high degree of connectivity among a complex karstic network with springs and abstractions in the ESSE catchment. However, karst networks can be highly complex with isolated conduit systems, making them challenging to fully understand.

Cook (2010) also suggested a potential connection between the Comet Way borehole to the west and the ESSE abstraction. Over a distance of 5.6 km, the calculated velocity was 786 m/day based on time to first arrival. However, tracer concentrations were near background concentrations, and therefore positives are not conclusive.

The results of tracer tests reported by Cook (2010) and Harold (1937), suggest a complex and extensive conduit network in the Water End area, in which the conduit system is connected to fissures and conduits supplying abstraction boreholes as well as to karstic springs. The karstic nature of these conduits mean that travel times and recoveries are likely to vary in different seasons and under different local pumping regimes (Farrant et al., 2017).

A plume of bromate originating around 11 km to the west of ESSE and detected in May 2000 provides additional understanding of the hydrogeology of the area (*Figure 2*). The study of the plume offers insight about the transport of pollutants and the speed and direction of the regional groundwater flow. The bromate plume was widely mapped and an extensive borehole monitoring programme set up to improve understanding of the bromate distribution, and used to inform mitigation measures and reduce the threat to public water supply. Bromate was found in the Chalk bedrock matrix of cored boreholes, and it may be that storage of the bromate is predominantly in the bedrock matrix and the unmodified fracture matrix. Bromate was also detected at the springs and boreholes in the Lea valley up to 20 km from the source, demonstrating that the plume has intersected the karstic network of conduits and fissures which enables the bromate to be transported over large distances. Bromate was found at varying concentrations in nearby boreholes, with some examples of bromate free boreholes near to contaminated boreholes, demonstrating the irregular karstic nature of the aquifer, with different flowpaths intersected at different boreholes.

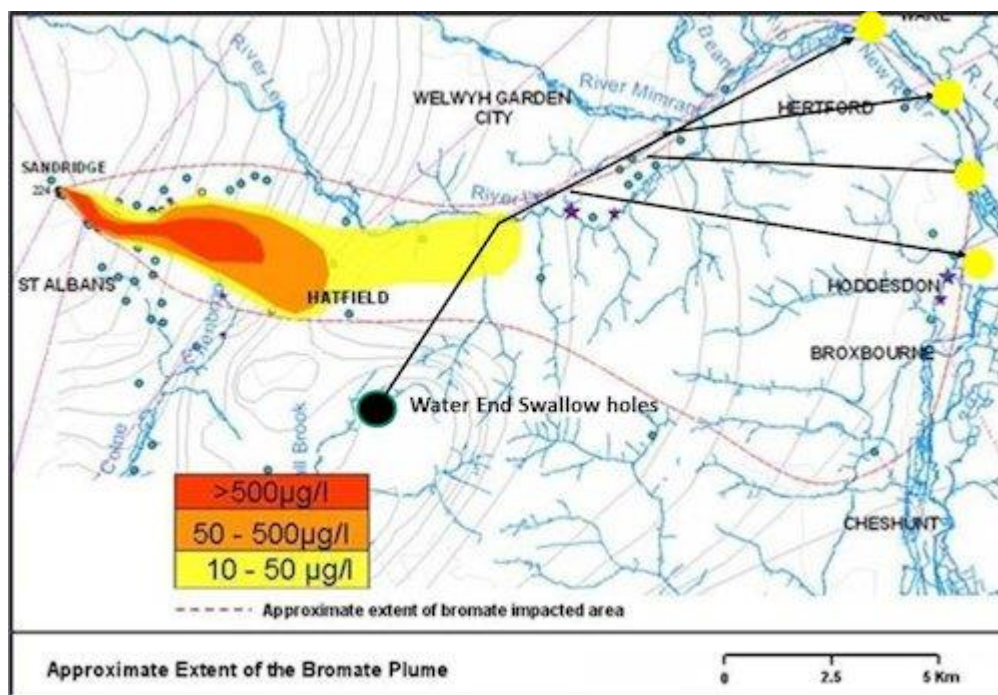


Figure 2: A plume of bromate originating near sandridge and demonstrating connectivity within the Lea Valley groundwater system. (Modified from a figure from the UK Groundwater Forum, from Cook (2010))

Bromate has also been detected at ESSE where it has been noted that seasonal fluctuations in bromate concentrations closely followed the seasonal cycle of Soil Moisture Deficit (Wyke et al., 2013). Higher bromate concentrations corresponded to dry conditions, and therefore lower groundwater levels. This suggests that under low water level conditions bromate may be transferred from storage in the matrix/unmodified fracture network into the karstic conduits and fissures through diffusion or advective mechanisms, and/or that there is more dilution of bromate during high water level conditions. Rapid responses in bromate concentrations at ESSE were observed to occur in response to changes in groundwater abstraction at Hatfield PWS which is 5.7 km to the southwest of ESSE (Cook et al., 2012). This suggests that there is likely to be a connected network of karstic conduits and fissures connecting these sites.

A study of the water chemistry at ESSE suggested that there was a combination of background regional groundwater and recently recharged water (Cook, 2010). The latter may reflect the known connectivity between ESSE and the Water End swallow holes, but could also indicate connectivity with other stream sinks, or with the nearby River Lea.

There remains some uncertainty about the actual catchment area of the ESSE abstraction, but evidence suggests some groundwater from the southwest via the Water End swallow holes, and contributions from the west as demonstrated by the bromate contamination.

9.6 Hydrodynamic characteristics of the borehole

Two operational boreholes at ESSE Pumping Station are used for public supply. Between 01/04/1995 and 31/01/2019 the daily average abstraction from ESSE was 4.11 Ml/day. The maximum recorded in this period was 10.80 Ml/day (July/August 1995). The average daily rate of abstraction has fallen since 1995.

Geophysical logging suggest that the ESSE supply comes from a small number of fissures/ small conduits. A geophysical log of borehole 3 highlights geothermal gradients at depths of 15.8 m, 20.1 m, 24.8 m, 34.0 m, 35.3 m and 38.1 m. Impeller flow logging was carried out to understand where large inflows occurred into the borehole. High flow zones were highlighted at a depth of 29-33 m (at the base of the casing) and 34.9-37.6 m, where velocity readings are between 0.75-0.95 m/min. A geophysical log and CCTV inspection of Borehole No 1 was carried out on 28/11/2000 (Morrison, 2017). Geophysical logging identified two adits to Borehole 2 and a number of smaller flow horizons. Significant turbidity is observed between the two adits, thought to be inflow of turbid waters linked to recharge events. The CCTV survey highlights high turbidity and reduced visibility at 31.5 mBD depth and 42.5 mBD, the second thought to be associated with an adit. A large fissure is observed at a depth of 57.7 mBD.

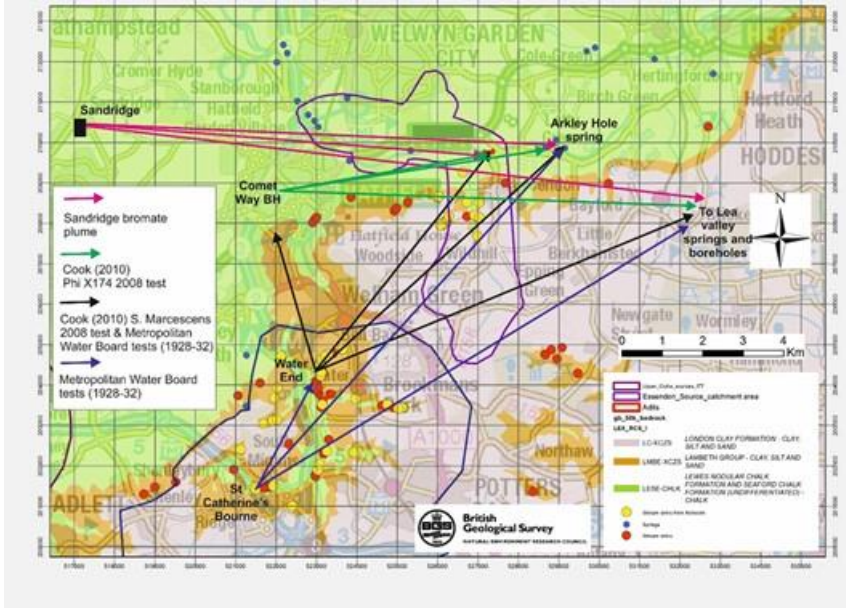
Turbidity and coliforms occur at ESSE and are known to increase following large precipitation events (Cook, 2010; Farrant et al., 2017). A large number of samples collected at ESSE contained high coliform counts (Farrant et al., 2017). More than 96% of samples had over 10 cfu/100 mls and more than 25% of samples had more than 1000 cfu/100mls. Pesticides are also found in high concentrations in water abstracted from ESSE. Concentrations are generally variable, reflecting the nature of the karst network, but peak during pesticide application (Farrant et al., 2017).

9.7 Data available for the project

1. ESSE borehole			
Data type	Time step	Monitoring period	Time period
Abstraction rates	Daily	24.5 years	04/1995 – 01/2019
Total coliforms	Variable (1-90 days)	9 years	01/2010 – 01/2019
Turbidity	Variable (1-85 days)	9 years	01/2010 – 01/2019
Bromate	Variable (1-74 days)	9 years	01/2010 – 01/2019
Pesticides and herbicides	Variable (1-149 days)	9 years	01/2010 – 01/2019
Electrical conductivity	Variable (1-320 days)	7 years	01/2013 – 01/2019
Nitrate	Variable (2-119 days)	9 years	01/2010 – 01/2019

*unreliable data

9.8 Summary

Pilot name	ESSE		
Country	UK	EU-region	
Area (km ²)		Lithology	Chalk
Short description:	Two operational boreholes at ESSE provide an average daily yield of 4.11 Ml/day from the boreholes and an adit system. Tracer tests link the abstraction to an extensive karstic network that is fed by swallow holes at Water End. Water from Water End is also discharged at six other outlets up to 19 km away with groundwater velocities of up to 5.8 km/day. A bromate contamination event at Sandridge demonstrates that ESSE also receives water from the west in an area of outcrop Chalk away from the karst stream sinks, and provides further information on the hydrogeology of the area.  <i>Selected tracer test connections in Hertfordshire, from Farrant et al. (2017), adapted from Cook (2010).</i>		
Monitored objects	Borehole		
Monitored data	Raw borehole data		
Contact person	sbun@bgs.ac.uk and loma@bgs.ac.uk		

9.9 References

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