River Ems Flow Investigation

Phase 1 Baseline Report

Portsmouth Water

1 December 2022

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1. Introduction

1.1. Background

The River Ems is an approximately 9 km long chalkstream, flowing from (at its greatest extent) Stoughton in the north, southwest through Westbourne to Emsworth in the South. Recent estimates suggest that there are only about 260 chalk streams in the world[1], of which most can be found in England and Northern France. Most chalk streams in England are affected by a combination of historical modifications, discharges and/or water abstraction and a new Chalkstream Strategy was launched in October 2021[2].

In a broad sense, the River Ems can be divided in a Lower, Middle and Upper reach (see Figure 1-1). Approximately 4-5 km of the Middle and Upper reaches of the river is naturally ephemeral, meaning it naturally stops flowing in dry weather conditions. Approximately 3 km of the Lower Ems and some part of the Middle Ems are perennial, meaning it flows throughout the year. Between the upper and lower section is a section of the Middle Ems (1-2 km long), which was historically perennial but is now ephemeral. This section has a series of natural springs in a woodland area called Racton Dell / Aldemoor.

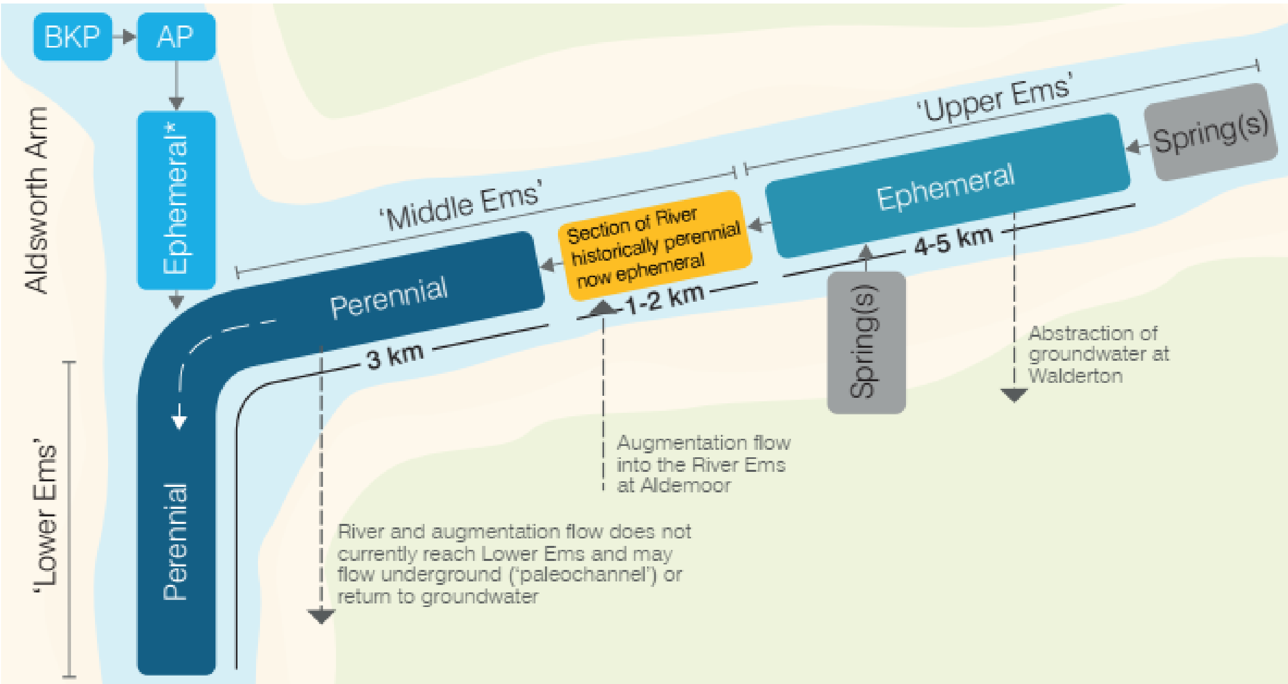

Figure 1-1 - Key reaches in the River Ems system. BKP = Brickkiln Ponds, AP = Aldsworth Pond. Does not show all springs in the catchment.

The River Ems has a number of unnamed tributaries in the Upper and Middle Reach. At Westbourne, the Lower Ems receives flows from the most significant tributary named the 'Aldsworth Arm'. Springs for the Aldsworth Arm are located north west of Westbourne in the eastern end of Southleigh Forest from where spring water enters Brickkiln Pond and Aldsworth Pond, which both have a level control structure.

[1] The battle to save England's chalk streams, one of the planet's rarest habitats | Rivers | The Guardian
[2] Chalk Stream Strategy - CaBA (catchmentbasedapproach.org)

1.2. Purpose of this report

In 2013, the Post Implementation Monitoring (PIM) and Water Framework Directive (WFD) investigations report authored by AMEC (now Wood PLC) concluded that whilst large sections of the River Ems are naturally ephemeral, Portsmouth Water's abstractions were having an exacerbating influence on this natural process. As a result of this investigation and after consultation with the Environment Agency, in 2017 Portsmouth Water voluntarily varied its abstraction licences for Walderton and Woodmancote to permanently change the discharge location approx. 500 m upstream to a location north east of Racton Dell, and to assign the Woodmancote abstraction exclusively to provide the augmentation discharge. The flow volumes were increased and the scheme is turned on based on a trigger at the Environment Agency Gauging Station located in the village of Westbourne.

As part of moving the augmentation scheme location approx. 500 m upstream to Racton Dell, in 2015/16, Portsmouth Water together with the Arun and Western Streams Catchment Partnership and the Environment Agency delivered a number of restoration projects in the Middle Ems (see Section 7.4), with a view of mitigating some of the habitat impacts identified in the 2013 report. This included resolving issues with channel braiding, in-channel structures and fish passage in the reach between The Canal and the new augmentation point.

Despite this work, Atkins understands that in 2020, there was a period during which the River Ems dried up within the Middle Ems downstream of the location where the augmentation flow discharges.

Portsmouth Water has asked Atkins to provide a catchment report that updated the datasets, assessment and conceptual understanding presented in the 2013 AMEC report with more recent datasets for hydrology, groundwater levels, water quality, aquatic ecology and wider catchment pressures, as appropriate. The objective of the report is to provide an evidence base for future work.

This report presents the findings of this piece of work (i.e. Task 1 of Atkins' study brief) and makes recommendations for next steps. The other tasks in the original study brief were:

Task 2 – Review groundwater models to identify benefits of changes to abstraction regime

Task 3 – Identify opportunities to develop triggers for changes in abstraction regime

Task 4 – Understand network constrains / opportunities

These further three tasks will be considered and incorporated where appropriate as part of future study recommendations (Section 11) which will generate a new set of tasks moving forward. It should be noted that the "new" set of tasks in Section 11 incorporates those mentioned above and should therefore be considered as the definitive development items moving forward.

1.3. Structure of this report

The structure of this report is as follows:

Section 2 covers the methodology used

Section 3 includes a general description of the River Ems catchment

Section 4 and 5 provide a detailed overview of the hydrology and hydrogeology of the River Ems catchment

Section 6 provides an overview of current WFD status

Section 7 covers river shape and form (morphology)

Section 8 covers water quality

Section 9 provides an overview of different aquatic ecology features including fish, macroinvertebrates, macrophytes, diatoms, conservation sites and terrestrial ecology features.

A summary of key topic areas is provided in Section 10 and Section 11 includes future recommendations.

2. Methodology

2.1. Main previous studies and reports

The spatial extent of the report covers the River Ems hydrological catchment, as shown in Figure 2-1 below.

The first significant study of the environmental setting of the River Ems was undertaken by Holmes (2007). While it focused on the ecology of the river, it included a survey of historical reports and local knowledge on the wetting and drying of the river over time.

Meanwhile, Entec (2006 & 2008) developed a groundwater flow model for the East Hampshire and Chichester Chalk (EHCC) aquifer (Figure 2-1). As can be seen in the figure, the River Ems catchment is a small proportion of the EHCC model area, which also includes the catchments of the rivers Meon, Hamble and Lavant, plus half of the catchment of the River Itchen in the west and the River Arun in the East. The model time series were updated, without updating the model itself, by Entec in 2009 (Entec, 2009).

AMEC (2012) subsequently updated and refined the EHCC model so that it could be used for the 2019 Price Review (PR19) investigations by Portsmouth Water, with emphasis on the representation of six of the watercourses within the model area, including the River Ems. With this refined model, AMEC (2013) compiled a study of the low flow setting of the chalk streams in the EHCC area.

The EHCC is currently being updated again by the Environment Agency, with an updated and refined model expected to be available in Spring 2022.

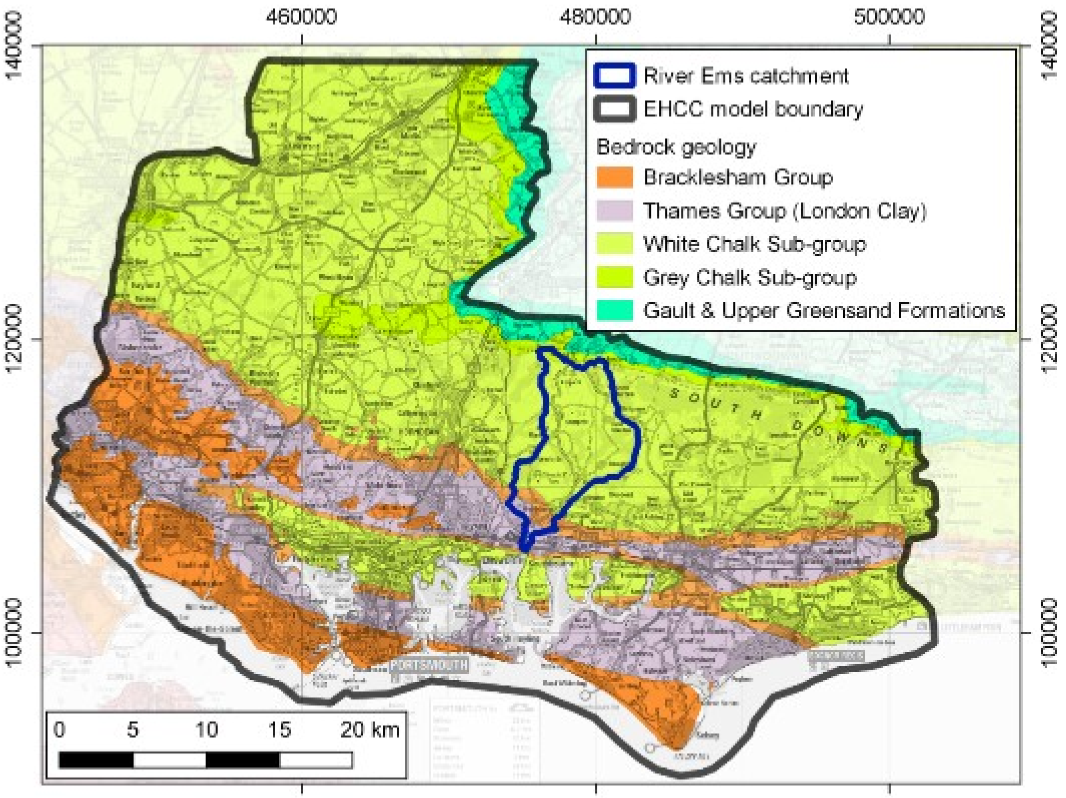

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Figure 2-1 - Boundary of the EHCC model and bedrock geology

2.2. Data sources

Atkins has reviewed the following more recent datasets (between 2000 and 2020) for:

- Hydrology:
- Model files for the EHCC model;
- Portsmouth Water's daily abstraction data and borehole level data for Walderton and Woodmancote sources;
- Flow records for the Woodmancote Flow Augmentation scheme;
- River spot flow data (where available) and gauged data at Emsworth; and
- Rainfall data from two locations: Walderton PS and Chilgrove House.
- Groundwater levels from 10 observation boreholes: Compton, Uppark, North Marden, East Marden, Pitlands, Little Busip and West Marden (all in-catchment) plus Chalton, Finchdean and Chilgrove (just out of catchment).
- Water quality, notably for key WFD physio-chemical determinants like pH, temperature, ammoniacal nitrogen, biochemical oxygen demand, orthophosphate and dissolved oxygen.
- Environment Agency Catchment Data Explorer (Environment Agency, 2021a).
- Aquatic ecology, notably surveys for fish and macroinvertebrates:
- Environment Agency Ecology & Fish Data Explorer (Environment Agency, 2021b);
- Environmental Quality Appraisal of the River Ems (Holmes, 2007);
- Ems and Hamble Macroinvertebrate Sampling Spring 2016 (AMEC, 2013);
- Report on the ecohydrology of the River Ems (CEH, 2013); and,
- Fish survey data for the River Ems collected by the Environment Agency in summer 2021.
- Wider catchment information, as appropriate:
- Any further groundwater and surface water abstractions: locations, licenced quantities, use codes, dates of operation;
- The Arun and Western Streams Catchment Based Approach (CaBa) Catchment Plans and projects planned and completed within the River Ems catchment; and
- Consented discharges / environmental permits: locations and dry weather flows.

In addition, Atkins received, with thanks, a range of inputs from Nick Rule, John Barker, Guy Schofield and Sandy Galloway (Friends of the Ems, FotE), including:

- A record of river sections and springs flowing over the period 30 October 2020 – 31 March 2021 along with comparisons to Compton groundwater levels;
- Photos showing low flows and evidence of fish mortalities in around the confluence of the Aldsworth Arm and River Ems and within the lower reaches of the Aldsworth Arm for 2003, 2009, 2010, 2011 and 2020;
- Biodiversity survey reports (Middleton Ecology, 2020); and,
- Notes and records of wildlife observations to supplement Environment Agency records, including as a result of two site visits undertaken on 15 April 2021; and 1 July 2021.

Further written records were received on wider (ecological) observations, which have been referenced accordingly. The use of quotes from historic 'Where To Fish' publications has been included but, to our knowledge, remains subject to formal approvals from Mr Richard Hewitt who owns the rights to the publications.

3. General description of the catchment

3.1. Settlements, land use and topography

The Ems catchment area lies very roughly around the southern limit of the last glaciation ice sheet, and at the end of that period as the ice retreated a much greater river took the melting icewater to the English Channel thorough what is now Chichester harbour. A 'large and possibly braided palaeochannel, some 32 m wide and at least 1.2 m deep' was identified during the construction of a housing estate in 1999/2000, this channel had formed the eastern side of the settlement now known as Westbourne, and had been inflled with 'later Bronze Age, Romano-British and Middle/Late Saxon pottery sherds, ceramic building material, worked flint, slag and animal bone.' [Wessex Archaeology Reference 46611.01, 29 Apr 2000, "Land at Foxbury Lane, Westbourne, West Sussex Archaeological Watching Brief"]

In mediaeval times the course of the river was much modified to form ponds and mill races for up to five watermills, plus several fisheries, watercress beds, and watermeadows, resulting in numerous weirs and several sluices.

At some point before 1640 the main eastern channel was diverted through 'The Canal' at 'Watersmeet', which is the point at which the River Ems and Aldsworth arm join. This was presumably to strengthen the flow past Westbourne Mill, which is located just downstream of Watersmeet on the Lower Ems, is certainly Tudor and thought to have been one of the River Ems mills listed in the Domesday book. A paleochannel is still visible along the course of the old River Ems.

The catchment of the River Ems is almost exclusively rural (Figure 3-1). There are a few small villages in the upper part of the catchment such as Compton, West Mardon, East Mardon, Stoughton and Walderton. Emsworth and Westbourne are near the bottom of the catchment. The main road in the middle and upper catchment is the B2146 which passes north to south and links up many of the settlements. The B2141 crosses part of the catchment on the South Downs, and the A27 crosses the very southernmost part of the catchment.

Land cover is mostly arable, with much woodland and some pasture (Table 3-1). Figure 3-2 shows the land cover in 2012 (on the right) and 1935 (on the left). While land use statistics equivalent to those in Table 3-1 cannot be generated for the historical dataset, it is clear that a substantial amount of land that is currently arable was formerly pasture.

Table 3-1 - Land cover within the catchment, from the 2012 CORINE dataset

Land cover	% of total topographic catchment area
Arable	53.9%
Pasture	15.9%
Broad-leaved woodland	15.3%
Mixed woodland	11.7%
Urban	1.1%

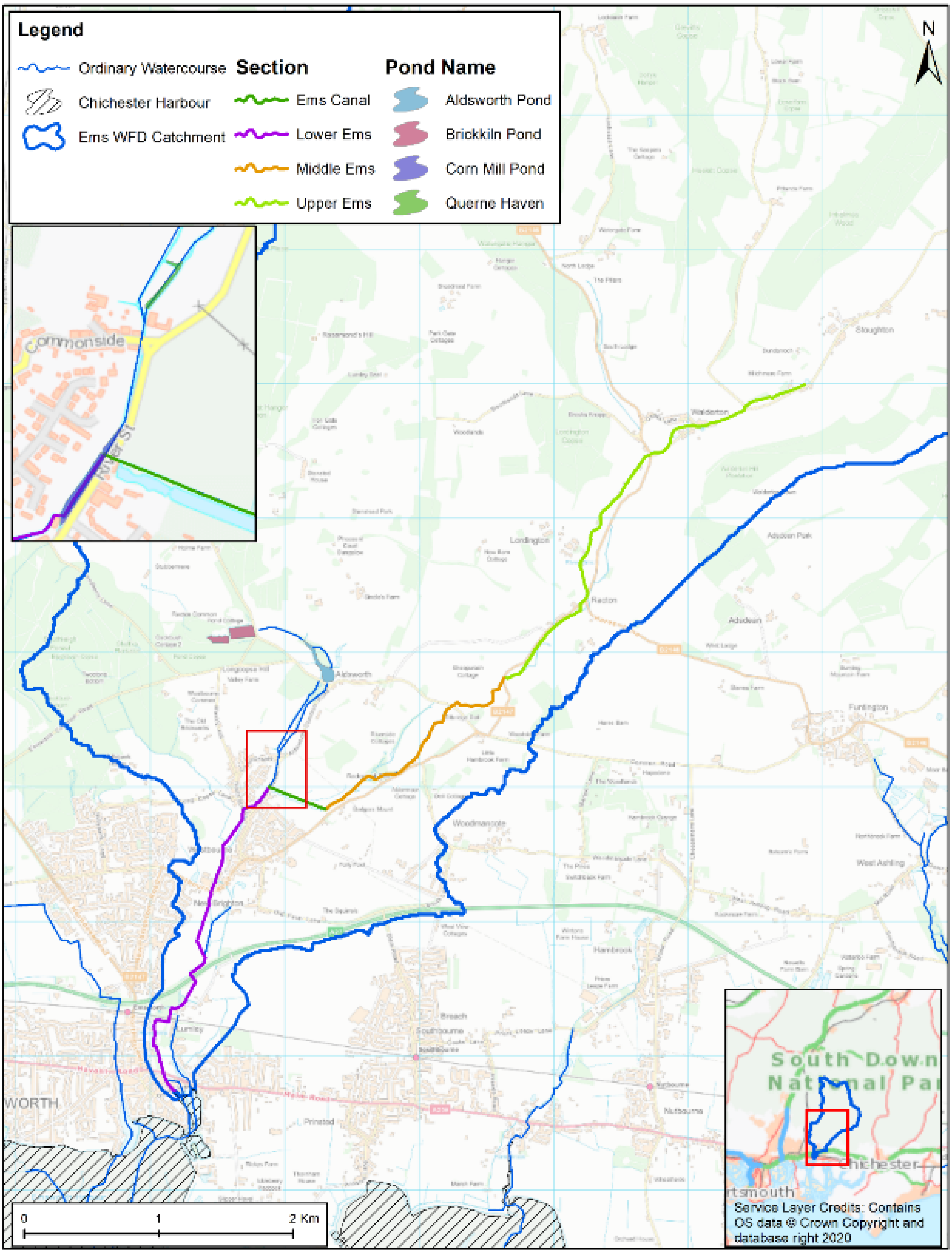
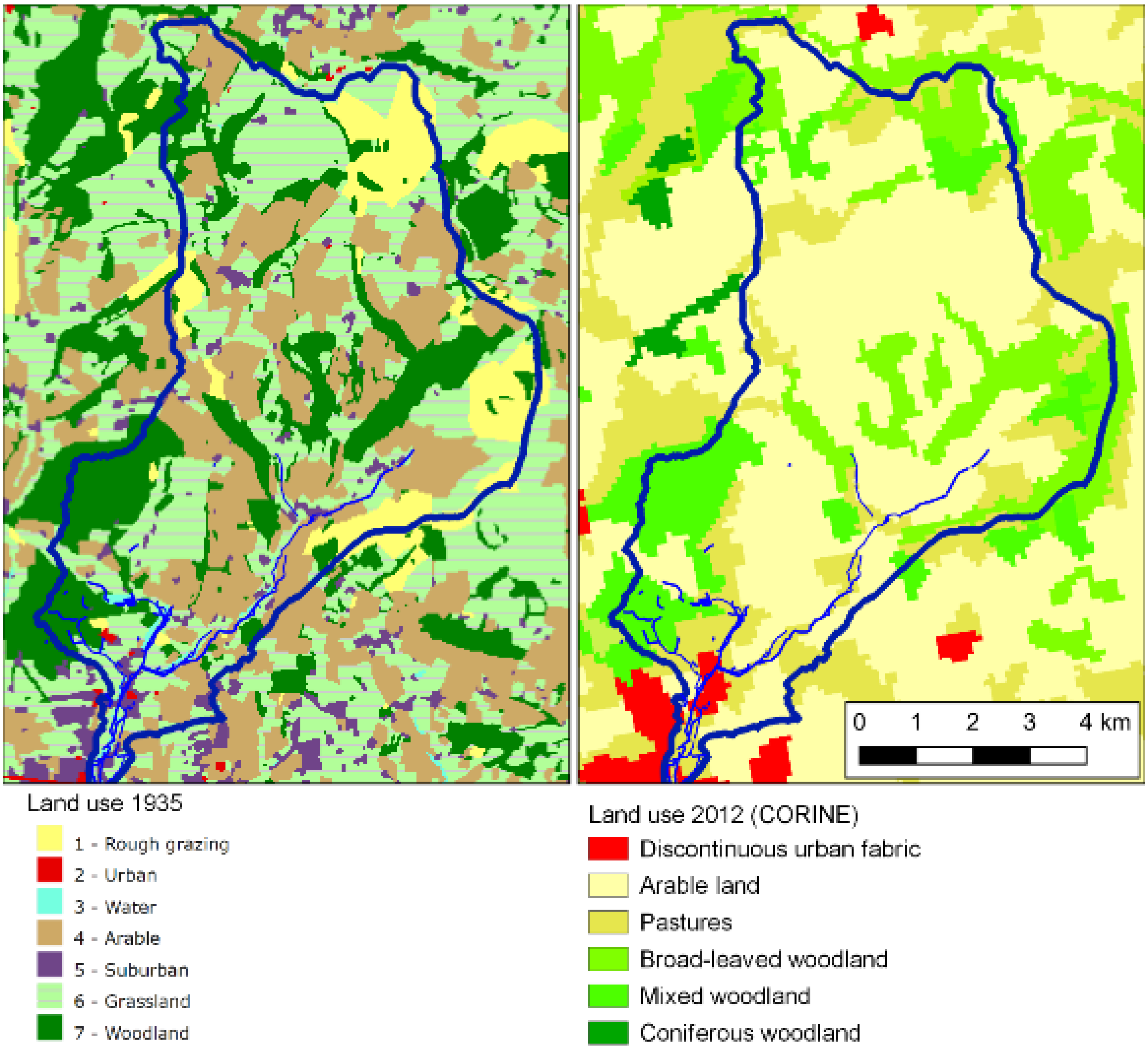


Figure 3-1 - General features of the River Ems and surrounding area



CORINE land cover is (c) the European Commission (Cole *et al.,* 2015)

1935 land cover is (c) the Environment Agency: Digital Land Utilisation Survey 1933-1949 (AfA213) (Geo-referenced for this project from the magic.gov website)

Figure 3-2 - Land use in 1935 and 2012

Topography of the catchment is dominated by the hills of the South Downs to the north, rising to nearly 250 m AOD, with three steep-sided, mostly dry, valleys incised into the hills (Figure 3-3). The lower half of the catchment flattens to become a coastal plain that falls southwards towards Chichester Harbour. A long profile of the mostly perennial section of the river, from Environment Agency bed survey data, is shown in Figure 3-4. This is mostly off the South Downs and shows a roughly linear profile, except south of Westbourne, where the channel bifurcates to supply the former Lumley Mill.

The main stem of the river passes close to the south eastern edge of the catchment, and is joined from the west by several small tributaries (Figure 3-1). Near Walderton an ephemeral tributary joins the ephemeral reach of the River Ems on the river right hand bank (apparently un-named this is referred to as the ‘western tributary’ in the following text). Moving down the catchment there are a series of minor tributaries that are probably historic drainage channels at Lordington and Racton. At Racton, there is a relatively small tributary on the left hand bank, although this was observed to provide a lot of flow during the site visit in April 2021 suggesting it is fed by a relatively large spring. Where the main stem of the river turns west a branch feeds ‘The Canal’ which is an artificial, linear, lake just north of Westbourne. At ‘Watersmeet’, a significant tributary, the Aldsworth Arm of the River Ems, comes to confluence with the main stem and the river again turns south-westwards. At the southern edge of Westbourne another un-named, and ephemeral, tributary which rises in Southleigh Forest, comes to confluence just upstream of the Westbourne flow gauge (Figure 3-1). It is hypothesized that this watercourse does not flow regularly. Below the Environment Agency Westbourne gauging station the river network becomes more complex as there are several mill leats and flood relief channels.

3.2. Anthropogenic factors

In most catchments the most profound anthropogenic impact is the change in land use. This has been discussed above, and this section deals with those anthropogenic factors that relate to the hydrogeology and river-aquifer interaction.

3.2.1. Abstraction

Groundwater from the Chalk aquifer of the River Ems catchment is used mostly for public water supply (PWS) by Portsmouth Water. Licensed abstractions are listed in Table 3-2 and locations are shown in Figure 3-5.

In addition to the site licence constraints in Table 3-2, there is a group constraint that the total annual abstraction from Portsmouth Water's sources at Walderton, Woodmancote, Fishbourne (licence no. 10/41/521502), Brick Kiln (10/41/522002) and Funtington (10/41/521301) must not exceed 23,739,727 m^3 per annum.

Table 3-2 - Licensed abstractions in the River Ems catchment

Source & licence no.	Source*	Use*	Max daily abstraction m^3/day	Max annual abstraction m^3/year	Average daily abstraction** m^3/day
Walderton (3 BHs) SO/041/0027/004	GW	PWS & Env.	36,364	9,954,545	20,273
Woodmancote (2 BHs) 10/41/520101	GW	PWS & Env.	3,024	1,103,760	737
Up Park 10/41/512101	GW	Agr.	46	15,002	n/a
Church Farm 10/41/512301	GW	Agr.	23	8,183	n/a
Sindles Farm 10/41/511202	SW	Agr.	818	45,460	n/a
Mill House, Westbourne 10/41/511005	SW	Aqu.	46	3,410	0***

* GW = groundwater, SW = surface water, PWS = public water supply, Env. = environmental flow support, Agr. = agriculture, Aqu. = aquaculture | ** For Portsmouth Water sources, average value from 2016-2020; for other sources, actual abstraction amounts were not available. The abstraction volumes are also not in the AMEC (2012) EHCC model. | *** pers. comm. owner of Mill House, Nick Rule, 2021

The abstraction at Woodmancote was the first borehole to be developed for public water supply in the River Ems catchment. Holmes (2007) reports that it had been operated 'for many decades' prior to the 1960s at a rate of approximately 1,000 m^3/day. Woodmancote borehole was constructed south of the southern edge of the Chalk outcrop, and here the Chalk aquifer is confined beneath 17 m of Lambeth Group clays.

The abstraction at Walderton was licensed for abstraction of up to 2 million gallons per day (9,092 m^3/day) in 1962, and abstraction started in 1963 or 1964 (Holmes, 2007). The Walderton supply comprises three boreholes which abstract water from the unconfined Chalk aquifer. In 1968 the maximum rate at Walderton was increased to 6 million gallons per day (27,277 m^3/day), and at the same time the need for augmentation of the Lower River Ems, by Portsmouth Water, was established.

Figure 3-6 shows the historical abstraction at Walderton and Woodmancote since 1960. Abstraction rates shown are the total abstraction, used for both public water supply and augmentation. Augmentation discharge points are marked in Figure 3-5. Prior to 2016 the augmentation was made by discharging part of the flow from

Walderton to the location just upstream of The Canal (Figure 3-5). From 2016 onwards most augmentation has been made from Woodmancote and discharged about 500 m upstream, upstream of Racton Dell, to provide flow through a newly restored reach of the river (the River Ems Restoration Project)[3].

The augmentation rule from 1968 until April 2016 was as follows.

> *When the measured flow at the Westbourne flow gauge falls below 2,273 m³/day an augmentation discharge of 1,136 m³/day should be released until the 'natural' flow exceeds 2,727 m³/day. (The measured flow threshold for ceasing augmentation can therefore be considered to be 3,863 m³/day.)*

When licence variations were issued for both Walderton and Woodmancote in April 2016 the augmentation points and trigger levels were changed. The current rules can be paraphrased as follows.

> *When the non-augmented flow at the [Environment Agency] Westbourne gauge falls below 31 L/s (2,678 m³/day) there should be a discharge of at least 25 L/s (2,160 m³/day) from Woodmancote via the discharge point at NGR SU 76986 08244. If, thereafter, the augmented river flow falls below 25 L/s (2,160 m³/day) for 30 consecutive days, or if at any time it falls below 15 L/s (1,296 m³/day), then the augmentation from Woodmancote should cease and be replaced by a discharge of at least 13 L/s (1,123 m³/day) from Walderton via the discharge point at NGR SU 76290 07830. Augmentation from whichever borehole should continue until the 'natural' flow at Westbourne exceeds 38 L/s (3,283 m³/day).*

An augmentation time series has been constructed from the time series compiled from Environment Agency and Portsmouth Water data in the EHCC model (AMEC, 2012) and later abstraction data from Portsmouth Water, and is shown alongside the total abstraction data in Figure 3-6. The time series is compared against drought conditions and river flows in Section 4.6.3.

There have been two periods since April 2016 when flows were low enough to switch augmentation from Woodmancote to Walderton as described above: in September to October 2019 and in September to October 2020. Both of these were because flows dropped below 15 L/s (1,296 m³/day) not because of the 30 consecutive days rule. Augmentation from Woodmancote was not turned off during these periods (except when the pumps at Woodmancote failed) and augmentation was not turned on at Walderton..

The augmentation discharge from Walderton was of treated water (meaning it contains treatment chemicals like chlorine), whereas the discharge from Woodmancote is raw water.

3.2.2. Discharges

There are no large sewage / waste water or industrial discharges in the catchment. There may be small discharges of treated sewage effluent via soakaway throughout the catchment as well as septic tank outfalls. There are also likely to be highway / road drainage, roof and other surface water run-off sources which will contribute to flows into the River Ems notably during high rainfall. These sources do not have permits (as issued under the Environmental Permitting Regulations) and are thus difficult to locate without a catchment walkover.

No large discharges have been simulated in the EHCC model, which is quite unusual.

[3] http://arunwesternstreams.org.uk/sites/default/files/uploads/River%20Ems%20Restoration%20Project-RRC'17-final.pdf

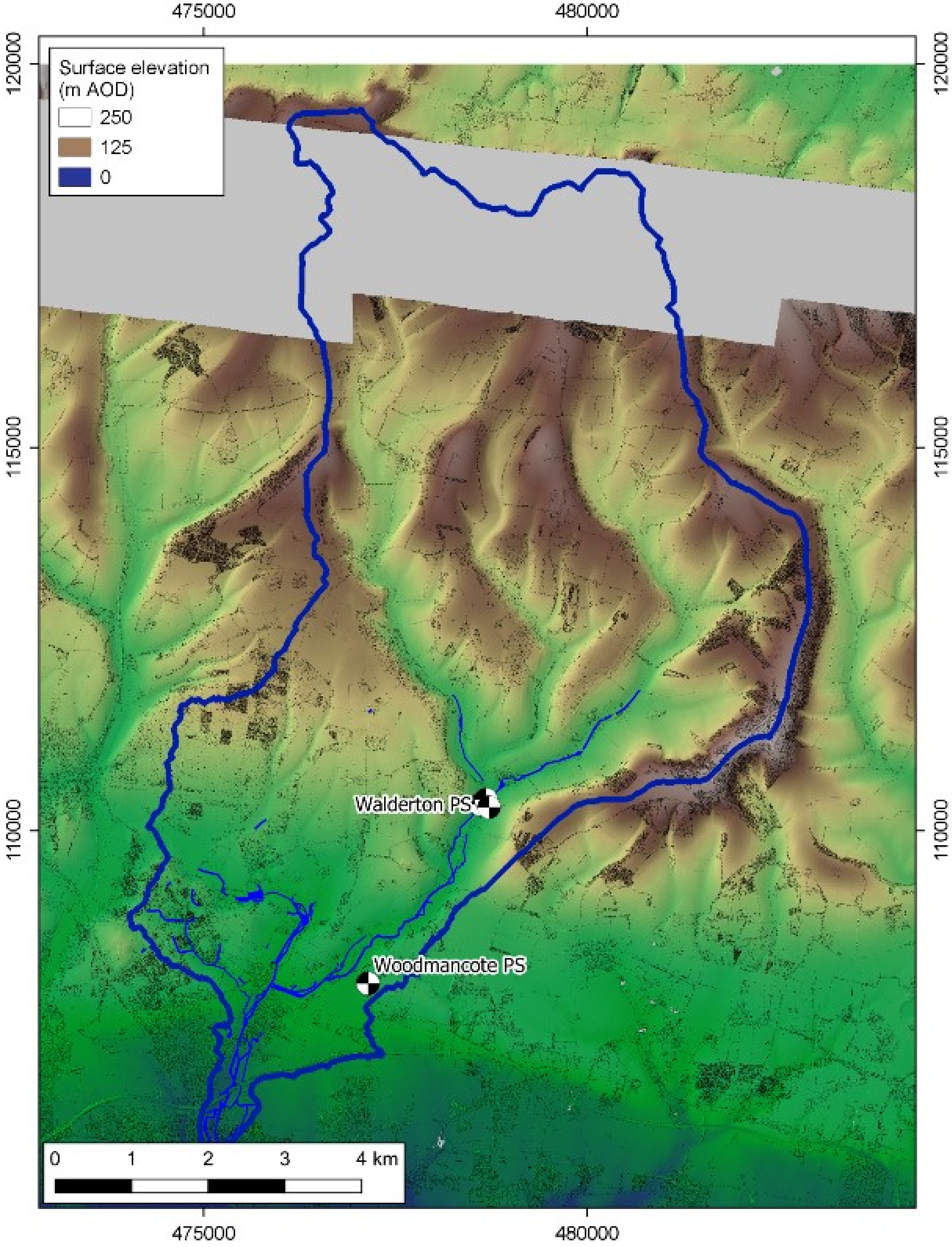


Figure 3-3 - LIDAR surface elevation of the catchment

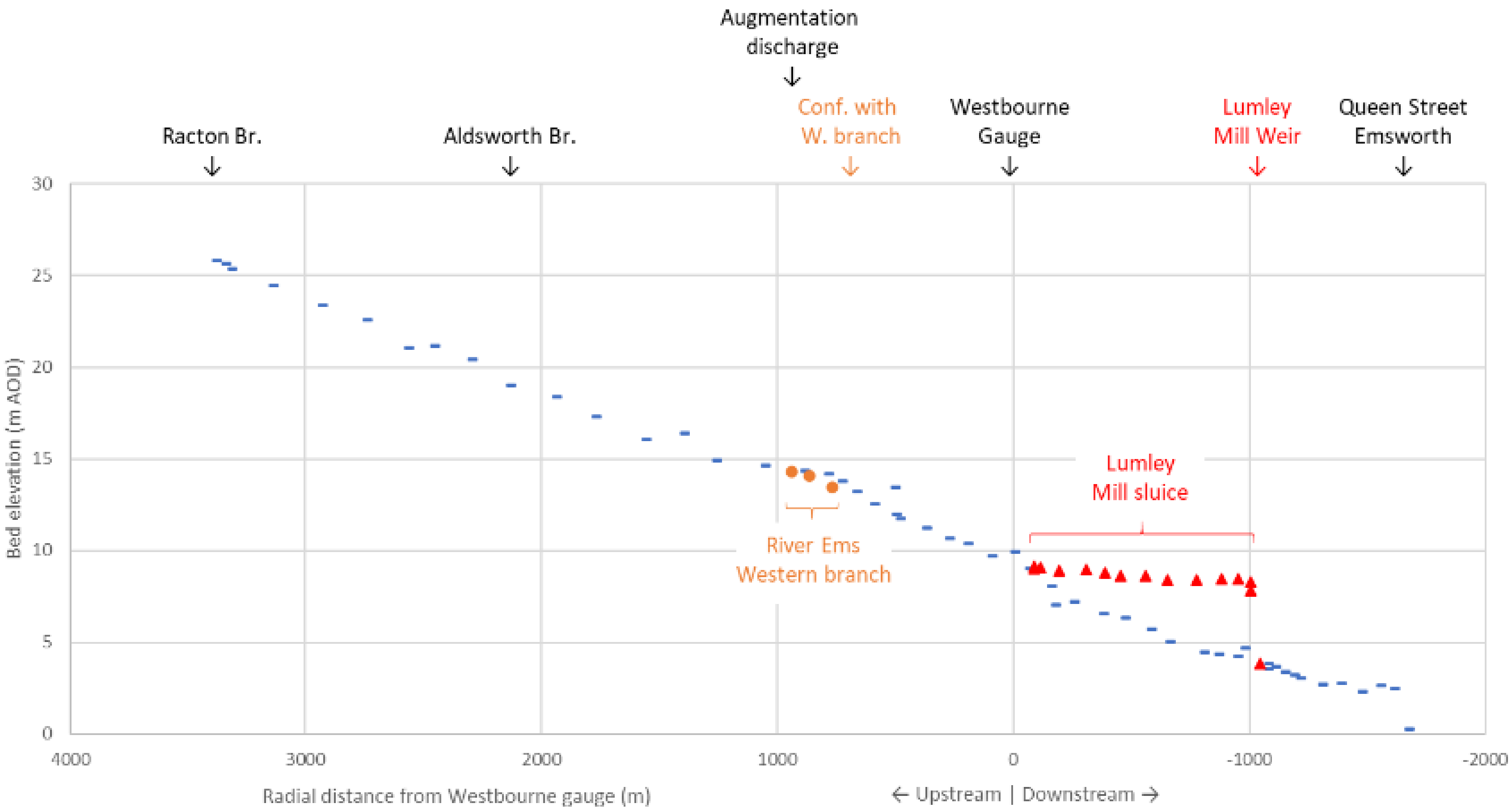


Figure 3-4 - Long bed profile of River Ems from Racton to Queen Street, Emsworth. Western Branch = Aldsworth Arm.

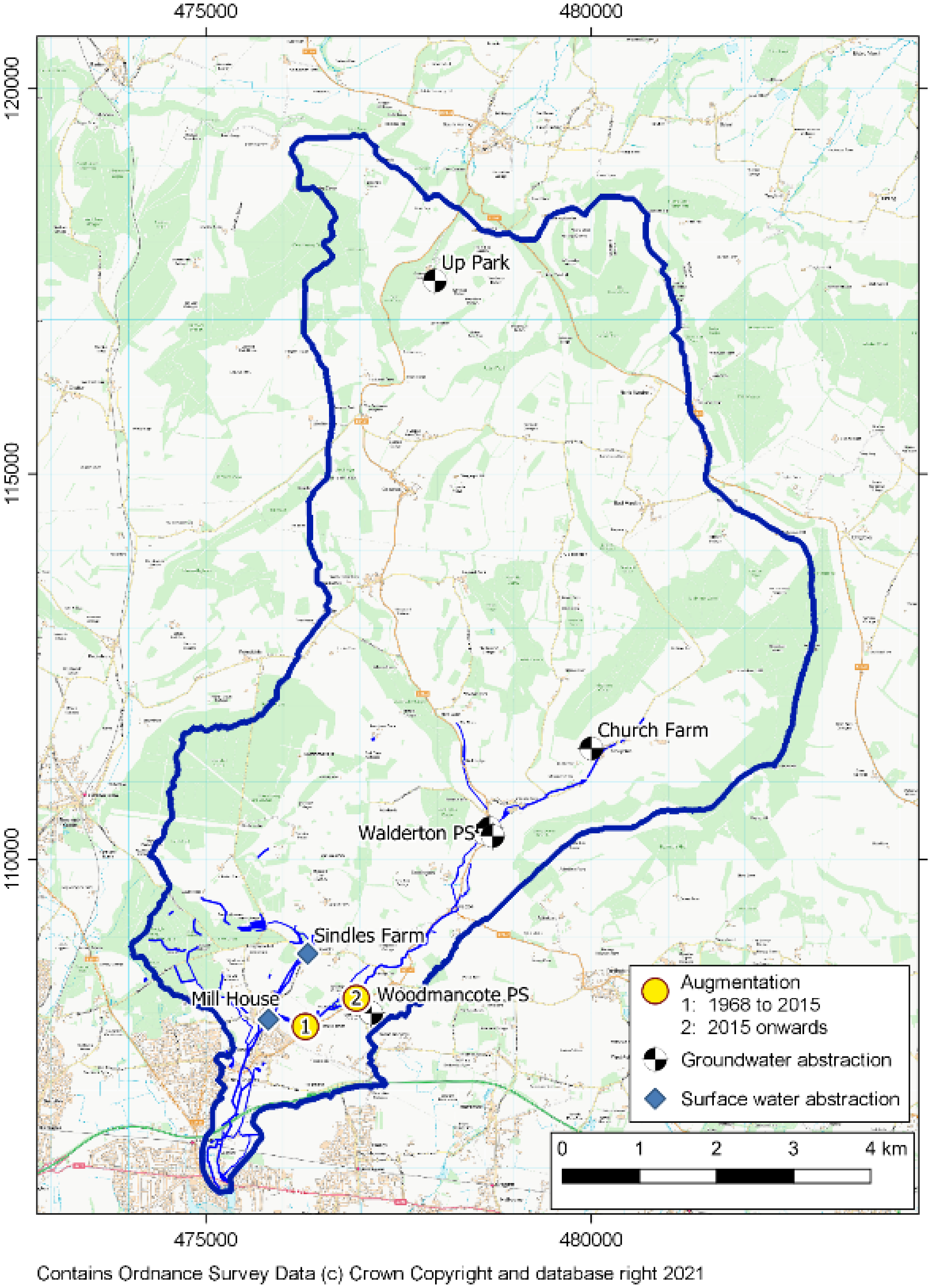
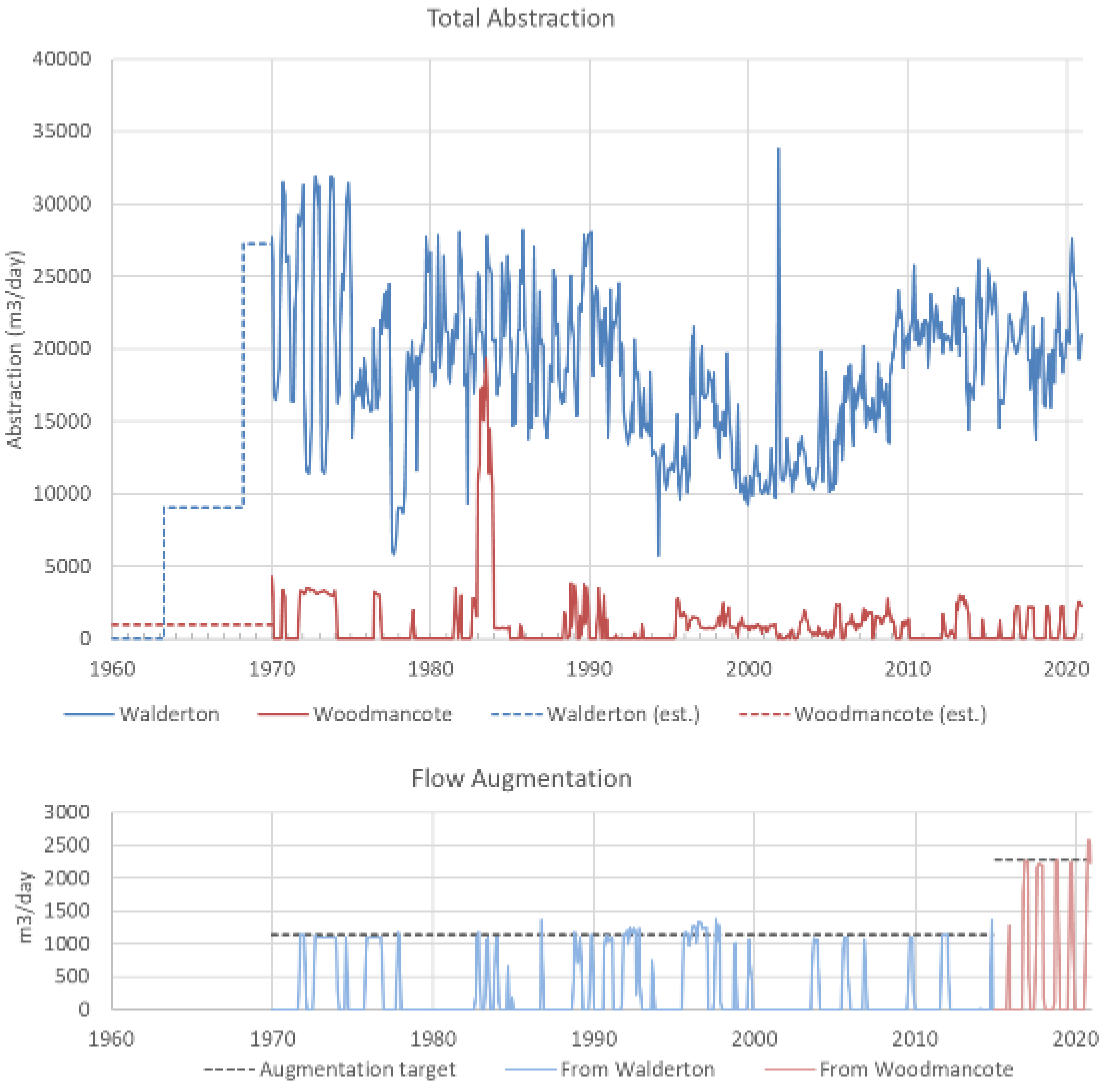


Figure 3-5 - Abstractions and augmentation discharge points



Initial estimated total abstraction rates are based on Holmes (2007). Data from 1970 to 2005 are from AMEC (2012), and subsequent data are from Portsmouth Water. (There was an overlap from both data sources between 2005 and 2010 and abstraction values are the same in each data set.)

Augmentation rates up to 2011 are from AMEC (2012), with Environment Agency-supplied data from 2011-2105. Thereafter the total abstraction from Woodmancote is used.

Figure 3-6 - Groundwater abstraction for public water supply and flow augmentation

4. Hydrology and hydrometry

4.1. Overview

The following section quantifies how rainfall, and the processes that lead to it become part of the groundwater system and then the river system in the River Ems catchment. The hydrological cycle of the catchment includes several variables, which are described as follows.

- **Precipitation** includes **rainfall**, hail, sleet, snow etc. and is what is measured at rain gauges (Section 4.2). Along the South Coast almost all precipitation occurs as rainfall and so it is referred to as rainfall in the sections that follow. When precipitation falls as hail or sleet it becomes liquid quickly so there is no need to consider it separately. When precipitation occurs as snow, there can be a delay of a few days before it melts and so for high-resolution modelling in the climate of the South Coast the distinction might be very occasionally important. However, in modelling English groundwater systems, the distinction between rainfall and snow is seldom made.
- **Runoff** is a proportion of the rainfall that does not enter the soil, and runs off the land to drain straight into the river network. The amount of runoff in the Ems catchment is quite low: probably only a few percent of the rainfall, which is typical for a chalk catchment.
- Once the rainfall reaches the soil zone, crops and other plants draw up some of the water. A little is used for growth and metabolism, but most is drawn through the plant and evaporated from the leaves (**evapo-transpiration)**. Typically, over a year, in Southern England, evapo-transpiration might account for about two thirds of rainfall (Section 4.2.2).
- If the soil is still saturated after the plants' demand is satisfied, water drains under gravity out of the soil zone and out of the reach of plant roots. Water leaving the base of the soil is termed '**infiltration**' (Section 4.2.3). In most of the Ems catchment none of the infiltration is intercepted before it reaches the water table where it becomes '**recharge**', so these are numerically the same.
- The distinction between infiltration and recharge is useful as, in the south of the catchment, the infiltration becomes recharge to a shallow groundwater body in the near-surface superficial deposits, and does not become recharge in the Chalk aquifer (Section 5.4.3).
- Once it is past the water table, recharge becomes groundwater, which flows through the Chalk aquifer to either be abstracted at boreholes, to discharge at springs, or directly into rivers via the river bed. It is practically difficult to distinguish spring flows from flows through the river bed in a flow dataset, so these are lumped together as '**baseflow**'. Almost all of the flow in the River Ems is baseflow (Table 4-4).

Rainfall, infiltration and flows are typically summed (or averaged) by hydrological year rather than by calendar year. A hydrological year is the period from 1 October in one year to 30 September in the next year. This is used, in part, so that the rainfall and recharge for any given winter (which would naturally span two calendar years) can be totalled together. Similarly, the end of September is usually when river flows are very low, because most of the previous winter's rainfall and recharge has moved through or out of the catchment through the river and groundwater system.

4.2. Climate and infiltration

4.2.1. Precipitation

The Environment Agency operates two rain gauges within, and close to, the catchment of the River Ems. Details and key statistics are presented in Table 4-1, and the locations are shown in Figure 4-1. Although the rain gauge at Chilgrove House is not within the catchment, it is noted here as it is at a greater elevation than the gauge at Walderton and may therefore be more representative of the rainfall on the South Downs.

Table 4-1 - Environment Agency rain gauges

Gauge name	Data available	Elevation (m AOD)	Mean rainfall* (mm/year)
Walderton	Feb 1991 - present	33	930
Chilgrove	Oct 1999 - present	78	1071

* Averaging period of data was the 20 years from Oct 1999 to Oct 2019 to enable fair comparison of the two locations

Daily average precipitation, aggregated by month, is shown in Figure 4-3. Winter precipitation at Chilgrove is much higher than that at Walderton, whilst summer rainfall is similar at both. Given that evapotranspiration is likely to be similar across the catchment, and that runoff is negligible, infiltration is therefore expected to be higher on the South Downs than in the lower parts of the catchment.

4.2.2. Evapo-transpiration

Potential evapo-transpiration (PE) from grass can be estimated from the Met Office MORECS dataset, or the more modern MOSES dataset (Entec, 2006, uses MOSES). The 1970-2000 long term average values for PE from grass within the EHCC model area are summarised in Table 4-2, along with the corresponding estimate of open water evaporation (OWE) using the methodology of Finch and Hall (2001).

Table 4-2 - Long term daily average (1970-2000) potential evapo-transpiration and open water evaporation (mm)

	J	F	M	A	M	J	J	A	S	O	N	D	Annual
MORECS	0.5	0.6	1.1	1.9	2.8	2.9	3.1	2.7	1.8	1.1	0.6	0.4	594
MOSES	0.2	0.4	0.9	1.7	2.7	3.0	3.1	2.6	1.6	0.7	0.2	0.1	525
OWE*	0.7	0.7	1.1	1.8	2.5	3.0	3.8	3.7	2.6	2.1	1.4	0.8	739

4.2.3. Infiltration

The various EHCC reports and updates do not present the estimated values of infiltration to the model, or to individual catchments. With that in mind, the latest 4R model (AMEC, 2012) has been re-run and the outputs processed to offer some insights.

Figure 4-4 shows the spatial distribution of average recharge for the whole of the EHCC model period (January 1965 to October 2011). Recharge is greater over the higher ground of the South Downs, with a spatial range across the catchment of 250 mm/year to 575 mm/year.

The 2012 version of the 4R model does not identify the River Ems catchment as a water balance zone. A change has been made to the model to identify the catchment as a water balance zone (but this is the only change that has been made for the current project). Key annual statistics are presented in Table 4-3.

Table 4-3 - Summary statistics for rainfall and recharge (mm/year), River Ems catchment, hydrological years 1965 to 2010

	Min.	25%ile	Mean	Median	75%ile	Max.
Rainfall	403	823	878	867	968	1237
Recharge	138	321	398	396	458	819
Year experienced	1975 / 76	-	-	-	-	2000 / 01

Figure 4-7 shows monthly average values for the soil moisture balance components, and Figure 4-6 shows the annual variation in rainfall and recharge for the River Ems since 1975. As expected, most of the recharge occurs in the period November to February. On average, about 45% of rainfall becomes recharge but more rainfall becomes recharge in wetter years (up to 66%) and in dry years less rainfall becomes recharge (down to 24%).

It has been noted in Section 3.1 that since the pre-war years, pasture has been converted to arable land; this is likely to be significant in relation to the water balance because there tends to be more recharge through arable land, while it is bare in the winter.

The EHCC reports do not describe the difference in recharge between different land use types. As a scoping estimate, the average recharge over loam soil in the Upper Thames Valley has been found to be 183 mm/year with pasture and 271 mm/year with wheat (Buss, 2020). There is more recharge over arable land than over pasture as the soil is bare during the winter recharge season. Using this as a rough estimate, if half of the current arable land was pasture in the pre-war years, there may be about 11.5% more recharge to the catchment than there was in 1935.

4.3. Climate

4.3.1. Meteorological drought

The standard precipitation index (SPI) is a metric that describes the variation of rainfall for a location (WMO, 2012). It quantifies observed precipitation as a standardised departure from a selected probability distribution function that models the raw precipitation data. It can be interpreted as the number of standard deviations by which the observed rainfall deviates from the long-term mean.

Periods with positive values were wetter than average, and periods with negative values were drier than average. SPI can be plotted for different periods: SPI values based on monthly average rainfall are more related to soil moisture and are not particularly relevant for groundwater studies, but values based on six-month average rainfall relate more closely to changes in groundwater storage.

For qualitative descriptions of dryness or wetness the SPI (and SGI, below) can be referred to using the following descriptors from UK CEH.

- SPI > 2.0 Extremely wet
- 1.5 < SPI < 2.0 Severely wet
- 1.0 < SPI < 1.5 Moderately wet
- -1.0 < SPI < 1.0 Typical conditions
- -1.0 < SPI < -1.5 Moderately dry
- -1.5 < SPI < -2.0 Severely dry
- -2.0 < SPI Extremely dry

SPI values for catchments are calculated by UK CEH and are available for download at https://eip.ceh.ac.uk/apps/droughts/. The River Ems is on the edge of two coastal catchment areas in the web app: to the west is the Hampshire Coastal Catchments area, and to the east is the Sussex Coastal Catchments area. The SPI values plotted in Figure 4-2 are for the Hampshire Coastal Catchments area which is more local to the River Ems (the Sussex Coastal Catchments extends as far east as Hastings).

As the averaging period of the data shown in Figure 4-2 increases, the more the plot seems to predict groundwater related events: the droughts of 1976 and the early 1990s are clear as very low negative numbers, as are the periods of groundwater flooding in 1994, 2001, 2013 and 2014 where there are high positive numbers.

4.3.2. Groundwater drought

Flow in the River Ems originates as groundwater discharge from the Chalk aquifer. Hence any discussion of drought and very low river flows is more related to groundwater drought, rather than surface water drought.

The standardised groundwater index (SGI) is a measure of the extent of a groundwater drought (Bloomfield and Marchant, 2013) that is calculated in a similar fashion to SPI (i.e. based on the average groundwater level in a month). The chart at the top of Figure 4-7 shows raw water level data at Compton borehole, while the next plot down shows the time series of SGI at Compton borehole computed by Bloomfield et al. (2018). This very closely resembles the 6-month SPI plot of Figure 4-2. (The location of Compton observation borehole is shown on Figure 5-6.)

The lower two plots of Figure 4-6 show heatmaps of SGI values which highlight the periods of the most persistent low groundwater levels (i.e. groundwater drought) and high groundwater levels (i.e. groundwater flooding). The upper heatmap clearly shows that the droughts of 1976, 1989 to 1993, and 1996 to 1998 and 2011 to 2012 are reflected in the groundwater record, and therefore are likely to have been experienced in surface water flows in the River Ems. While the yellow-red SPI heatmap shows periods of drought, periods of persistent wetness are shown in the lowest, blue, heatmap. Here the periods of local groundwater flooding of 1994, 2001, 2013 and 2014 stand out.

The groundwater drought heatmap will be used in the following sections in discussions about other environmental time series variables (river flows and losses, gravel groundwater levels).

4.4. Flow gauging

4.4.1. Qualitative evidence of flow character

Qualitative evidence of historical flows in four 'assessment reaches' was compiled by Holmes (2007), as follows (the four reaches described are shown in Figure 4-7):

- The 'Upper Ems': the reach between Stoughton and Broadwash (seemingly incorrectly identified as Aldsworth Bridge in the spot gauging data of Table 4-5; and also known as Ell Bridge) is, and is considered to have always been, ephemeral. This is a straight-line distance of about 4 km. Holmes says, for this reach, "*Flows are expected to fail for several months in most years, and no flow for periods exceeding two years is possible*."
- The 'Middle Ems': flow along the reach from Broadwash to Watersmeet is believed to have been more consistent in the past than at present. Broadwash was reported as perennial in the past, and there were commercial cressbeds and fish ponds 250 m and 750 m downstream of Broadwash, respectively, as late as the 1970s. Holmes says, for this reach, "*Perennial flow might have been expected throughout the majority of the reach except in the most extreme droughts*." Mr Holmes identified ephemeral (winterbourne*) flora at Broadwash and flora typical of perennial flow at Racton Dell (*Berula* and *Hildenbrandia*) and downstream of the (historic) augmentation point (*Ranunculus pseudofluitans, Berula, Callitriche obtusangula*).
- The Aldsworth Arm of the River Ems comes to confluence with the main stem at Watersmeet. There are perennial artificial ponds close to the source (Brickkiln) and historically there were cress beds, suggesting flow failure would have been rare in the upper parts of the catchment. Parts of the Aldsworth Arm between Brickkiln Ponds and Aldsworth Pond appear to be conveyed underground, presumably by pipework.
- The 'Lower Ems' is the reach downstream of Watersmeet. "*Historically flows are reported to have never failed until recent decades (and then only in the top 300-400 m). Downstream of Westbourne Mill there is no record of the flow ever failing, but the gauge within the reach indicates extreme low flows occur, and did so before significant groundwater abstraction occurred.*" [By "significant abstraction" Holmes refers to the increase in 1968, since the Hampshire Bridge data shows very low flows in most summers between 1962 and 1967]. It is worth noting that this flow regime has included the original augmentation point.

*It is noted that Holmes (2007) describes some sections of the Aldworth Arm and River Ems as ‘winterbournes’, but this definition has been removed.

4.4.2. Continuous flow gauging

There is one current operational flow gauge on the River Ems, at Westbourne (Figure 4-1), for which data have been collected since 1967. There was formerly a gauge further upstream at Walderton, which was installed in 1966 but abandoned in 1984 as there was mostly zero flow.

There was a period of flow measurement at Hampshire Bridge (just downstream of Westbourne gauge) prior to installation of the permanent gauge (Holmes, 2007). The whole record is from May 1962 to July 1967 but for the statistics and analyses that follow, only data for complete hydrometric years (i.e. 1962/63 to 1965/66) are reviewed (so as not to skew the results).

Details and key flow statistics for these three gauge records are presented in Figure 4-3, and the locations are shown in Figure 4-1. For comparison with the estimate of recharge in Section 4.2.2 of 398 mm/year, the mean flow at Westbourne in Figure 4-3 is equivalent to 268 mm/year.

Table 4-4 - Details of continuous flow gauges

	Date range	Catchment area (km^2)	Mean flow (m^3/day)	Q95 flow (m^3/day)	BFI*
Hampshire Bridge**	1962-1967	-	42,541	2,133	-
Westbourne	1967-present	58.3	42,768	1,382	0.92
Walderton	1966-1984	41.5	6,307	0	0.83

* BFI = base flow index, the proportion of flow derived from groundwater discharge. BFI, catchment area and flow statistics are from the National River Flow Archive (https://nrfa.ceh.ac.uk/). ** Data points for the Hampshire Bridge gauging record were automatically digitised from the image in Holmes (2007) so may be subject to error particularly at low flows.

Flow duration curves for these gauged flows are presented in the upper chart of Figure 4-9. The y-axis represents the measured flow, and the x-axis is the proportion of days in a year that flow is expected to exceed the value plotted, so the 95% mark on the axis represents the Q95 measurement. The normal probability x-axis emphasises the values at extremes. Charts are shown with a linear y-axes to emphasise the magnitude of flows across the full range of data, and with log y-axes to visualise the differences at low flows. Where log y-axes are used the charts do not plot zero flows.

There was always flow in the River Ems at Westbourne gauge, which is almost always greater than about 1,000 m^3/day. Peak flows are more than two orders of magnitude higher than low flows, and are often in excess of 100,000 m^3/day (Figure 4-11).

The plot for Hampshire Bridge represents data for only four complete hydrometric years, so is not representative of long term conditions, but shows flows when abstraction at Walderton was at a lower rate. Nevertheless the key statistics (Table 4-4) and the flow duration curves are very similar to Westbourne (except at very high flows because the monitoring period did not include a period of extreme high flows).

During the period of gauging at Walderton there were long periods of zero flow: on average for 70% of the days per year.

The charts on the right of Figure 4-9 show the same flow data as those on the left but the flow measurements are normalised by catchment area. (The unit displayed on this axis could be (m^3/day)/km^2 but to display the value in terms a hydrogeologist might better be able to appreciate, the normalised measurements are converted to mm/day to tie in with recharge estimates. These charts emphasise how the substantially lower flows at Walderton were not related to the catchment to the gauge being smaller. Given that the spatial recharge distribution in each catchment is similar (Figure 4-4) the area-normalised flow should be similar. The conclusion here is that most of the recharge in the Walderton catchment does not enter the river and bypasses the gauge as groundwater flow.

Seasonal flows for Westbourne and Walderton are shown in Figure 4-10 (winter is defined as the period from December to March and summer is June to September). Clearly winter flows are consistently higher than summer flows at both gauges. It is interesting to see that the summer flows at Westbourne follow a roughly straight line on the chart, but winter flows show pronounced kinks at Q50 and Q90. Perhaps this is related to runoff.

During the period of gauging at Walderton in the Upper Ems there was flow only on 10% of summer days.

4.4.3. Spot flow gauging

There have been two systematic spot-gauging campaigns in the catchment. The first involved the Environment Agency measuring flows at nine locations measured between June 2006 and July 2011. AMEC (2013) undertook a campaign of monthly spot gauging in 2011-13 but the data sets from this have not been made available. Data points are likely to have been plotted as part of the figures for Appendix C of AMEC (2013), but these figures have not been made available. Only the results from the Environment Agency campaign are discussed below.

Locations of Environment Agency spot gauging sites are listed, from upstream to downstream, in Table 4-5, and shown in Figure 4-1, as recorded by the Environment Agency. All locations are upstream of the Westbourne continuous flow gauge.

Table 4-5 - Spot gauging locations

Recorded gauging location name*	NGR	Chainage** upstream of Westbourne gauge (m)	Date range
Stoughton Village	SU 8025 1145	7,160	Oct 2008 – Jul 2011
Walderton Bridge	SU 7873 1049	5,211	Jan 2007 – Jul 2011
Lordington	SU 7825 0976	4,299	Jan 2007 – Jul 2011
Racton d/s road bridge	SU 7819 0936	3,851	Jun 2006 – Jul 2011
Racton d/s confluence	SU 7818 0932	3,806	Jan 2007 – Jul 2011
Broadwash (Ell) Bridge	SU 776 088	3,000	Jan 2007 – Jul 2011
Aldsworth Bridge	SU 7724 0862	2,516	Jan 2007 – Jul 2011
Foxbury Lane	SU 7629 0783	1,181	Jun 2006 – Jul 2011
Westbourne Commons***	SU 7595 0821	954	Jun 2006 – Jul 2011

*Note that the location names were recorded and provided by the Environment Agency and some appear to be incorrect, the NGR are understood to be correct and these have been plotted and used to calculate the chainage
**Chainage is a stepped increase away from the source (in metres) following the bends of the river
*** The flow point at Westbourne Commons is on the Aldsworth Arm of the River Ems and is not in sequence with the others.

4.4.3.1. Accretion profiles

Accretion profiles are a useful method of understanding the magnitude of flow ‘gains’ and ‘losses’ along a river or stream.

Four sets of flow gauging data were made available, all of which occurred during periods of significant flow: January to May 2007, January to April 2009, January to June 2010, and January to May 2011 (there was no monitoring in early 2008). Figure 4-11 and Figure 4-12 show the pattern of accretion along the main stem of the river. A step in flow is added at the confluence with the Aldsworth Arm, with magnitude equal to the gauged flow at Westbourne Commons (which is actually about 200 m upstream of the confluence).

The dataset from early 2009 is the most complete as this was the only period that included measurements at Foxbury Lane, so this best shows the pattern of flow accretion along the river. The most notable feature is how flow accretes at a roughly steady rate all along the main stem of the river until the confluence with the western branch.

The flow contribution of the western branch (Aldsworth Arm) of the river is significant: on average it contributes about 32% of the total flow at Westbourne, but at low flows it may contribute up to half of the total flow (Figure 4-13).

There are often flow losses, or at least no constant flow, between Walderton Bridge and Lordington. During the periods of modest flow in 2009 and 2011, there was sometimes no flow at Lordington, and losses were not normally regained until Broadwash Bridge. During 2010 when flows were much higher, there were no apparent losses, but constant flow.

Flow losses downstream of the Racton confluence, at high flows, were apparently observed in February 2009 and January 2010. The tributary at Racton is not an anthropogenic discharge, and so ought to be in equilibrium with groundwater level in the Chalk, just like the main stem of the river, so observing a loss here is surprising and may be an error. In fact, field observations and hydrometric monitoring in 2021 suggest that there is a large spring in this area.

There were often losses downstream of Broadwash Bridge, for instance in January and April 2009, February to April 2010, and January 2011. The flows are always gained again downstream (more than can be accounted for by augmentation, even if it was operating at the time).

During the spot gauging campaign there were two occasions when flow at Westbourne was low enough to have triggered augmentation: August to October 2009 and September to October 2010 (and indeed augmentation was operating). Because it was summer/autumn at each of these times, the spot gauging coverage was limited but at all of those times, there was no flow gauged upstream of Westbourne, either at Aldsworth Bridge or at Westbourne Commons (flow at Foxbury Lane was not measured at these times).

In addition, a comparison between the new augmentation flow volume and flows at Westbourne Gauge suggest flow losses occur within this reach also (see Section 4.5 below).

4.4.3.2. Time series

The whole set of time series datasets are plotted together in Figure 4-15 to show the relative timing of periods with and without flow. All of the sites down to Aldsworth Bridge gauging point (also known as 'Broadwash Bridge') were clearly ephemeral during the period of monitoring because there were several months each year when there is no flow. Foxbury Lane was probably similar, though the data coverage is sparse. Holmes (2007) suggests that flows at Broadwash and Foxbury Lane should, in the absence of abstraction, be perennial but they were clearly not, during the period of monitoring.

At Stoughton, in the ephemeral reach of the River Ems (the 'Upper Ems'), periods without flow were eleven months or more each year. Moving down to Aldsworth Bridge/Broadwash the periods without flow were six months in length. Flows from the Aldsworth Arm of the river appeared to have been more regular, and to suffer much fewer periods of zero flow than those on the main stem. But it seems likely that they dwindled to zero for two or three months each year.

4.5. Flow augmentation

The effects of augmentation on flows at Westbourne are examined in this sub-section. In Figure 4-16 flow duration curves for summer periods are compared for the periods before and after the augmentation rate was increased from 1,136 m^3/day to 2,160 m^3/day, and was moved upstream to Racton Dell, i.e. from summer 2016 onwards.

It is not completely robust to compare data from summers 1967-2015 with data from summers 2016-2020 due to the short duration of the last period. However, it does appear the most recent data points are higher than the long-term data points at flows less than 3,500 m^3/day (Q70) and greater than 1200 m^3/day (Q95). However the difference in flow never approaches the additional augmentation volumes added sine 2016: at Q90 the difference is only 510 m^3/day. This seems to indicate that some (about half) of the additional augmentation is seen at the gauge, but not all of it. But at very low flows, less than Q95, there are more losses than before 2016.

The apparent benefit of augmentation can be seen by naturalising the flows as they might have been without augmentation. For the years since 2016, it is very clear what the amount of augmentation was (i.e. it was equal to abstraction from Woodmancote). There are three graphs in Figure 4-17. The uppermost plot (a) shows the measured flows at Westbourne and naturalised flows, i.e. measured flows at Westbourne minus the augmentation discharge. Autumn flows can be seen to be considerably supported by the augmentation, and in some cases the naturalised flows are apparently zero for several months at a time.

This is a slightly simplistic appraisal, however, as no account is made for the flow from the Aldsworth Arm, which during the lowest flows for the period 2007-2011 contributed typically one third of the measured flows at Westbourne gauge (Section 4.4.3). This is probably not the case, however, when flows are so low that augmentation is required.

The lower charts of Figure 4-17 (b and c) compare the discharged amount against the estimated amount of that discharge that reached the gauge at Westbourne. This shows that in most years there were minimal losses along the reach downstream of the augmentation, but in 2019 and 2020 there were losses of up to 2,000 m^3/day.

These apparently considerable losses (relative to the augmentation) are at odds with the observation of spot gauging data undertaken in September 2011 (reported by AMEC, 2013) which indicated that most of the augmentation reached the Westbourne gauge. Further review of this data from Appendix C of the report (not currently available) would be worthwhile as well as new data collection during fresh releases.

For comparison the open water evaporation from the 1 ha 'Canal' which lies next to the river downstream of the augmentation point, assumed to be about 4 mm/day in summer months (see Table 4-2), is expected to be about 40 m^3/day. This is therefore not a significant contributor to loss downstream of the augmentation point.

4.6. Modelled flow impacts

AMEC (2013) explored in detail, using the EHCC model, the impact of abstraction on flows in the River Ems. At that time, augmentation was being provided by flows from Walderton so the situation was slightly different to that at present. Nevertheless, the overall catchment water balance was similar. Five scenarios were reported on:

- "naturalised" which simulates the effect on flows if there were no abstractions;
- "recent actual" which looks back at the historical patterns from 2006 to 2010;
- "fully licensed" which assumes all abstractions are operated at their permitted maximum rates;
- "MAX" is as the recent actual, but with Walderton only at its permitted maximum rate; and
- "OFF" which is as the recent actual, but with Walderton not operating.

(The naturalised scenario does not include augmentation. It is not explicitly stated in any of the EHCC reports but it seems like in each scenario, except the naturalised scenario, augmentation is operated automatically within the model according to the set on/off thresholds.)

The model fit to the flows at Westbourne was also not excellent (Figure 4-18) so its predictions of absolute flows were indicative only, but predictions of relative impacts should be reliable. That said, most of the scenarios were outside the limits of calibration of the model, for instance, there was no significant period in the model when there was no abstraction, or even no abstraction from Walderton.

The average abstraction rate at Walderton was 20,256 m^3/day between 2016 and 2020 was 10% higher than the modelled abstraction rate of 18,412 m^3/day from 2006 to 2010.

4.6.1. Flows at Westbourne

Firstly, there was a clear difference in simulated flows at Westbourne gauging station between these scenarios. Figure 4-16 shows simulated flow duration curves for flow at Westbourne: the upper plot shows the whole range of flows and the lower plot shows just the low flows. Abstraction in the recent actual scenario is shown to deplete Q95 flows from the naturalised state by about 70%, and Q70 flows by about 61%.

These depleted flow rates, as a proportion of flow, were considerably less than the environmental flow indicators (EFI) for the catchment. The River Ems has been assigned abstraction sensitivity band (ASB) 2, which means that gauged flows that are compliant with good ecological potential (GEP) are defined as follows (Environment Agency, 2013):

- depletion in Q95 must be no more than 15% from natural flows;
- depletion in Q70 must be no more than 20% from natural flows;
- depletion in Q50 must be no more than 24% from natural flows; and
- depletion in Q30 must be no more than 26% from natural flows.

Levels of certainty of in the adequacy of flows to support GEP are also given with reference to the depletion relative to the natural Q95 flow:

- depletion in Q95 < 15% from natural flows: adequate to support GEP
- depletion in Q95 < 40% from natural flows: flows not adequate to support GEP: low confidence

- depletion in Q95 < 65% from natural flows: flows not adequate to support GEP: moderate confidence
- depletion in Q95 > 65% from natural flows: flows not adequate to support GEP: high confidence

The Q70 and Q95 EFI values, and the levels of certainty (in bars from yellow to red), are superimposed on the lower chart of Figure 4-19. The outcome of this assessment is that it is quite certain that current flows in the River Ems at Westbourne have not been capable of supporting GEP, as defined using the EFI. Since recent abstraction at Walderton is 10% higher than in the model, the non-compliance with EFI values is potentially greater at present.

Importantly, establishing EFI values involves adoption of a large number of assumptions and they therefore constitute a valuable first pass screening tool rather than a prescriptive tool for exact flow values.

4.6.2. Flows along the River Ems

Figure 4-20 shows simulated flow accretion along the reach of the River Ems from just downstream of Walderton to 2 km downstream of the gauge at Westbourne. The flows are generated for June 1993, which was a time of ‘average’ groundwater levels, receding from the winter peak but not yet at the seasonal low. None of the scenario flows are low enough to lead to simulation of augmentation.

If it is assumed that the modelled flows at this time can be considered to be similar to the actual Q50 flow, it is easy to see that the flows in the recent actual scenario are more than 24% depleted from the natural flow, and so are not capable of supporting the EFI’s GEP.

The modelled accretion profiles also show how abstractions bring the point of emergence of groundwater from the stream bed southwards by about 1500 m, moving approximately from Lordington to Broadwash. While this is based on a snapshot in time it is indicative of the order of magnitude of the potential length of reach that has changed from perennial to ephemeral. Flow emergence does not, in this snapshot, reach as far upstream as Walderton, but it would at times of higher flow.

The contribution to flow from the Aldsworth Arm seems to be underestimated compared to the spot flow data presented in Section 4.4.3.

In a new model, plotting the location of emergence as it moves through the seasons, under different abstraction scenarios, would be very informative.

4.6.3. Benefits of flow augmentation

Simply put, in the naturalised scenario the Q95 flow above the point of augmentation at Foxbury Lane is about 4,000 m^3/day, but in all scenarios with the abstraction at Walderton operational the Q95 flow is zero. The augmentation discharge appears, therefore, to be essential in maintaining perennial flows downstream.

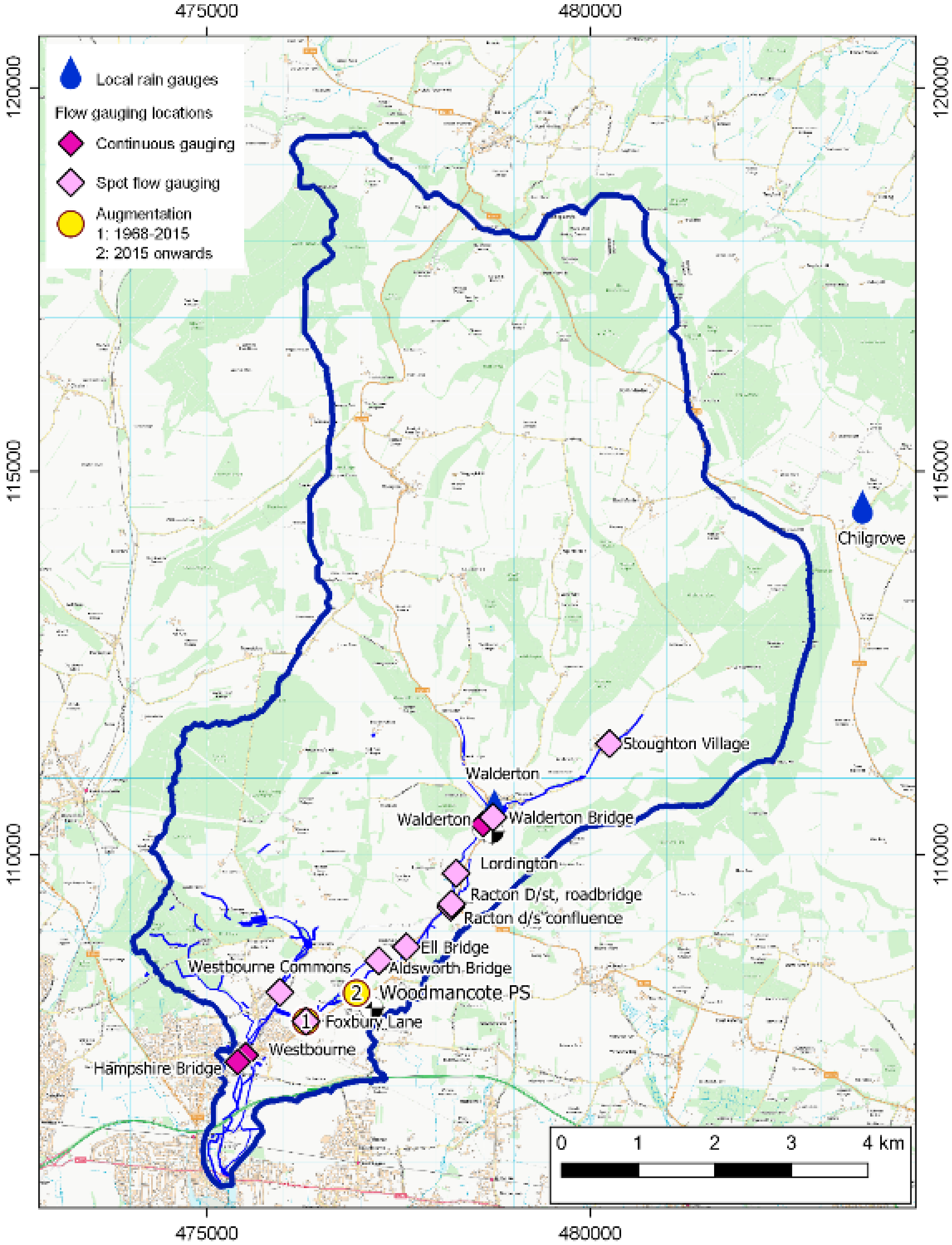


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Figure 4-1 - Hydrometric monitoring points

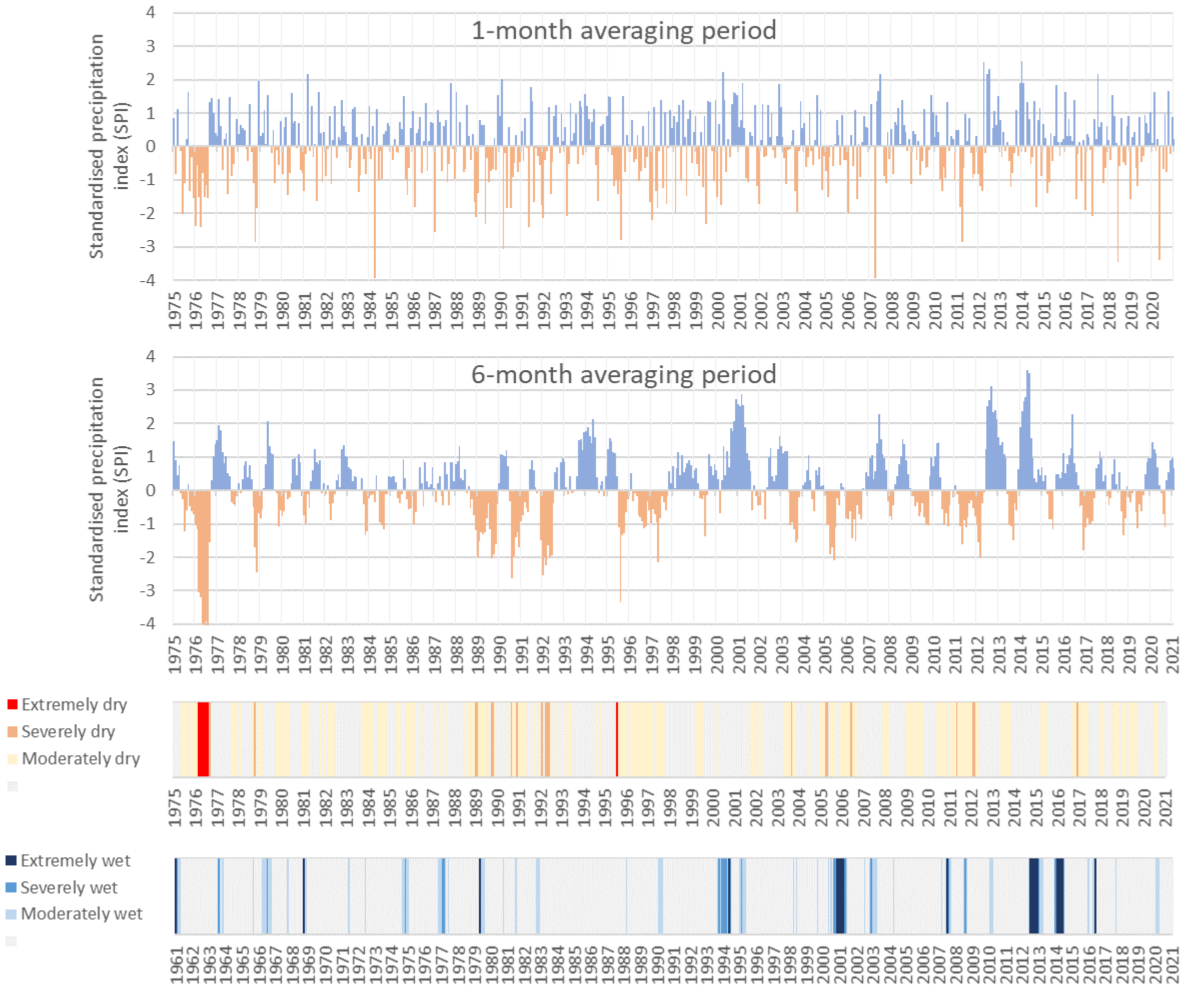

Figure 4-2 - Standardised precipitation index (SPI), Hampshire Coastal Catchments

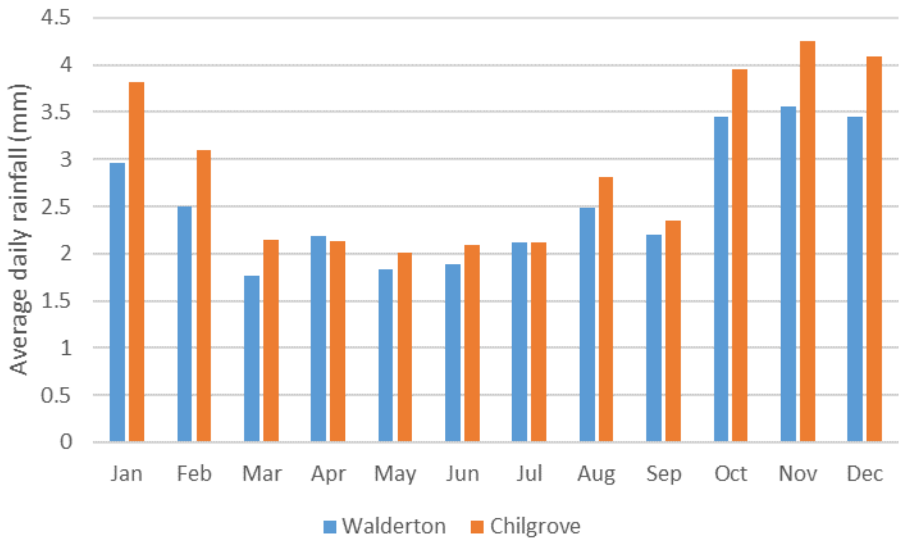

Figure 4-3 - Average daily rainfall, by month

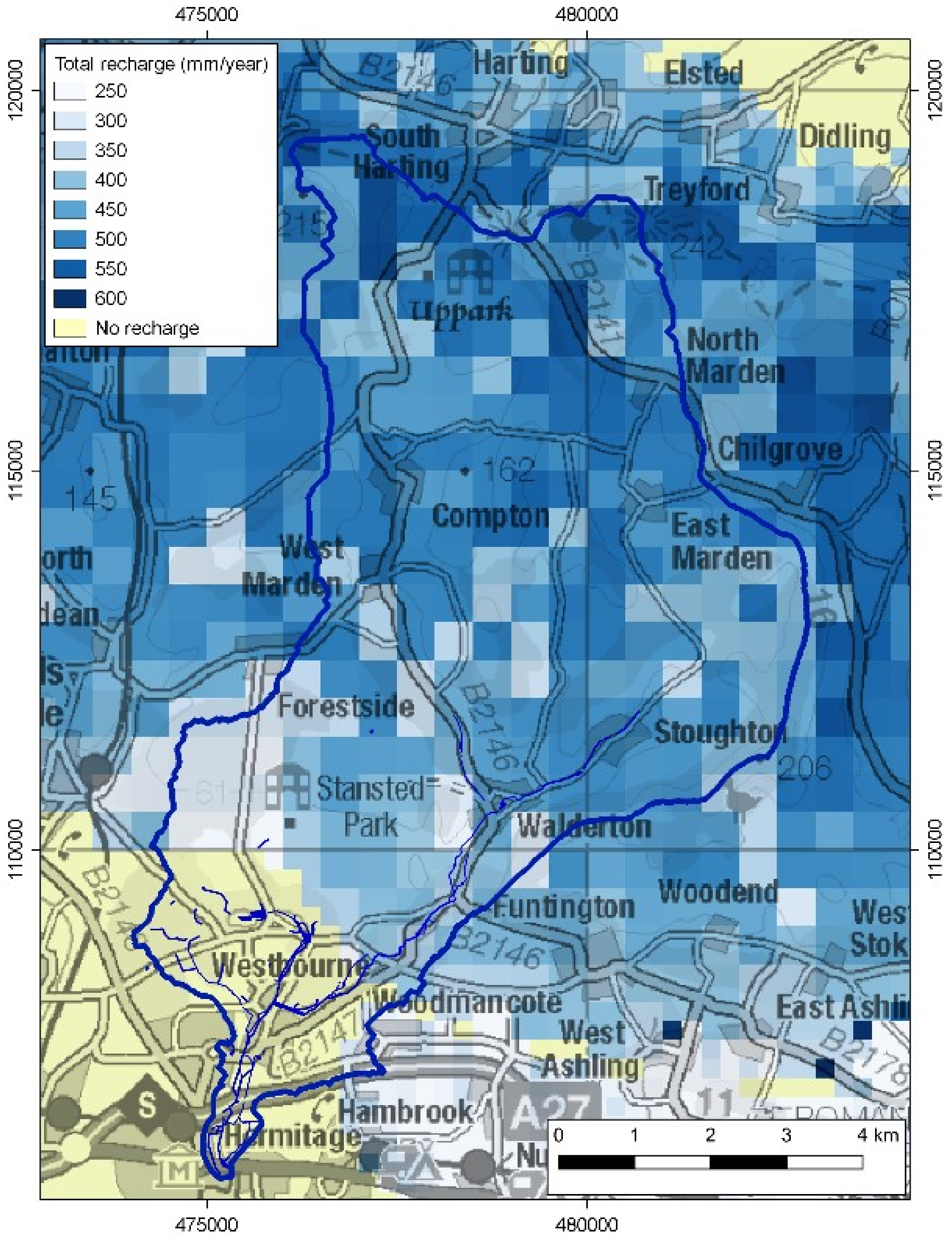

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Figure 4-4 - Average recharge for the EHCC model period January 1965 to October 2011

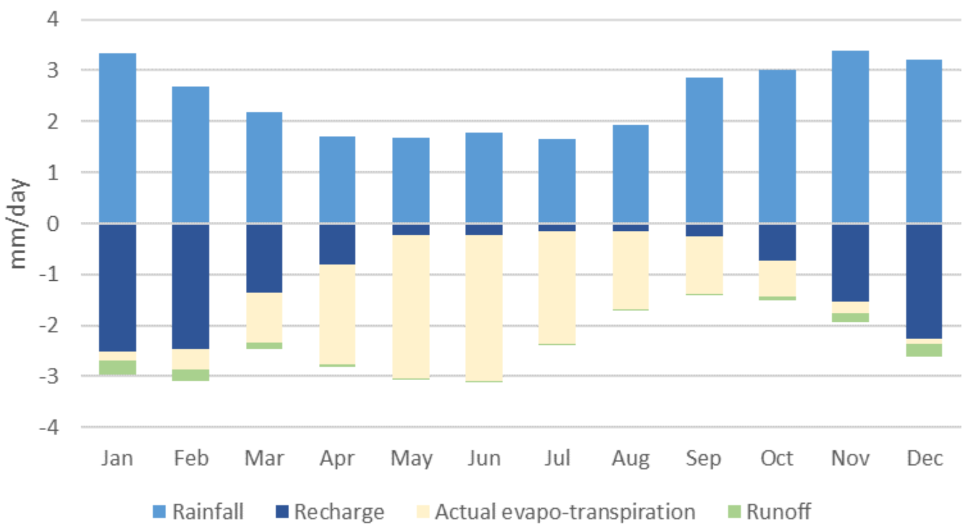


Figure 4-5 - Average daily natural water balance components for the River Ems catchment, by month

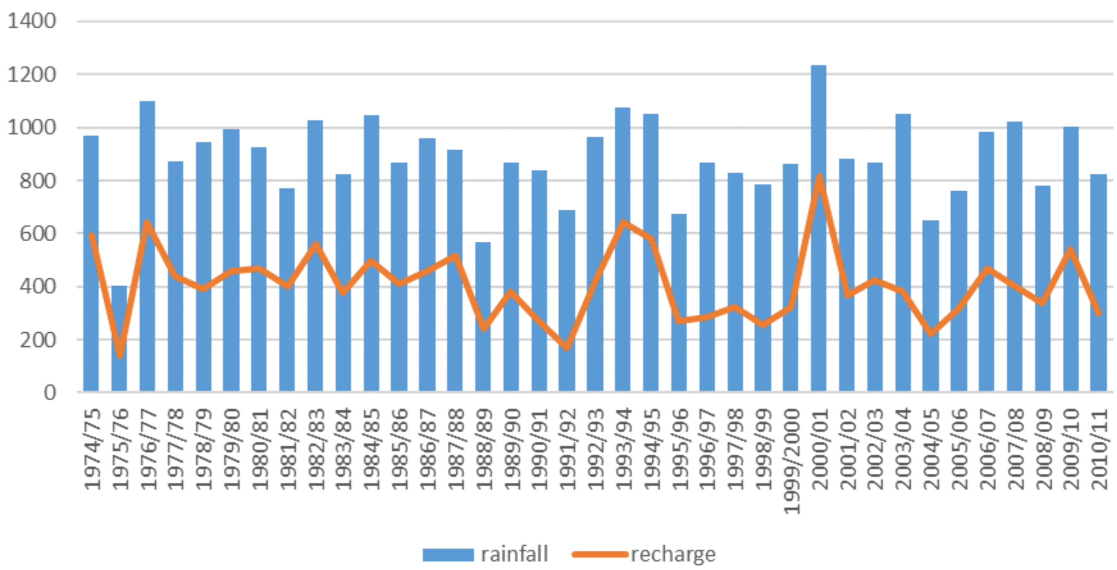


Figure 4-6 - Annual rainfall and recharge totals for the for the River Ems catchment

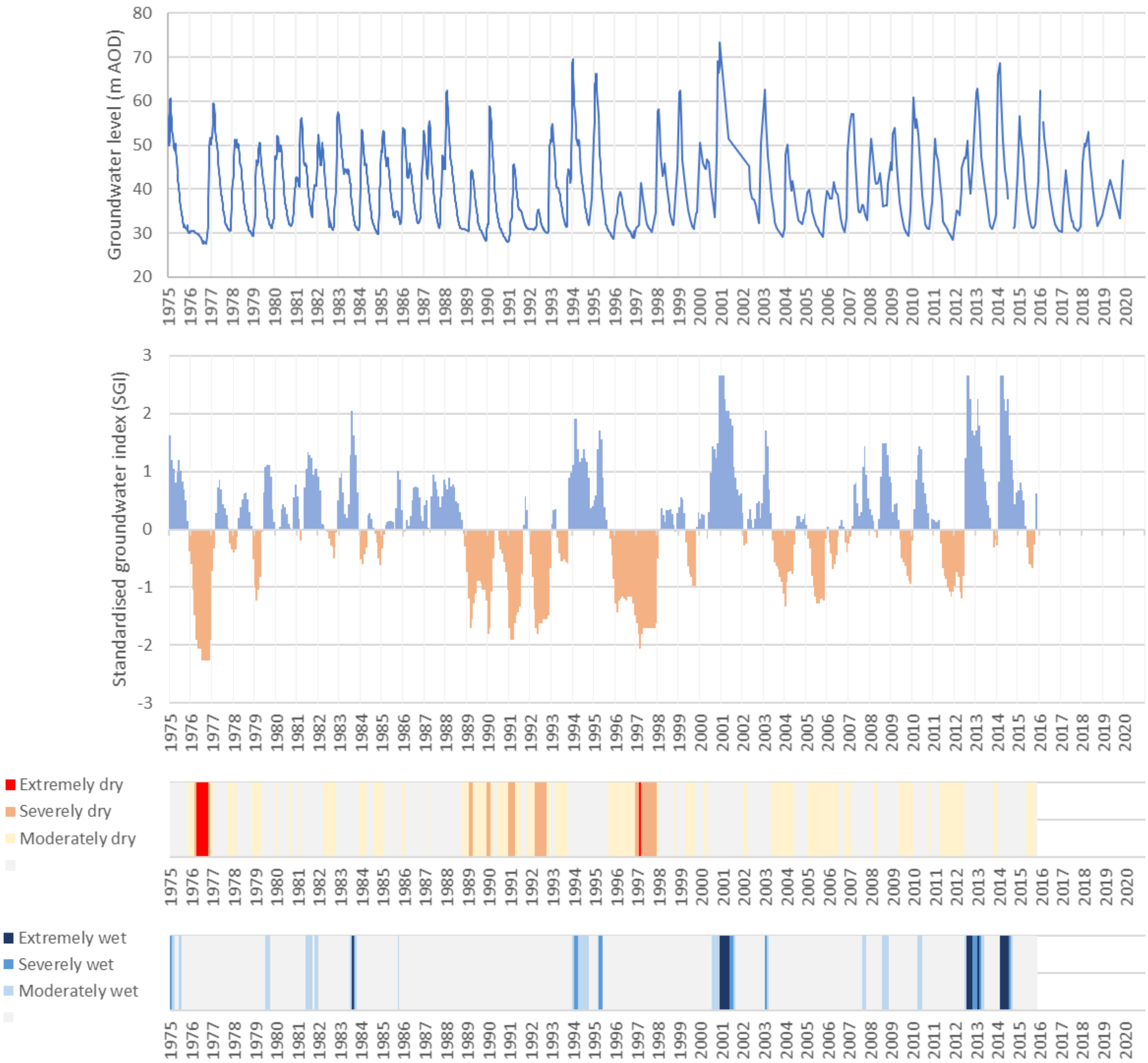


Figure 4-7 - Standardised groundwater index (SGI) and periods of groundwater drought for Compton borehole (SGI dataset is only updated to 2015)

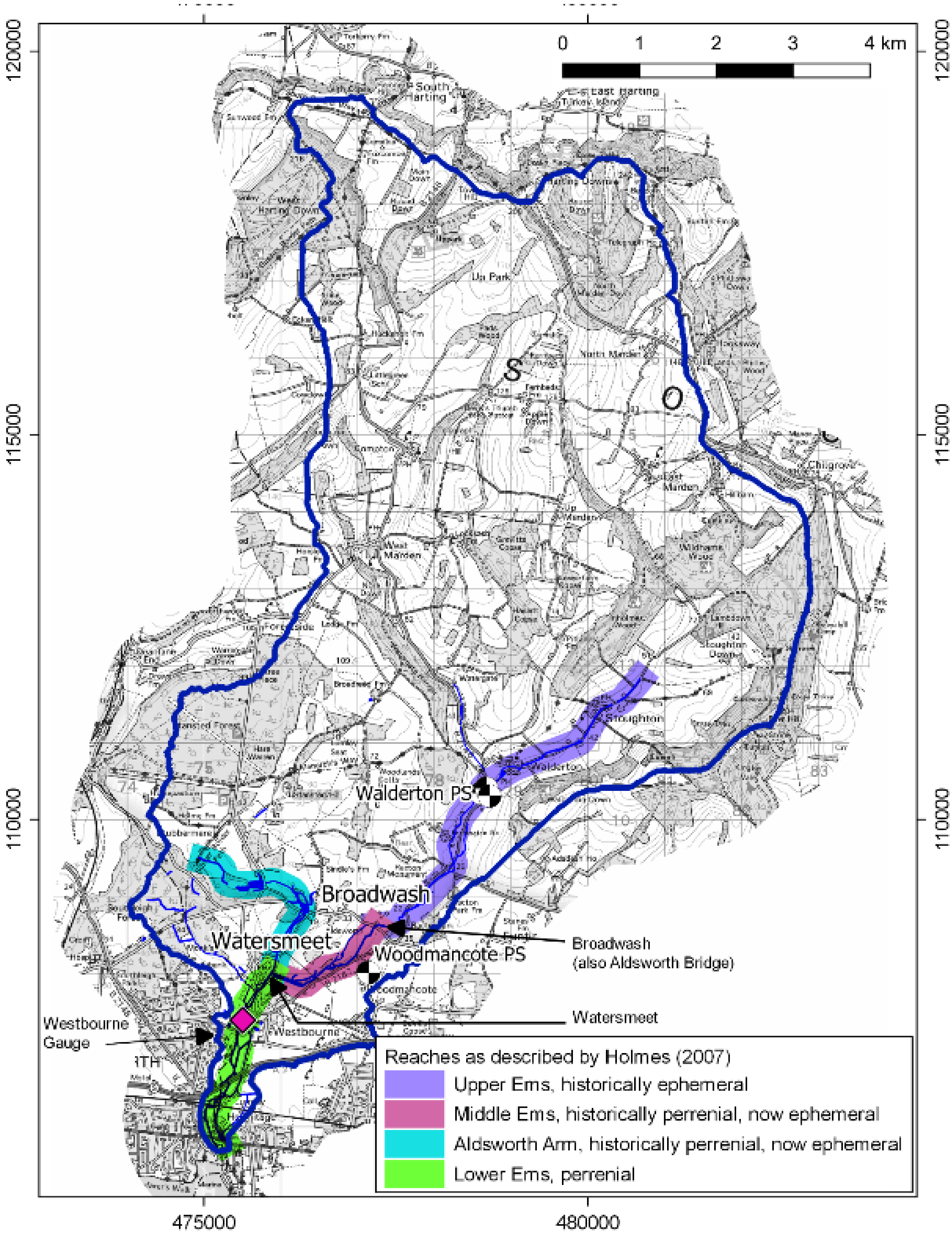


Figure 4-8 - Reaches of the River Ems, described by Holmes (2007)

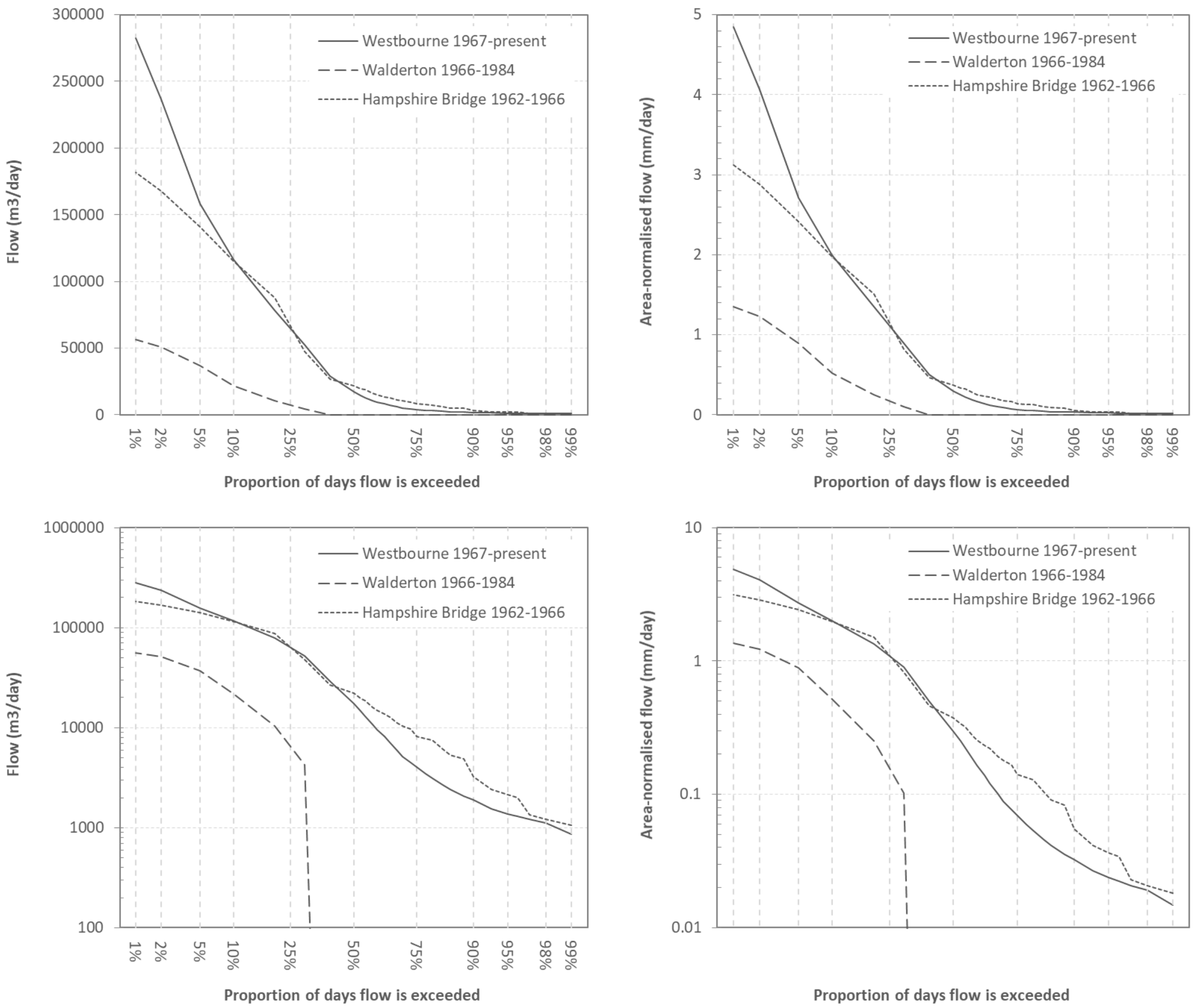


Figure 4-9 - Flow duration curves (top = linear flow axes, bottom = log flow axes; left = flows in m³/day, right = catchment area-normalised flows)

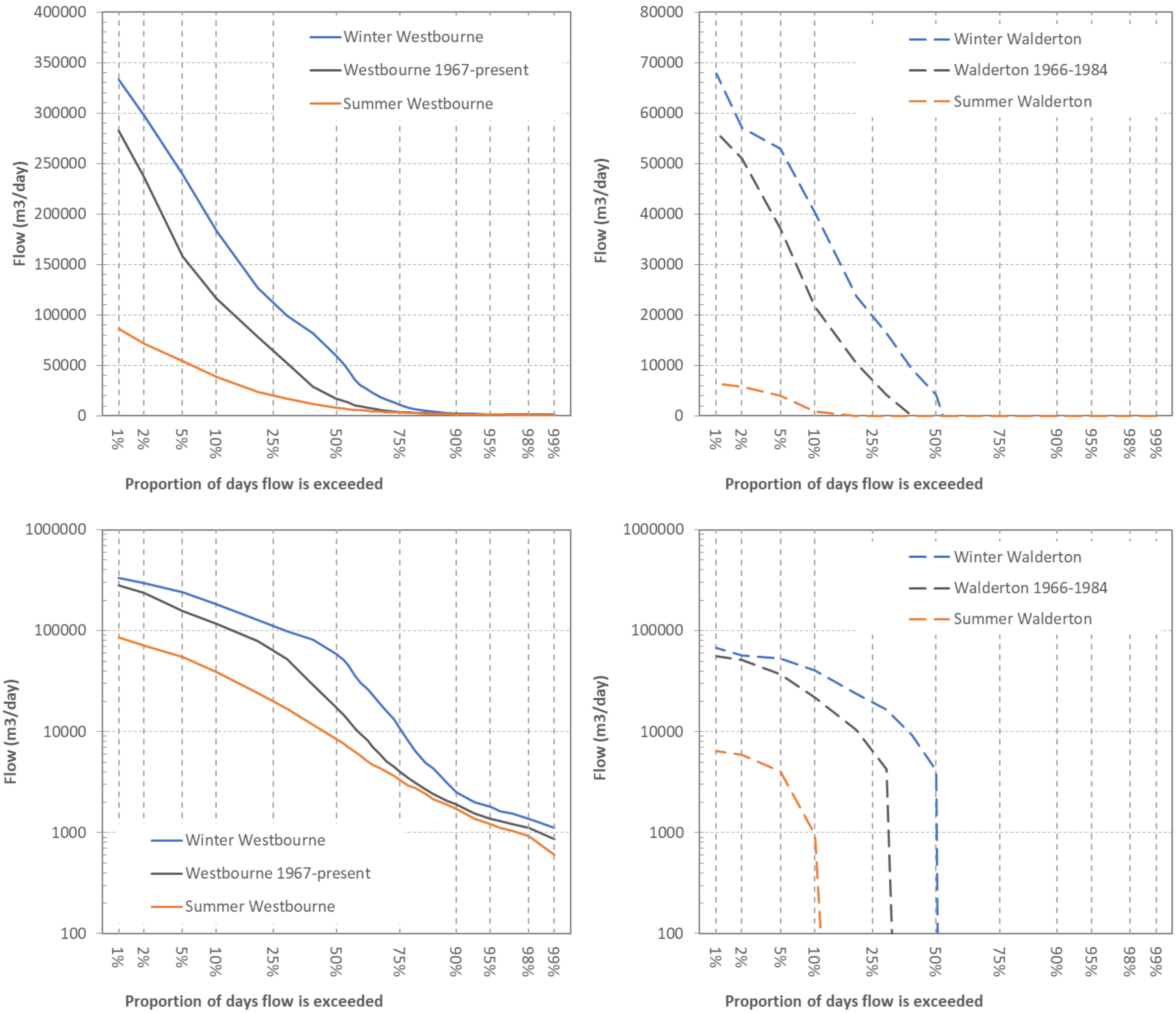


Figure 4-10 - Seasonal flow duration curves: Westbourne gauge (1967-present) and Walderton gauge (1966-1984). Winter = December to March, summer = June to September. top = linear flow axes, bottom = log flow axes)

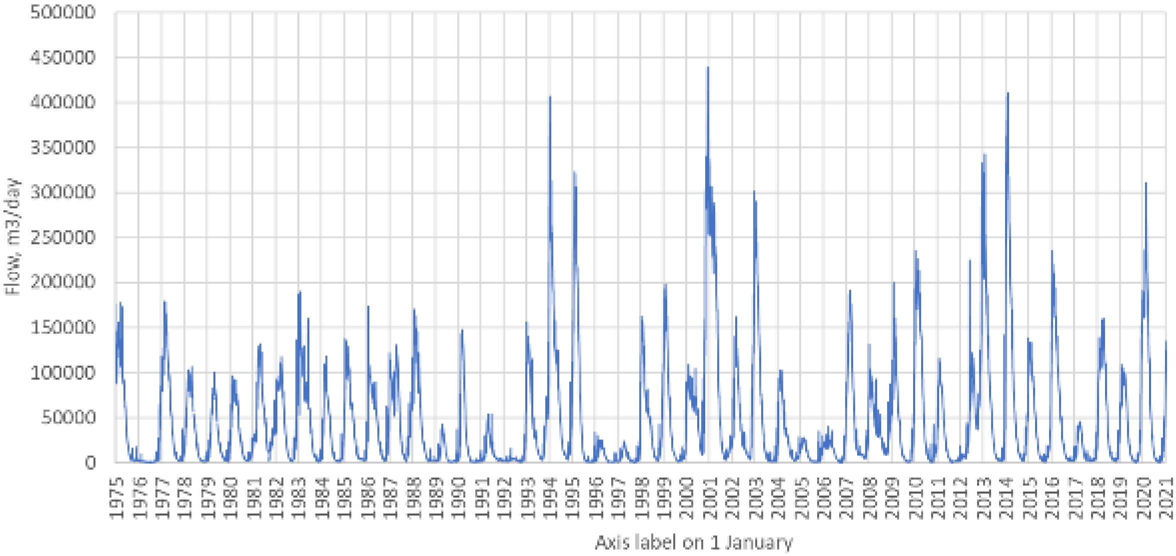
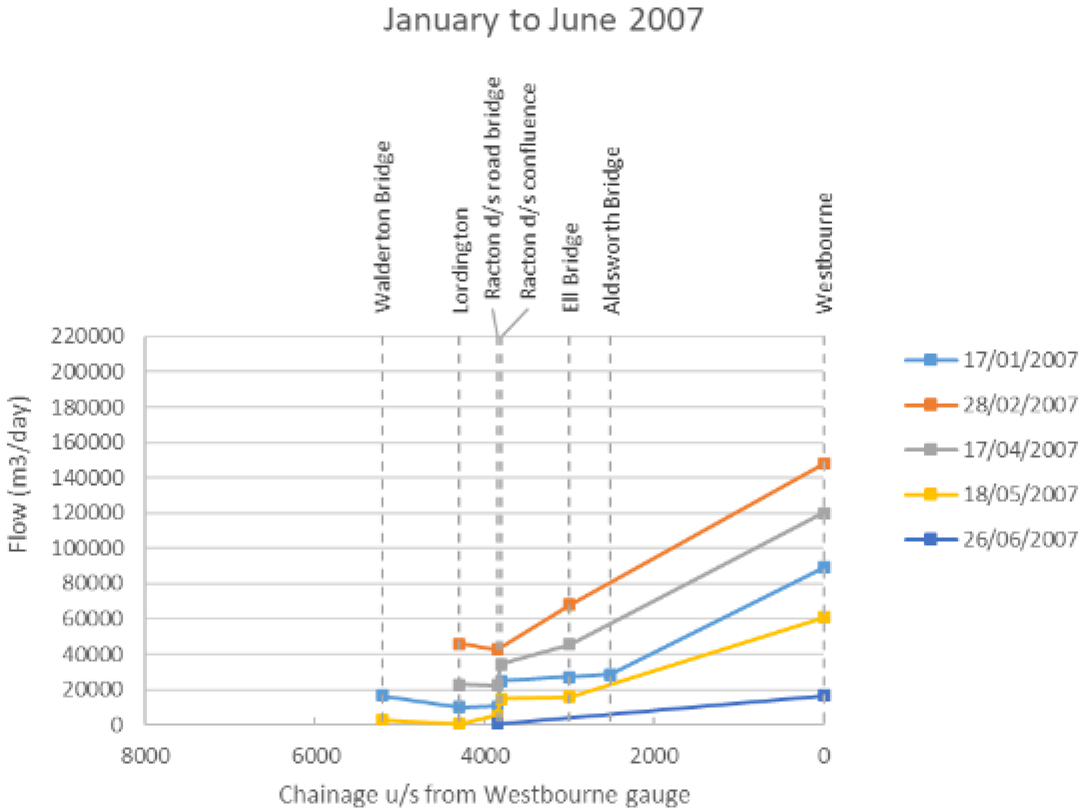


Figure 4-11 - Flow hydrograph for Westbourne gauge



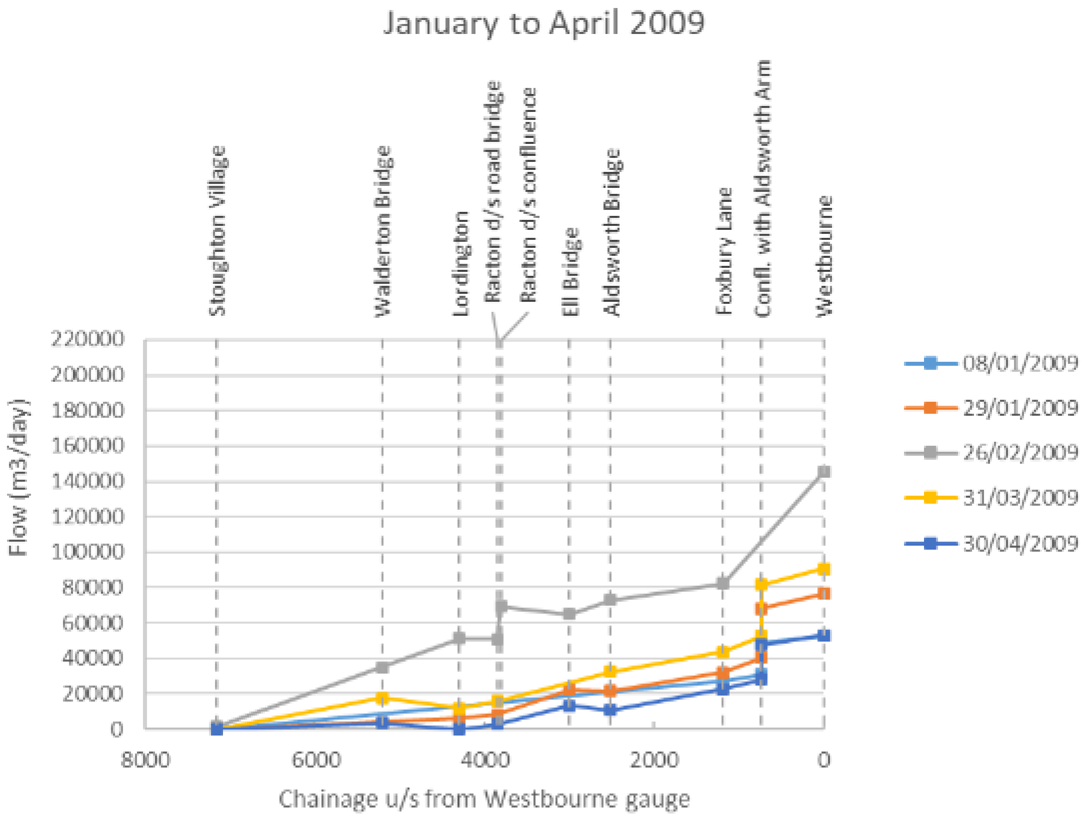
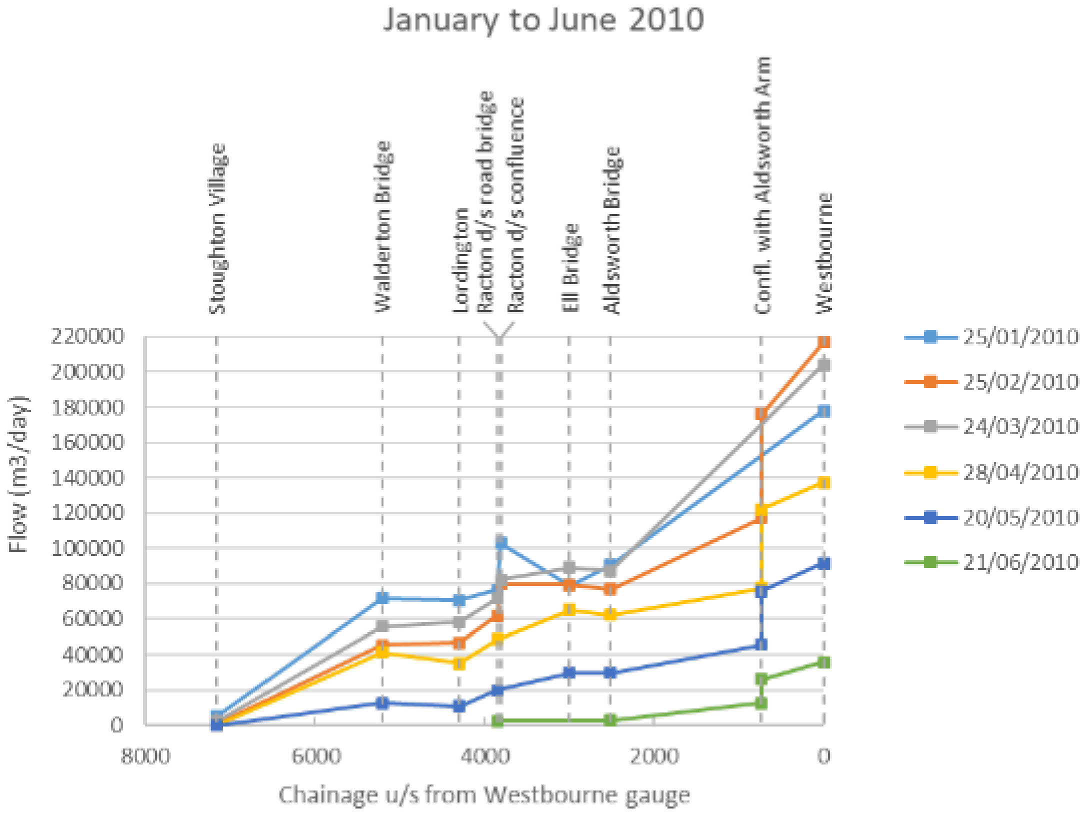


Figure 4-12 - Flow accretion profiles from spot gauging, 2007 and 2009



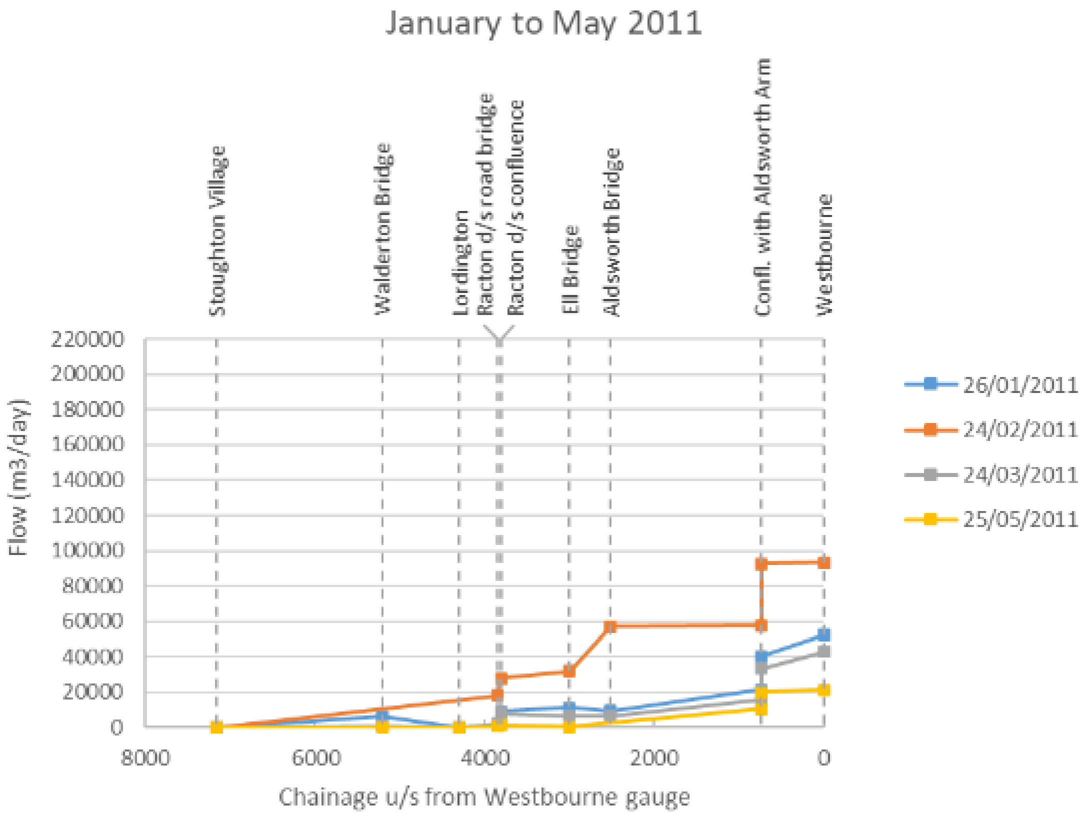


Figure 4-13 - Flow accretion profiles from spot gauging, 2010 and 2011

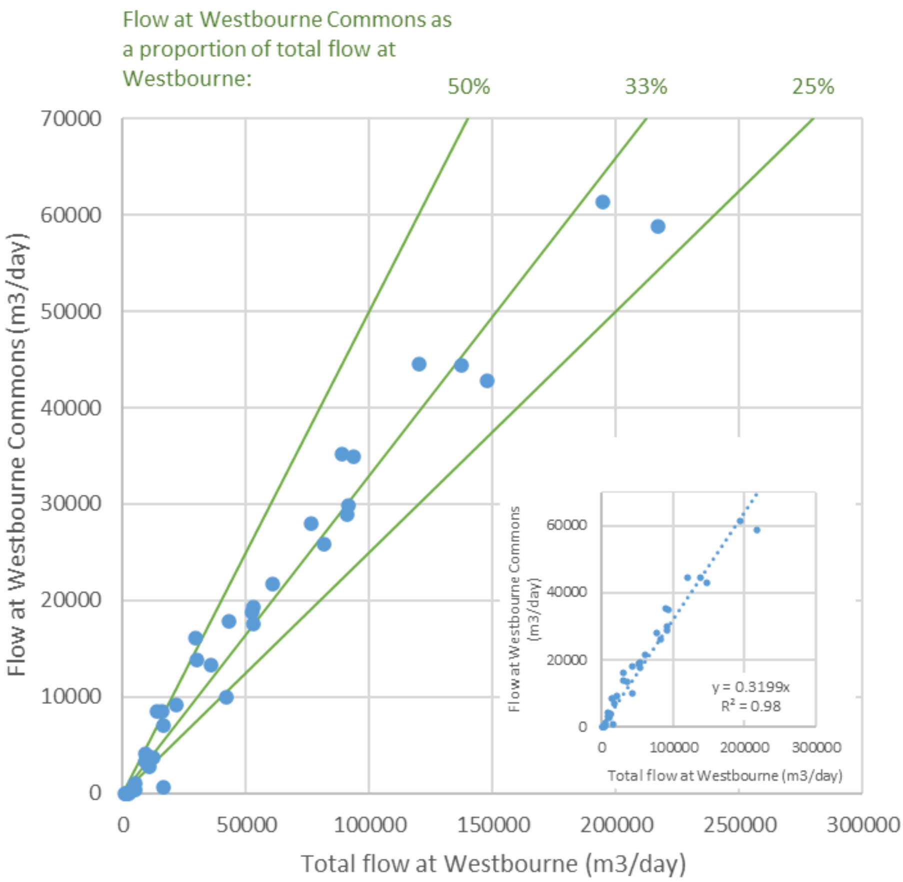


Figure 4-14 - Contribution of flow from the western branch of the River Ems

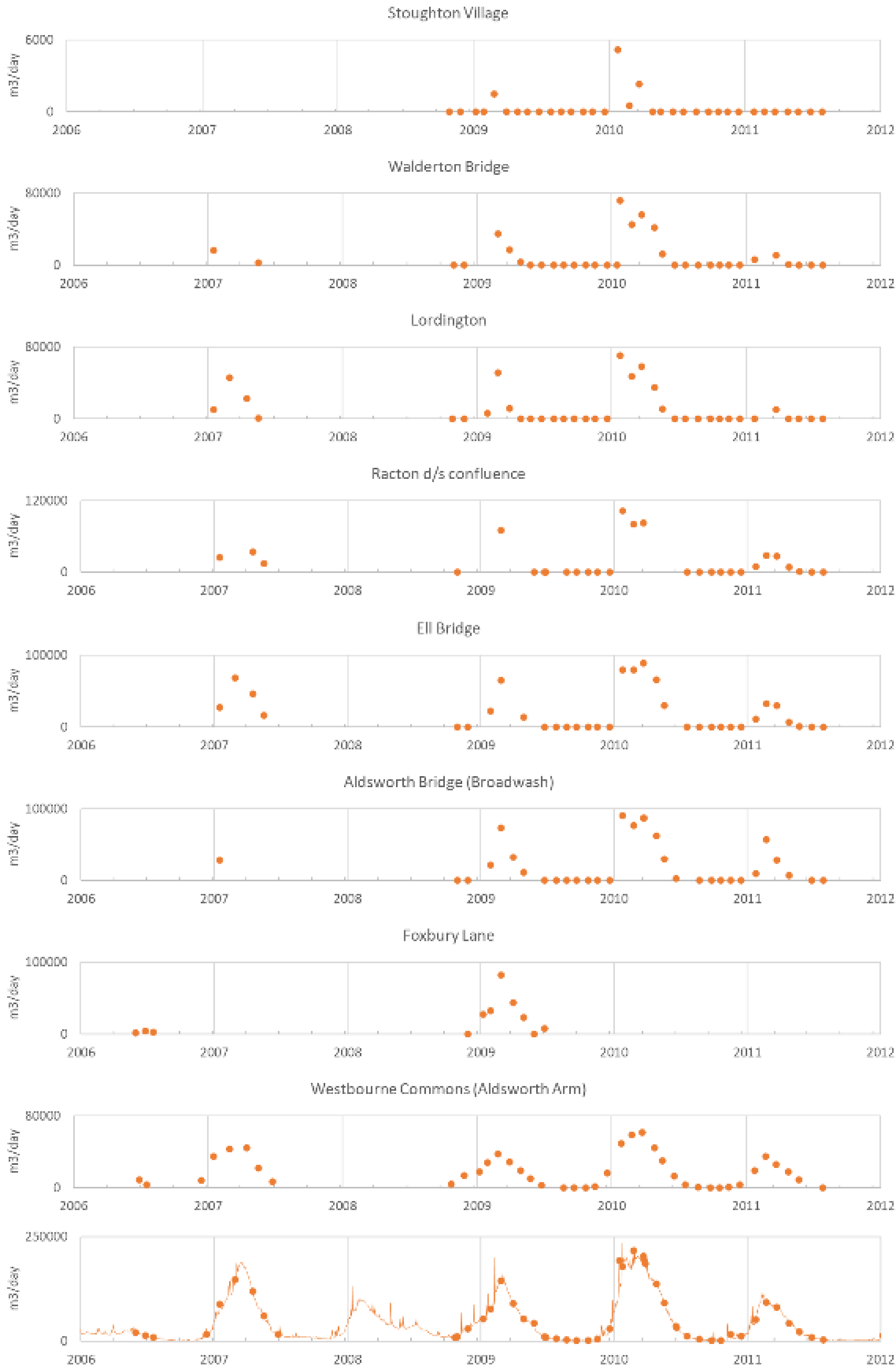
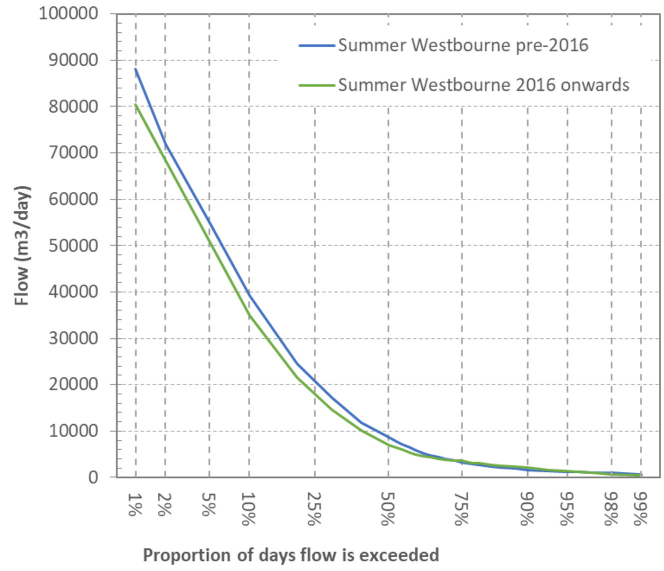


Figure 4-15 - Spot gauging data from upstream sites (top) to downstream sites (bottom)



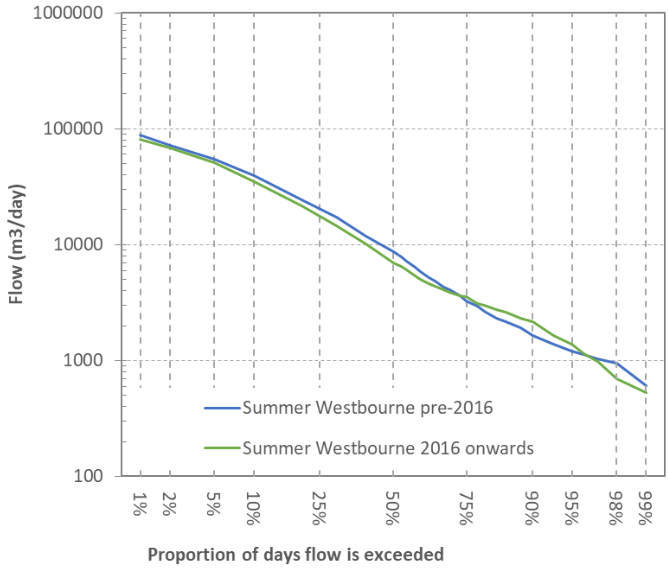
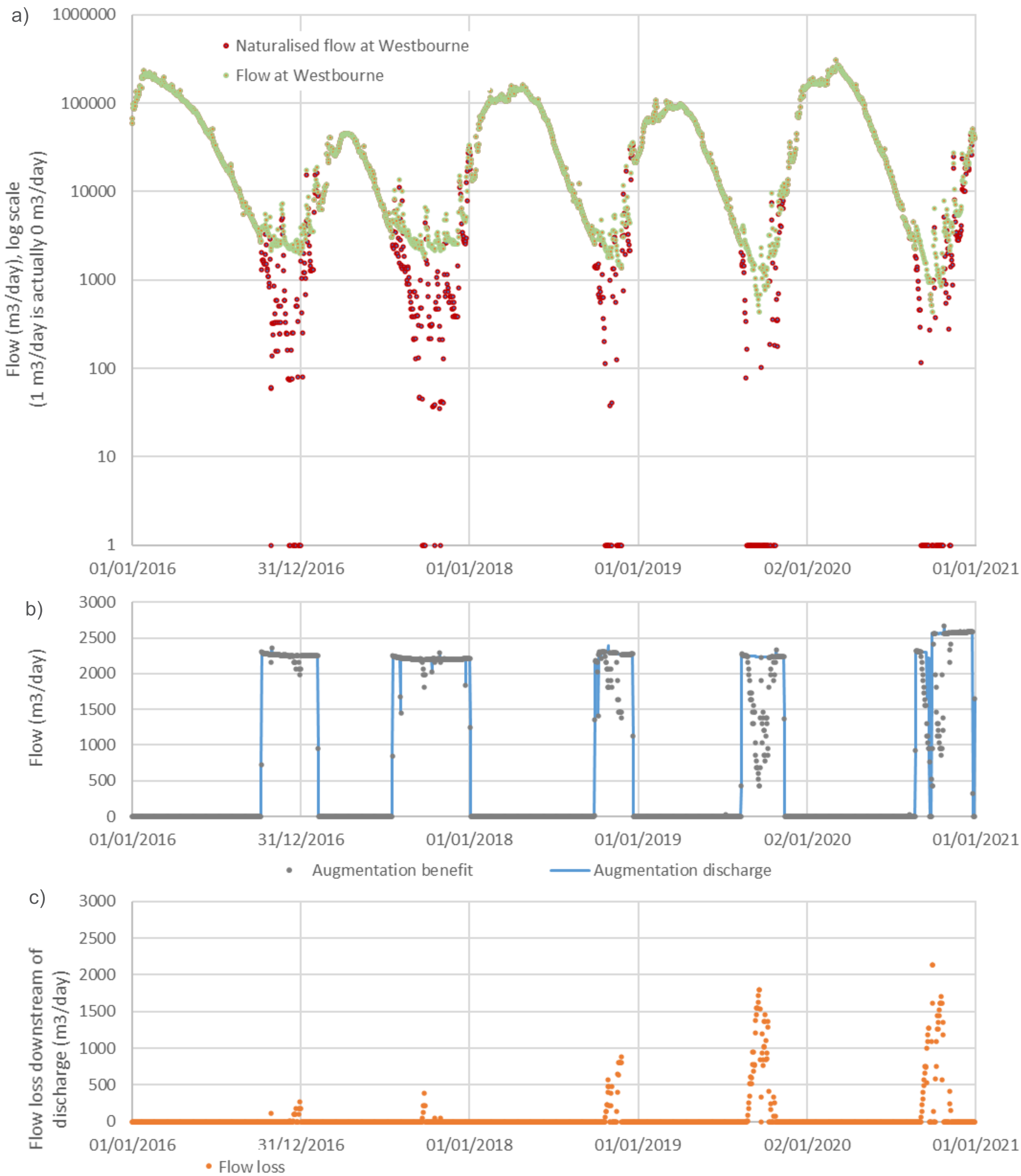


Figure 4-16 - Flow duration curves for summers pre- and post-2016 change in augmentation from Walderton to Woodmancote (top = linear y-axis, bottom = log y-axis)



(Naturalised flow is the estimated flow in the eastern branch (measured flow at Westbourne gauge x (1 - 0.32)) minus the recorded augmentation discharge. Zero flows do not plot on a log-scale chart so these are plotted as 1 m^3/day.)

Figure 4-17 - Estimated and naturalised flow of the main branch of the River Ems (a), augmentation benefit (b) and flow losses downstream of the augmentation point (c). Please note top graph kept at log scale to show differences not normally seen without log scale. No daily augmentation data available pre-2016.

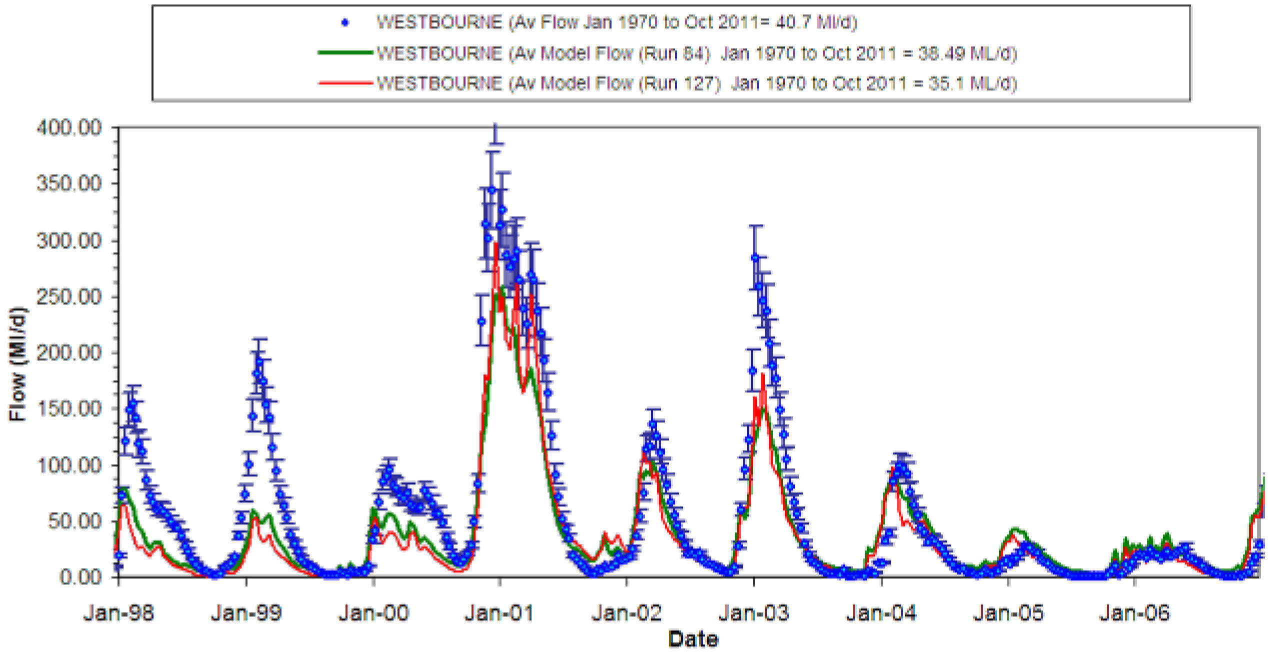
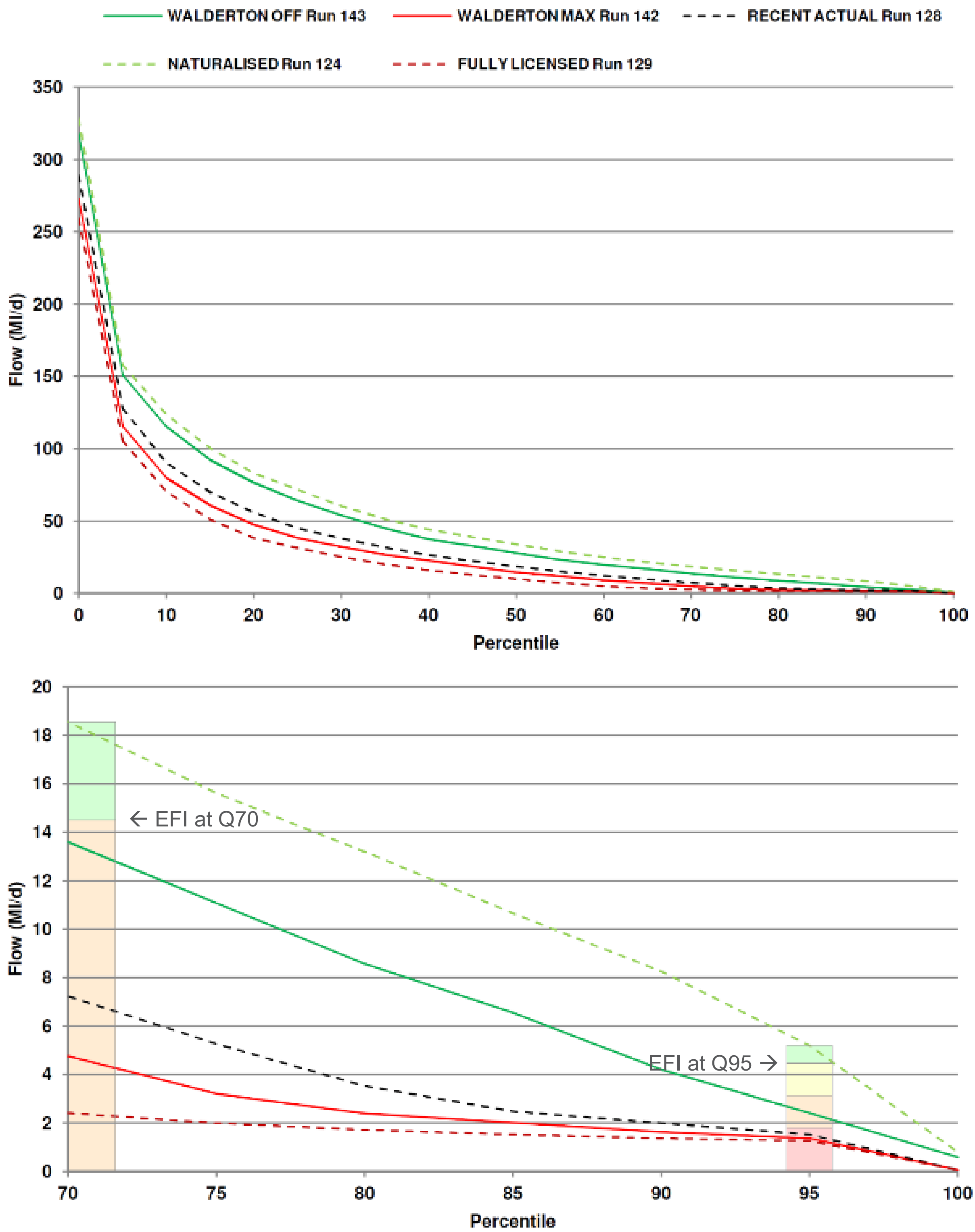


Figure 4-18 - Model fit and flow data for the EHCC model (run 84 using the EHCC model of Entec, 2008, run 127 using the EHCC model of AMEC, 2013)



After AMEC, 2013. EFI bars have been added as follows: green: flow is adequate to support GEP | yellow: flow is not adequate to support GEP [low confidence] | amber: flow is not adequate to support GEP [moderate confidence] | red: flow is not adequate to support GEP [high confidence].

Figure 4-19 - Simulated flow duration curves for the River Ems and environmental flow indicators

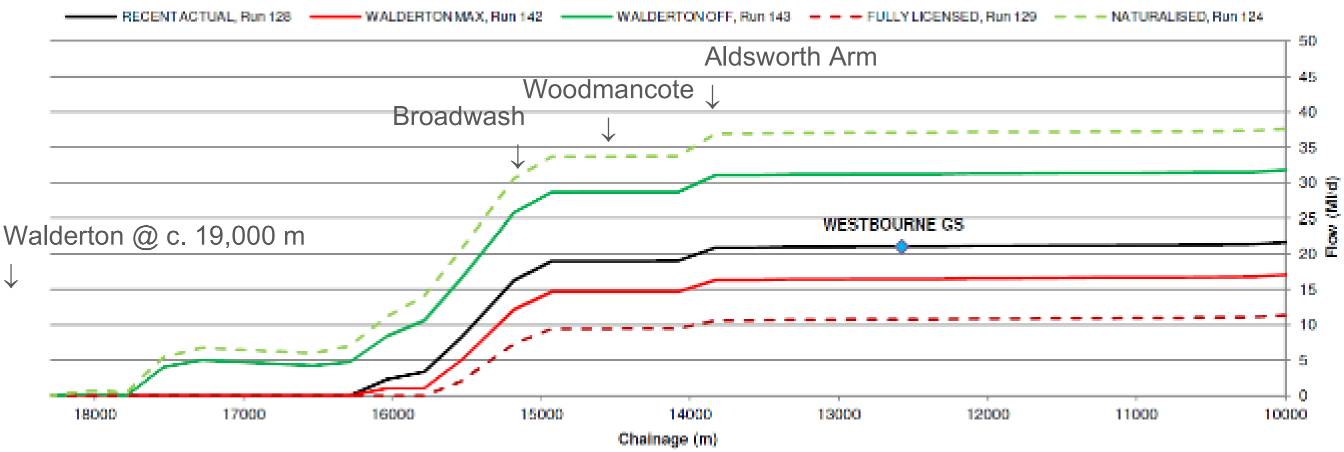


Figure 4-20 - Simulated flow accretion along the River Ems at 'average' groundwater levels (augmentation will not have been running for any of these flow rates)

5. Hydrogeology

5.1. Geological setting

The River Ems catchment is mostly within the boundary of British Geological Survey (BGS) map sheet 316: Fareham, with a small area (east of Easting 418000) within the adjacent map sheet 317/332 Chichester and Bognor. A geology map of the catchment is shown in Figure 5-1. A cross-section through a line just west of the River Ems catchment is shown in Figure 5-2.

Bedrock geology at outcrop within the catchment mostly comprises chalk. Chalk is a very fine-grained, white, limestone with flint and marl bands, and extensive fracturing. It is described comprehensively by Entec (2006) apart from the nature of the modern sub-divisions of the Chalk Group that are shown on the geological map. Table 5-1 presents the modern sub-divisions, with brief lithological descriptions based on the geological map, and Jones and Robins (1999). The total thickness of the Chalk beneath the South Downs is almost 500 m, of which 320 m comprises the uppermost four members (i.e. the former Upper Chalk).

In the lower, south-western, part of the River Ems catchment, the Chalk Group is overlain by clays of the Lambeth Group and London Clay Group.

Bedrock structure is also described comprehensively by Entec (2006). Throughout most of the catchment the formations dip gently southwards (Figure 5-2). In the very southernmost part of the catchment the Chichester Syncline the formations veer upwards again so that the Chalk Group comes to outcrop just south of Emsworth, beneath Chichester Harbour.

There are also some minor folds that trend north east to south west, to the east and west of Walderton.

Table 5-1 - Bedrock stratigraphy

Former name	Modern name	Total thickness	Lithological description
-	London Clay Group	90-120 m	Silty clay and sand, including: Bognor Sand Member, a glauconitic fine- to medium-grained sand
-	Lambeth Group	30-40 m	Mottled clay, locally sandy
Upper Chalk	Spetisbury Chalk Member	40 m	White chalk with flints
	Tarrant Chalk Member	30-40 m	White chalk with flints
	Newhaven Chalk Member	50-75 m	White chalk with flints and many thin marl bands
	Seaford Chalk Member	55-80 m	White chalk with flints
	Lewes Nodular Chalk Member	35-75 m	Hard, nodular chalk with flints.
Middle Chalk	New Pit Chalk Member	25-35 m	White chalk with many thin marl bands
	Holywell Nodular Chalk Member	15-35 m	Hard, nodular chalk, some shelly. The Melbourn Rock is at the base, comprising dense flint bands and hardgrounds.
Lower Chalk	Zig Zag Chalk Member	40-60 m	Grey chalk
	West Melbury Marly Chalk Member	10-35 m	Marly chalk and thin limestone
-	Upper Greensand Formation	28-30 m	Fine-grained glauconitic clayey sands and sandstone
-	Gault Formation	80-95 m	Calcareous and silty mudstones

Superficial deposits are present over much of the catchment area (Figure 5-3). Overlying the Chalk, on the interfluve areas between the dry valleys, is Clay-with-flints, while on the valley sides are lobes of head. In the base of the valleys that host the surface water bodies there is thin alluvium.

Moving further south, onto the Sussex coastal plain, superficial deposits comprise head and river terrace deposits. The river terrace deposits were deposited in post-glacial times by a tributary of the former Solent River. Further to the south, and almost outside the Ems catchment, there are raised beach deposits and storm beach deposits.

There is no stratigraphic sequence in the superficial deposits (though some strata are obviously older than others) but Table 5-2 presents brief lithological descriptions based on the geological map.

The margin of the Clay-with-flints deposit is associated with the presence of solution pipes into the Chalk.

Table 5-2 - Superficial deposits

Formation	Lithological description, and distribution
Head	Variable deposits of sandy silty clay, locally gravelly; chalky and flinty in dry valleys. Present on sides of the valleys when on Chalk outcrop, across the lower part of the catchment when on clayey bedrock.
Clay-with-flints	Clay with numerous nodular and well-rounded flints; derived from in-situ weathering of the Lambeth Group overlying the Chalk. Present mostly on the hilltops between dry valleys.
Alluvium	Clay, silt and sands, locally organic, with gravel. In the valley bottoms where there are (or were) watercourses.
Alluvial fan deposits	Clayey gravel. Not present in the catchment area, but downstream of Funtington in the south east of Figure 5-3.
River terrace deposits	Sand and gravel, typically thin. Overlying clayey bedrock in the south of the catchment.
Beach & tidal flat deposits	Silty and sandy clay with sand and gravel. Overlying clayey bedrock in the south of the catchment.
Raised marine deposits	Silt and silty sand, Overlying clayey bedrock in the south of the catchment.
Raised storm beach deposits	Gravel and gravelly sand, Overlying clayey bedrock north west of Westbourne.

5.2. Aquifers and aquifer properties

Chalk comprises the main aquifer in the River Ems catchment and groundwater discharge is the principal component of flow in the river. This section briefly explores the nature of the aquifer.

Aquifer properties are not collated here as these are not relevant to the qualitative conceptual model being developed, and are summarised adequately by Allen *et al.,* (1997), Jones and Robins (1999) and in model reports (AMEC, 2008). No more recent information has been identified.

However, it is worth noting that the stratigraphic sub-divisions of the Chalk aquifer have different aquifer characteristics. This is due to the subtle differences in rock properties (i.e. fracturing), the presence of marl/flint bands and disposition to dissolution.

All of the flow within the Chalk aquifer, and almost all of the water storage, is hosted by the fracture network: the entrances to pores are too narrow to permit drainage under gravity or even moderate suction. Several factors influence fracturing in the Chalk, including tectonic effects (i.e. folding), stiffness of the chalk, the presence or absence of marls, and alternations of hard and soft chalk (Jones and Robins, 1999).

Intensity of fracturing in the different units of the Chalk Group significantly influences water storage capacity and potential yield. Jones and Robins (1999) provide a summary that is included as Figure 5-4. Broadly speaking, from this interpretation, it might be suggested that the best aquifers in the River Ems catchment comprise the Tarrant Chalk Member and the Seaford Chalk Member, whereas the Newhaven Chalk Member may be a poorer aquifer (in terms of the amount of water it holds). Aquifer properties of the stratigraphically lower formations of the Chalk Group are of less interest as they crop out in the north, well away from the river.

Due to dissolution enhancement of chalk nearer to ground level the aquifer can exhibit increased hydraulic conductivity in the upper layers (‘VKD’: variable permeability with depth). This is most commonly exhibited by stream flows increasing non-linearly with head (Section 5.4.1 presents evidence for it in the River Ems catchment). Hydraulic tests on short intervals of a borehole (‘packer tests’) in an interfluve of the Chichester Chalk block, cited by Allen et al. (1997), found a thin but transmissive layer just above the water table. Post-event analysis of the Chichester flood of 1994 indicated that there was rapid flow off the Chalk interfluves once groundwater levels had risen to a certain point (Taylor, 1995).

Transmissivity of Chalk aquifers is also enhanced in valleys, including dry valleys, leading to a typically complex distribution of transmissivity in a catchment. In the EHCC model (AMEC, 2012) transmissivity is also enhanced along the axes of synclines, and reduced along the axes of anticlines including the anticline on the eastern edge of the River Ems catchment (Figure 5-5).

The spatial distribution of hydraulic properties in the latest EHCC model (AMEC, 2012) is shown in Figure 5-5. Transmissivity values in the legend are the values for the lowest observed water levels: because of the modelled non-linear increase in transmissivity with depth (VKD) these can be considerably higher at times of peak water levels. Values in the calibrated model broadly conform with the description above: with enhanced hydraulic conductivity (by about four times) down the valleys, lower values for the stratigraphically lower formations of the Chalk Group, and a block of low transmissivity chalk east of Walderton where there is an anticline.

5.3. Groundwater levels

5.3.1. Observation boreholes

19 groundwater level datasets have been provided by the Environment Agency. One of these is one of the longest-running groundwater level datasets in the UK, from Compton borehole, where data collection started in 1893. Data were first collected from the other 18 boreholes in the mid-1970s, but monitoring at 12 of these boreholes was discontinued in the early 1980s. Groundwater level monitoring continues at six boreholes, two of which are telemetered and have recording intervals of one day.

Table 5-3 lists the observation boreholes, which are mapped in Figure 5-6. The north-south divide in these is notable: all of the active boreholes being north of Walderton. The inactive boreholes, however, are mostly close to the river, and head up the dry valley to the west of Walderton, and may be used to highlight how groundwater levels and river levels interact (Section 5.4).

Table 5-3 - Observation boreholes

Name	NGR	Earliest data	Latest data	Current
West Marden Farm	SU 7711 1359	05/01/1976	04/12/2020	Y
East Marden Well	SU 8070 1461	27/08/1976	23/08/2010	N
Uppark Deerkeepers Cottage	SU 7782 1654	05/01/1976	09/12/2020	Y
Walderton Little Busto	SU 7793 1189	01/08/1975	04/12/2020	Y
Walderton Pitlands Farm	SU 7967 1238	08/01/1976	01/10/2020	Y (logger)
Compton	SU 7755 1489	06/01/1900	04/12/2019	Y (logger)
North Mardon Meredon Farm	SU 8077 1613	03/11/1975	09/12/2020	Y
Funtington Racton Park	SU 7810 0900	21/01/1976	18/11/1981	N
Westbourne Deep	SU 7670 0800	05/01/1976	07/02/1980	N
Aldsworth Broadwash	SU 7720 0860	05/01/1976	01/07/1983	N
Westbourne Aldsworth	SU 7680 0870	03/10/1975	07/02/1980	N
Brocsnapp Keepers Cottage	SU 7820 1090	05/01/1976	02/01/1981	N
Walderton Brookside	SU 7860 1150	01/08/1975	07/02/1980	N

Name	NGR	Earliest data	Latest data	Current
Compton Fernbeds	SU 7920 1540	08/01/1976	01/07/1983	N
Walderton Francis	SU 7830 1130	03/10/1975	07/02/1980	N
Walderton Martlett	SU 7880 1070	08/01/1976	07/02/1980	N
Walderton Dibbens	SU 7880 1040	04/08/1975	07/02/1980	N
Stoughton Old Barton	SU 8040 1150	21/01/1976	18/11/1981	N
Stoughton Wildham	SU 8110 1280	21/01/1976	05/04/1982	N

For reference, the BGS logs of the observation boreholes are listed in Table 5-4. Entries for extant boreholes are emboldened, though few of these contain much useful information for the purpose of this study. However, several of the historical borehole records include water level data from 1957-1963.

Table 5-4 - BGS references and hyperlinks for historical observation borehole records

Site name	BGS borehole reference	Website link
West Marden Farm	SU71/SE9	http://scans.bgs.ac.uk/sobi_scans/boreholes/425850
Uppark Deerkeepers Cottage	SU71/NE12	http://scans.bgs.ac.uk/sobi_scans/boreholes/425809
Walderton Little Busto	SU71/SE18	http://scans.bgs.ac.uk/sobi_scans/boreholes/425859
Walderton Pitlands Farm	SU71/SE5	http://scans.bgs.ac.uk/sobi_scans/boreholes/425846
Compton	SU71/SE10	http://scans.bgs.ac.uk/sobi_scans/boreholes/425851
North Mardon Meredon Farm	SU81/NW25	http://scans.bgs.ac.uk/sobi_scans/boreholes/430228
Funtington Racton Park	SU70/NE119	http://scans.bgs.ac.uk/sobi_scans/boreholes/425354
Westbourne Deep	SU70/NE147	http://scans.bgs.ac.uk/sobi_scans/boreholes/425382
Aldsworth Broadwash	SU70/NE146	http://scans.bgs.ac.uk/sobi_scans/boreholes/425381
Westbourne Aldsworth	SU70/NE116	http://scans.bgs.ac.uk/sobi_scans/boreholes/425351
Brocsnapp Keepers Cottage	SU71/SE13	http://scans.bgs.ac.uk/sobi_scans/boreholes/425854
Walderton Brookside	SU71/SE29	http://scans.bgs.ac.uk/sobi_scans/boreholes/425870
Compton Fernbeds	SU71/NE24	http://scans.bgs.ac.uk/sobi_scans/boreholes/425821
Walderton Francis	SU71/SE19	http://scans.bgs.ac.uk/sobi_scans/boreholes/425860
Walderton Martlett	SU71/SE25	http://scans.bgs.ac.uk/sobi_scans/boreholes/425866
Walderton Dibbens	SU71/SE28	http://scans.bgs.ac.uk/sobi_scans/boreholes/425869
Stoughton Old Barton	SU81/SW24	http://scans.bgs.ac.uk/sobi_scans/boreholes/430276
Stoughton Wildham	SU81/SW27	http://scans.bgs.ac.uk/sobi_scans/boreholes/18736615

5.3.2. Groundwater level hydrographs

Groundwater level datasets for the six extant observation boreholes extend back to at least the mid-1970s but in Figure 5-7 just the most recent years' data (2000-2020) are shown for ease of comparison. The hydrographs from Compton, West Marden Farm and Walderton Pitlands Farm show the full range of seasonal variation (typically 20 to 30 m but 10 to 45 m in the extremes) and are very similar in shape. Walderton Little Busto is a relatively shallow borehole and dries out every year, so it is impossible to judge the range. The hydrographs for Uppark Deerkeepers Cottage and North Mardon Meredon Farm are very unusual for the unconfined Chalk aquifer so they are probably more representative of groundwater levels in deeper Chalk layers that are confined, or semi-confined, by marl bands.

The hydrograph at Compton has already been compared to drought conditions (Section 4.3). The three hydrographs in Figure 5-8 show the similarity of groundwater level time series across the northern half of the River Ems catchment. Compton, being further up the catchment than the other two boreholes, has a slightly greater amplitude but that is the only notable difference.

Figure 5-9 shows groundwater level hydrographs for the observation boreholes that are no longer used, but were monitored during two periods between the late 1950s and the early 1980s. Of these boreholes there are, again, only three which show the full range of groundwater levels: Compton Fernbeds, East Marden Well and Stoughton Wildham. Most of the other boreholes were constructed to too shallow a depth to be used as a watersource and frequently dried out. It is hypothesised that these were observation boreholes.

Some of the historical boreholes that were sited next to the river show flat peaks in groundwater level: Walderton Brookside, Walderton Francis, Brocsnapp Keepers Cottage, Walderton Martlett, Walderton Dibbens, Funtington Racton Park, Westbourne, Aldsworth and Aldsworth Broadwash. This indicates that at those times the groundwater level was being controlled by baseflow discharge to the river.

Many of the historical time series in Figure 5-9 span the period when abstraction at Walderton commenced. Of these, it does seem that at Funtington Racton Park and Brocsnapp Keepers Cottage there was a change in hydrograph behaviour over the course of the 1960s and 1970s, with summer lows being considerably lower than previously. The same effect might be seen at Compton Fernbeds, Pitalnds Farm and Stoughton Old Barton but a robust comparison of historical weather would be necessary to demonstrate that these differences were due to the abstraction, and not the weather.

Westbourne Deep, located near Deep Springs, shows a very flat hydrograph but here the chalk is confined by the Lambeth Group, so groundwater may be disconnected from the river here.

There must have been surface water near Aldsworth Broadwash borehole most of the time, though it will have dried up most summers (when the groundwater level dropped several metres). In the other boreholes with rounded peaks the amplitude of groundwater level fluctuations was often 10 m or more and so indicate seasonal drying-out of the river.

Groundwater level peaks do not occur at the same time across the catchment: there is clear movement of the peak from the top of the catchment to the bottom, over a series of months. Most of the datasets have data from winter 1976/77 and the progression of the peak in that year, along with daily rainfall from CEH-GEAR (Tanguy *et al.,* 2019), is shown in Figure 5-10.

- At Compton Fernbeds, the furthest north borehole, groundwater levels started rising immediately as the heavy rainfall of autumn 1976 started. This probably implies that there was a considerable amount of bypass recharge over the South Downs, through cracked soil following the 1975/76 drought. The groundwater level peaked around late November and receded thereafter.
- At all the other observation boreholes groundwater levels started to rise in November, more than two months after the onset of rainfall. This was presumably once there was no longer a soil moisture deficit (as is expected).
- At East Marden and Compton groundwater levels rose quickly and there was one peak around mid-December, and then a higher peak in late February. Rainfall in most of January and February 1977 was still quite high so a double peak is expected (this is seen in the 3-month SPI in Figure 4-2).
- At Stoughton Wildham there is a suggestion that a peak might have been observed in late December 1976 if the data points were more closely spaced, but the main peak was in early March. At West Marden Farm the early peak did not occur at all and there is a continuous rise to a peak, also in early March.
- Finally, at Walderton Little Busto the peak is low and spread through March to May.

5.3.3. Groundwater level contours

Groundwater contours have been hand-drawn for wet conditions and dry conditions and are shown in Figure 5-11.

Contours for the wet conditions were developed using groundwater levels from the observation boreholes with data points from February/March 1977. This date, although it was not an exceptionally wet time, was chosen to allow the use of all the available groundwater level datasets. There are several later winter peaks that have been higher (1993/94, 1994/95, 2000/01 and 2013/14 notably so: Figure 5-8). Groundwater levels for the observation boreholes at Uppark and North Marden have not been used as they appear to be unrepresentative of the unconfined aquifer.

With reference back to the spot gauging of Section 4.4.3, the observation that there is groundwater discharge all the way down the main stem of the river during very wet periods means that the contours can be pinned at the corresponding bed elevation of the river at all points downstream of Stoughton Village gauging point. In the absence of stream bed levels in the upper part of the catchment, LIDAR data are used.

The most datapoints available for a drought period are from summer 1976. Most of the historical boreholes were dry but there are still some data points that mean this has the best coverage. Again, the groundwater levels at Uppark and North Marden have not been used.

Both sets of contours show a similar pattern, albeit at different elevations:

- Towards the north of the catchment, the water table drops steeply southwards. This is roughly where the outcrop of potentially more permeable Seaford Chalk (to the north) changes to outcrop of the potentially less permeable Newhaven Chalk (to the south).
- The steep gradient flattens out south of Compton and East Marden and falls regularly towards the south. During the wet period there is a slight upstream V-ing of the contours which reflects how flow is converging on the river. This is, of course, not seen during the dry period.
- Between Walderton and Racton the water table shallows further, corresponding to the outcrop area of more permeable Tarrant Chalk.
- The water table steepens again towards Aldsworth village because this is where the Chalk aquifer dips below clays of the Lambeth Group, and where there is a spring line at a constant level of about 20 m AOD.

The elevation difference between wet and dry contours is about 35 m in the north of the catchment, probably about 10 m around Walderton, and very little at the southern end of the catchment at the edge of the Chalk outcrop.

There is no apparent difference in the seasonal range between the east and the west of the catchment, suggesting that abstraction at Walderton may not influence the seasonal range in groundwater levels greatly (though the resolution of the data and therefore the map is not fine enough to be able to say this robustly).

For comparison with the hand-drawn contours the groundwater levels from the model of Entec (2008) are reproduced in Figure 5-12. These were created without the benefit of the historical observation boreholes, so the extreme steepness to the north is not seen to such a degree. In the results for the wet period there is much more of a ‘V’ in the contours along the valley of the River Ems due to the modelled sharp changes in transmissivity here. In the results for the dry period there are two lobes of slightly higher groundwater levels either side of the River Ems upstream of Walderton.

5.4. Groundwater-surface water interaction

The interaction between rivers and groundwater can be subtle, though the two end-points are simple to understand. In winter, when groundwater levels are high, the water table reaches the river bed and so groundwater discharges into the river channel; or the water table intercepts a spring point where groundwater emerges as a spring. In the late summer when groundwater levels are low, any runoff that does reach the river bed will infiltrate through it to part-replenish groundwater in the aquifer.

When groundwater levels are in-between the two extremes (above) the gradient of the river bed and the gradient of the water table can be similar and so groundwater might flow to the surface at points up-river, only to infiltrate at points down-river. This often occurs where there are multiple steps or weirs in the river bed profile: baseflow occurs downstream of a step where the river is incised but then recharges the aquifer upstream of a step where the river bed is higher than the water table. Or sometimes there are geological features (e.g. faults) that lead to steps in the water table.

The point of this is to illustrate how - in a groundwater dominated river - the water table and the river surface are essentially the same. River channels can convey water quickly because they do not contain any aquifer, but it is often the case that the concentration of flows causes erosion of the aquifer fractures leading to higher permeability along river valleys. Hence the aquifer beneath river valleys can infiltrate quite high amounts of water if the water table is lower than the bed of the river.

5.4.1. River flows and groundwater levels

Hydraulic conductivity varies vertically in the Chalk aquifer, and that this leads to non-linear increase in transmissivity and therefore spring discharge. This is very clear in the plot of flows vs. groundwater level in Figure 5-13, which shows all coincident measurements of flow at Westbourne and groundwater level at Compton, and particularly highlights the data from winter 2013/14.

At the end of a summer, when groundwater levels are low, the flow rate at Westbourne increases at a rate of 50,000 m^3/day for a rise in groundwater levels of about 15 m. But as the groundwater level passes 40 to 45 m AOD, there is a kink in the trend and an additional 50,000 m^3/day is released for every 5 m rise in groundwater level. After passing 66 m AOD, flow increases considerably: at a rate of about 50,000 m^3/day for each 1 to 2 m. This very strongly points to the existence of disproportionately higher transmissivity as the groundwater levels rises, and in particular a high transmissivity feature above the normal water table, as found elsewhere in the Chichester area (Allen et al., 1997).

The other interesting feature of Figure 5-13 is the hysteresis in the tracks for the rising limb and the falling limb of the hydrograph: flows were lower for a given groundwater level as the hydrograph rises and higher as the hydrograph falls. It is worth noting how the winter 2013/14 points delineate the outer edge of the other data points: because it was a very wet winter there was more water in the system.

This hysteresis points to a common feature of some Chalk aquifers (this has been observed in the Chilterns [Atkins, 2009] and in the North Downs [ESI, 2010] at least) whereby there is maintenance of stream flows in droughts at times of very low groundwater levels. This is believed to arise from slow-draining porosity in dead-end fractures (Price et al., 2000). It would be difficult to disentangle this effect from the effect of augmentation at low flows.

Losses of augmentation water were estimated in Section 4.6.3. Conceptually, it might be expected that the losses would be greater when there are lower groundwater levels. Figure 5-14 compares calculated losses against groundwater level at Walderton Pitlands Farm. On close examination of the hydrograph there is clearly very limited difference in the seasonal low level from year to year, so there is no relationship to be seen there. Likewise the magnitude of losses do not seem to correspond with the height of the previous winter's peak. What can be seen is that losses start when groundwater level at Walderton Pitlands Farm falls below about 32 m AOD, and cease when groundwater level rises above 32 m AOD or possibly 33 m AOD. The losses are, clearly, related to groundwater level, but the observation borehole may be too distant to allow any reliable interpretation.

It is noted that FotE have undertaken an exercise linking river flow to the Compton borehole which warrants further review, ideally with the collection of (continuous) in-river level data.

5.4.2. River bed levels and groundwater levels

Comparison of drawn ground levels with wet (February/March 1977) and dry (September 1976) water table elevations illustrates clearly how the water table changes relative to stream bed elevation throughout wet and dry seasons (Figure 5-15). The seasonal fall in water level throughout the catchment is considerable compared to the topography. At the locations where the water table is at or close to the base of the valley, groundwater discharge can be expected.

As discussed in Section 5.3.2 many of the hydrographs from the historical observation boreholes adjacent to an ephemeral western tributary of the river (which comes to confluence just south of Walderton, upstream of the pumping station) show a rounded peak, which is characteristic of a level control due to local baseflow discharge. In Figure 5-16 the peak groundwater levels in the mid- to late 1970s fall with distance from the head of the tributary. The duration of baseflow discharge near each location (i.e. the time during which the groundwater level peaked) seems to have been broadly similar each winter: typically from December/January to May/June.

Since there is not a gradual decline in groundwater levels (and associated flows) apparent at the resolution of the data, the conclusion is that the groundwater level falls sharply each year and flow along this tributary must come and go within just a few weeks.

5.4.3. Interaction with superficial deposits

The river reach south of Racton Dell / Woodmancote no longer flows across the Chalk aquifer but over alluvial and head deposits, over the Lambeth Group. Therefore the flow losses downstream of the augmentation discharge points (Section 4.5) may not be re-circulated into the Chalk aquifer but may be lost to a near-surface groundwater system. There is no evidence available to describe this process, and the head deposits are probably not particularly permeable, but the potential for this loss pathway is present.

It is noted that the Woodmancote abstraction is quite close to the River Ems. Further work is needed to determine if the abstraction could reduce groundwater levels locally and thus derogate some of the river flows.

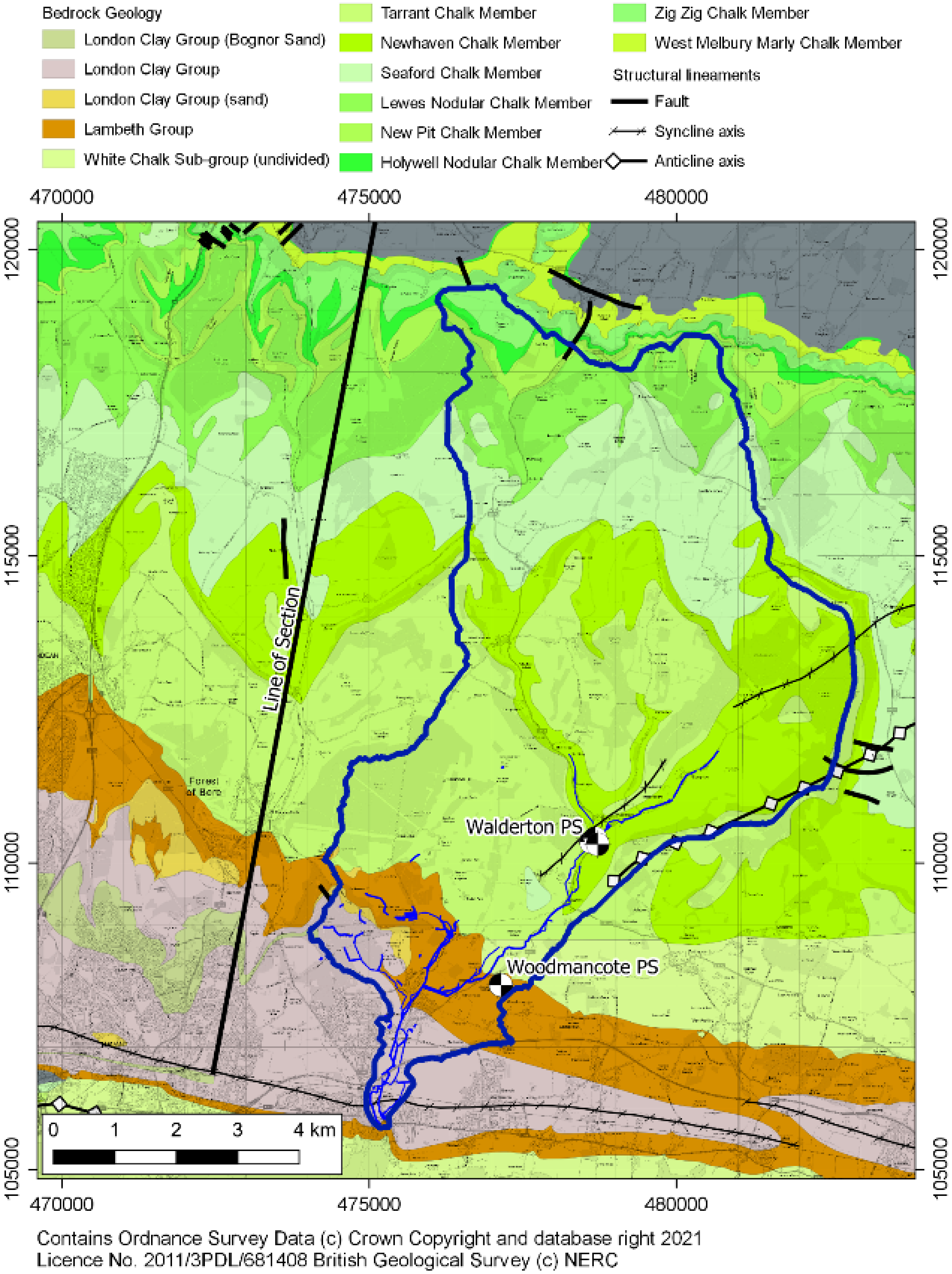


Figure 5-1 - Bedrock geology (showing line of section shown in Figure 5-2)

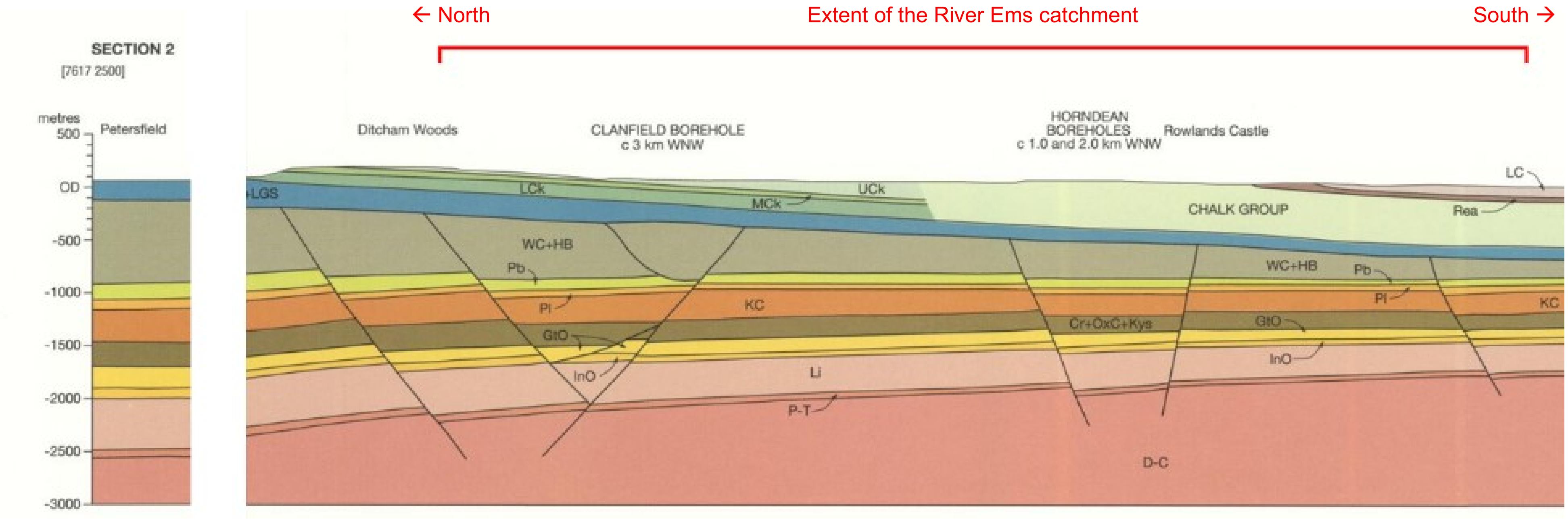
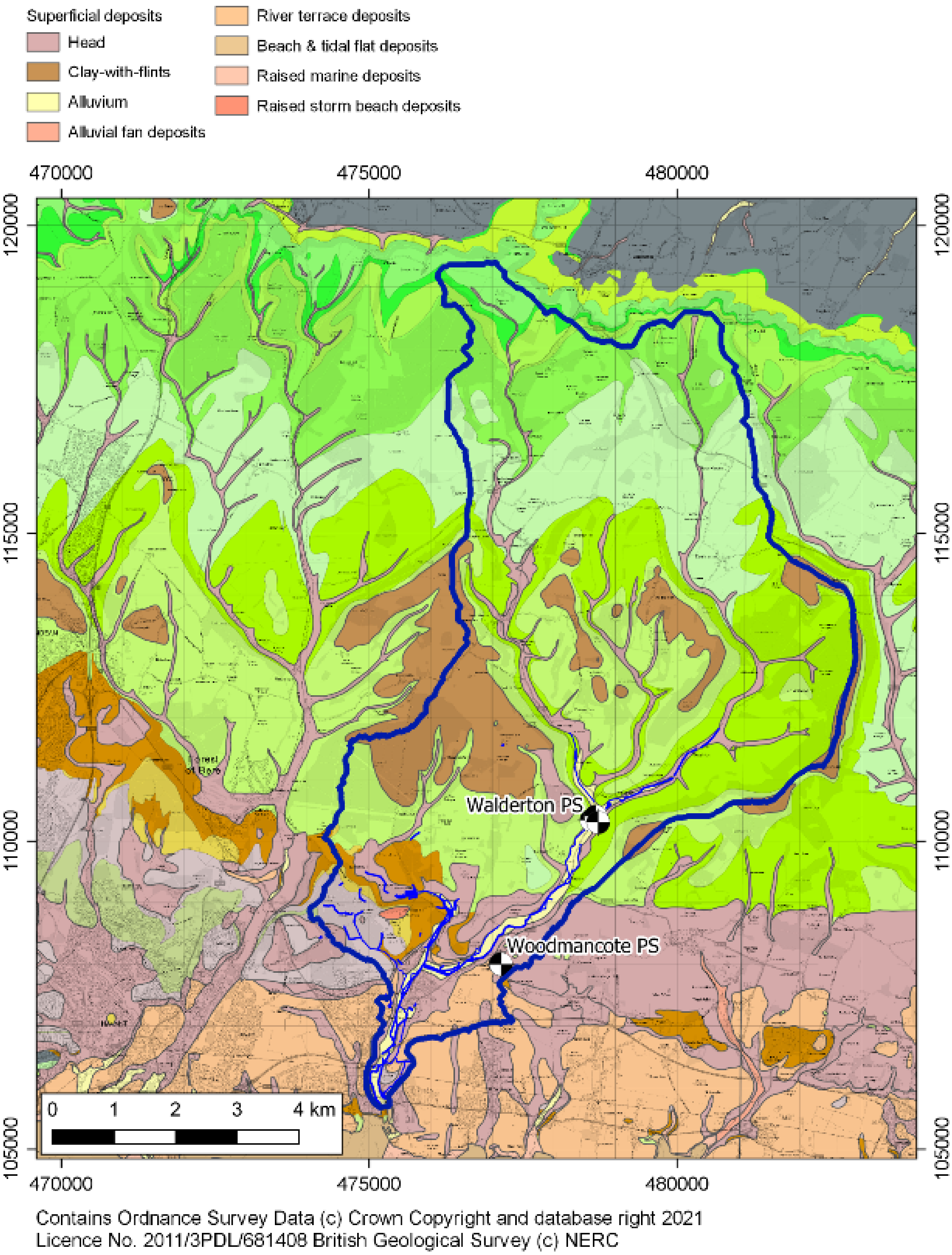


Figure 5-2 - Bedrock geological section

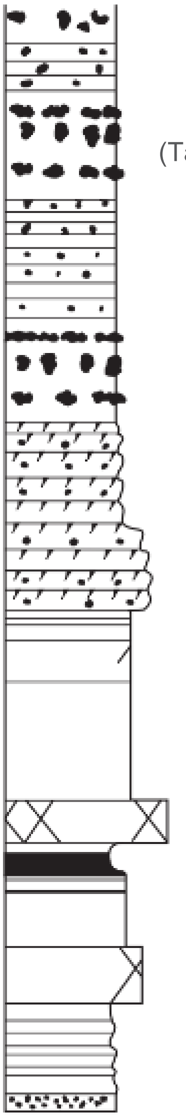
Key to abbreviations:

LC = London Clay Group
Rea = Lambeth Group ('Reading Beds')
UCk = Upper Chalk
MCk = Middle Chalk
LCk = Lower Chalk
UGS+G+LGS = Upper Greensand, Gault Clay and Lower Greensand



(Bedrock geology legend as in Figure 5-1, showing line of section shown in Figure 5-2.)

Figure 5-3 - Superficial geology



	HARDNESS	FRACTURE FREQUENCY	AQUIFER POTENTIAL
PORTSDOWN	very soft to medium hard		
CULVER (Tarrant)	extremely soft to soft	medium spaced regular joints	high
NEWHAVEN	soft to medium hard except on highs where it is extremely soft	medium to widely spaced conjugate sets of joints with sheet flint	karstic features on marls, local flows
SEAFORD	very soft to medium hard	medium spaced regular joints	high
LEWES	alternating from very soft to very hard, some massive bands	nodular chalk fracturing and widely spaced conjugate joints	mixed; low except on faults
RANSCOMBE	medium hard	medium to widely spaced conjugate joints, Holywell Beds more jointed	locally good where well fractured
MELBOURN ROCK	hard	medium spaced conjugate sets	high
PLENUS MARLS	medium hard	poorly fractured	low
GREY CHALK	hard	conjugate sets	low
CHALK MARL	alternating medium to very hard	poorly fractured	low

Figure 5-4 - Fracturing and aquifer potential in the Chalk Group of Sussex (reproduced from Jones and Robins, 1999; after Mortimore et al., 1990)

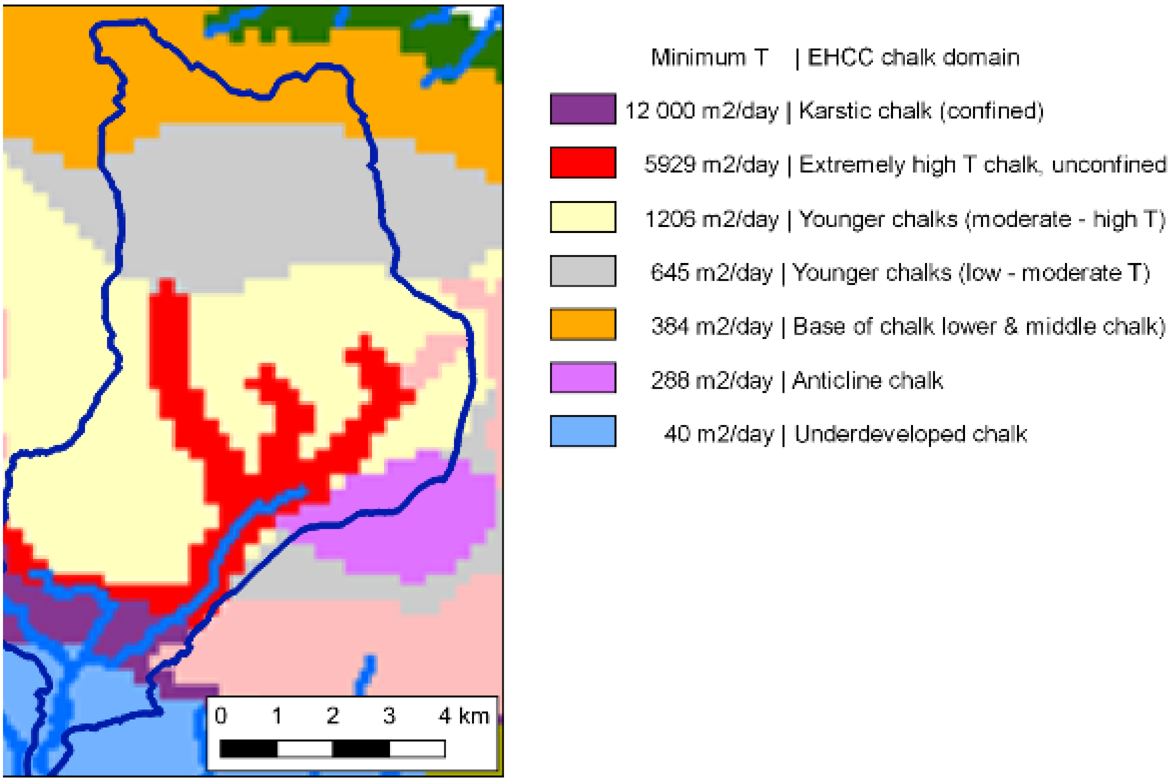


Figure 5-5 - Hydraulic properties from the EHCC model (AMEC, 2012)

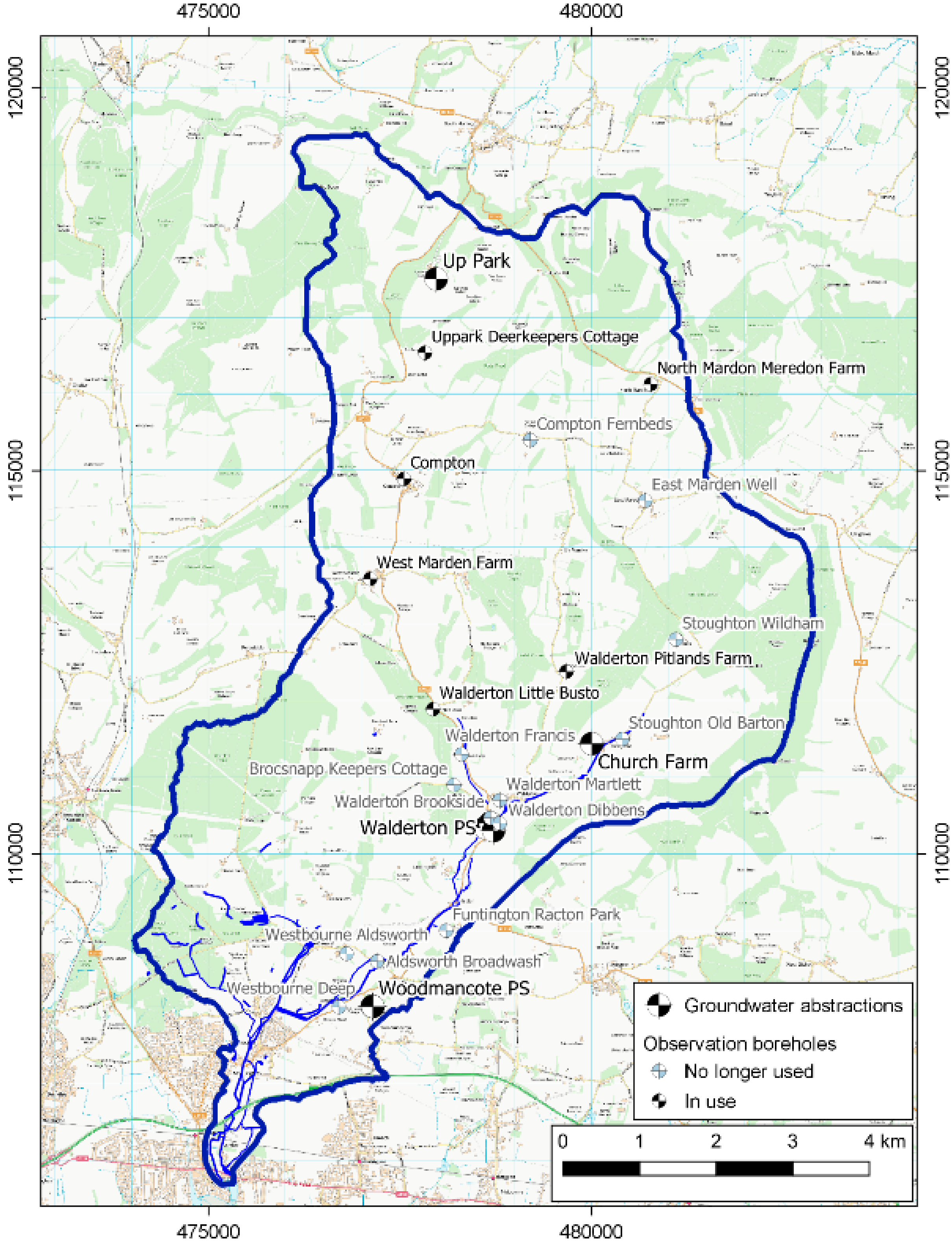
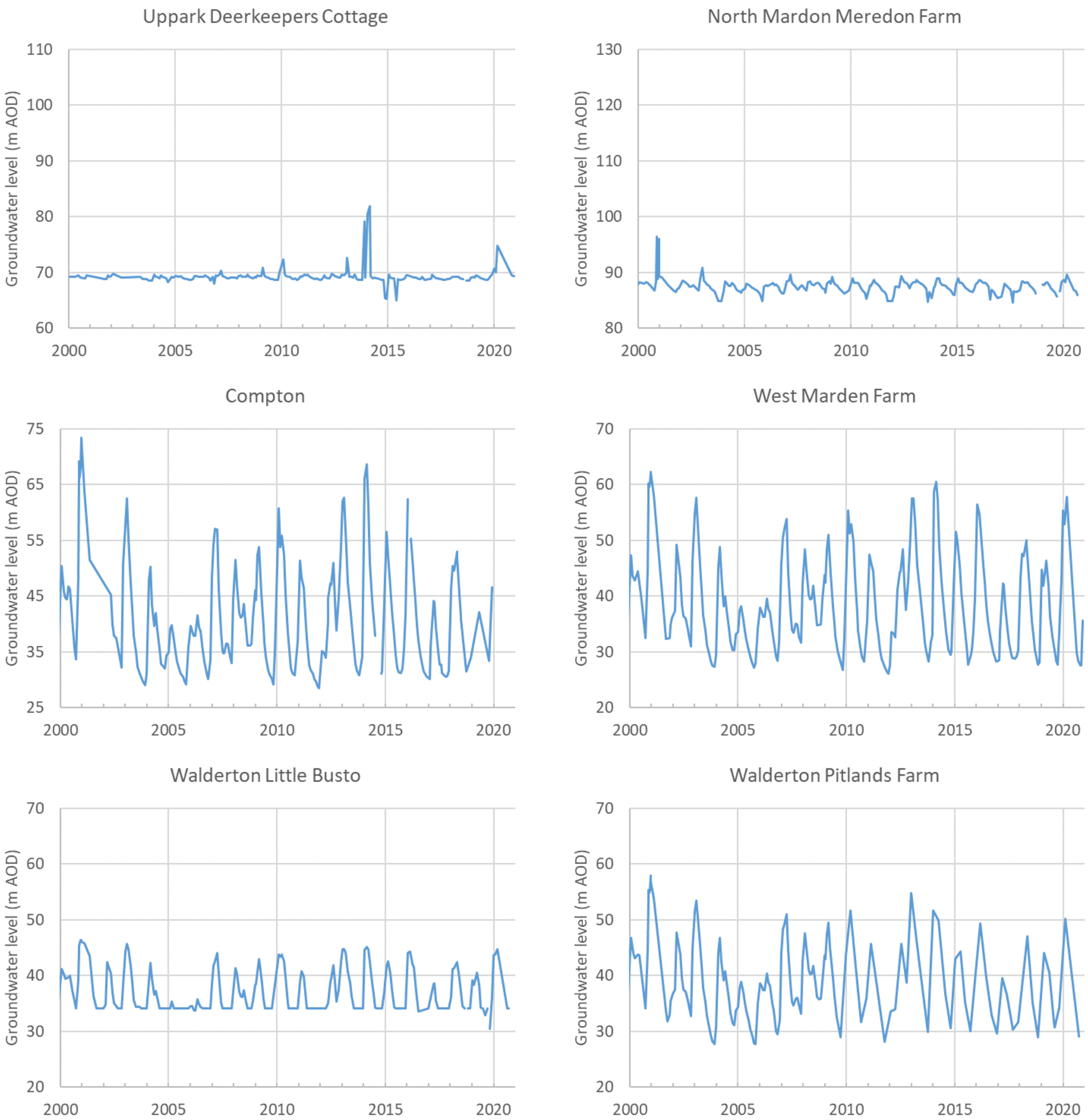
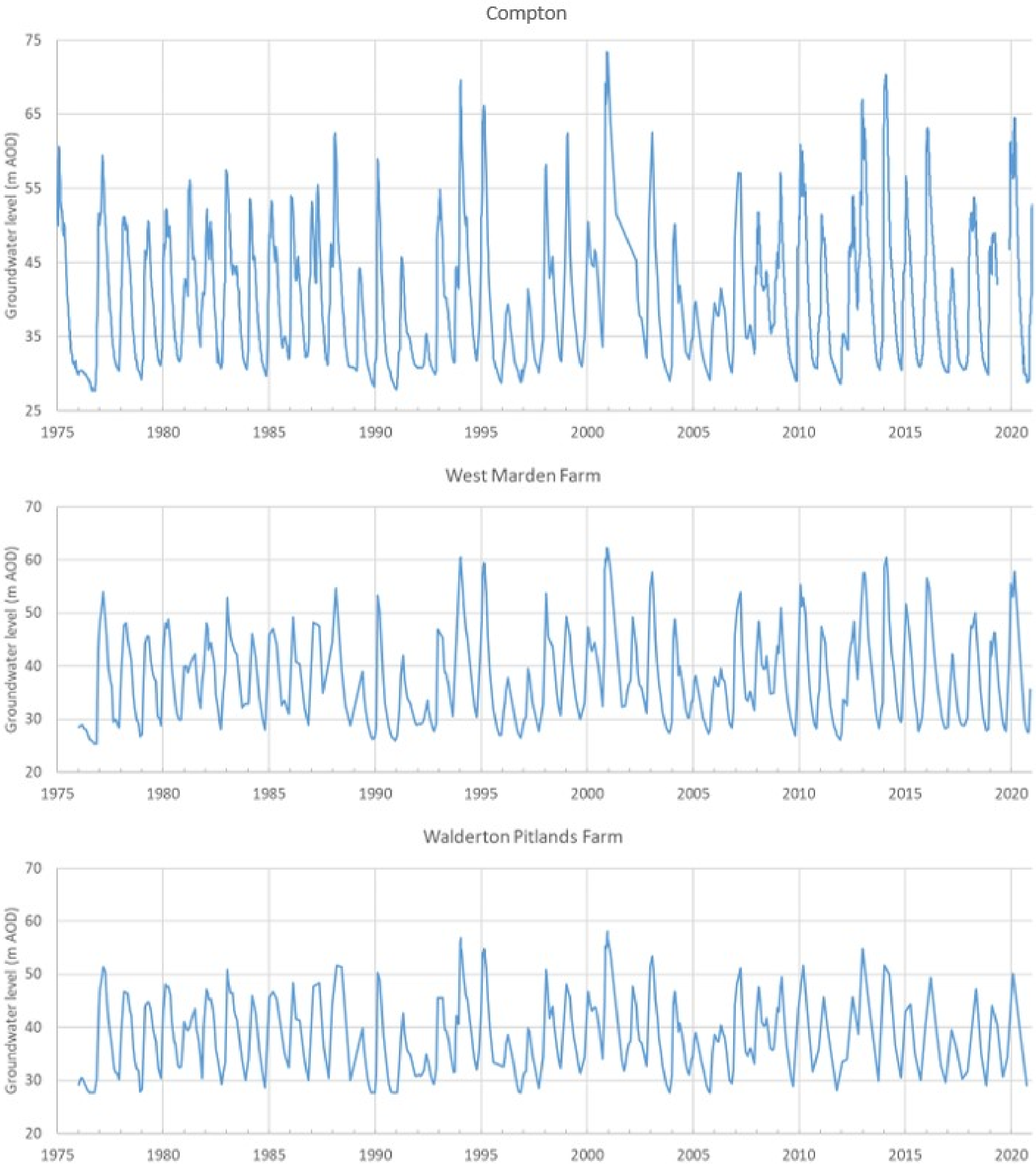


Figure 5-6 - Locations of observation boreholes



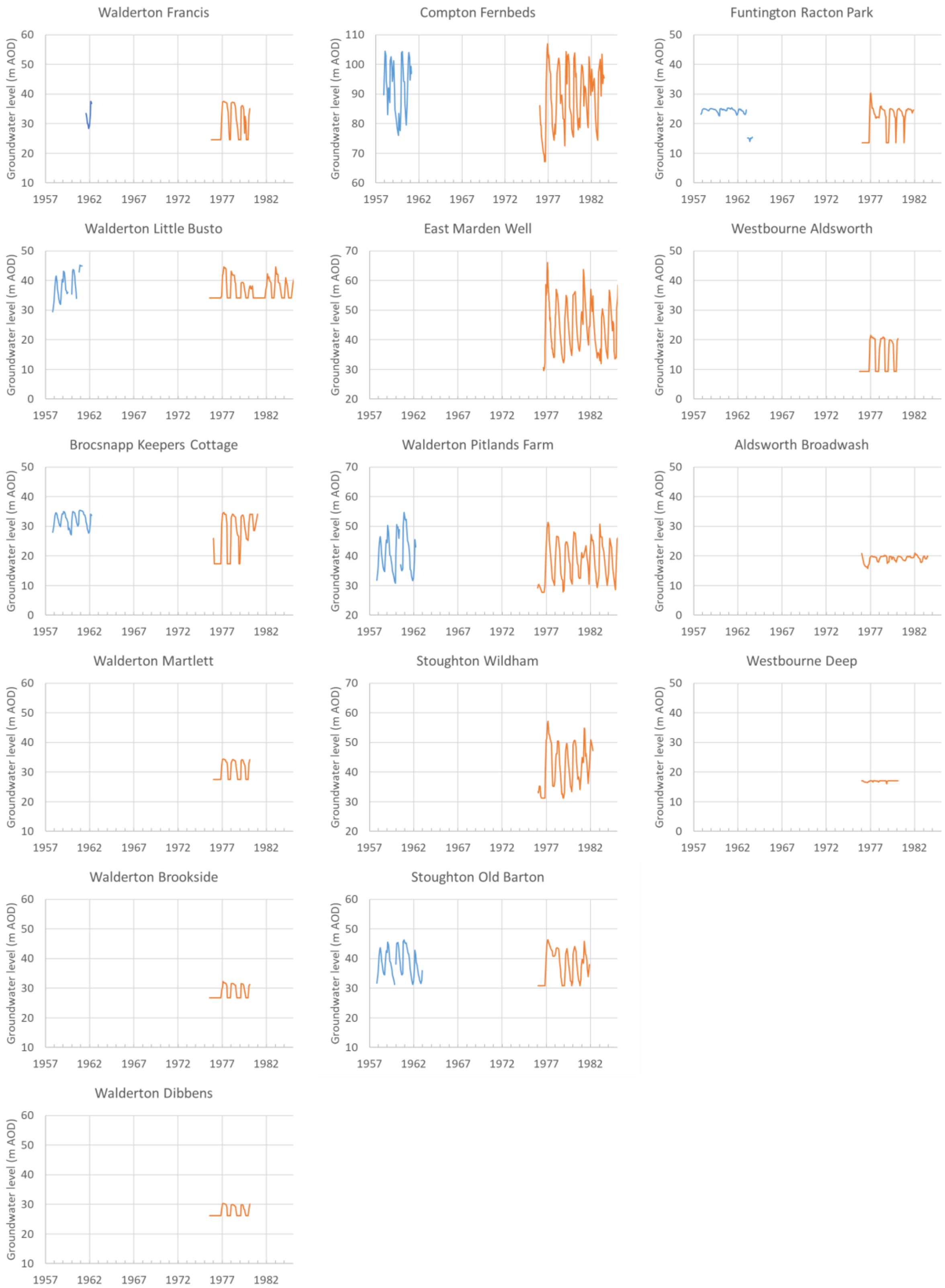
(All y-axes are to a common scale for comparison of amplitude)

Figure 5-7- Recent groundwater level hydrographs for extant monitoring wells



(All y-axes are to a common scale for comparison of amplitude)

Figure 5-8 - Long-term groundwater level hydrographs for extant monitoring wells



(All y-axes are to a common mAOD scale for comparison of amplitude)

(Blue data: from the BGS GeoIndex weblinks in Table 5-4 | orange data: from Environment Agency records)

Figure 5-9 - Groundwater level hydrographs for historical monitoring wells

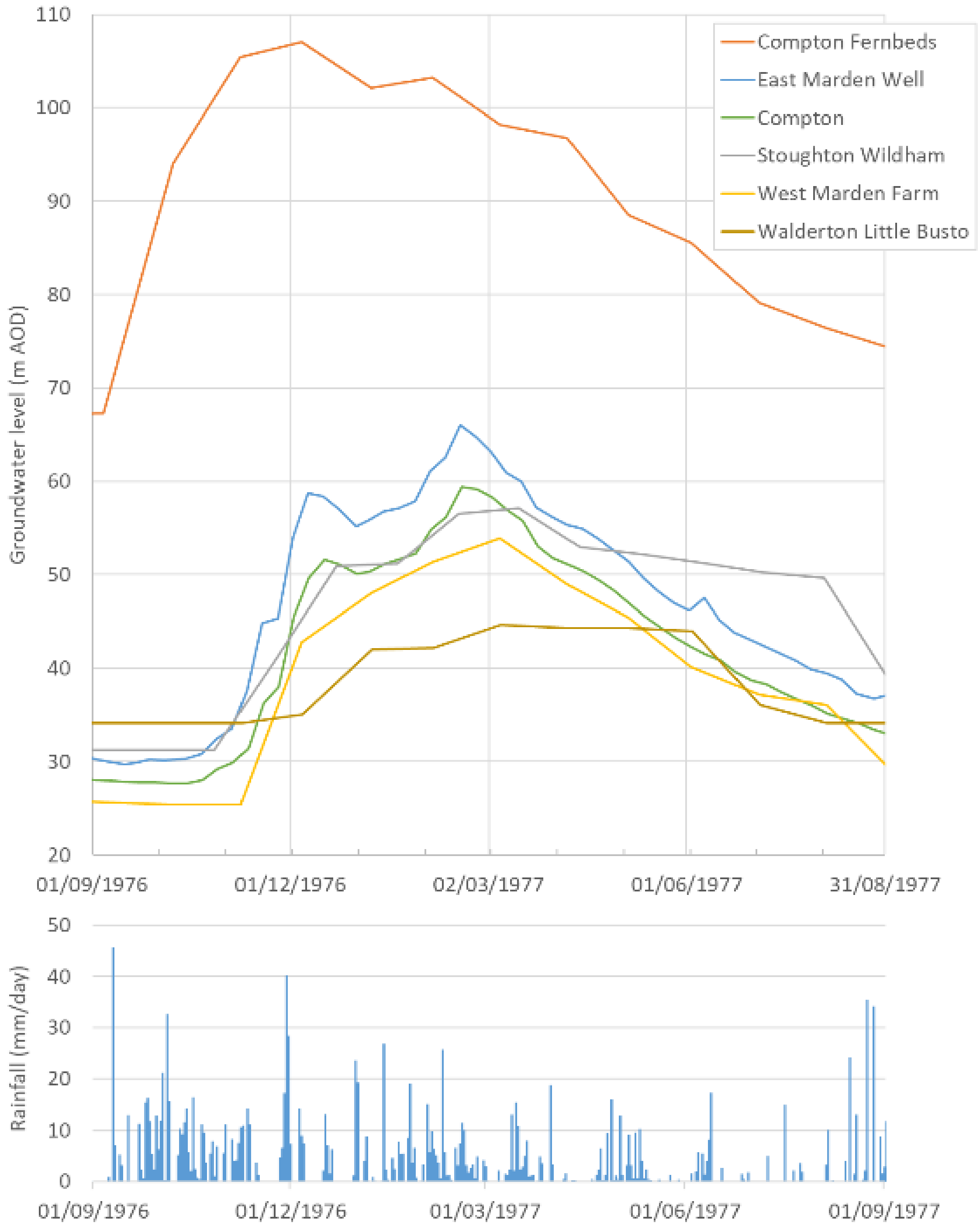
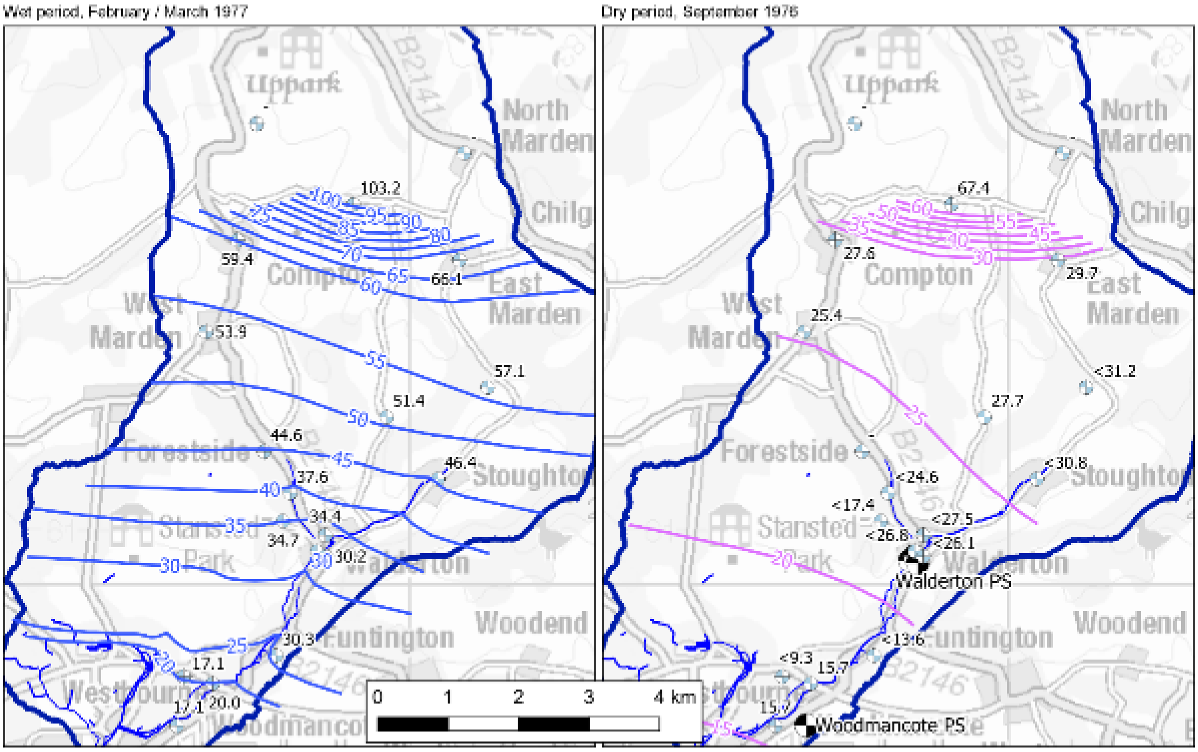


Figure 5-10 - Groundwater levels and rainfall over the wet Winter 1976/77



(Where heads are indicated <, the well is dry and the base of the well is at the elevation indicated.)

Figure 5-11 - Hand-drawn groundwater contours (m AOD) using wet (February/March 1977) and dry (September 1976) water table records

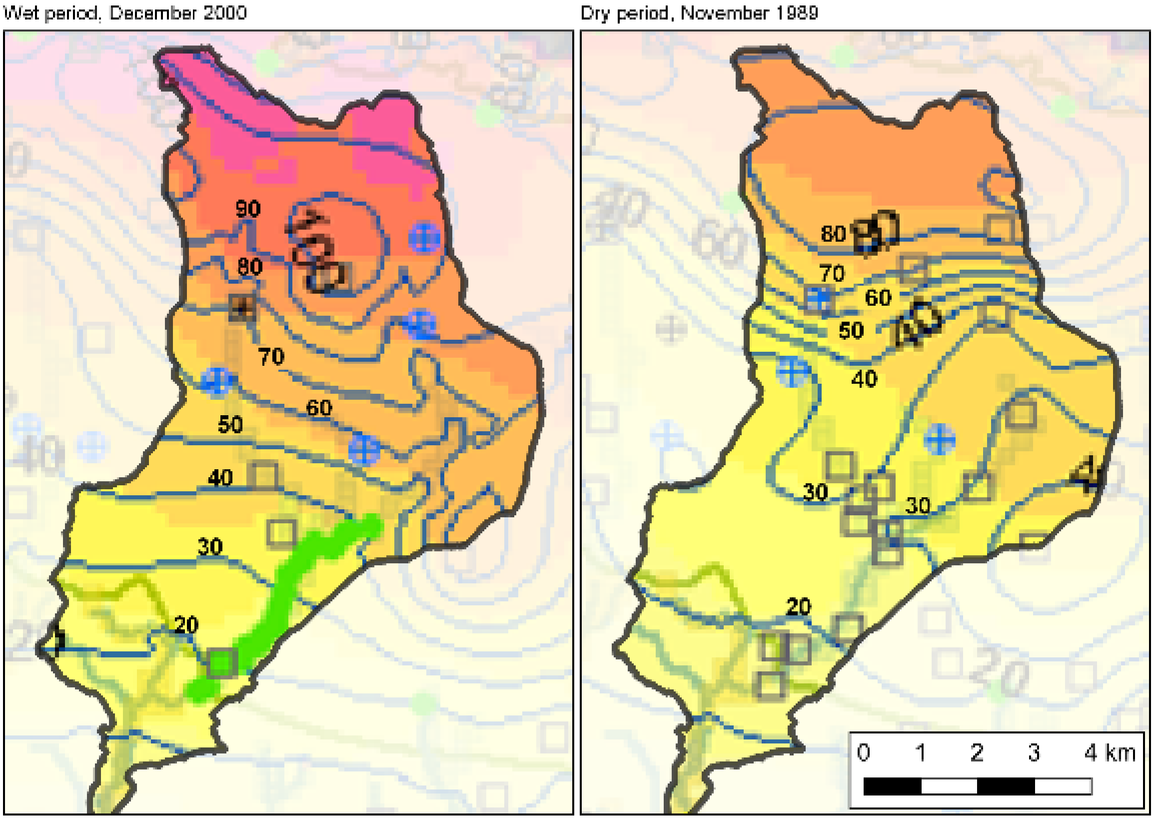


Figure 5-12 - Model groundwater contours (m AOD) for wet and dry periods (Entec, 2008)

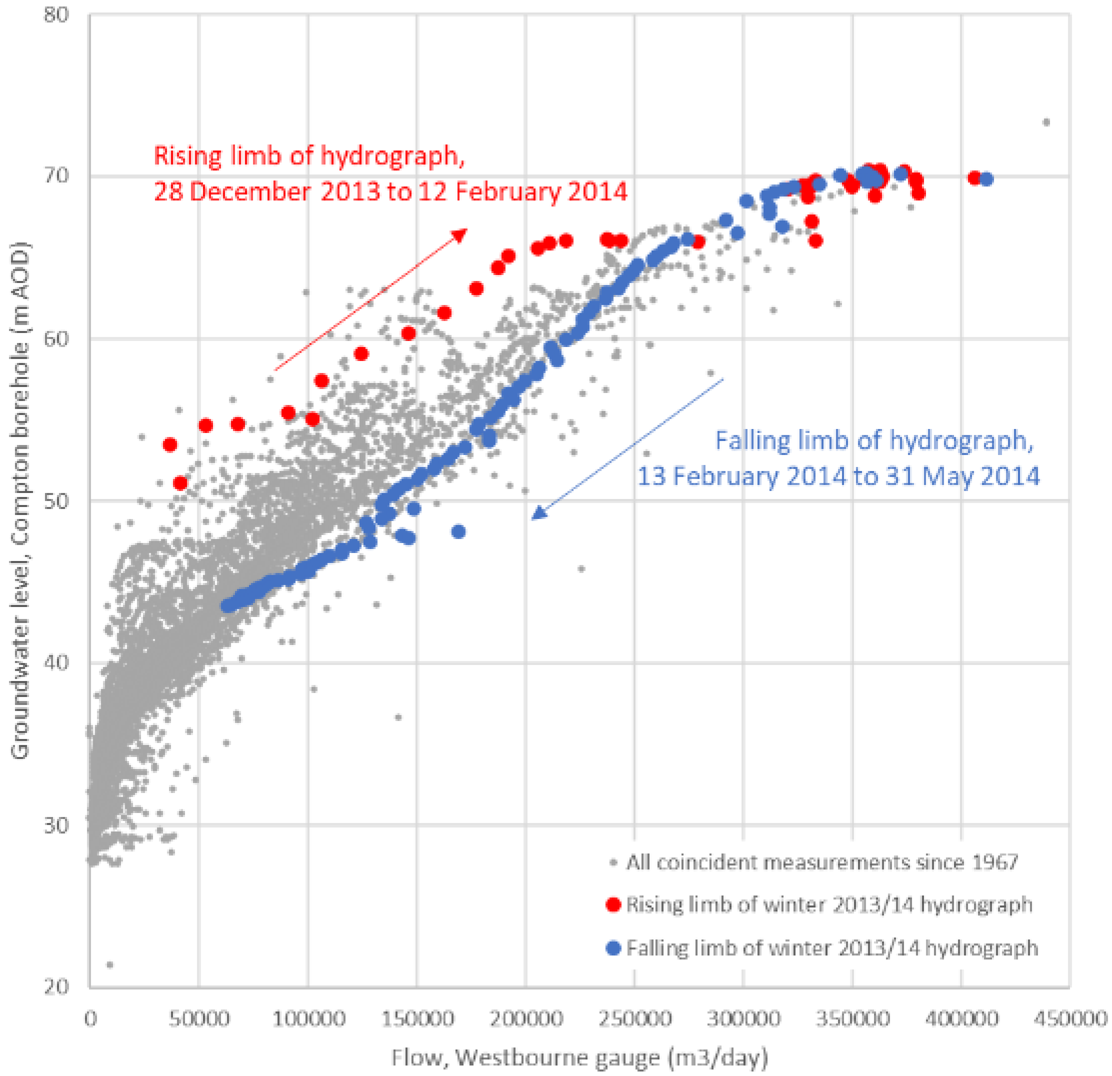


Figure 5-13 - Coincident flows at Westbourne and groundwater level at Compton

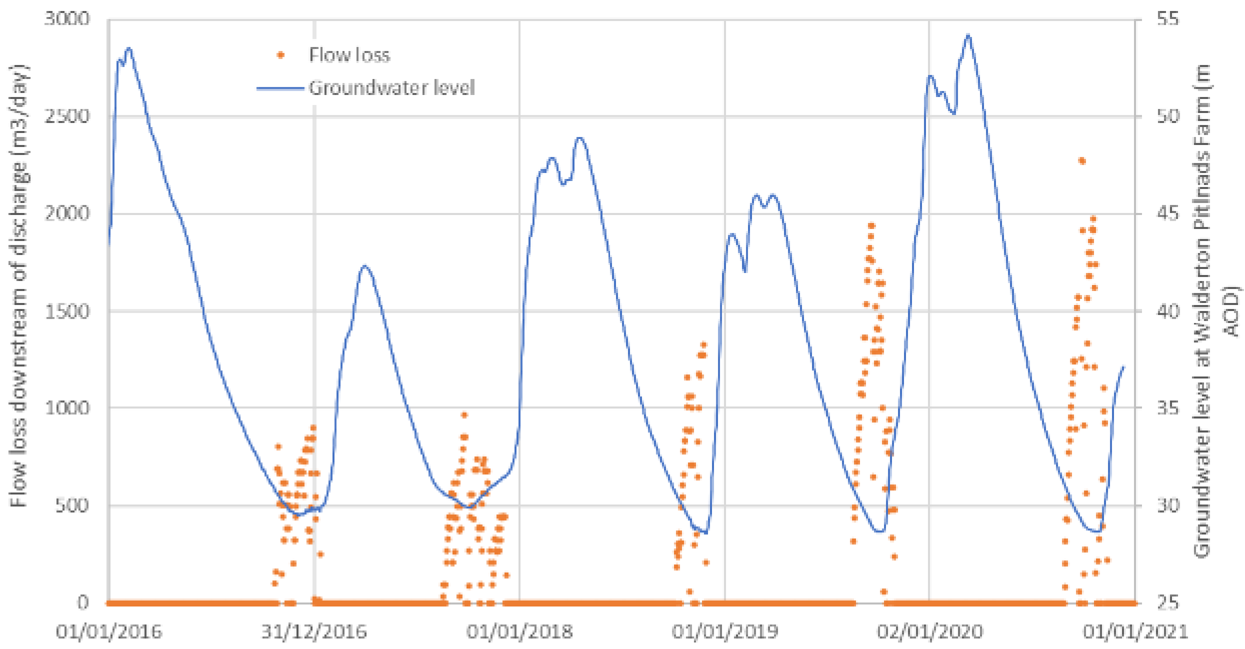
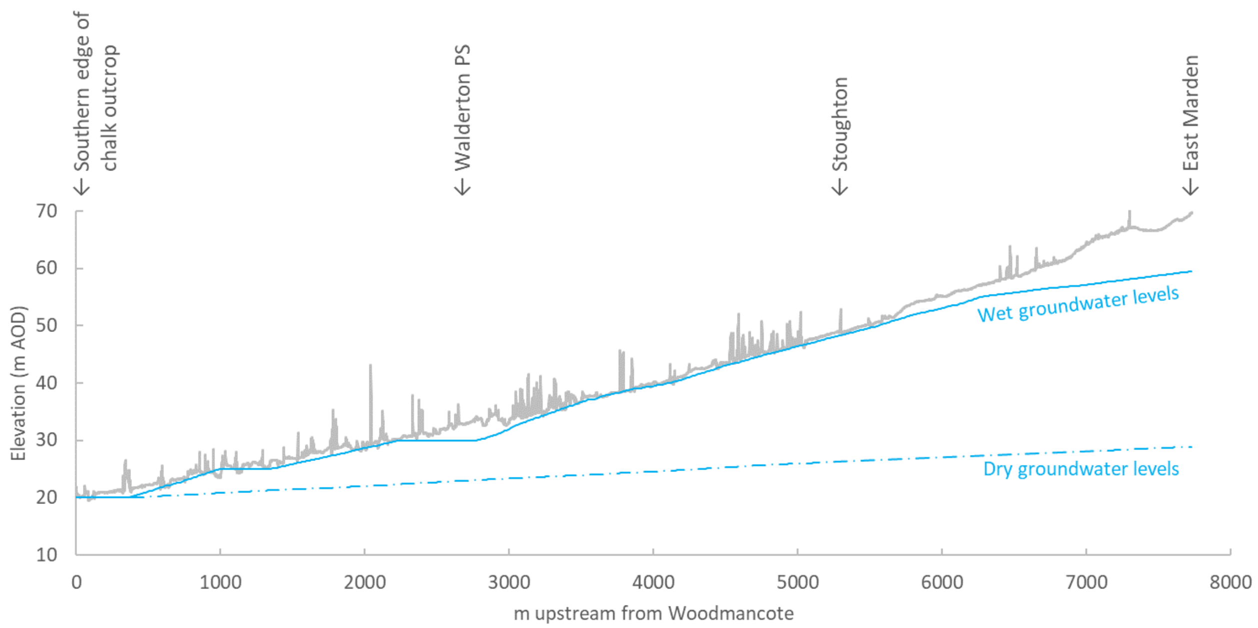


Figure 5-14 - Losses of augmentation discharge vs. groundwater level



(Surface elevation is spiky because the digital surface model used includes trees and buildings)

Figure 5-15 - Surface elevation along the base of the river valley (using EA LiDAR), and water table elevation (using wet (February/March 1977) and dry (September 1976) water table records) Note: 'Southern edge of chalk outcrop' is at Woodmancote.

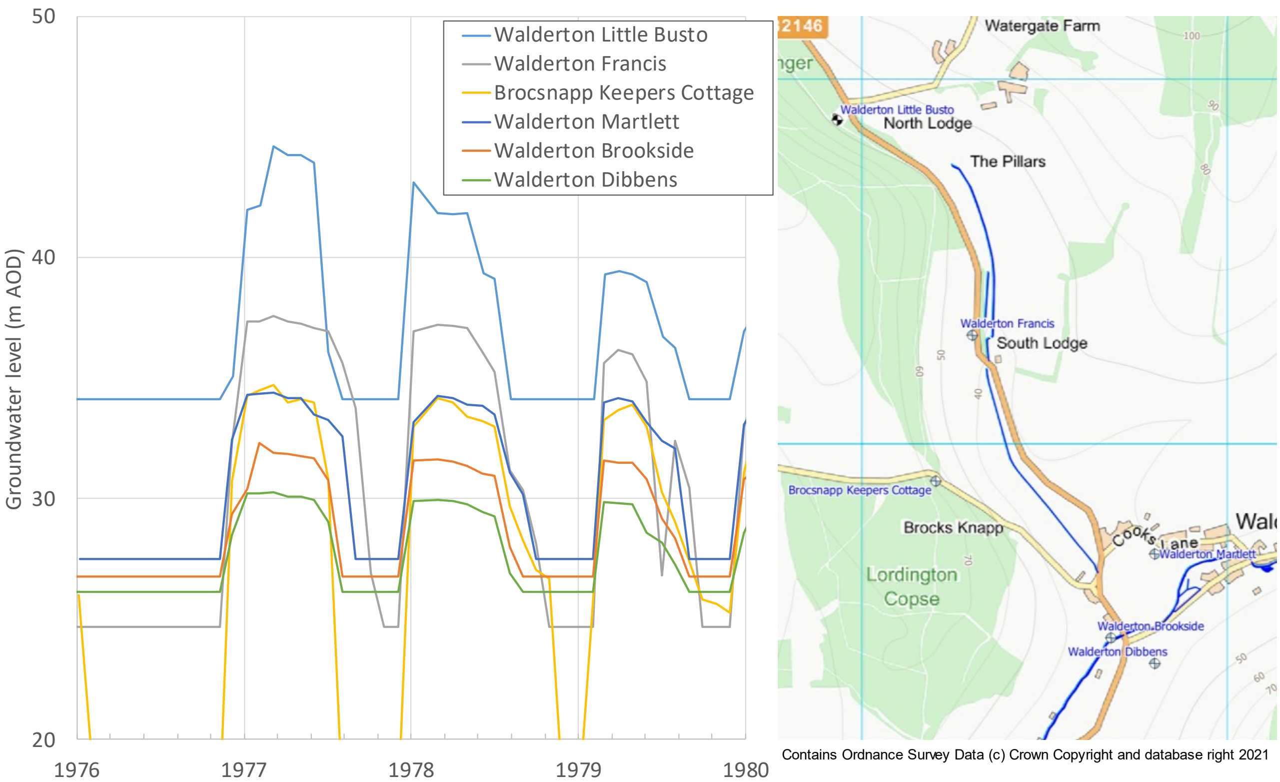


Figure 5-16 - Groundwater levels adjacent to the ephemeral western tributary of the River Ems

6. Water Framework Directive

The European Union (EU) WFD (Council Directive 2000/60/EC) aims to protect and enhance the quality of the water environment across all EU member states. Whilst the United Kingdom is no longer a member of the EU (as of 31 January 2020), the WFD is transposed into English and Welsh law through The Water Environment (WFD) (England and Wales) Regulations 2017 which revoke and replace The Water Environment (WFD) (England and Wales) Regulations 2003 and its amendments.

The WFD requires all natural surface water bodies to achieve Good Chemical Status (GCS) and Good Ecological Status (GES). Artificial and Heavily Modified Water Bodies (A/HMWBs) may be prevented from reaching GES due to modifications necessary to maintain their "use" (e.g. navigation). They are instead required to achieve GEP through the implementation of Mitigation Measures.

Only one WFD waterbody makes up the whole Ems catchment which is the surface water body River Ems (GB107041012370) (Figure 6-1) (Environment Agency, 2021a). Noting this length does not comprise the entire river system nor its tributaries, according to the Environment Agency Catchment Data Explorer, the River Ems WFD waterbody is 8.799km in total length, with a catchment area of 60.125km². It is located within the Western Streams operational catchment and is in the South East River Basin Management Plan (RBMP). Under the WFD, the river was designated as 'heavily modified' as a result of flood defences in the bottom part of the waterbody, however, as it is all classed as one waterbody this designation applies to the whole river (AMEC, 2013).

Under the WFD, the River Ems is currently classified overall as 'Poor' as part of the 2019 Cycle 2 interim classification, with overall ecological status classified as 'Poor' and overall chemical status as 'Fail' (Table 6-2). Under the ecological items, supporting elements and physico-chemical are classified as 'Moderate', biological as 'Poor' and hydromorphological supporting elements as 'Supports Good'. The last formal classifications were 2009 (RBMP 1) and 2015 (RBMP 2) with a new formal classification awaited in 2021 (RBMP3) in which the future 'good' objective for ecological status has been set for 2027; and 2063 has been identified as the year in which 'good' chemical status would be attained.

Only the Environment Agency can complete WFD classifications. It is noted that the classification of 'Poor' for fish will be based on the data presented in Section 9.2, for macroinvertebrates the datasets in Section 9.3 and for macrophytes and phytobenthos the data presented in Sections 9.4 and 9.5.

In 2019, the chemical status was failing as a result of the priority hazardous substances Polybrominated diphenyl ethers (PBDEs – a group of man-made organobromine compounds used as flame retardants in a wide range of products [Environment Agency, 2021c] that have an adverse effects on aquatic life and humans) and 'Mercury and Its compounds'. Further detail on past and current WFD status of the river can be found in Table 6-2 overleaf. One of the key documents for the assessment of water quality status is the 2015 Directions (WFD, 2015). The 2015 Directions included the reporting of additional substances from December 2018. These were not formal status elements at the start of RBMP2 and thus were not considered in full in 2015. They do now contribute to chemical status and thus have been included in the 2019 interim and 2021 formal status reports.

There are a number of reasons for recent deterioration (RFD) and not achieving good (RNAG) status published in the draft RBMP3 plan (dRBMP3) which are shown in Table 6-1 and include:

Table 6-1 - RFD and RNAG for River Ems WFD waterbody published in dRBMP3

Reason type	SWMI	Activity	Category	Classification element affected
RFD	Point source	Sewage discharge (intermittent)	Water Industry	Dissolved oxygen
RNAG	Physical modification	Other*	Local and Central Government	Mitigation Measures Assessment
RNAG		Flood protection - structures	Urban Transport	Invertebrates
RNAG				Fish
RNAG				Dissolved oxygen
RNAG	Flow	Groundwater abstraction	Water Industry	Invertebrates
				Hydrological Regime

				Fish

*Limited information available, suggest this may be a government related development / infrastructure scheme

It was observed that whilst the hydrological regime (flow) was classified as ‘Does not support good’, that the hydromorphological support element was deemed to ‘support good’. Clarification was sought from the Environment Agency who confirmed that[4]: “*As the River Ems is a heavily modified water body, the classification rules do work slightly differently and so it would not necessarily follow the ‘one out all out’ approach used for other water bodies. For the hydromorphology status, the hydromorphological assessments are not to be used to drive a waterbody status class below good, but are used in heavily modified waterbodies to determine whether or not sensitive biological elements should be excluded from the one-out-all-out calculation. On the Ems, the hydrological regime is “does not support good” and the reason for this is due to groundwater abstractions. As this element will not impact on the overall waterbody classification, then Hydromorphological Supporting Elements is recorded as “Supports Good”.*”

As described above, Mitigation Measures form an important part of attaining Good Ecological Potential for heavily modified waterbodies. In RBMP2, the Mitigation Measures ‘in place’ included[5]:

- Maintain channel bed/margin
- Vegetation control timing
- Vegetation control
- Selective vegetation control

Those ‘not in place’ included:

- Educate landowners
- Water level management
- Retain habitats
- Floodplain connectivity
- Set-back embankments
- Flood bunds
- Alter culvert channel bed
- Re-opening culverts
- Bank rehabilitation
- In-channel morph diversity
- Preserve or restore habitats
- Remove or soften hard bank
- Remove obsolete structure

In terms of other RNAG, fish populations were at ‘poor’ potential despite good numbers of Brown/sea trout (*Salmo trutta)*, European eel (*Anguilla anguilla*) and Bullhead (*Cottus gobio*) being recorded as part of 2015 Environment Agency fish surveys. The WFD Fisheries Classification System (FCS2) was expecting a high probability of there being Roach (*Rutilus rutilus)* and Chub (*Leuciscus cephalus*) which were not recorded and it is the absence of these two species that resulted in the ‘poor’ potential classification. This is a wider issue with other streams where FCS2 predicts a mixed coarse and salmonid fish community but where this is not found. An example of how FCS2 was applied to the 2013 River Ems surveys was provided by the Environment Agency under Open Government Licence and provided in Figure 6-2.

Finally, the river also flows into two protected areas which are areas that have been designated as requiring special protection under EU legislation. These are Chichester harbour (Emsworth Channel) under the Shellfish Water Directive and Chichester harbour under the Urban Waste Water Treatment Directive. These waterbodies form their own (transitional) WFD waterbodies which are reported separately to the River Ems.

[4] Email from Alison Matthews (Environment Agency) to Peter Mulder (Atkins) on 14 April 2021.
[5] From: Custom Waterbody Summary Report Cycle 2, dated 26 March 2021, provided by Environment Agency.

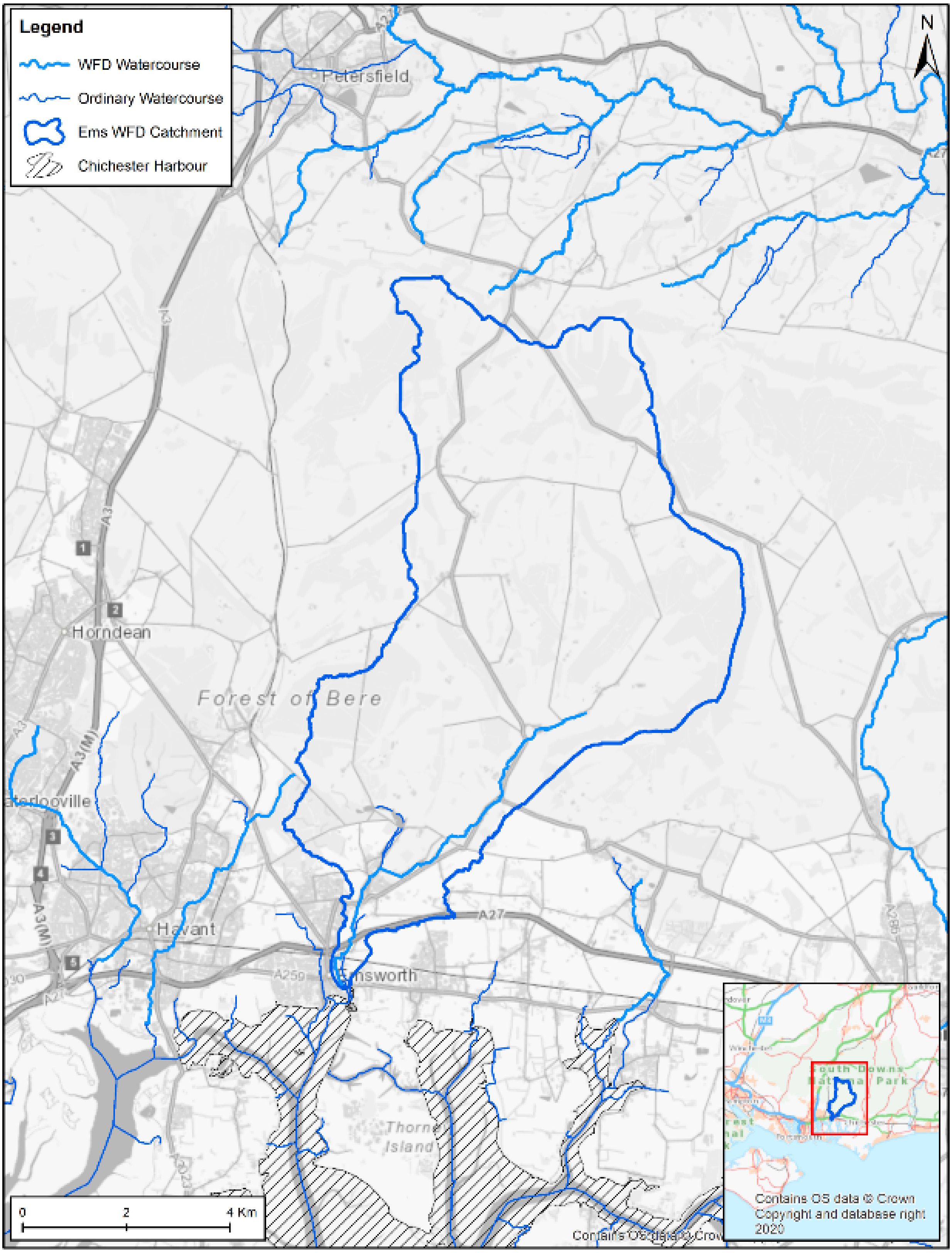


Figure 6-1 - WFD surface water body River Ems (GB107041012370)

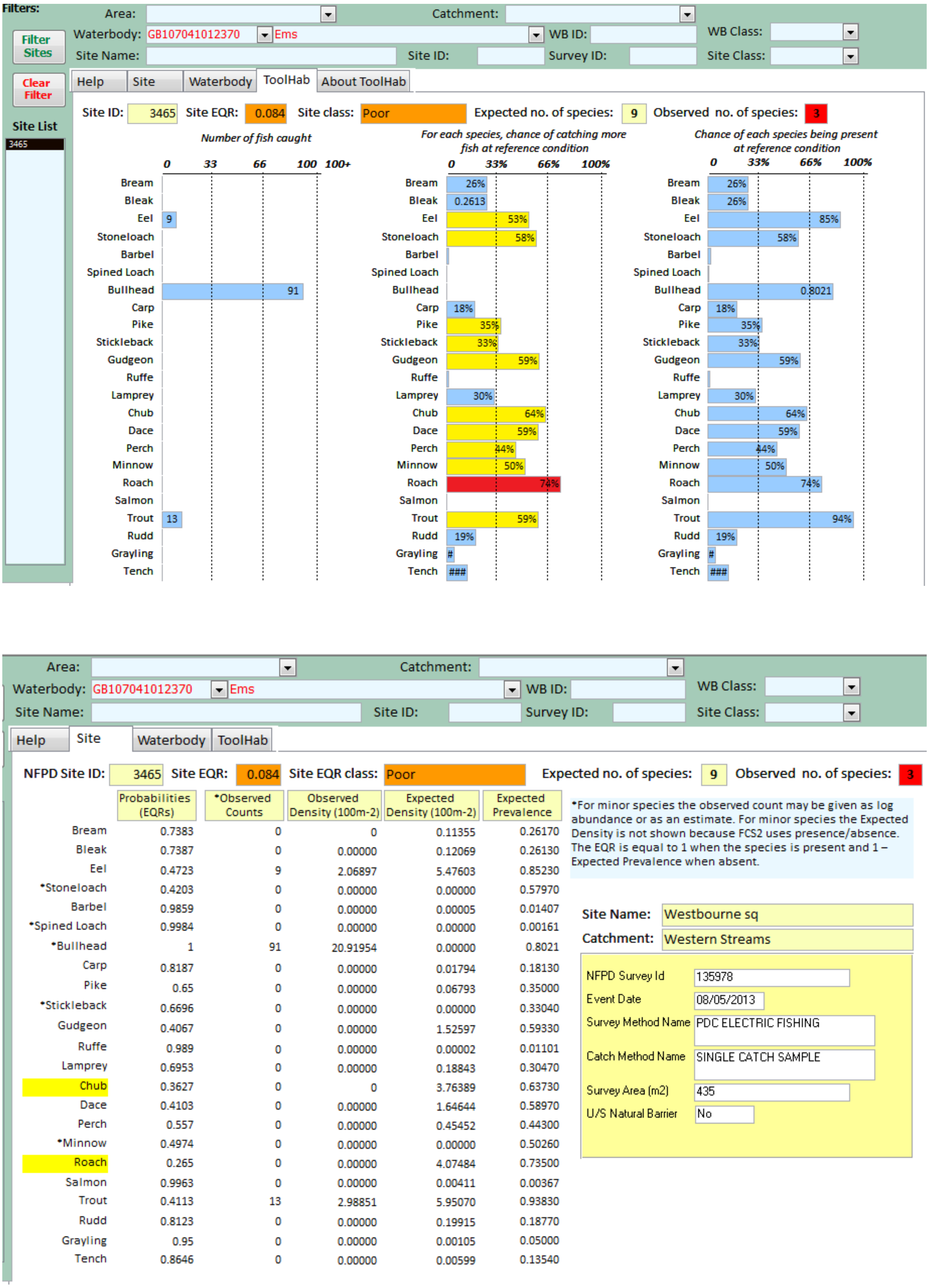
Table 6-2 - WFD classification summary of the River Ems

Water body name	Ems			
Water body ID	GB107041012370			
River Basin District	South East			
Management catchment	Arun and Western Streams			
Operational catchment	Western Streams			
A/HMWB	Heavily modified			
Classification	2009 Cycle 1	2015 Cycle 2	2019 Cycle 2 (Interim)	Objectives (set out in dRBMP3)
Overall water body	Poor	Poor	Poor	Good (2027)*
Ecological	Poor	Poor	Poor	Good (2027)*
Supporting elements (Surface Water)	Moderate	Moderate	Moderate	Good (2027)*
Mitigation Measures Assessment	Moderate or less	Moderate or less	Moderate or less	Good (2027)*
Biological quality elements	Poor	Poor	Poor	Good (2027)*
Macrophytes and phytobenthos	-	High	High	Good (2027)*
Fish	Poor	Poor	Poor	Good (2027)*
Invertebrates	Moderate	Moderate	Moderate	Good (2027)*
Hydromorphological supporting elements	Supports Good	Supports Good	Supports Good	Supports Good (2015)
Hydrological regime	Does Not Support Good	Does Not Support Good	Does Not Support Good	Supports Good (2027)
Physico-chemical quality elements	Good	Moderate	Moderate	Good (2015)
Acid Neutralising Capacity	-	High	High	Good (2015)
Ammonia	High	High	High	Good (2015)
Dissolved Oxygen	Good	High	Moderate	Good (2015)
pH	High	High	High	Good (2015)
Phosphate	High	High	High	Good (2015)
Temperature	High	Good	High	Good (2015)
Specific pollutants	High	High	High	High (2015)

Manganese	-	-	High	High (2015)
Copper	High	High	High	High (2015)
Iron	-	-	High	High (2015)
Zinc	High	High	High	High (2015)
Ammonia (Annex 8)	High	-	-	-
Chemical	Does Not Require Assessment	Good	Fail	Good (2063) **
Priority substances	Does Not Require Assessment	Good	Good	Good (2015)
Cypermethrin (Priority hazardous)	-	-	Good	
Fluoranthene	-	-	Good	
Lead and Its Compounds	-	Good	Good	Good (2015)
Nickel and Its Compounds	-	Good	Good	Good (2015)
Other Pollutants	Does Not Require Assessment	Does Not Require Assessment	Does Not Require Assessment	Does Not Require Assessment
Priority hazardous substances	Does Not Require Assessment	Good	Fail	Good (2063) **
Polybrominated diphenyl ethers (PBDE)	-	-	Fail	Good (2063) **
Perfluorooctane sulphonate (PFOS)	-	-	Good	-
Benzo(a)pyrene	-	-	Good	-
Cadmium and Its Compounds	-	Good	Good	Good (2015)
Dioxins and dioxin-like compounds	-	-	Good	-
Heptachlor and cis-Heptachlor epoxide	-	-	Good	-
Hexabromocyclododecane (HBCDD)	-	-	Good	-
Hexachlorobenzene	-	-	Good	-
Hexachlorobutadiene	-	-	Good	-
Mercury and Its Compounds	-	-	Fail	Good (2040) **

*RBMP3 quotes as reasons: 'Disproportionately expensive, disproportionate burdens'

**RBMP3 quotes as reasons: Natural conditions: Chemical status recovery time



	Probabilities (EQRs)	*Observed Counts	Observed Density (100m-2)	Expected Density (100m-2)	Expected Prevalence
Bream	0.7383	0	0	0.11355	0.26170
Bleak	0.7387	0	0.00000	0.12069	0.26130
Eel	0.4723	9	2.06897	5.47603	0.85230
*Stoneloach	0.4203	0	0.00000	0.00000	0.57970
Barbel	0.9859	0	0.00000	0.00005	0.01407
*Spined Loach	0.9984	0	0.00000	0.00000	0.00161
*Bullhead	1	91	20.91954	0.00000	0.8021
Carp	0.8187	0	0.00000	0.01794	0.18130
Pike	0.65	0	0.00000	0.06793	0.35000
*Stickleback	0.6696	0	0.00000	0.00000	0.33040
Gudgeon	0.4067	0	0.00000	1.52597	0.59330
Ruffe	0.989	0	0.00000	0.00002	0.01101
Lamprey	0.6953	0	0.00000	0.18843	0.30470
Chub	0.3627	0	0	3.76389	0.63730
Dace	0.4103	0	0.00000	1.64644	0.58970
Perch	0.557	0	0.00000	0.45452	0.44300
*Minnow	0.4974	0	0.00000	0.00000	0.50260
Roach	0.265	0	0.00000	4.07484	0.73500
Salmon	0.9963	0	0.00000	0.00411	0.00367
Trout	0.4113	13	2.98851	5.95070	0.93830
Rudd	0.8123	0	0.00000	0.19915	0.18770
Grayling	0.95	0	0.00000	0.00105	0.05000
Tench	0.8646	0	0.00000	0.00599	0.13540

Figure 6-2 – Example FCS2 output for the River Ems for 2013

7. River morphology

Fluvial geomorphology involves an understanding of the processes of water and sediment movement in river channels, and their catchments and floodplains. Rivers are dynamic systems which respond to changes including catchment land use, climate-related variations in precipitation, frequency and magnitude of abstractions and discharges, and other human-induced modifications. As a result of these factors, rivers can respond to change by moving laterally or vertically, modifying their cross-section and channel shape (planform), and altering their flow and sediment regimes. Therefore, rivers are highly sensitive systems that require specific attention to inform sustainable and robust design decision-making in order to ensure that human interaction with the water environment does not cause degradation of our rivers and their natural functioning.

7.1. Hydromorphological setting

The Ems catchment is predominantly agricultural, with significant woodland cover in the upper reaches and increasing urbanisation in the lower reaches through towns such as Westbourne and Emsworth. As detailed in Section 5.1, the catchment is dominated by chalk bedrock geology with superficial cover (i.e. gravels and alluvium) overlying the chalk in the lower reaches.

As detailed in Section 6, the Ems WFD river water body (GB107041012370) is designated as “heavily modified” (Environment Agency, 2021), indicating that the natural condition of the water body is substantially altered. The Hydromorphological Supporting Elements attain ‘Supports Good’, although the Hydrological Regime sub-element attained ‘Does Not Support Good’ and has done so since 2009 (Cycle 1).

7.2. Channel modification

The River Ems has been subject to physical modification for anthropogenic factors for centuries (Holmes, 2007), with most changes being linked to either agricultural or industrial practices. Figure 7-1 depicts the distribution and extent of known structures (including bridges, culverts, weirs and sluices) and other channel modifications within the catchment[6].

The Ems channel has also been widened, deepened, straightened and diverted throughout the catchment (Holmes, 2007). Agricultural modifications include implementation of enhanced land drainage systems and artificial irrigation systems (AMEC, 2013), and also creation of watercress beds and water meadows across the catchment (Holmes, 2007). Local industry has been dominated by milling, resulting in the impounding of water at weirs (e.g. Brickkiln Ponds, Lordington Mill Pond, Aldsworth Pond) and also the diversion of water through numerous sluices (the definition of sluice is that they can be opened and closed - many are privately owned and operated (Holmes, 2007)) and artificial canalised sections and mill races (e.g. near Westbourne). There are also a number of other modifications, which are best described as concrete sills or weirs – meaning that they are fixed in their position and cannot be opened or lowered – many of these weirs are likely to form a significant barrier to fish movement as unless they are overwhelmed by river flows, migratory fish like trout are unlikely to pass them. The Middle and Lower Ems catchment is also characterised by significant flood defences comprised of embankments and walls. Additionally, there are numerous road, rail and footbridge crossing locations along the River Ems and the river was diverted and modified as part of constructing the A27.

In 2015/16, Portsmouth Water together with the Arun and Western Streams Catchment Partnership and the Environment Agency delivered a number of restoration projects in the Middle and Lower River Ems (ARRT, 2017), with a view of mitigating some of the impacts identified in the 2013 report. This included resolving issues with channel braiding, in-channel structures and fish passage (see Section 7.4).and also river bank fencing to prevent livestock incursions and their impacts on the river and river bank habitat.

[6] These structures and modifications have been identified using the following data sources: Holmes (2007), AMEC (2013), ARRT (2017), National Library of Scotland (NLS) (2021), and Ordnance Survey (OS) open-source mapping.

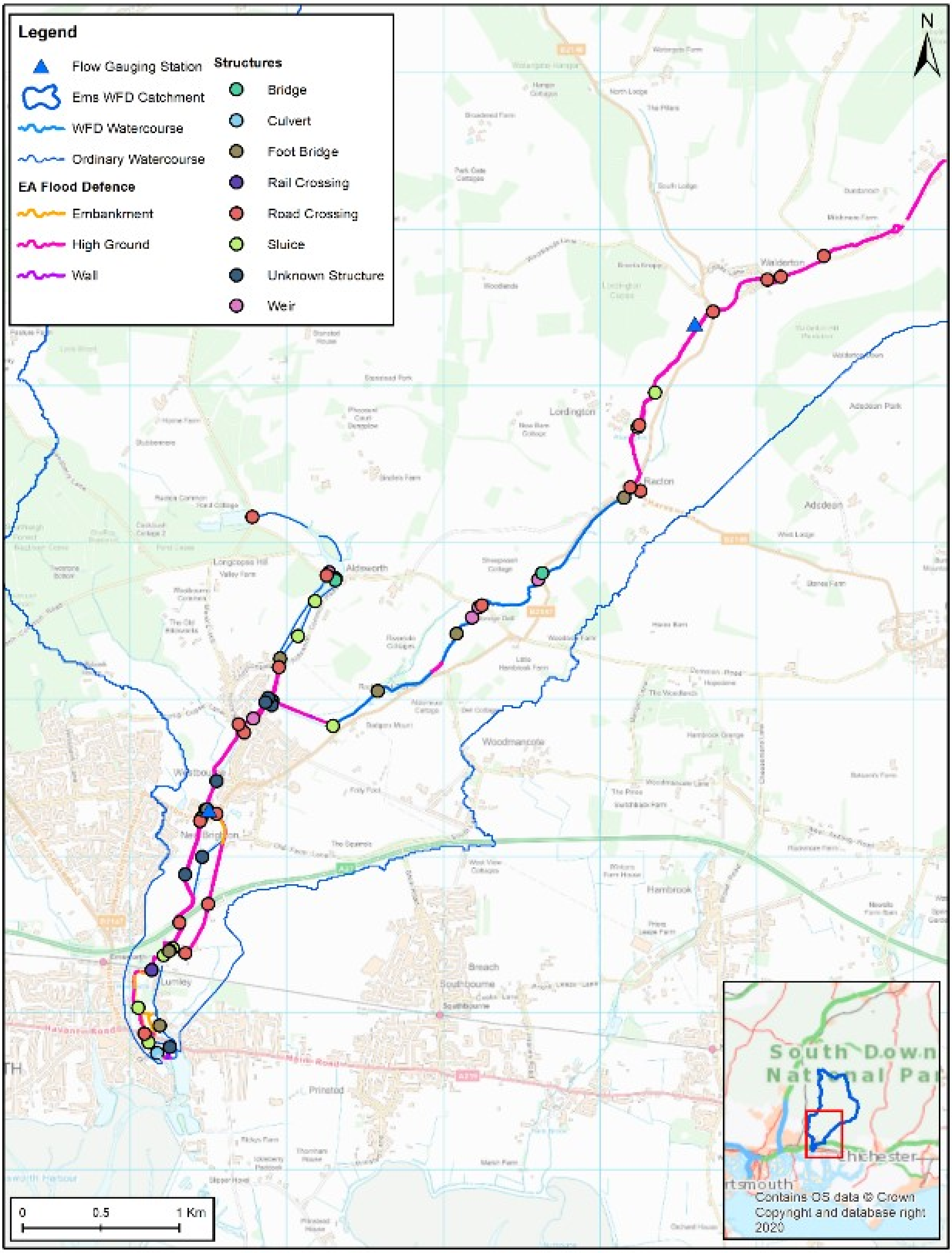


Figure 7-1 - Distribution and extent of structures and other channel modifications within the catchment

7.3. Hydromorphological character

A summary of the hydromorphological character of the River Ems is presented below, using findings from catchment surveys undertaken by Holmes (2007) and AMEC (2013).

Where the Ems flows through open farmland in the upper catchment, the watercourse exhibits a predominantly "ditch"-like character, where the channel been deepened, widened and straightened in order to enhance connectivity and drainage from adjacent agricultural land. There is evidence of poaching by livestock on the banks, contributing to channel siltation. The flow regime has little variation and is dominated by smooth flow, and few geomorphological features are evident. Some tree cover is present in the riparian zone, although little woody material was present in the channel at the time of survey.

The Middle Ems has been modified throughout in order to accommodate the impoundment of water for cressbed development, fish ponds, milling and water sources. The Middle Ems also contains a pond (Lord's Pond) and wetland area at Racton Park Dell, which appears to offer high quality habitat for a range of aquatic flora and fauna. The structure that keeps the pond back is, however, typically a barrier to fish passage but we understand can be overwhelmed at higher flows.

The Lower Ems us also dominated by physical modifications for impoundment and diversion of water, and also appears over-widened and over-deepened for flood protection. Some, albeit limited, semi-natural channel features are exhibited for a length downstream of Westbourne as the Ems appears to retain its natural channel unlike elsewhere in the catchment. As described above, to accommodate the construction of the A27 the river was diverted for around 150 m resulted in near 90 degree bends.

River Habitat Survey (RHS) data provides a measure of the degree of modification to a watercourse through the Habitat Modification Score (HMS) which is then translated to a Habitat Modification Class, scored from 1 (Pristine/Semi-natural) to 5 (Severely Modified). The available RHS data for the Ems water body is summarised in Table 7-1 and mapped in Figure 7-2.

There are thirteen survey datasets in total, dating between 1994 and 2012. The survey sites were well-distributed along the River Ems between Walderton and Lumley (Figure 7-2). Six of these surveys were undertaken as part of the AMEC (2013) catchment investigation study, two of which (sites E3 and E6) were also assessed using the GeoRHS methodology. The remaining seven surveys were identified using the Environment Agency RHS dataset (Environment Agency, 2020).

All but one of the thirteen surveys resulted in a Habitat Modification Class of either 4 (Significantly Modified) or 5 (Severely Modified). Sites 6767 (located downstream of Westbourne in the lower reaches) and 5453 (at Walderton near the source) attained the highest HMS scores (3695 and 3090 respectively). Only survey E3, which was located directly downstream of Common Road near Ellbridge Dell in the middle catchment, resulted in a class of 3 (Obviously Modified) with an HMS of 380.

In terms of the ecological consequences of modifications, in addition to the barriers to fish passage, these modifications result in a limited diversity of flows and can result in excessive siltation locally, notably in impounded reaches. Some species benefit e.g. eel benefit from sediments, but the majority of chalk stream species are adversely affected, for example trout, water crowfoot and macroinvertebrates.

Table 7-1 - Summary of available RHS data within Ems water body. * indicates that GeoRHS was undertaken at this location.

Source	Site ID	Site Name	Year	Habitat Modification Score	Habitat Modification Class
Environment Agency (2020)	1423	Trib. of Emsworth Channel	1994	730	4
Environment Agency (2020)	6766	Ems	1995	1405	5
Environment Agency (2020)	6767	Ems	1995	3695	5
Environment Agency (2020)	6768	Trib. of Ems	1995	1055	4
Environment Agency (2020)	5453	Unnamed	1996	3090	5
Environment Agency (2020)	17180	Ems	2004	1900	5
Environment Agency (2020)	23621	Trib. of Ems	2008	625	4
AMEC (2013)	E1	Walderton	2012	1600	5
AMEC (2013)	E2	Lordington Manor	2012	1855	5
AMEC (2013)	E3*	-	2012	380	3
AMEC (2013)	E4	Downstream of augmentation	2012	1340	4
AMEC (2013)	E5	Rivers Street tributary	2012	2440	5
AMEC (2013)	E6*	Upstream of Westbourne gauging station	2012	1040	4

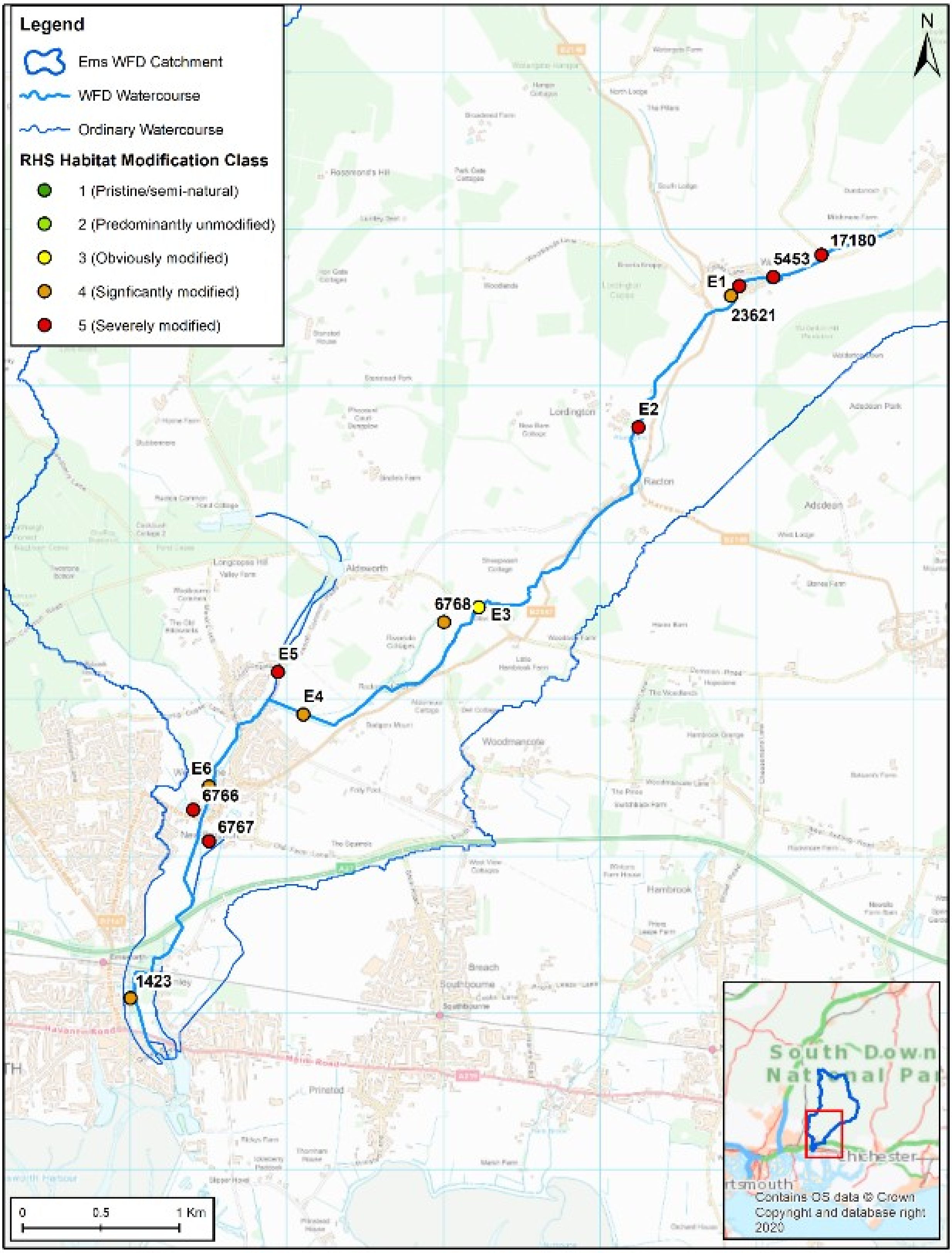


Figure 7-2 - Distribution of River Habitat Survey sites within the catchment, colour-coded by Habitat Modification Class.

7.4. Middle Ems river restoration work

Funded by Portsmouth Water as part of their Water Industry National Environment Programme (WINEP), a number of river restorations were undertaken along the River Ems in 2015-2016 by the Arun and Rothers Rivers Trust (ARRT) and Wild Trout Trust (WTT) with a view to reducing the effect of physical modifications on the river and restoring it to a high quality chalk stream with a healthy and diverse ecology. These are summarised below (ARRT, 2016):

- Improved flow augmentation point, moving this upstream from its original location to benefit a longer section of watercourse.
- Deepsprings restoration – the channel at Deepsprings (~300m) was restored from a river that lacked sinuosity and had high levels of algal blooms and sediment deposition due to weirs and cattle poaching, to a sinuous 2-stage channel with built in pools for variation and it was also narrowed to increase the velocities through the reach. Stock fencing was also installed to reduce poaching and sediment ingress to the river. Initial observations that were recorded following the restoration were a reduction in sediment, increased flora and fauna biodiversity improved flow dynamics, self-cleaning gravel reaches and young brown trout were spotted at Watersmeet.
- Watersmeet canal taken off-line – restoration of two weirs to prioritise flow down the main river channel.
- Mill meadows reach improved – the Mill Meadows reach has been improved through bed restoration, fencing, cattle-drinks, cattle-crossings and weir modifications.
- Weirs lowered and notches for fish passage and prioritise main Ems channel during low flows (CPAF).
- Queen Street culverts improved – enhancements to culvert to enhance fish passage.
- Brook Meadows Habitat enhancement project/workshop – implement of brushwood berms and large wood flow deflectors.

8. Water quality

8.1. Data availability

Data available consisted of fourteen Environment Agency freshwater water quality monitoring locations in the River Ems waterbody. Only one of these sites – River Ems at A259 Road Bridge (SO-F0003395 – see Figure 8-1) – had a long-term record (19/01/2000-05/03/2020). It is noted that we understand from the Environment Agency that water quality monitoring was halted at this site in March 2020 due to UK wide lockdown as a result of the Coronavirus (COVID19) global pandemic. WFD status is often assessed at the downstream-most point in catchments as it is the point at which 'all' detrimental impacts are likely to be seen and it is presumed that this is thus the site used by the Environment Agency to assess WFD status. Due to the long data record, this sampling site was used to perform water quality analysis for this report. The other thirteen sites within the catchment had short term data records largely from 2006 to 2008 which appear to form part of a local investigation. These data were excluded from the analysis on this basis but are recorded in Table 8-1 for completeness. Figure 8-1 shows the location of all the freshwater monitoring sites and Table 8-2 contains the location coordinates for all sites.

8.2. Water quality sampling results

Figure 8-2 shows graphs for the six WFD physico-chemical elements have been produced for the River Ems at the A259 Road Bridge monitoring location, which is the monitoring site with the longest data record within the catchment. Particular attention has been paid to patterns in dissolved oxygen, which can often decrease as river flows slow and/or river temperature increases. Additionally, three non-WFD elements have also been included (suspended solids, nitrate and un-ionised ammonia). For all elements except biochemical oxygen demand and suspended solids, data were available from January 2000 to March 2020 (at the time of writing the report, March 2020 was the last month for which water quality data were made available on the Environment Agency Water Quality Archive). The specific WFD Environmental Quality Standard values for the physico-chemical elements can be found in Table 8-3, noting each has its own compliance statistic.

8.2.1. Dissolved oxygen

Dissolved oxygen is paramount to all aquatic life, notably fish and macroinvertebrates. Chalkstream species such as trout, mayflies, caddisflies and stoneflies all require good or high oxygen levels to thrive. Lower dissolved oxygen levels can result in stress and sometimes also death.

The charts in Figure 8-2 confirm that although most of the dissolved oxygen concentrations are indicative of 'High' or 'Good' classification, throughout the data period there were certain years where dissolved oxygen concentrations were indicative of less than 'Good' classification. A couple of dissolved oxygen samples taken in these years were indicative of 'Poor' conditions for these years however the rest of the concentrations are generally classed as either 'High' or 'Good'. From the data available there does not appear to be a consistent trend with lower dissolved oxygen concentrations and drier years as not all drier years have corresponding low dissolved oxygen concentration records. Some of these lower dissolved oxygen concentrations coincided with some of the lower flow years shown in Figure 4-2 such as 2005, 2009 and 2015, but there was no relationship to other years reported to exhibit lower flows such as 2010, 2011 or 2020. Similarly, these dissolved oxygen concentrations do not seem to coincide with any of the other physico-chemical elements that may affect dissolved oxygen concentrations such as water temperature.

A significantly low dissolved oxygen concentration was recorded in September 2018 reading at 47.8%. It is unknown if there was a significant dry period that coincides with this reading or if it was the result of a pollution event in the catchment.

As dissolved oxygen levels do not meet the standard for Good Ecological Potential, the Environment Agency has deployed automatic water quality loggers in the lower Ems in 2021-22 to understand what is driving these lower oxygen levels.

8.2.2. Other physico-chemical elements

Orthophosphate is a plant nutrient that typically limits algal and plant growth in freshwater systems. Elevated levels of phosphate can lead to the proliferation of more opportunistic species like algae, which can outcompete and/or shade slower-growing species that are characteristic of chalkstreams such as water crow foot. The analysis also indicates there have been occasions of elevated orthophosphate levels within the waterbody in the past with lower flow events occurring in 2003, 2006, 2009 and 2011 which were indicative of 'Poor' classification. However, since 2011 orthophosphate levels have been largely indicative of 'Good' or 'High' classification with only a few samples indicative of 'Moderate' levels. As the WFD compliance statistic is based on an annual average, the WFD classification has, nevertheless, remained as 'High' throughout the WFD assessment periods. It is unknown what the origin of the orthophosphate is, but it is suspected that this is linked to fertilisers and small package plants / septic tanks.

Water temperature in the River Ems has been classed as 'High' in the WFD 2019 interim update. Throughout the data period, water temperatures have been largely of 'High' or 'Good' classification. There was a significant event recorded in July 2014 with a temperature of 24.2°C that is within the 'Moderate' range. Species like trout are sensitive to fluctuating temperatures and would likely have been stressed in those conditions.

All other WFD physico-chemical parameters (pH, Biological Oxygen Demand (BOD) and Total Ammonia as N) and Non-WFD elements also shown were indicative of largely 'Good' or 'High' classification, matching the classifications stated within the WFD interim status update for 2019.

Specific pollutants were all classed as 'High' in the WFD since 2015 and as such were not assessed in detail. There were long term datasets available for copper and zinc from 2000/2002 to 2015 and short term monitoring for manganese and iron from 2015 to 2016, the purpose of which was for the 2016 WFD assessment.

8.2.3. Chemical

The WFD 2019 interim status update indicates that the River Ems currently fails under Chemical status due to priority hazardous substances PBDE and mercury and its compounds. Noting datasets run up to March 2020, the Environment Agency Water Quality Archive did not contain any results for these compounds at any of the water quality monitoring sites within the catchment and it is considered likely that the Fail status has been determined by expert judgement in absence of the required water quality data.

This view requires confirmation by the Environment Agency.

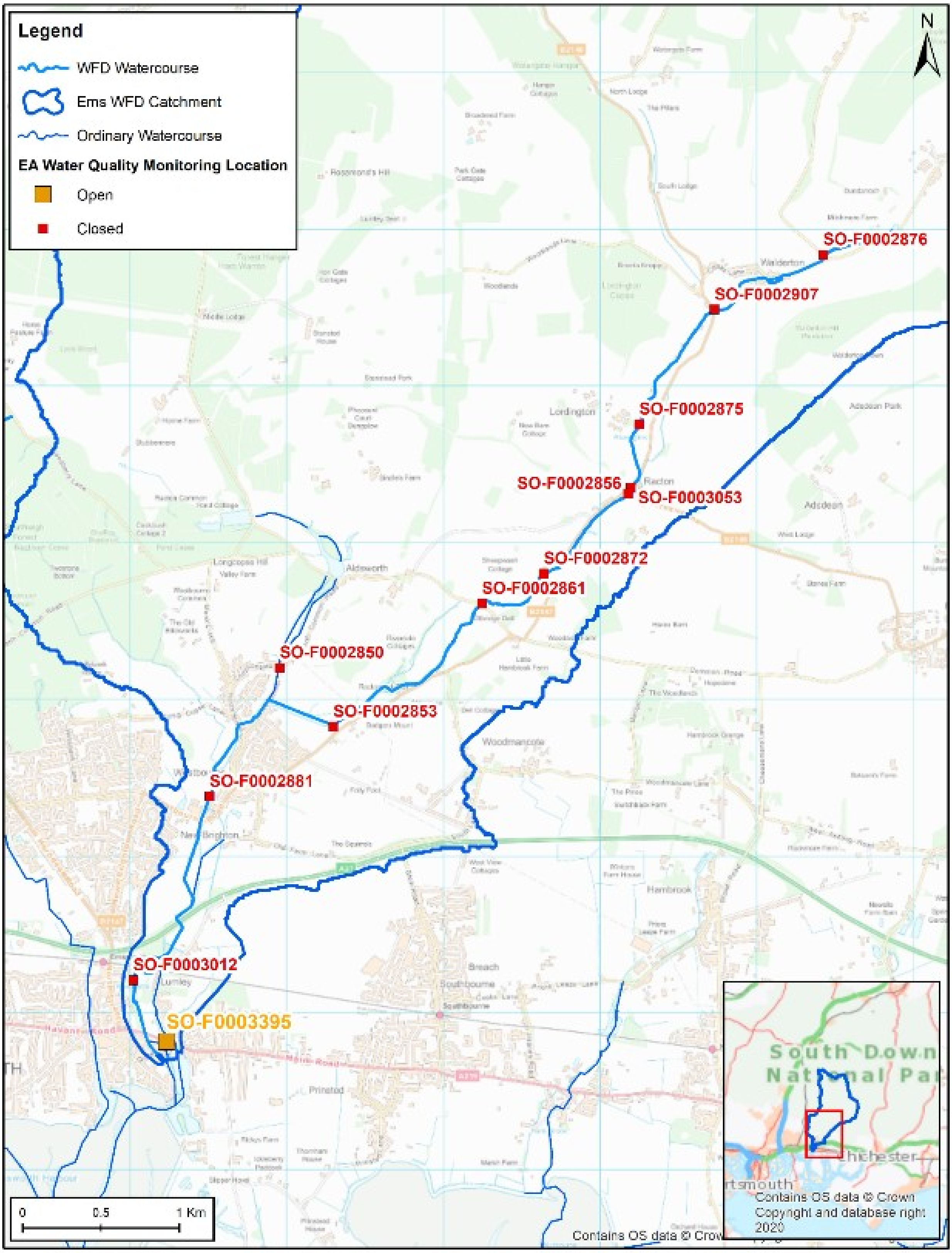


Figure 8-1 - Water quality monitoring locations

Table 8-1 - Environment Agency water quality monitoring locations

Waterbody	Sampling location ID	Sampling location name	First sample	Last sample	No. of samples	Average no. of sampling events per year
River Ems	SO-F0003395	River Ems A259 Road Bridge	19/01/2000	05/03/2020	240	11 (max=14, min=3)
River Ems (Aldsworth Arm)	SO-F0002850	R STREET WESTBOURNE-*CLOSED*	28/06/2006	16/01/2008	16	8 (max=11, min=5)
River Ems	SO-F0002853	R EMS FOXBURY LANE-*CLOSED*	28/06/2006	27/11/2007	8	4
River Ems	SO-F0002856	D/S RACTON ROAD BR-*CLOSED*	28/06/2006	16/01/2008	8	2 (max=6, min=1)
River Ems	SO-F0002861	D/S ALDSWORTH BRIDGE-*CLOSED*	17/01/2007	16/01/2008	2	1
River Ems	SO-F0002872	R EMS ELL BRIDGE-*CLOSED*	17/01/2007	16/01/2008	7	4 (max=6, min=1)
River Ems	SO-F0002875	NEW BARN LANE-*CLOSED*	17/01/2007	16/01/2008	6	3 (max=5, min=1)
River Ems	SO-F0002876	DITCH ROAD TO MARDEN-*CLOSED*	28/02/2007	17/04/2007	3	3
River Ems	SO-F0002879	STOUGHTON CULVERT-*CLOSED*	17/01/2007	26/03/2007	3	3
River Ems	SO-F0002881	U/S WESTBOURNE GAUGE-*CLOSED*	28/06/2006	16/01/2008	8	3 (max=5, min=1)

Waterbody	Sampling location ID	Sampling location name	First sample	Last sample	No. of samples	Average no. of sampling events per year
River Ems	SO-F0002907	WALDERTON BRIDGE-*CLOSED*	17/01/2007	16/01/2008	6	3 (max=5, min=1)
River Ems	SO-F0003012	BROOK MEADOW-*CLOSED*	19/07/2006	16/01/2008	8	4
River Ems	SO-F0003053	RACTON D/S OF CONF-*CLOSED	17/01/2007	16/01/2008	7	3 (max=6, min=1)

Table 8-2 - Grid references for water quality monitoring locations

Name	Easting (X)	Northing (Y)
R STREET WESTBOURNE-*CLOSED*	475952	108208
R EMS FOXBURY LANE-*CLOSED*	476293	107833
D/S RACTON ROAD BR-*CLOSED*	478193	109359
D/S ALDSWORTH BRIDGE-*CLOSED*	477241	108618
R EMS ELL BRIDGE-*CLOSED*	477635	108808
NEW BARN LANE-*CLOSED*	478246	109760
DITCH ROAD TO MARDEN-*CLOSED*	479419	110844
STOUGHTON CULVERT-*CLOSED*	480253	111452
U/S WESTBOURNE GAUGE-*CLOSED*	475505	107388
WALDERTON BRIDGE-*CLOSED*	478726	110493
BROOK MEADOW-*CLOSED*	475017	106213
RACTON D/S OF CONF-*CLOSED*	478175	109318
RIVER EMS A259 ROAD BRIDGE	475230	105820

Figure 8-2 - Water quality analysis for the River Ems at A259 Road Bridge

Table 8-3 – Specific physico-chemical WFD standards as shown in Figure 8.2.

Determinand	High	Good	Moderate	Poor	Bad[7]
Ammonia (mg/l)[8]	0.3	0.6	1.1	2.5	>2.5
Reactive Phosphorus (µg/l)[9]	41.60	74.68	174.30	871.78	>871.78
Dissolved Oxygen (% saturation)[10,11]	80	75	64	50	<50
Biochemical Oxygen Demand (mg/l)[12]	3	4	6	7.5	>7.5
Water Temperature (°C)[13]	20	23	28	30	>30
pH[14]	>=6 to <=9	>=6 to <=9	4.7	4.2	<4.2

[7] It is noted that the 2015 Directions do not recognise a 'Bad' category, so this has been interpreted as any results exceeding the 'Poor' status band
[8] Total ammonia as nitrogen (in mg/l) – 90th %ile.
[9] Annual mean reactive phosphorus concentration (in µg/l).
[10] Standards for Dissolved Oxygen, Biochemical Oxygen Demand and Water Temperature are based on salmonid waters.
[11] Dissolved Oxygen (percent saturation) – 10th %ile.
[12] Biochemical Oxygen Demand (in mg/l) – 90th %ile.
[13] Water Temperature (in °C) as an annual 98th %ile.
[14] High and Good standards for pH are 95th and 5th %ile. 'Moderate' and 'Poor' standards for pH are 10th %ile.

9. Aquatic ecology

9.1. Data availability

Various sources of information have been used to describe the past and current diversity of aquatic species along the River Ems including:

- Environment Agency Fish & Ecology Data Explorer (Environment Agency, 2021b).
- Environment Agency Catchment Data Explorer (Environment Agency, 2021a).
- Environmental Quality Appraisal of the River Ems (Holmes, 2007).
- Report on the Ecohydrology of the River Ems (CEH, 2013).
- PIM and WFD investigation (AMEC, 2013).
- Ems and Hamble Macroinvertebrate Sampling Spring 2016 (AMEC, 2016).
- Ems Botanical Corridor Survey (Middleton Ecology, 2020).
- Riverfly Partnership Data Explorer (Riverfly Partnership, 2021).
- Natural History Museum (NHM) ‘Search of a UK species’ website (NHM, 2021).
- Additional fish survey data information provided by the Environment Agency fisheries team for surveys undertaken in 2021.

Table 9-1 and Figure 9-1 show the invertebrate, fish, macrophytes and diatom data available from Environment Agency sampling. In total there are 17 invertebrate sampling sites, one macrophytes sampling site, two diatom sampling sites, and five fish sampling sites along the River Ems. The spatial spread of the data is largely limited to the bottom half of the river, apart from invertebrate sampling which are also undertaken further up the catchment. The data was downloaded from the Environment Agency Fish & Ecology Data Explorer (Environment Agency, 2021b), using the outline of the catchment as the download boundary. The Environment Agency database allows download of data from 1965-present however the earliest data for the River Ems is 1995. There are no fish or macroinvertebrate data for the last 5 years in the catchment.

Table 9-1 - Environment Agency data available on the Ecology & Fish Data Explorer

Water body	Site ID	Site name	First sample	Last sample date	Number of samples	Type of samples
EMS RIVER	42971	n/a	23/11/1989	17/04/2007	8	Invertebrate
EMS RIVER	43022	n/a	18/04/1995	04/10/2007	12	Invertebrate
EMS RIVER	75936	n/a	25/08/2000	30/03/2010	15	Invertebrate
EMS RIVER	79021	n/a	23/05/2001	23/05/2001	1	Invertebrate
EMS RIVER	82657	n/a	04/07/2001	20/10/2010	17	Invertebrate
EMS RIVER	82658	n/a	04/07/2001	20/10/2010	13	Invertebrate
EMS RIVER	95241	n/a	10/07/2002	05/11/2003	4	Invertebrate
EMS RIVER	95243	n/a	10/07/2002	05/11/2003	4	Invertebrate
EMS RIVER	95452	n/a	11/04/2003	30/03/2010	3	Invertebrate
EMS TRIBUTARY	96641	n/a	11/04/2003	30/03/2010	11	Invertebrate
EMS RIVER	96645	n/a	11/04/2003	30/03/2010	7	Invertebrate
EMS RIVER	156030	n/a	19/10/2010	19/10/2010	1	Invertebrate
EMS RIVER	156031	n/a	19/10/2010	19/10/2010	1	Invertebrate

Water body	Site ID	Site name	First sample	Last sample date	Number of samples	Type of samples
EMS RIVER	78499	n/a	05/04/2001	30/03/2010	3	Invertebrate
EMS RIVER	79096	n/a	12/06/2001	12/06/2001	1	Invertebrate
EMS RIVER	79097	n/a	12/06/2001	12/06/2001	1	Invertebrate
EMS RIVER	79098	n/a	12/06/2001	11/04/2003	3	Invertebrate
EMS RIVER	82657	n/a	20/08/2013	13/08/2014	2	Macrophytes
EMS RIVER	43022	n/a	17/04/2007	17/04/2007	1	Diatom
EMS RIVER	75936	n/a	17/04/2007	17/04/2007	1	Diatom
EMS RIVER	3464	Lumley Mill sq	29/10/2001	07/06/2007	2	Fish
EMS RIVER	3465	Westbourne sq	25/10/2001	20/05/2015	4	Fish
EMS RIVER	36495	D/S Hampshire bridge	19/10/2010	19/10/2010	1	Fish
EMS RIVER	48223	Brook Meadow	08/05/2013	08/05/2013	1	Fish
EMS RIVER	63983	Brook meadow Footbridge	20/05/2015	20/05/2015	1	Fish
EMS RIVER	TBC*	Mill Meadows Farm	12/08/2021	12/08/2021	1	Fish
EMS RIVER	TBC*	Deep Springs	12/08/2021	12/08/2021	1	Fish

*Results received by email from the Environment Agency fisheries team 17 August 2021.

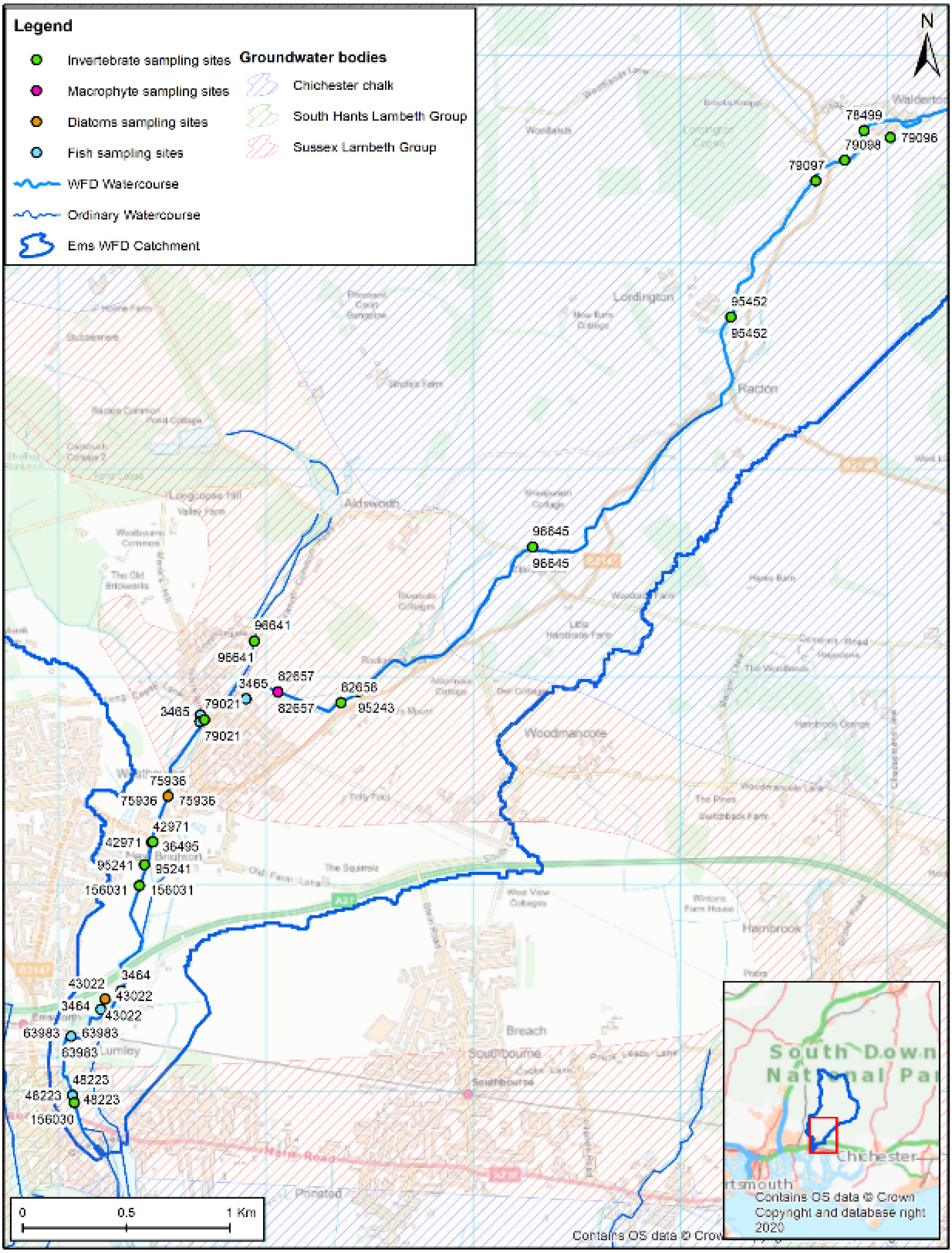


Figure 9-1 - Location of the invertebrate, fish, diatom and macrophyte monitoring locations along the River Ems

9.2. Fish

9.2.1. Data availability

There were five Environment Agency fish sampling points along the River Ems, as shown on Figure 9-1. All these surveys were single anode runs, therefore there were no population data, but only records of the number of fish caught on a single 'run' and provide a minimum population size, in that not all individuals of all species will be captured.

Environment Agency fish data were available sporadically from 2001-2015 at five sites along the River Ems; these are all located in the bottom 2km of the river, with no fish sampling sites in the upstream reaches. The locations of the fish sampling sites can be seen in Figure 9-1 and the full list of fish species found in the Environment Agency surveys in Table 9-2.

Additional data were provided for two surveys undertaken 12 August 2021. Again, these included single-run electric fishing, using a battery powered backpack; one at Mill Meadows Farm (SU7542007095) and one at Deep Springs (SU7649207976). Deep Springs was located within the new river restoration site between Racton Dell and The Canal and was a new site not previously surveyed.

9.2.2. WFD status

The River Ems was assessed as 'Poor' for fish in the 2019 WFD interim classification and has been classed as 'Poor' for fish since 2009. There are two named RNAG associated with fish which are "flow – groundwater abstraction" and "physical modification – flood protection (structures)".

According to the South East RBMP, Annex C from 2009 the river is designated as 'salmonid'. The definition of salmonid includes species such as Atlantic salmon (*Salmo salar)* and Brown/sea trout. As described in Section 6, the WFD status classification was driven by a lower catch than expected for Roach and Chub whilst Bullhead, European eel and Brown/sea trout were all present in good numbers.

9.2.3. Results

Across the 14 years of Environment Agency sampling, a total of eight different fish species were recorded in the River Ems: 10-spined stickleback (*Pungitius pungitius)*, 3-spined stickleback (*Gasterosteus aculeatus)*, Atlantic salmon, Brown/sea trout, Bullhead European eel, Pike (*Esox Lucius)* and Roach. Eel are catadromous (meaning they return to sea to spawn) whilst Atlantic salmon and sea trout are anadromous (meaning they move into freshwater from the sea to spawn). Like many salmonids, the 10-spine and 3-spine stickleback are a partially migratory species, meaning that the species are split into migratory (anadromous) populations as well as 'resident' populations, meaning that they do not migrate to spawn. Brown trout, bullhead, pike and roach migrate within freshwater systems to spawn and to feed but not to sea.

The 2021 surveys revealed that:

- The brown trout abundance, condition and diversity of age groups recorded at Mill Meadows was, according to the Environment Agency, comparable with some of the best quality chalkstreams elsewhere in Solent & South Downs Area. The site clearly provided the species with the range of habitats it needs to thrive, as well as a lack of disturbance, which is often underrated as an influence on fish populations.
- The abundance of one and two year old trout at Mill Meadows suggests that sea trout may be an important component of the population at this site: a proportion of these fish can be expected to 'smolt' meaning they migrate to sea in March / April each year. In some chalkstreams, sea trout can make to riverine trout populations (Goodwin et al., 2016).
- The catch demonstrated successful spawning and recruitment of brown trout, but adults were notable by their absence despite the presence of multiple pools providing good adult habitat. Given the apparent constraints on migratory access to this reach (sea trout), it's likely that the resident population is largely dependent on a small number of broodstock, none of which were caught on this occasion. A particular feature of such populations is their increased risk of extinction as a result of unusually high mortality events, for example, drought or pollution.
- Nine-spined stickleback were recorded at Deep Springs – locally, this species is typically found in the vegetated margins of chalkstream headwaters, so it's presence in the Ems is welcome and another indication of natural habitat conditions.

The survey team noted that the aquatic habitat, the richness of the chalkstream plant community and the water quality at Deep Springs were remarkably good at the time of the survey. The team noted that some narrowing or higher flows would make habitat even more suitable. Some photos for the 2021 surveys, courtesy of Mr Nick Rule, are provided in Appendix C.

Prior to the 2021 surveys, the most recent records were from May 2015 for two survey sites along the River Ems. Brown/sea trout (*Salmo trutta*), European eel (*Anguilla anguilla*), Atlantic Salmon (*salmo salar*) and Bullhead (*Cottus gobio*) were recorded at these sites and there is a commonality between species composition, including these species, across the other survey sites.

Brown/sea trout, Atlantic Salmon and European eel are species of principal importance for nature conservation in England under the Natural Environment & Rural Communities (NERC) Act 2006, which sets out the duty for public authorities to conserve biodiversity in England. European eel are also listed as Critically Endangered on the International Union for Conservation of Nature red list of threatened species.

Three of the survey sites only have a single sample, therefore patterns of change cannot be extracted at this point.

For those sites with multiple datapoints, the presence of European eel at Westbourne Sq and Lumley Mill Sq has significantly reduced over time. Some 118 eel were present at Lumley Mill Sq in 2001 and 63 at Westborne Sq. However, in the latest survey, in 2007 and 2015 respectively, only 19 and 7 were recorded. Brown / sea trout numbers also reduced at Lumley Mill Sq between the 2001 and 2007 surveys from 28 to 7, but no other cases have been located. It is likely that sea trout enter the catchment from the sea via Chichester Harbour and it is understood that there is an open connection between the sea and the River Ems. Overall, trends like those described above should be interpreted with caution given the low number of data points.

9.2.4. Comparison to other studies

Further fish data is presented in Holmes (2007) from a variety of sources including reports from individuals, local people and literature. This report confirms that sea trout have, historically, been able to migrate up the River Ems, as far upstream as Westbourne where there are barriers to fish migration.

This report also states that the river, in terms of a healthy fishery, has deteriorated over the last 20 years, which is conducive with the limited patterns and number of fish species identified within the Environment Agency data. There is mention to 1994 Halcrow report in Section 4.3.3 of Holmes (2007) (which was not obtained). Holmes' report contained a range of literature quotes on fishing in the Ems catchment. Of note is a 1928 'Where to Fish' publication which mentions '*Ems rises above Racton, where is good trouting, but preserved*'. Mr Nick Rule (FotE) undertook further review work subsequently and where copies were made available, the same quote is provided in the 'Where to Fish' publications of 1949-50, 1959-60, 1963-64 and 1965-66. In 1967-68, the publication states "*Rises above Racton and runs 2 m to Westbourne; trout, but upper reaches are dry most of summer; preserved*". In 1969-70, the publication states "*Trout, but upper reaches dry most of summer; preserved*".

Of note is the distance specified in the 'Where to Fish' publications – 2 m east of Westbourne is up to Racton. After this year, where copies were made available, no entries for the River Ems were found. Holmes also provides records of trout fishing from local people (Section 4.3.2 in Holmes, 2007) as well as literature (Section 4.3.3 in Holmes, 2007), highlighting that in some cases dams and obstructions are in place to hold back water including at Lords Fish Pond (Racton Park Dell).

The report identifies species that have been historically recorded but no longer present within the Ems and concludes that the Environment Agency data reviewed by Mr Holmes at the time of writing the report (2007) does not show the much richer communities that were present historically.

Table 9-2 - Fish species found at the River Ems sampling sites

Site ID	Site Name	Event Date	Survey Method	Survey Strategy	Species Name	Latin Name	Number
3464	Lumley Mill sq	29/10/2001	PDC ELECTRIC FISHING	SINGLE CATCH SAMPLE	Brown / sea trout	*Salmo trutta*	28
					European eel	*Anguilla anguilla*	118
					Bullhead	*Cottus gobio*	16
					3-spined stickleback	*Gasterosteus aculeatus*	3
3464	Lumley Mill sq	07/06/2007	ELECTRIC FISHING	SINGLE CATCH SAMPLE	Brown / sea trout	*Salmo trutta*	7
					European eel	*Anguilla anguilla*	19
					Roach	*Rutilus rutilus*	2
3465	Westbourne sq	25/10/2001	PDC ELECTRIC FISHING	SINGLE CATCH SAMPLE	European eel	*Anguilla anguilla*	63
					Brown / sea trout	*Salmo trutta*	11
					Bullhead	*Cottus gobio*	56
3465	Westbourne sq	13/08/2007	ELECTRIC FISHING	SINGLE CATCH SAMPLE	European eel	*Anguilla anguilla*	25
					Pike	*Esox lucius*	2
					Bullhead	*Cottus gobio*	45
					Brown / sea trout	*Salmo trutta*	25
3465	Westbourne sq	08/05/2013	PDC ELECTRIC FISHING	SINGLE CATCH SAMPLE	Bullhead	*Cottus gobio*	91
					European eel	*Anguilla anguilla*	9
					Brown / sea trout	*Salmo trutta*	13
3465	Westbourne sq	20/05/2015	PDC ELECTRIC FISHING	SINGLE CATCH SAMPLE	Brown / sea trout	*Salmo trutta*	27
					Bullhead	*Cottus gobio*	500
					European eel	*Anguilla anguilla*	7
36495	D/S Hampshire Bridge	19/10/2010	ELECTRIC FISHING	SINGLE CATCH SAMPLE	Brown / sea trout	*Salmo trutta*	59
					Bullhead	*Cottus gobio*	18
					European eel	*Anguilla anguilla*	17

Site ID	Site Name	Event Date	Survey Method	Survey Strategy	Species Name	Latin Name	Number
48223	Brook Meadow	08/05/2013	PDC ELECTRIC FISHING	SINGLE CATCH SAMPLE	Bullhead	*Cottus gobio*	23
					Pike	*Esox lucius*	1
					European eel	*Anguilla anguilla*	30
					Brown / sea trout	*Salmo trutta*	5
					10-spined stickleback	*Pungitius pungitius*	4
63983	Brook Meadow Footbridge	20/05/2015	PDC ELECTRIC FISHING	SINGLE CATCH SAMPLE	European eel	*Anguilla anguilla*	15
					Bullhead	*Cottus gobio*	50
					Atlantic salmon	*Salmo salar*	1
					Brown / sea trout	*Salmo trutta*	46
TBC	Mill Meadows Farm	12/08/2021	PDC ELECTRIC FISHING	SINGLE CATCH SAMPLE	European eel	*Anguilla anguilla*	8
					Bullhead	*Cottus gobio*	25
					Brown / sea trout	*Salmo trutta*	38
TBC	Deep Springs	12/08/2021	PDC ELECTRIC FISHING	SINGLE CATCH SAMPLE	European eel	*Anguilla anguilla*	15
					Bullhead	*Cottus gobio*	15
					Pike	*Esox lucius*	3
					Brown / sea trout	*Salmo trutta*	11
					10-spined stickleback	*Pungitius pungitius*	2

9.3. Macroinvertebrates

9.3.1. Data availability

There are 13 Environment Agency invertebrate monitoring sites, as shown in Table 9-1 and Figure 9-1, all of which are downstream of Lordington. In total, 176 different invertebrate species have been identified in the river. However, it is important to note that only since 2000 have the data been analysed at species level, pre-2000 the data was only analysed at family level. The sample dates range from 1989-2010, with no spatial or temporal pattern of sampling or consistency over that period.

In 2013 Centre for Hydrology and Ecology (CEH) presented a report on the ecohydrology of the upper and middle River Ems. This report used data from the River Habitat Survey (RHS) and macroinvertebrate biomonitoring, to build on the work of Holmes (2007).

A further report was produced by AMEC in 2016 which presents results of macroinvertebrate sampling undertaken in spring 2016. Results for the 2021 macroinvertebrate surveys undertaken by the Environment Agency were not available at the time this report was written.

No Riverfly monitoring has been undertaken on the River Ems according to the Riverfly Partnership Data Explorer (Riverfly Partnership, 2021), but FotE have been taking macroinvertebrate samples. Data for these samples would be gratefully received to aid further analysis.

9.3.2. WFD status

The River Ems is currently assessed as 'Moderate' for invertebrates in the 2019 WFD classification and has been since 2009; before which there was no classification. There are two named RNAG associated with invertebrates which are flow – groundwater abstraction and physical modification – flood protection (structures).

9.3.3. Results

9.3.3.1. Community overview

There are have been no protected freshwater invertebrate species found in the River Ems[15], however there are a number of notable species identified, defined by those scoring six or above for the conservation score (Chadd & Extance 2004); anything above six is regionally notable or above (e.g. RBD status). These were then cross referenced with the JNCC taxa list and NHM 'Search for a UK species' website (NHM, 2021) for further information and removed if described to be widespread (e.g. *Baetis buceratus):*

- *Allotrichia pallicornis* – nationally scarce caddisfly (Eaton, 1873) which was recorded in 2001 (2) and 2003 (1)
- *Amphinemura standfussi* - nationally scarce stonefly (Ris, 1902) which was recorded in 2003 (1), 2007 (1) and 2010 (1)
- *Caenis pusilla* – nationally rare mayfly (Navas, 1913) which was recorded in 2008 (1)
- *Gyraulus laevis* – nationally scarce mollusc (Alder, 1838) which was recorded in 2004 (1)
- *Nebrioporus depressus* (Fabricius, 1775) – near threatened beetle which was recorded in 2008 (1) and 2010 (1)
- *Niphargus aquilex* (Schoidte, 1855) – although no conservation status, this groundwater-dwelling amphipod was recorded in 2003 (1), 2004 (2) and 2005 (1)
- *Oxycera morrisii* (Curtis, 1833) – nationally scarce true fly which was recorded in 2003 (1) and 2004 (1)
- *Oxycera pygmaea* (*nigripes*) (Fallen, 1817) – nationally scarce true fly which was recorded in 2003 (1)
- *Paraleptophlebia werneri* (Ulmer, 1919) - nationally scarce mayfly which was recorded in 2010 (1)
- *Rhyacophila septentrionis* (*fasciata*) (Hagan, 1859) – nationally notable caddis fly recorded in 2009 (1)
- *Riolus cupreus* (Muller, 1806) – nationally scarce beetle which was recorded in 2000 (1) and 2009 (1)

[15] Estuarine notable species such as Tentacled Lagoon Worm and Starlet Sea Anemone are associated with Slipper Mill at the mouth of the Ems – see https://www.smppa.org.uk/

- *Riolus subviolaceus* (Muller, 1806) – nationally scarce beetle which was recorded in 2003 (2), 2005 (1), 2006 (1) and 2008 (2)
- *Sympetrum nigrescens* (Lucas, 1912) – dragonfly red listed, which was recorded in 2004 (1)
- *Vanoyia tenuicornis* (Macquart, 1834) – nationally scarce true fly which was recorded in 2003 (1) and 2004 (1)

NB: the number in brackets refers to the number of times the species was recorded in each year.

The full list of invertebrate species can be found in Appendix A, with biotic scores provided in Appendix B.

9.3.3.2. LIFE scores

Figure 9-2 show the Lotic Invertebrate for Flow Index (LIFE) scores each site over time. LIFE scores link macroinvertebrate data with flow data and is calculated by assigning each taxa to one of six groups depending to their perceived ecological flow conditions. The groups range from rapid flows to drought impacted sites. A secondary category related to abundance is then assigned to each taxa and these are then used to calculate LIFE scores (Extance *et al.,* 1999 & Clarke *et al.,* 2003). LIFE Family (F) scores were chosen for analysis as all samples have been given a family score, whereas only more recent samples had a LIFE species (S) score.

Table 9-3 below shows the interpretation values for LIFE scores. If a community has a higher LIFE score (>7.26 and above) this suggests that species present have a 'high sensitivity to reduced flows' meaning that higher flows are more often than not present and that reduced flows are less typical otherwise this community would not be able to survive.

Table 9-3 - LIFE score interpretation (Extence *et al.,* 1999; Clarke *et al.,* 2003)

LIFE index	Macroinvertebrate community flow sensitivity
7.26 and above	High sensitivity to reduced flows
6.51 – 7.25	Moderately sensitive to reduced flows
6.5 and below	Low sensitivity to reduce flows

For LIFE (F) there was no real pattern of change over time, with large fluctuations seen both over time and between sites. Some sites, for example 82658 which is located just upstream of the canal, decreased over time. The two sites with the longest record, 82657 and 75936, show periods of both increase and decrease over time. A shorter-term analysis will be useful once 2021 results are available.

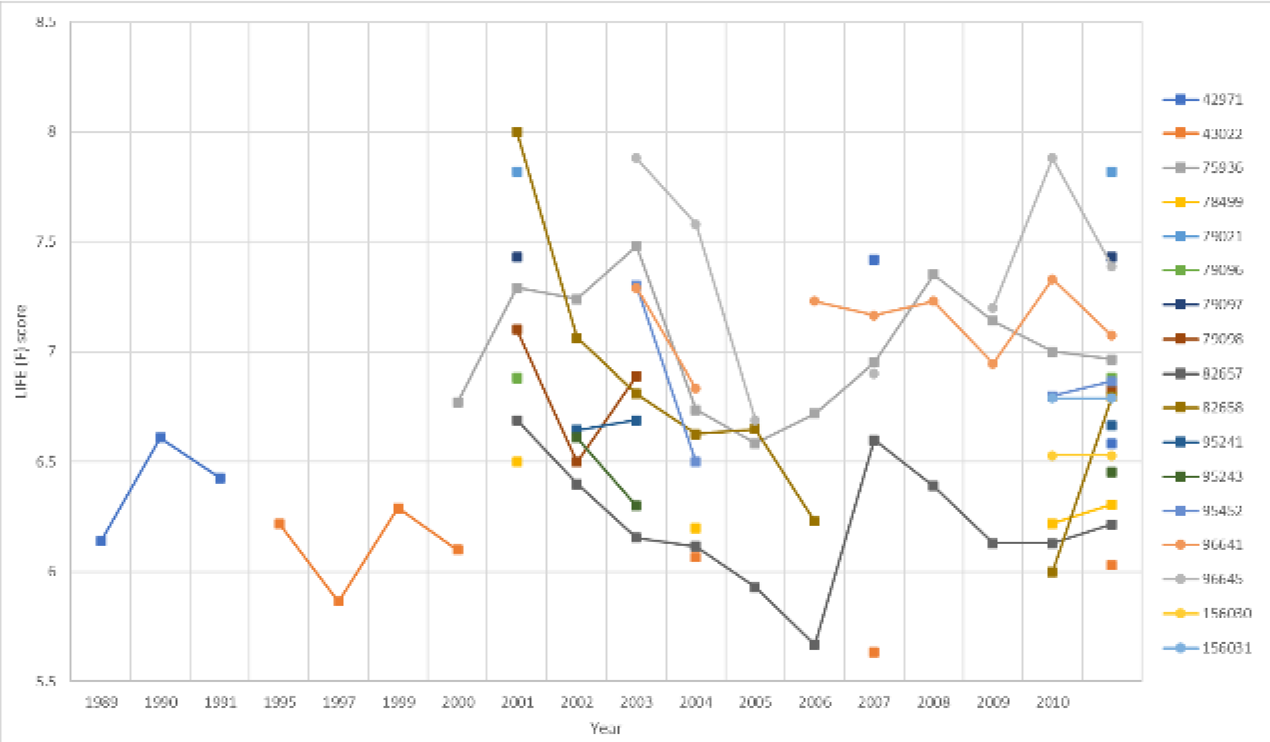


Figure 9-2 - LIFE (F) scores for each monitoring site along the River Ems over time

As shown, most of the scores fall within the medium-low sensitivity to reduced flow, however in periods of time at some sites the scores are within those that suggest a high sensitivity to reduced flows.

Figure 9-3, Figure 9-4, Figure 9-5, Figure 9-6 and Figure 9-7 show the LIFE (F) index score plotted against the flow data from Westbourne gauge on the River Ems, for each sampling site and for sites 82657 (River Ems at the Canal), site 82658 (River Ems upstream of The Canal), site 75936 (River Ems at Westbourne, just upstream of the Wren Centre) and site 43022 (River Ems downstream of the A27).

Use macroinvertebrate LIFE (F) scores as an indicator for a community indicative of 'better' flow conditions, Table 9-4 shows:

- Where it was sampled, the downstream-most site (River Ems downstream A27, site ID 43022) had communities with low sensitivity to reduced flows.
- Noting there was only one year in which these two sites were sampled at the same time, the next site upstream near The Wren centre (site ID 75936) had communities with high sensitivity to reduced flows in almost all years except 2001 and 2004.
- The site at The Canal (site ID 82657) had generally reduced sensitivity to reduced flows, presumably as a result of impoundments in this reach.
- Upstream of The Canal and downstream of the historic augmentation point (site ID 82658), the community really ranged between low and high sensitivity to reduced flows, showing a low sensitivity to reduced flows in recent years.
- Of interest is the site at Broadwash (site ID 96645) which, where it was sampled, had communities either moderately sensitive or highly sensitive to reduced flows. This is contrary to hydrological data suggesting this reach has ephemeral flows.

- Where it was sampled, the upstream-most site (River Ems at Walderton, site ID 78499) had communities with low sensitivity to reduced flows, except in 2001 where it had a community with a moderate sensitivity to reduced flows.

Table 9-4 – Longer-term monitoring sites with LIFE scores above 7.26 (highlighted in green), below 6.5 (amber) and between 6.5 and 7.26 (yellow). Note that years with no data / not monitored are not coloured in.

Site ID	43022	75936	82657	82658	96645	78499
Site description	River Ems downstream A27	River Ems at Westbourne, just upstream of The Wren Centre	River Ems at The Canal	River Ems upstream The Canal	River Ems at Broadwash	River Ems at Walderton
1995						
1996						
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2008						
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2010						

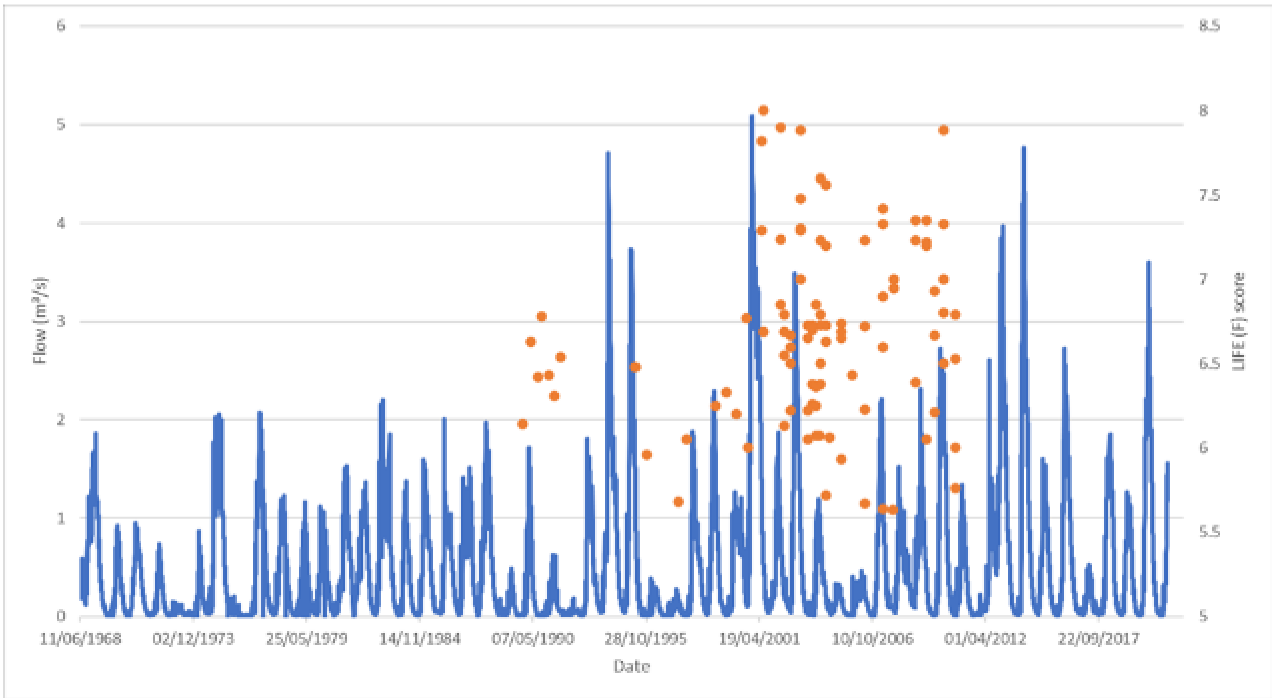


Figure 9-3 - Long term flow data and LIFE (F) scores for all sites along the River Ems

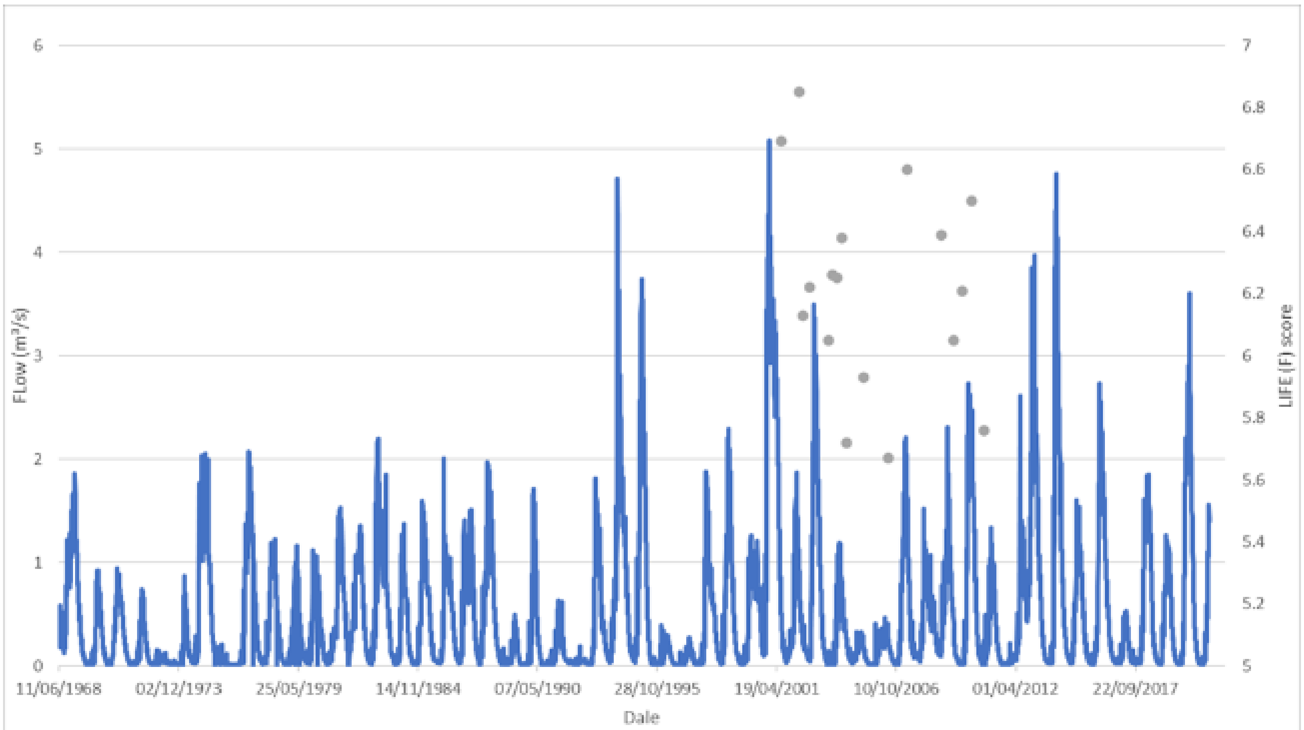


Figure 9-4 - Long term flow data and LIFE (F) scores for site 82657 – River Ems at The Canal

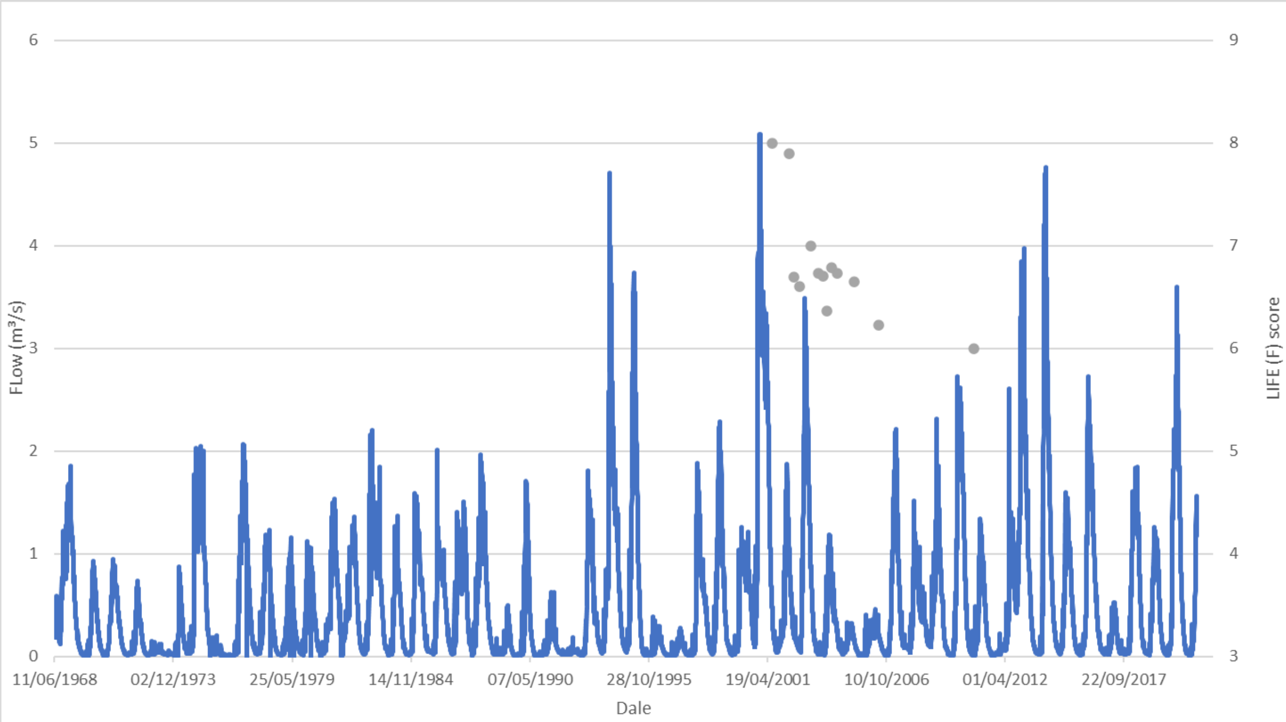


Figure 9-5 - Long term flow data and LIFE (F) scores for site 82658 - River Ems upstream of The Canal

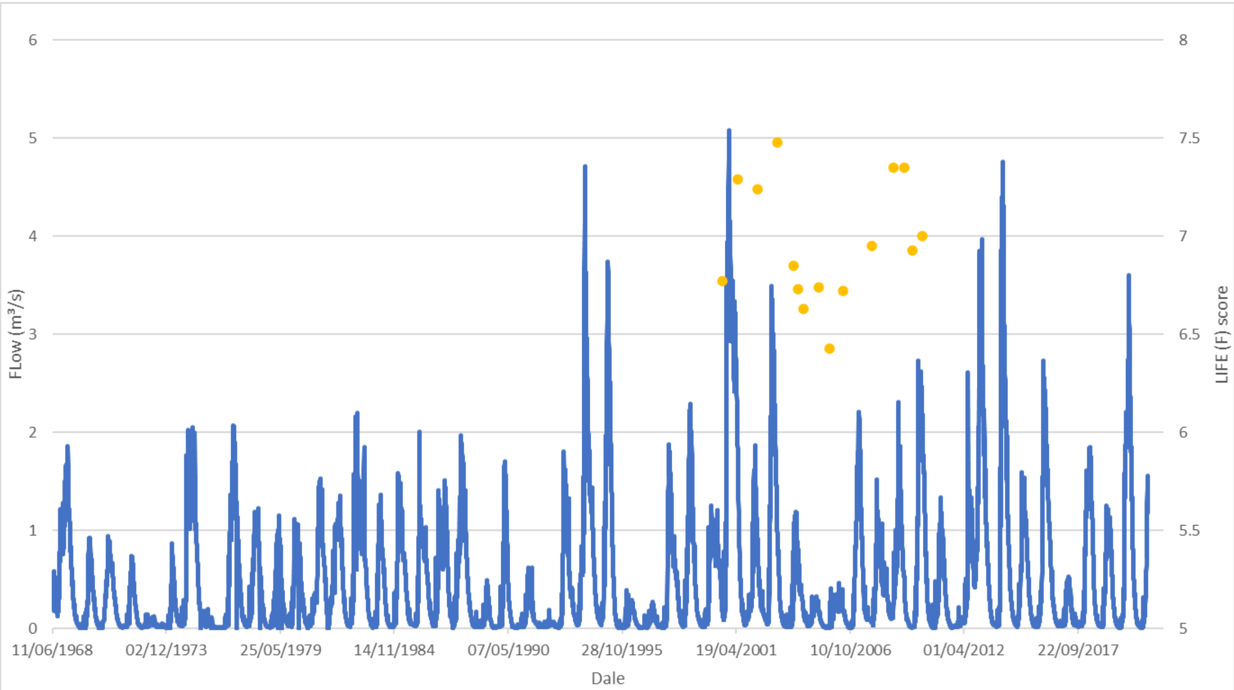


Figure 9-6 - Long term flow data and LIFE (F) scores for site 75936 - River Ems at Westbourne, just upstream of the Wren Centre

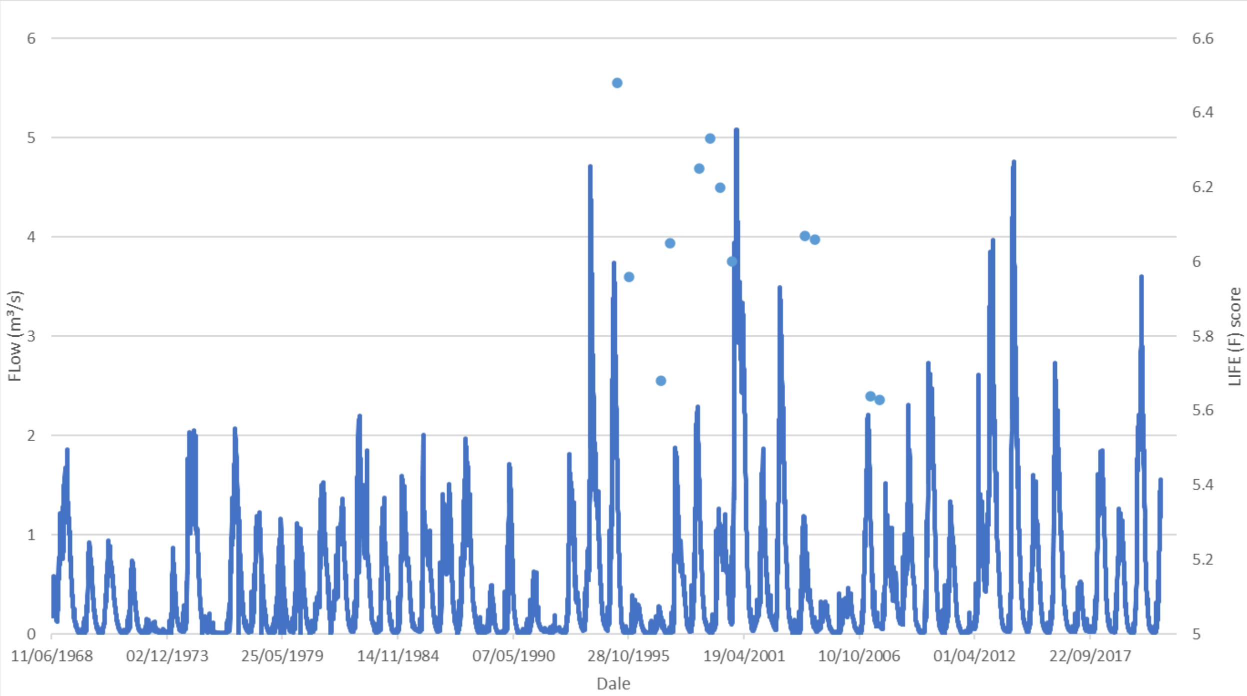


Figure 9-7 - Long term flow data and LIFE (F) scores for site 43022 - River Ems downstream A27

9.3.3.3. WHPT scores

The invertebrate WFD classification is now based on the Walley Hawkes Paisley Trigg (WHPT) scoring system. WHPT metrics replaced the Biological Monitoring Working Party (BMWP) metrics used for WFD status classifications in the first river basin planning cycle (RBMP1). WHPT differs from BMWP in a number of ways. The main difference being that the biotic indices for each taxon have been updated from the 1-10 BMWP scores based on the latest scientific understanding of macroinvertebrate groups. This means that groups that previously did not have BMWP scores have now been added to the scoring system. The biotic indices are also abundance weighted rather than solely working on a presence / absence basis. A full overview of WHPT scores per taxon can be found in UKTAG (2021c). Total WHPT and WHPT APST scores are key indicators of general water quality and have been presented below.

The WHPT ASPT (Average Score Per Taxon) is the average of the pressure sensitivity scores of all macroinvertebrate families or taxa found during each sample at a site. This is calculated by dividing the total of the scores by the number of scoring families or taxa. The pressure sensitivity score ranges from -0.9 to 13. As mentioned, these scores are weighted by abundance and therefore species scores can increase or decrease depending on the abundance within the sample.

Figure 9-8 and Figure 9-9 show the Total WHPT and the WHPT ASPT scores as an average for each year for each site. As shown, the scores variate significantly both between sites and over time.

Sites 75936 and 82657 have the longest records. For WHPT APST both of these sites vary over time, but 75936 has a higher score in 2010 than at the start of the record in 2000. Whereas, at site 82657, the score decreases between 2001 and 2010, despite large increases in 2005 and 2007. These sites again both show periods of both increasing and decreasing but for Total WHPT both end with a higher score in 2010 than in 2000/2001. It remains difficult to extract any real patters of change from the remaining sites due to short and / or intermittent records.

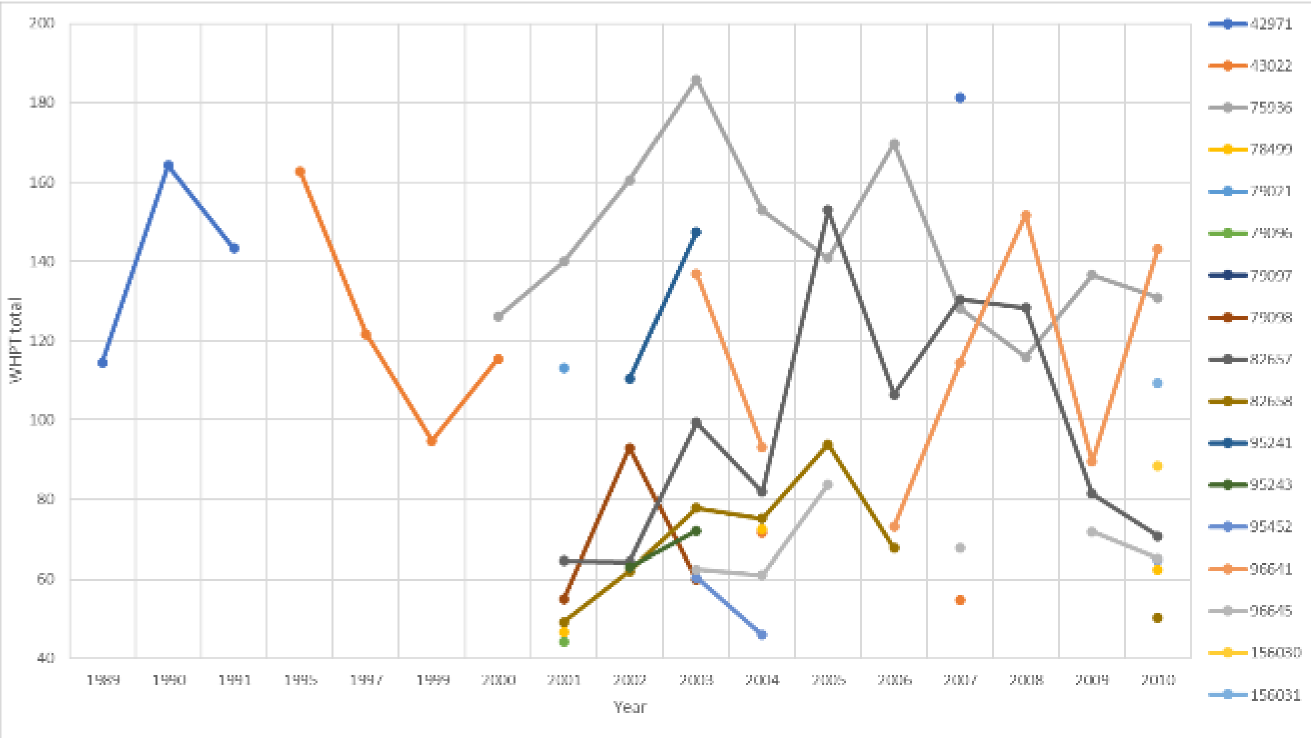


Figure 9-8 - WHPT total scores for each monitoring site along the River Ems over time

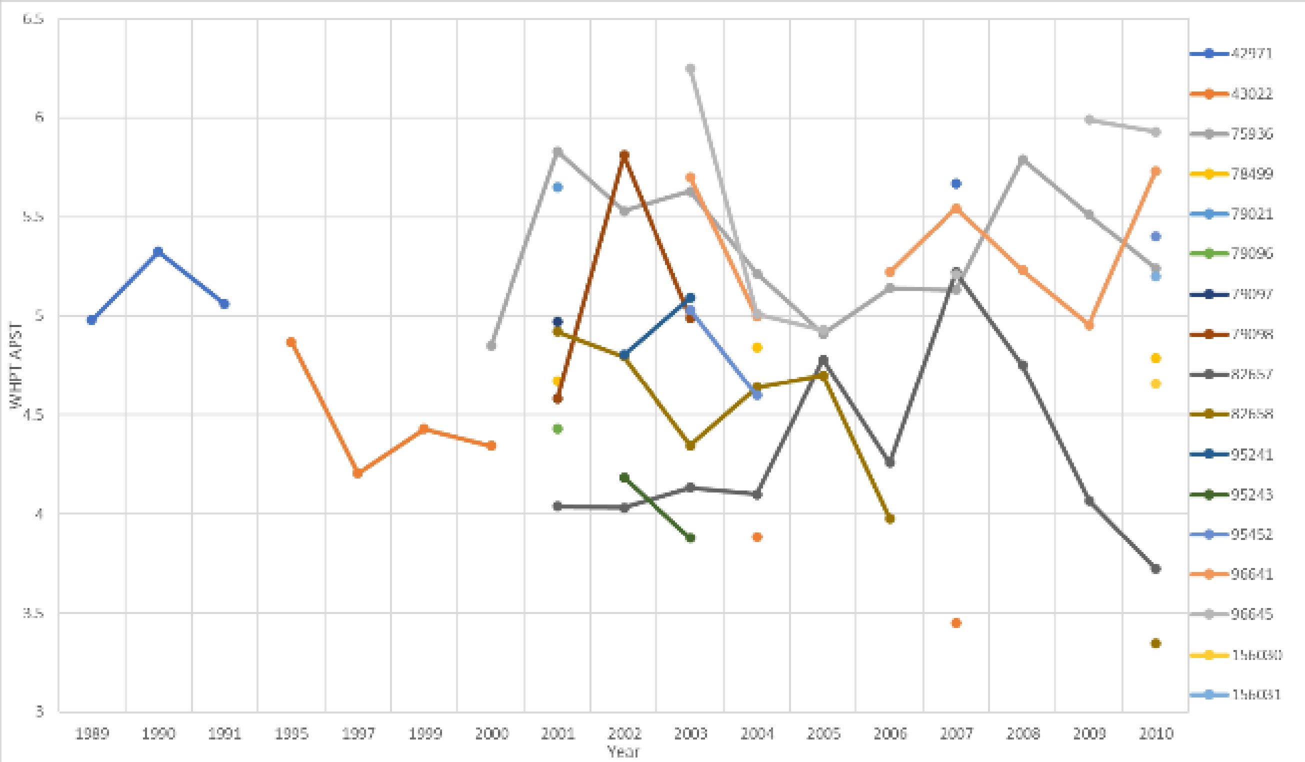


Figure 9-9 - WHPT ASPT scores for each monitoring site along the River Ems over time

9.3.3.4. Comparison to other studies

In 2013 Centre for Hydrology and Ecology (CEH) presented a report on the ecohydrology of the upper and middle River Ems. This report used data from the River Habitat Survey (RHS) and macroinvertebrate biomonitoring, to build on the work of Holmes (2007). The results showed a clear distinction in ecology between the ephemeral sites in the upper Ems to the perennial sites further downstream. The ephemeral sites tend to fall below the expected biomonitoring values but do present unusual species. The perennial sites, whilst sometimes falling below the expected biomonitoring values, often also exceed them.

A further report was produced by AMEC in 2016 which presents results of macroinvertebrate sampling undertaken in spring 2016. The results from this study suggested that the WFD status at the time would be ‘good’ or ‘high’ at all but one site, from the APST and WHPT APST Observed over Expected (O/E) ratios, but that the sample diversity (measured as number of taxa – NTAXA) was lower than this. It is suggested that this may mean there are issues with habitat supporting fewer species than expected but that water quality, as indicated by the ASPT, is ‘Good’.

Invertebrate samples have also been collected by FotE in 2021. Whilst we have not received the results, we understand that this recorded two stonefly families (Perlodidae – *Isoperla grammatica* Nemouridae – *Nemoura* sp.) at Broadwash bridge. Freshwater shrimp *Gammarus pulex* were also abundant along with occasional molluscs such as ramshorn snails (*Planorbis* sp.) and limpets (*Ancylus fluviatilis*). Broadwash Bridge would be an interesting site to keep monitoring.

9.4. Macrophytes

Macrophytes are plants, mosses, liverworts and some algal groups identifiable with the naked eye. They are easily sampled within rivers and streams and used to assess the impact of nutrients or flow on primary production. The macrophyte survey methodology followed was based on the WFD UK Technical Advisory Group (WFD UKTAG[16]) (2014) LEAFPACS2 methodology, which was based the Mean Trophic Rank (MTR) methodology (Holmes, 1999), which was used for assessing compliance with the Urban Waste Water Treatment Directive and WFD prior to the development of LEAFPACS and LEAFPACS2.

The MTR and LEAFPACS2 surveys are undertaken by wading the river and recording macrophytes that are likely to be submerged for >50% of the year, together with estimated percentage cover of each taxon. The LEAFPACS2 analysis methodology allows the calculation of the following biotic indices[17]:

- **River Macrophyte Nutrient Index (RMNI)** – This is a measure of which plants grow in the river and their association with high nutrients and is measured on a scale from 1-10. High scores are associated with species that dominate under enriched conditions. For example, fennel-leaved pondweed has a high RMNI score (9.6) and is therefore expected to dominate in highly enriched rivers. Other plants, such as broad-leaved pondweed have a lower score (5.7) and are replaced as nutrients increase. The overall observed RMNI score for the river is the cover weighted average of the individual scores of the different species found there.
- **Number of macrophyte taxa (N_TAXA)** – The number of different aquatic macrophytes present.
- **Number of functional groups of macrophyte taxa (NFG)** – A measure of how many different growth forms of aquatic plants are present in the river.
- **Percent cover of filamentous algae (ALG)** – The extent of green filamentous algae in the channel.
- Macrophyte species cover values are as found in the table below.

Table 9-5 - Macrophyte Percentage Cover Value (PCV)

PCV	Percentage cover of macrophyte species
C1	<0.1%
C2	0.1-1%
C3	1 to 2.5%
C4	2.5 to 5%
C5	5 to 10%
C6	10 to 25%
C7	25 to 50%
C8	50 to 75%
C9	>75%

Interpretation of the four scores is undertaken by comparing the scores found against those predicted for each site using statistical models. For each of the five characteristics, a ratio is calculated to compare what is observed in the river with what would be found in a similar river with no or very low human disturbance. The five ratios are combined into a single number, the Ecological Quality Ratio (EQR), that ranges from 1 (unimpacted or natural state) to 0 (highly degraded by pollution or other disturbance). The EQR is subdivided equally into five bands as required by the WFD.

In addition to these indices, derived from the LEAFPACS2 methodology, MTR scores can be also calculated, although this index is no longer used under WFD, it still provides valuable information on the status of rivers within the UK. At a high level, the interpretation of MTR scores is as follows:

[16] UKTAG stands for United Kingdom Technical Advisory Group.
[17] It is noted that since the introduction of LEAFPACS2, River Macrophyte Hydraulic Index (RMHI) has been removed from the analysis methodology (Personal Communication, Patrycja Meadows, Environment Agency Technical Specialist).

- Sites with MTR scores of more than 65 are unlikely to be eutrophic. However, these sites could be at risk of becoming eutrophic and the MTR should be compared with that expected in an un-impacted, physically similar reach.
- Sites with MTR scores of less than 25 are badly damaged by either eutrophication, organic pollution, toxicity or are physically damaged.
- Sites with MTR scores between 25 and 65 are likely to be either eutrophic or at risk of becoming eutrophic. However, as the MTR may be limited purely by the physical nature of the site, the MTR should be compared with that expected in an un-impacted, physically similar reach. This is probably most relevant to those sites with MTRs between 45 and 65 (see Table 1); below an MTR of 45, it is likely that the site is impacted by eutrophication. Sites with a high number of species which are unimpacted may often have MTR scores in the range 45–65. This is due to the large number of species with STRs of 4–6 which biases the MTR to 40–60. Sites which are obviously unimpacted (eg >20 species present) should be recognised as such within this category.

A downstream change in MTR is deemed to be significant if the difference is at least 4 MTR units or 15%.

9.4.1. Data availability

Environment Agency data were limited to one site on the River Ems, sampled one year apart on 20/08/2013 and 13/08/2014. The site is located on The Canal in the Middle Ems, upstream of Watersmeet and the confluence with the Aldsworth Arm (Figure 9-1).

Holmes (2007) carried out five surveys at seven sites between September 2005 and May 2007, with four additional sites surveyed in 2006 and 2007. The full analysis of the data can be found in the 2007 report and a summary is provided below.

AMEC (2013) completed macrophytes surveys in September 2011 and 2012 at six locations along the river Ems.

Two botanical surveys were undertaken by Bruce Middleton in August 2020, covering a total of five sites including one site (Site 1) on the Aldsworth Arm and four sites on the Lower Ems south of Westbourne (Middleton Ecology, 2020).

9.4.2. WFD status

The River Ems was classified as ‘High’ for macrophytes and phytobenthos combined in the 2019 Cycle 2 WFD classification; it has been classified as ‘High’ since 2015, before which there was no classification. However, the classification is based on only two surveys (2013 and 2014) when usually a minimum of three samples are required to complete a classification.

9.4.3. Results

In the most recent record from August 2014, 23 taxa were recorded. 17 were recorded in the 2013 survey. The list of taxa found during each sample can be found in Table 9-6. The River Macrophyte Nutrient Index (RMNI) for the site was 7.55 in 2014, an increase from 6.97 the previous year, indicative of a macrophyte assemblages’ preference for enriched nutrient conditions. Table 9-6 also shows the percentage cover band of each taxa found in 2013 and 2014. These results show there has been a substantial increase in the coverage of some species, which is quite unusual e.g. *Sparganium erectum*. This species can become more dominant in channels with lower flows.

A number of chalkstream species indicative of clean water were also recorded including lesser water parsnip *Berula erecta*, water cress *Rorippa nasturtium-aquaticum agg.,* starwort *Callitriche obtusangula* and water crowfoot *Ranunculus (Batrachian)* spp. and a red algae, *Hildenbrandia rivularis*, which grows as a crust on rocks and boulders.

Table 9-6 - Macrophytes taxa found at the monitoring site in 2013 and 2014, showing PCV for each species recorded (see Table 9-5 for explanation of each PCV)

Latin name	Percentage Cover Value (PCV)	
	2013	2014
	20/08/2013	13/08/2014
Apium nodiflorum	1	3
Berula erecta	1	1
Blue-green algal scum / pelts		1
Bryophyta (mosses)		1
Callitriche sp.	1	2
Callitriche obtusangula	1	
Carex riparia		1
Chiloscyphus polyanthos	1	
Cladophora (filamentous algae)	1	
Epilobium hirsutum		1
Equisetum fluviatile		1
Fissidens sp.	1	
Hildenbrandia rivularis	1	
Lemna minor	1	2
Lemna minuta		1
Lemna trisulca	1	1
Mentha aquatica	1	6
Myosotis scorpioides	1	5
Oenanthe crocata	1	
Pellia endiviifolia	1	1
Persicaria hydropiper		1
Phalaris arundinacea		1
Ranunculus (Batrachian) spp.	1	3
Rhynchostegium riparioides	1	
Rorippa nasturtium-aquaticum agg.		3
Rumex hydrolapathum		1
Schoenoplectus lacustris		1
Sparganium erectum		7
Typha angustifolia		2
Veronica anagallis-aquatica		1
Veronica anagallis-aquatica/Veronica catenata	1	
RMNI	6.97	7.55
RMHI	6.95	7.7

9.4.4. Comparison to other studies

The Holmes 2007 report presents data undertaken through surveys at seven sites, five times between September 2005 and May 2007. The method used was Holmes' MTR methodology, which is described above.

According to Holmes, the river varies significantly along its reach in terms of flora. A dryland community, with wetland taxa, dominates the reach upstream of Broadwash, with taxa such as Water-mint *Mentha aquatica* and Fool's Water-cress were found. These taxa can be found in either wet, dry, or ephemeral systems, but are more reflective of dry conditions. At Racton Farm Pond, characteristically of wetter conditions, a richer array of (according to Holmes) classic winterbourne taxa were found, e.g. *Ranunculus peltatus* (Pond Water Crowfoot – a 'species associated with winterbournes' according to Holmes (2009)).

The community changes at Broadwash to reflect perennial flow conditions, with taxa such as *Berula erecta, Ranunculus penicillatus* subsp. *pseudofluitans* (a "classic species of chalk rivers" according to Holmes (2009)) and *Callitriche obtusangula* found which are typical of perennial chalk streams. Holmes concludes that the flora recorded within these surveys is "reflective of a classic winterbourne". It has a downstream progression from largely terrestrial species upstream of Walderton to wetland and aquatic taxa closer to Broadwash. Full macrophytes data can be found in Annex 2 of the Holmes (2007) report.

AMEC (2013) completed macrophyte surveys in September 2001 and 2012 at six locations along the Ems, using the LEAFPACS methodology. Full results can be found in Appendix M of the AMEC report. The report summarises that the macrophyte community retains some of the characteristics of a perennial systems, but that restoring a more frequent flow would improve the communities.

Table 9-7 provides a selected species list of chalkstream indicator species as 'present' in the Middleton Ecology (2020) report.

Table 9-7 - Indicator species recorded by Middleton Ecology (2020)

Latin name	Common name
Ranunculus pencillatus subsp. *pseudofluitans*	Brook Water Crowfoot
Veronica anagalis aquatica	Blue Water Speedwell
Rorippa-nasturtium-aquaticum	Water-cress
Callitriche obtusangula	Blunt-fruited Water Starwort
Glyceria fluitans	Floating Sweet-grass
Hildenbrandia rivularis	(red algae on stones)
Hygroamblystegium tenax	Fountain Feather-moss
Platyhypnidium ripariodes	Long-beaked Water Feather-moss
Cratoneuron filicinum	Fern-leaved Hook-moss
Pellia endiviifolia	Endive Pellia

During a catchment walkover in spring 2021, long sections of the Aldsworth Arm's westernmost channel were observed to be almost entirely covered by *Hildenbrandia rivularis*. In terms of other species not recorded by the Environment Agency, *Batrachospermum*, an alga colony associated with hard or neutral waters not associated with polluted water, was also recorded in the lower Aldsworth Arm whilst the red alga *Lemanea* was found in the River Ems in Westbourne village. *Hildenbrandia rivularis* was exceptionally abundant in Racton Dell, especially under tree cover and both on the main course of the River Ems as well as its local tributary.

In addition, it is our understanding that as part of a water vole survey undertaken on 11/06/2020, *Audouinella pygmaea* was recorded to be present in the lower Ems, which has been verified by the Natural History Museum[18]. It is understood that this species was last seen in England about 1904 in West Yorkshire and the River Ems is the only site where it is still extant in England. There is also a 2015 record for the lower Wye, Wales[19] It will only survive desiccation for very short periods of time.

[18] Personal communication, Sandy Galloway, March 2021.
[19] https://www.algaebase.org/search/species/detail/?species_id=32441&sk=10

9.5. Diatoms

Diatoms are a type of phytobenthos, typically living in a layer on top of hard substrate and plant material, and are considered a good indicator of nutrient enrichment (most notably phosphorus) and other pressures which can be used to understand the water quality of a river (WFD UKTAG, 2021b). Diatoms, a large type of algae, are used to determine one part of the macrophyte and phytobenthos quality element of the WFD status of a river using a tool called DARLEQ2. DARLEQ2, which stands for Diatoms for Assessing River and Lake Ecological Quality, is based on the Trophic Diatom Index (TDI), originally developed by Martyn Kelly (e.g. Kelly *et al.*, 2001)

9.5.1. Data availability

The Environment Agency diatom data are limited to two sites, with one sample at each taken on 17/04/2007. Both sites are in the bottom third of the river, just over 1km apart (Figure 9-1). At the upstream sampling location (Site ID: 75936), 32 different taxa were counted, and 25 counted at the downstream sampling location (Site ID: 43022).

9.5.2. WFD status

The River Ems has been classified as ‘High’ for macrophytes and phytobenthos combined in the 2019 Cycle 2 WFD classification; it has been classified as ‘High’ since 2015, before which there was no classification. However, the classification is based on only two samples (2013 and 2014) when usually a minimum of three samples are required to determine a classification and it is expected that this classification has, at least in part, been linked to the orthophosphate analysis results.

9.5.3. Results

From upstream to downstream the Trophic Diatom Index (TDI5) decreased from 82 to 65, with the percentage of motile valves[20] decreasing from 38% to 30%. Use of the look up table in Kelly *et al.*, (2001) suggests that the change is due to an increase in nutrients, notably phosphorus. However, it is important to note that single surveys should not be used to make decisions and/or infer patterns.

Table 9-8 - List of diatom taxa found at the two sampling sites on the River Ems in 2007

Taxa	Site ID	
	43022	75936
	17/04/2007	17/04/2007
Achnanthidium	58	
Amphipleura		6
Amphora (Other)	1	2
Amphora pediculus	91	81
Caloneis	2	1
Cocconeis (Other)		1
Cocconeis pediculus	1	3
Cocconeis placentula	4	16
Cyclotella	3	7
Cymatopleura		1
Denticula tenuis		1
Diploneis	2	5
Ellerbeckia arenaria		1

[20] Each individual diatom cell is contained within a case called a ‘frustule’. Each frustule is made out of two valves that typically overlap and interlock with one another, almost like an old fashioned snuff case. The valves are made out of silica and are there for protection. They are covered in small pores, grooves and other features which allow the identification of the diatom cells to species level.

Taxa	Site ID	
	43022	75936
	17/04/2007	17/04/2007
Encyonema - minutum-type	2	
Encyonema minutum		2
Eunotia		2
Frustulia		1
Gomphonema (Other)	16	2
Gomphonema parvulum		1
Gyrosigma		27
Karayevia clevei		2
Luticola		1
Melosira varians		1
Navicula - small forms	68	36
Navicula (Other)		12
Navicula cryptotenella	7	6
Navicula tripunctata	1	46
Neidium	2	
Nitzschia (Other)	6	4
Nitzschia amphibia	3	4
Nitzschia dissipata	12	
Planothidium	18	48
Psammothidium lauenburgianum		4
Reimeria sinuata	5	
Rhoicosphenia abbreviata	37	
Staurosira	4	18
Staurosirella		1
Surirella	2	
Synedra (Other)	1	
Tryblionella	3	
Ulnaria ulna	4	4
TDI5 score	**65.23**	**82.07**
Motile Taxa Score	**30.59**	**38.04**

9.5.4. Comparison to other studies

No other diatom studies were found to allow a comparison.

9.6. Conservation sites

There are no aquatic conservation sites in the catchment itself but the River Ems drains into Chichester Harbour Site of Specific Scientific Interest (SSSI), Chichester and Langstone Harbour Special Protection Area (SPA), Chichester and Langstone harbour Ramsar and Solent Maritime Special Area of Conservation (SAC). Brook Meadow Local Nature Reserve (LNR) is right at the bottom of the catchment in Emsworth. Chichester Harbour is also an Area of Outstanding Natural Beauty (AONB). Slipper Mill has been designated as a Site of

Nature Conservation Importance (SNCI). The whole catchment is also classified as a Nitrate Vulnerable Zone. The upper part of the Ems flows though the South Downs National Park and AONB.

There are a number of priority habitats identified within the Ems catchment, including: Deciduous woodland, Good quality semi-improved grassland, Saline Lagoons, Mudflats and Intertidal Substrate Foreshore. There is also ancient woodland along parts of the river. The River Ems also flows through Zone 1, Zone 2 and Zone 3 Source Protection Zones (SPZ) (Defra, 2021). SPZ are in place to protect public water supplies from diffuse and point source chemical pollution and put restrictions on development e.g. soakaways, heavy industry, storage of chemicals etc. within the SPZ[21].

The River Ems is recognised as a chalk stream in the World Wildlife Fund (WWF) Chalk Streams report and has patches of Woodpasture and Parkland Biodiversity Action Plan (BAP) habitat within the catchment.

9.7. Terrestrial ecology

Although it was not part of the scope to develop a whole list of terrestrial habitats and species, including review of NBN Gateway and biological records centre datasets, a number of ecological reports have been produced relating to the habitat of the River Ems and the surrounding area. These include the Desktop Biodiversity Report (Sussex Biodiversity Record Centre, 2014), Preliminary Water Vole Survey Report (Southgate, 2014) and a Botanical Survey (Middleton Ecology, 2020).

The Desktop Biodiversity Report includes Sussex protected Species Register, Sussex Bat Inventory, Sussex Bird Inventory, UK BAP Species Inventory, Sussex Rare Species Inventory, Sussex Invasive Alien Species, Full Species List and Environmental Survey directory records from Watersmeet (plus a 1km buffer) on the River Ems, from data held by Sussex Biodiversity Record Centre (2014).

The Water Vole Survey Report (Southgate, 2014), presenting results of a 2014 survey of Watersmeet, showed conclusive signs of water voles, including feeding stations, runs, burrows and latrines within this area and concluded that Water Vole were likely also present along other reaches of the River Ems also.

Atkins also understand from the FotE that a series of wildlife corridors have been identified by Chichester District Council as critical in maintain the connection between the South Downs national park / chalk downlands and the coastal plain. Of the five different wildlife corridors reviewed, the River Ems has been identified as the most important and consists of the river and the riparian woodland and grassland habitats that it supports . Species of interest include Kingfisher, Wintering Green Sandpipers, Snipe and Woodcock which we understand are all found along the river as well as summer migrants to be expected breeding throughout. We also understand that Water voles have been doing well along the river due to specific conservation actions and recent surveys have shown their movement into new areas

[21] See more information on the UK Government website: [Groundwater source protection zones (SPZs) - GOV.UK (www.gov.uk)]

10. Summary

10.1. Physical and geological setting

The study area is the catchment of the River Ems, in West Sussex. The River Ems is a chalk stream that rises from the foot of the South Downs. The northernmost point of emergence in wet periods is approx. 600 m beyond the centre of the village of Stoughton, but the river becomes perennial just upstream of Westbourne about 5 km from the source. After passing through Westbourne the river finally discharges into Chichester Harbour at Emsworth (Section 3.1). The topography of the catchment is dominated by the hills of the Downs to the north, with steep-sided mostly dry valleys incised into the hills. The lower half of the catchment flattens to become a coastal plain.

Land use within the catchment comprises a mixture of arable land, pasture and woodland (Section 3.1). There are a few small settlements and the only significant urban area is at its southern extent.

The principal aquifer within the River Ems catchment comprises the Chalk aquifer of the South Downs (Section 3.2). The catchment is on the dip slope of the Downs so many of the constituent formations of the Chalk Group come to outcrop. In the southern part of the catchment the Chalk is overlain by clays of the Lambeth Group and London Clay. There are several minor folds within the Chalk body which can lead to varying degrees of fracturing.

Superficial deposits on the Chalk outcrop comprise mostly Clay-with-flints on the hilltops, some lobes of Head on the valley sides, while alluvium lies in thin bands along the valley bottoms. The clay bedrock in the south, on the coastal plain, is mostly covered with head and fluvial sand and gravel deposits.

10.2. Abstraction

Significant groundwater abstraction, for public water supply, has been undertaken in the catchment since the 1960s when the boreholes at Walderton were first operated. From 1962 the permitted abstraction rate at Walderton was about 9,000 m^3/day. Impacts on stream flows were perceived and, when the abstraction limit was raised to about 27,000 m^3/day in 1968, a flow augmentation scheme was established. Between 2016 and 2020, the average daily abstraction rate was around 20,000 m^3/day.

From 1968 to 2015 the augmentation scheme discharged water into the river at a location at the edge of Westbourne. After river restoration work on a reach of the river downstream of Racton Dell, in 2016 the discharge point was moved about 500 m upstream to provide more regular flow through the restored reach. From 1968 to 2015 the flow was taken as a proportion of the abstracted water at Walderton, but from 2016 the water has been sourced directly from the Woodmancote abstraction. Also from 2016 onwards the flow trigger level at the downstream gauge has been raised, and the augmentation discharge rate has been doubled.

There are minimal anthropogenic discharges in the catchment.

10.3. Hydrology

Rainfall and recharge is highest over the hills of the South Downs (Section 4.2). Over the Chalk outcrop, most recharge occurs in the period November to February. On average, about 45% of rainfall becomes recharge but more rainfall becomes recharge in wetter years (up to 66%) and in dry years less rainfall becomes recharge (down to 24%). With historical change in land use from pasture to arable (which tends to be bare in winter, allowing for more water to soak in the ground), recharge is expected to have increased by about 12% since the pre-war years.

The River Ems shows a clear transition from ephemeral headwaters (Upper Ems) to perennial lower sections of the river (Lower Ems). The exact transition within the Middle Ems is unknown and is expected that the perennial head is currently somewhere between the new (2016) augmentation point near Woodmancote and Broadwash Bridge.

The main stem of the River Ems rises in very wet years at Stoughton but lower down the river in dry years. About 5 km of the length of the Upper and Middle Ems south of Stoughton is ephemeral, meaning that it stops flowing in dry weather. Holmes (2007) reviewed qualitative evidence to suggest that prior to the development of significant groundwater abstraction in the catchment in the late 1960s, the ephemeral reach was only about 4 km in length (Section 4.4.1).

Flow augmentation is discharged to the river near Woodmancote and the river is perennial downstream of this point, but can experience very low flows (Section 4.4.2). The augmentation is clearly necessary at some times to prevent total loss of flow in the river, even though sometimes much of the augmentation flow appears to be lost (Section 4.6) and is not recorded at Westbourne Gauge. It is hypothesised the flow could be lost to ground due to its local geology.

The Aldsworth Arm is a tributary of the River Ems that comes to confluence with the river at Watersmeet. It contributes about one third of the flow at the Westbourne gauge but to date it has received little attention. Flows in this reach are also ephemeral.

10.4. Hydrogeology

The Chalk Group forms the principal aquifer within the catchment, and provides baseflow to the river and yield to the boreholes. There is considerable spatial and vertical heterogeneity in the aquifer properties of the Chalk, due to stratigraphic differences in fracture development, dissolution enhancement of flow pathways in the above the normal water table and along valleys, and because of compression and tension near the cores of minor folds.

Groundwater levels vary seasonally, and there is minor influence of long-term variation in recharge (Section 5.3.2). The seasonal amplitude in groundwater levels in the upper catchment is about 40 m, while closer to the ephemeral stretches of river the amplitude is nearer to 20 m. At Broadwash, where the river is said to have been formerly perennial, the amplitude is about 5 m. As a response to winter recharge, the peak in groundwater level moves southwards through the catchment and can take several months to reach the edge of the Chalk outcrop.

Groundwater contours fall southwards from a high point of 100 m AOD or higher beneath the South Downs (Section 5.3.3). The gradient of the water table is relatively even for both wet and dry conditions. In wet conditions there is minor 'V'ing next to rivers that gain baseflow discharge, and perhaps steepening where the water table crosses lower permeability Chalk strata (the Newhaven Chalk Member which stretches across the centre of the catchment: Figure 5-3).

In dry conditions the water table is considerably lower than river bed level over most of the catchment. During spring and summer, as groundwater levels fall more upstream the point of flow emergence moves downstream. This may happen in weeks so it will appear that the river dries up quickly.

There is some evidence that commencement of pumping of Walderton affected local summer groundwater levels, but not winter groundwater levels. This is because the winter groundwater levels in the boreholes where this was observed are controlled by stream bed levels (below).

10.5. River-aquifer interaction

When the water table is at river bed level there is baseflow discharge (Section 5.4). The regional water table rises and falls so quickly that there is likely little transition period between conditions when there is baseflow along much of the ephemeral reach and when there is not.

There are non-linear head-flow responses in the aquifer, whereupon when the water table rises to a certain elevation, flows increase considerably - leading to groundwater flooding.

10.6. Water balance

A full water balance has not been undertaken as part of this study, as the existing and future models can provide more accurate and consistent quantification. From preceding sections, however, mean annual inflows and outflows for the catchment are presented in Table 10-1. Whilst this is not an internally consistent water balance the inflows and outflows are very close. On average, abstraction accounts for 34% of annual recharge.

Table 10-1 - Long term average (1965-2010) inflows and outflow of water to and from the Chalk outcrop of the River Ems catchment

	Inflows (mm)	Outflows (mm)	Reference
Soil moisture balance			
Rainfall	878		Table 4-3
Evapotranspiration		480	Table 4-3

	Inflows (mm)	Outflows (mm)	Reference
Aquifer water balance			
Recharge	398		Table 4-3
River flow		268	Table 4-4 (flow divided by catchment area)
Abstraction		134	Table 3-2* (flow divided by catchment area)

* Average abstraction from Portsmouth Water boreholes (2016-2020) plus licensed daily rates for other abstractions.

10.7. Hydromorphology

The Ems catchment has been physically modified for anthropogenic purposes (such as milling and farming) for centuries. Therefore, in the present day, the River Ems exhibits a highly modified channel (i.e. over-deepened, over-widened, straightened, diverted) which contends with numerous obstructions along its course (including mill ponds, weirs, sluices and artificial canalised sections) which act to impound water, can cause (excessive) siltation but also prevent fish migration.

10.8. Water quality

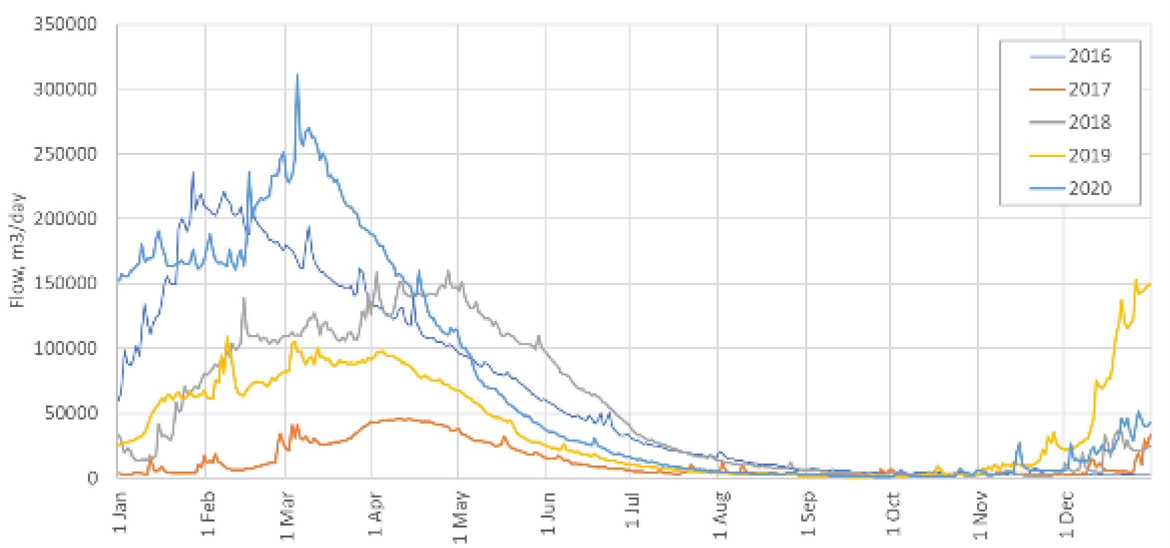
Analyses carried out for one monitoring location within the lowermost River Ems catchment indicates that dissolved oxygen concentrations have been indicative of 'Moderate' classification at a number of occasions throughout the data period (2000-2020) of which some coincide with drier years. All other WFD physico-chemical elements are shown to be indicative of 'Good' or 'High' classification, reflecting the absence of 'common' pressures such as diffuse or point source pollution sources. The Priority (Hazardous) Substances for which the River Ems is currently failing have not been monitored within the waterbody and have been expertly judged to be failing the required standards. Further discussion and verification of these compounds is required with the Environment Agency.

10.9. Flow influences on aquatic ecology

Whilst the Environment Agency has undertaken fish and macroinvertebrate surveys in 2021, prior to this date there were no surveys for macroinvertebrates for a period of 11 years ; and for the last 5 years for fish. The most recent formal aquatic macrophyte survey was undertaken in 2014, although some more recent biodiversity surveys have been undertaken in the catchment which have also recorded aquatic plant species. Those datasets available suggest that the current ecology has a number of chalk stream indicator species as well as notable and nationally rare taxa. With regard to fish, the 2021 survey revealed good numbers of European eel, Brown/sea trout and Bullhead in the Lower and Middle Ems, but absence of Roach and Chub meant that for WFD purposes the fish community is considered as 'poor'.

Modelling by AMEC (2013) indicates that, despite augmentation, the Q95 flow at the flow gauge at Westbourne was depleted by about 70%, and Q70 flows were depleted by about 61% (Section 4.6.1). EFIs are a screening tool to determine how far flows are away from naturalised. Compared with the EFI equirements for GEP (also in Section 4.6.1) it is quite certain that flow in the River Ems at Westbourne is not capable of supporting GEP, even with all the Walderton abstraction flows returned into the environment. The 'natural flows' modelled do not ignore Woodmancote and there are other abstractions from the same aquifer which pull water sideways out of the catchment.

Figure 10-1 Annual flows at Westbourne (2016-2020) compared to a flow hydrograph for ecological maintenance from WFD UKTAG (2013) compares the most recent years' flow hydrographs at Westbourne with the idealised hydrograph for maintenance of good ecology from WFD UKTAG (2013). Certainly, the spring flows are present, but the summer / autumn flows and flood flows are notably absent.



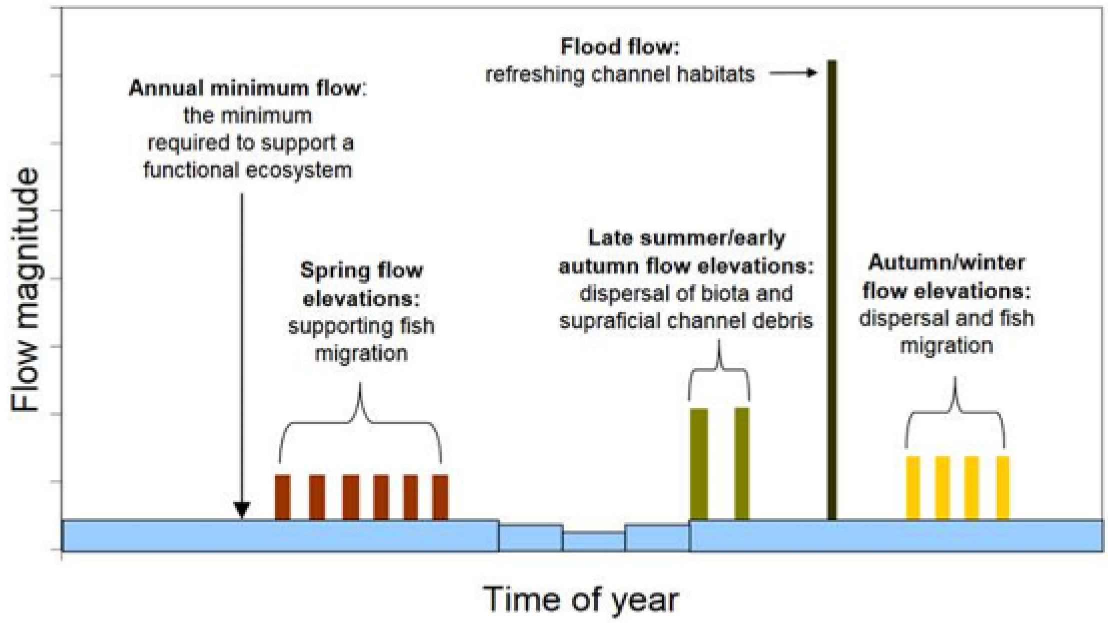


Figure 10-1 Annual flows at Westbourne (2016-2020) compared to a flow hydrograph for ecological maintenance from WFD UKTAG (2013)

11. Recommendations

Three main work packages are recommended, noting that there are some obvious and also less obvious synergies between the different tasks.

11.1. Task 1 – Hydrological monitoring & evidence gathering

Main objective: Collect necessary evidence to support tasks 2 & 3 and to justify requests for financial support from Ofwat, as appropriate.

Key questions to answer include:

- How does baseflow discharge move up and down the Middle Ems now and historically? What is the change in frequency of dryness at points along the river?
- What flows are expected in the tributaries and are these impacted by abstraction?

11.1.1. Hydrometric monitoring

The exact current location of the perennial head needs validation through more detailed hydrological monitoring over the course of a hydrological year, linking findings back to groundwater levels as well as the Walderton abstraction.

It is proposed that this uses a network of continuous water level loggers. Locations proposed include:

1. River Ems at Mitchmere Farm
2. Groundwater well at Lordington
3. River Ems at Walderton Water Pumping Station
4. River Ems at Lordington
5. River Ems at Racton (B2146/B2147 junction)
6. Tributary at Racton
7. River Ems at Broadwash Bridge
8. River Ems at Woodmancote augmentation point
9. River Ems upstream The Canal
10. Piezometer around The Canal
11. River Ems upstream Watersmeet
12. Alsworth Arm upstream River Ems

We propose that Onset HOBO U20L-01 Water Level Data logger (0-9m) (tempcon.co.uk) are used as these can be easily installed at bridges, in ponds and within the river bed's substrate. The loggers measure barometric pressure every 15 or 30 minutes and can collect data for up to 10 years. When coupled to a 'blank' logger on the bank, the difference between the logger underwater and surrounding air pressure will give a measure of water depth at a 0.1% accuracy. HOBO loggers are quite small and can be installed relatively easy and discretely even in areas with public access. Gauging boards will also be required to calibrate the loggers. Untelemetered loggers require data downloads via a USB port every 2-3 months or so to prevent the logger's memory from filling up. The Ordnance Datum (OD) should also be collected for each logger.

Additional data sources which should be used for assessment and will provide a whole catchment assessment include:

- Environment Agency rainfall data
- Environment Agency groundwater data (e.g. Compton) – to correlate this long-term dataset to the River Ems hydrology
- Mitchmere Farm water level records (weekly measurements)
- Portsmouth Water abstraction data
- Environment Agency Westbourne gauging station data

Data will need to be collated every year in a short technical report and the monitoring network reviewed as appropriate.

11.1.2. Flow gauging

Further spot gauging studies should be undertaken now that the source of the augmentation discharge has moved from Foxbury Lane to Racton Dell, and as the discharge rate has been increased. A denser set of measurements along the reach between Racton Dell and Watersmeet would be beneficial, including during augmentation release scenarios, to understand whether some of the augmentation discharge is lost to ground, or not.

Flow gauging should also be undertaken at each of the level logger installation points so water depth can be translated ('rated') to river discharge.

Closer examination of the 2011-2013 spot gauging data cited by AMEC (2013) would be of benefit as not all records were made available at time of writing his report.

11.1.3. Aquatic ecology surveys

The macroinvertebrate and fish datasets in particular require updating, particularly to determine the ecological benefits (or not) of the river restoration work undertaken upstream of The Canal as well as benefits (or not) of changes to the new augmentation flow regime. A site at Broadwash Bridge would also be useful.

The methodology should follow Environment Agency standard methodologies to allow comparisons to historic datasets and include:

- Fish surveys (1 per year, summer to align with historic surveys)
- Macroinvertebrate surveys (minimum 2 per year in spring and autumn, ideally 3 to cover the summer season also)
- Macrophyte surveys (1 per year June-September)

11.1.4. Water quality surveys

Evidence for WFD 'failures' for Priority Hazardous Substances should be evaluated and new data collected if this is not already planned.

We understand that the Environment Agency are investigating dissolved oxygen issues already using continuous monitoring sondes and that is flagging .

11.2. Task 2 – Update conceptual understanding and investigate flow augmentation discharge in Middle Ems

Main objective: Ensure that the augmentation flow regime supports the Lower Ems and lowermost Middle Ems

It is accepted between the various parties (FotE, Portsmouth Water, Environment Agency) that it is the Middle Ems reach which warrants further investigational work. The current baseline will be understood through the Task 1 hydrological monitoring and evidence gathering (ecological monitoring).

Key tasks include:

- Quantify any ecological benefits (or not) of the new augmentation regime within the Middle Ems.
- Establish the issues around the current augmentation flows for the benefit of any future flow improvements – i.e. Portsmouth Water have increased the flow, moved it upstream but less flow is making it to the lower reaches – so any changes in future are unlikely to provide any further benefits unless this is understood better. The timing, magnitude and frequency of occurrence needs to be understood. In addition, this reach is important for connecting the Lower Ems to upstream reaches now and in future.
- Identify potential 'easy' wins in the short term within this reach using the existing set up as well as through simple adjustments, e.g. different flow rates, timing, etc. It is noted that this requires some simulation of different future abstraction/flow augmentation discharge scenarios – which would need to be done as part of Task 4.

11.2.1. Gather ground condition data

Borehole logs available for this area highlight a transition in geology around the new augmentation point, but we lack the necessary detail to be conclusive. A more detailed understanding of ground conditions needs to be developed within the reach that receives the new augmentation flow to understand the superficial lithology better and understand if this is contributing to river flow losses in this reach. Ideally this is through hand augering, but if this is not possible a drilling rig should be used and shallow boreholes can be installed next to spot gauging stations, which can then be dipped in future or have telemetry installed. These data can then also be used to determine if the Woodmancote abstraction is reducing groundwater levels locally - or not.

11.2.2. Update conceptual understanding

Once the ground investigations are completed, we would need to review this report's conceptual understanding of the local geology in the Middle Ems.

11.2.3. Evaluate solutions to adjust the discharge point

Discussions are needed with the Environment Agency, FotE and other interested parties notably land owners to consider and if appropriate, trial adjustments to the flow augmentation discharge location. This should consider options available to move the discharge point including identifying potential locations, practicalities and permissions necessary e.g. to allow running temporary pipework down the riverbed, for instance.

The options will need to be informed by the updated conceptual understanding and flow monitoring around augmentation releases (Tasks 1 & 2). We highlight that this needs consultation with the local landowner, Alex Elms, who has recently undertaken improvements to Lord's Pond in Racton Dell.

The final output of this task is an options report for discussion with Portsmouth Water, Environment Agency and local landowners. There will need to be indicative drawings of the changes highlighting key assumptions and characteristics of the scheme as well as any constraints. Supplementary surveys and assessment may be required in future e.g. geomorphology and ecological surveys, Flood Defence Consents / WFD assessments.

11.3. Task 3 – Scenario testing of different abstraction regimes

Main objective: Recommend longer-term opportunities for flow betterment within the catchment

This Work Package is scoped on the assumption that some of the effects of abstraction will be better understood through the Task 1 hydrological monitoring and evidence gathering.

Tasks should include:

- Use the EHCC model and run two different scenarios in this to understand what reduction in abstraction at Walderton would make a material difference to flows in the river and from an ecological perspective identify what frequency of drying out is acceptable within the Middle Ems. Develop and agree scenarios for model with the Environment Agency and FotE.
- Flow monitoring during abstraction reduction experiments, covering both high groundwater / river level scenario and low groundwater / river level scenarios.
- Develop, with stakeholders, a set of feasible catchment objectives which cover habitats, flow and ecology for the Middle and Lower Ems.

11.4. Stakeholder discussions

Atkins recommend regular stakeholder discussions are held. These should include:

- Continuation of (monthly) discussions with FotE, Environment Agency, Arun and Rother Rivers Trust (ARRT) and other local interested individuals / organisations to integrate the FotE 'springwatch' findings and other observations into the overall catchment understanding.
- Continue alignment of the study with emerging government strategy work for chalk streams.
- Discussions with the Arun & Western Streams Catchment Partnership (led by the Wild Trout Trust) who have published a number of catchment plans on their website (dated March 2020) which includes future projects for the River Ems e.g. improving fish passage at Westbourne Mill in partnership with the Environment Agency, ARRT and Wild Trout Trust.
- Discussions with the Environment Agency to understand ecological monitoring findings, discuss results from follow-on surveys and assessments commissioned by Portsmouth Water and the latest thinking on WFD objectives and GEP Mitigation Measures.
- Discussions with the above parties to develop a set of feasible catchment objectives for the River Ems.

11.5. Future tasks

The practical implications of any changes to local abstraction regime need to be understood through the tasks outlined above. This could provide the evidence or scope for answering other questions such as:

- Would a change in the seasonal pattern of abstraction benefit flows in the river. Assuming that the water supply network could manage this, would reduction or cessation of abstraction in the early summer lead to material benefits in flows later in summer?
- The effectiveness, costs and benefits of solutions.

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Appendices

Appendix A. Full invertebrate list (ordered alphabetically)

Taxon	Year											Total
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	
Agabus biguttatus				1								1
Agabus bipustulatus			1			1	1			1		4
Agabus guttatus			1			1						2
Agabus nebulosus						1				1		2
Agabus paludosus							2					2
Agapetus fuscipes	1	3	5	5	2	2		2	1	3	3	27
Agraylea multipunctata			1									1
Allotrichia pallicornis		2		1								3
Amphinemura standfussi				1				1			1	3
Amphinemura sulcicollis					1							1
Anabolia nervosa										1		1
Anacaena globulus			1									1
Anacaena limbata						1	1					2
Anacaena lutescens										1		1
Ancylus fluviatilis	1	2	4	4	2	2		1		2	1	19
Anisus leucostoma			1	2	3	1		1		1	2	11
Anisus vortex		1	2	7	1	3	3				3	20
Apatania muliebris				1								1
Argyroneta aquatica										1		1
Asellus aquaticus	1	1	7	9	8	4	3	3	1	4	7	48
Asellus meridianus		1		7	9	2	2	2	1	5	5	34
Athripsodes albifrons							1					1
Athripsodes aterrimus						1				1		2
Athripsodes bilineatus			1									1
Athripsodes cinereus		2	2	1	2				1	3		11
Baetis buceratus											1	1
Baetis vernus			1	3	2	3					2	11
Bathyomphalus contortus				2								2
Bithynia leachii					1				1			2
Bithynia tentaculata		1	1	3	1	3	2	1		2	2	16
Brachycentrus subnubilus									1			1

Taxon	Year											Total
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	
Brychius elevatus				1	1					1	1	4
Caenis horaria						1						1
Caenis luctuosa		1	2	3	4	3	2		1	2	2	20
Caenis pusilla									1			1
Caenis rivulorum					1			3			1	5
Caenis robusta										1	1	2
Callicorixa praeusta				3							1	4
Calopteryx splendens							1		1			2
Centroptilum luteolum	1		1	1	3	3	1					10
Chaetopteryx villosa								1				1
Cloeon dipterum				4	1	1				1		7
Coelostoma orbiculare							1					1
Corixa punctata				2								2
Dendrocoelum lacteum	1	4	3	8	9	3	2		1		3	34
Dixa nebulosa					3		1					4
Donacia simplex				1								1
Drusus annulatus			3	2	1	1						7
Dryops luridus						1	1					2
Dugesia polychroa		1			2		1					4
Dugesia tigrina	1			2		1						4
Dytiscus semisulcatus							1					1
Elmis aenea	1	1	4	5	6	4	2	3	2	3	2	33
Ephemerella ignita						4	3					7
Erpobdella octoculata	1	2	9	10	8	3	3	4	2	4	5	51
Erpobdella testacea					7			1		1		9
Esolus parallelepipedus				1								1
Glossiphonia complanata	1	2	7	9	10	3	3	4	2	3	6	50
Glossiphonia heteroclita	1			1	1						1	4
Glyphotaelius pellucidus					2	1						3
Goera pilosa				2	1							3
Gyraulus laevis					1							1
Halesus digitatus						1						1
Halesus radiatus			1	1		1		1		1		5
Haliplus lineatocollis	1		1	1		1			1		1	6
Haliplus ruficollis							1					1

Taxon	Year											Total
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	
Helobdella stagnalis	1	1	8	8	10	4	2	3		2	3	42
Helophorus aequalis							1					1
Helophorus arvernicus					1							1
Helophorus brevipalpis					3		1			3		7
Helophorus grandis			1		1							2
Hemiclepsis marginata											1	1
Hesperocorixa sahlbergi				1								1
Hydrobius fuscipes							1					1
Hydroporus discretus											1	1
Hydroporus palustris									1		1	2
Hydroporus pubescens					1							1
Hydropsyche siltalai		1	1	2	2	1		2	1	2	2	14
Ilybius fuliginosus			1			1						2
Ischnura elegans						1	1					2
Isoperla grammatica		1	1	2	3		1	3		1	3	15
Laccobius biguttatus				1								1
Laccobius bipunctatus						1	1					2
Laccobius minutus										1		1
Lepidostoma hirtum		1	3	3	3	1	1	2	1	2	2	19
Limnephilus auricula					1						1	2
Limnephilus bipunctatus					1						3	4
Limnephilus centralis											1	1
Limnephilus flavicornis						1						1
Limnephilus lunatus		2	6	5	13	4	4	3		4	7	48
Limnephilus luridus									1			1
Limnephilus marmoratus						1					1	2
Limnephilus rhombicus						1						1
Limnius volckmari	1	2	3	3	2	3	2	3	1	2	2	24
Limnophora riparia			1	2								3
Lymnaea peregra			4	4	5	2	1			2	5	23
Lymnaea stagnalis							1					1
Lymnaea truncatula				1	1			1			1	4
Lype phaeopa						1						1

Taxon	Year											Total
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	
Lype reducta					1			1		1		3
Mesovelia furcata									1			1
Micropterna lateralis									1			1
Mystacides azurea				1	1	1			1			4
Mystacides longicornis											2	2
Nebrioporus depressus									1		1	2
Nebrioporus elegans	1				3	2	1			1	1	9
Nemoura cinerea			1	2	3			2			3	11
Nemoura erratica								1				1
Nepa cinerea				1								1
Niphargus aquilex				1	2	1						4
Ochthebius minimus						1	1					2
Orectochilus villosus				3	3	1	1	1			1	10
Oxycera morrisii				1	1							2
Oxycera nigricornis								1				1
Oxycera nigripes				1								1
Paraleptophlebia submarginata					1	2			1	1		5
Paraleptophlebia werneri											1	1
Peripsychoda fusca			1									1
Physa fontinalis			1	8	6	2	3	1	1	3	6	31
Physella acuta										2		2
Pilaria discicollis				3								3
Pisidium milium	1	1	2	2		2	3					11
Pisidium nitidum	1	1	2	3		3	2					12
Pisidium pulchellum						1						1
Pisidium subtruncatum		1	1	1		3	3					9
Planorbis planorbis	1				2			3				6
Platycnemis pennipes									1			1
Plea leachi				1								1
Plectrocnemia conspersa									1		1	2
Polycelis felina			1	3					1		1	6
Polycelis nigra		2	2	3		3	4	2				16
Polycelis tenuis			6		1			1				8
Polycentropus flavomaculatus	1		1	1	3	3	1	1		1	2	14

Taxon	Year											Total
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	
Polycentropus kingi									1		1	2
Potamophylax latipennis				1	1	1		1		1	1	6
Potamophylax rotundipennis		1								1		2
Potamopyrgus antipodarum						1					1	2
Prasocuris phellandrii						1						1
Procloeon pennulatum				1	1		1					3
Ptychoptera lacustris							1					1
Rhyacophila dorsalis		2	1	1	1			1		1	1	8
Rhyacophila septentrionis										1		1
Riolus cupreus	1									1		2
Riolus subviolaceus				2		1	1		2			6
Sericostoma personatum	1	1	4	7	4	4	1	4	2	5	4	37
Serratella ignita	1	4	8	7	8			4		4	4	40
Sialis lutaria			3	4	4	2	1	1	1	2	3	21
Sigara concinna											1	1
Sigara dorsalis			3	5	3	3			1	1	1	17
Sigara falleni				2	1	2	1					6
Sigara lateralis						1						1
Sigara limitata						1			1	1		3
Sigara nigrolineata				2							1	3
Sigara scotti									1			1
Sigara venusta				5	2	1	1		1		1	11
Silo nigricornis			1	3	1	2		1			2	10
Simulium angustitarse	1					2	1					4
Simulium aureum				1			2					3
Simulium costatum								1				1
Simulium equinum								4				4
Simulium erythrocephalum								3				3
Simulium lundstromi							1					1
Simulium noelleri							1					1
Simulium ornatum		2	1			1		2				6
Simulium vernum			2	4	1	2		2				11
Stagnicola palustris/fuscus/corvus			1	1		2	2	2		2		10

Taxon	Year											Total
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	
Stenophylax permistus										1	3	4
Stictotarsus duodecimpustulatus							1				1	2
Succinea putris										1		1
Sympetrum flaveolum					1							1
Sympetrum nigrescens					1							1
Theromyzon tessulatum	1			2			2			1	2	8
Tinodes unicolor					2							2
Tipula lateralis											1	1
Tipula montium		1	1	1								3
Trocheta subviridis			1									1
Valvata cristata				1		2	2					5
Valvata piscinalis				2	1	2	2		1	2	2	12
Vanoyia tenuicornis				1	1							2

Appendix B. Biotic scores for macroinvertebrate samples

Red colouring indicates samples with LIFE score <6.50; Blue colouring indicates sample with LIFE score >7.26.

SITE_ID	SAMPLE_DATE	WHPT_N_TAXA	WHPT_TOTAL	WHPT_ASPT	LIFE_FAMILY_INDEX
42971	23/11/1989	23	114.5	4.98	6.14
	11/04/1990	28	151.4	5.41	6.63
	10/08/1990	38	193.9	5.1	6.42
	23/10/1990	27	147.4	5.46	6.78
	01/03/1991	27	136.9	5.07	6.43
	05/06/1991	29	146	5.03	6.31
	26/09/1991	29	147.2	5.08	6.54
	17/04/2007	32	181.3	5.67	7.42
43022	18/04/1995	37	197.9	5.35	6.48
	31/10/1995	29	127.4	4.39	5.96
	15/05/1997	31	127.3	4.11	5.68
	13/10/1997	27	116.1	4.3	6.05
	08/03/1999	19	87.5	4.61	6.25
	07/09/1999	24	102.1	4.25	6.33
	06/03/2000	24	102.1	4.25	6.2
	02/10/2000	29	128.7	4.44	6
	17/03/2004	17	67.6	3.98	6.07
	07/09/2004	20	75.8	3.79	6.06
	17/04/2007	13	46.7	3.59	5.64
	04/10/2007	19	62.8	3.31	5.63
75936	25/08/2000	26	126.1	4.85	6.77
	23/05/2001	24	140	5.83	7.29
	23/04/2002	29	160.5	5.53	7.24
	11/04/2003	33	185.9	5.63	7.48
	20/01/2004	25	130.4	5.22	6.85
	09/04/2004	32	172.6	5.39	6.73
	06/07/2004	31	155.8	5.03	6.63
	11/04/2005	38	207.7	5.47	6.74
	10/10/2005	17	74	4.35	6.43
	05/06/2006	33	169.7	5.14	6.72
	31/10/2007	25	128.2	5.13	6.95
	04/11/2008	20	115.8	5.79	7.35
	20/05/2009	31	178.7	5.76	7.35
	12/10/2009	18	94.6	5.26	6.93
	30/03/2010	25	130.9	5.24	7
78499	05/04/2001	10	46.7	4.67	6.5

SITE_ID	SAMPLE_DATE	WHPT_N_TAXA	WHPT_TOTAL	WHPT_ASPT	LIFE_FAMILY_INDEX
	09/04/2004	15	72.6	4.84	6.2
	30/03/2010	13	62.3	4.79	6.22
79021	23/05/2001	20	113	5.65	7.82
79096	12/06/2001	10	44.3	4.43	6.88
79097	12/06/2001	7	34.8	4.97	7.43
79098	12/06/2001	12	54.9	4.58	7.1
	23/04/2002	16	93	5.81	6.5
	11/04/2003	12	59.9	4.99	6.89
82657	04/07/2001	16	64.6	4.04	6.69
	23/04/2002	18	87.9	4.88	6.85
	10/07/2002	18	66.1	3.67	6.13
	16/10/2002	11	39.1	3.55	6.22
	27/08/2003	26	108.4	4.17	6.05
	05/11/2003	22	90.3	4.1	6.26
	20/01/2004	19	80.3	4.23	6.25
	09/04/2004	19	77.4	4.07	6.38
	06/07/2004	22	88	4	5.72
	11/04/2005	32	153	4.78	5.93
	05/06/2006	25	106.4	4.26	5.67
	17/04/2007	25	130.4	5.22	6.6
	04/11/2008	27	128.3	4.75	6.39
	20/05/2009	23	107	4.65	6.05
	12/10/2009	16	55.8	3.49	6.21
	30/03/2010	19	82.1	4.32	6.5
	20/10/2010	19	59.4	3.13	5.76
82658	04/07/2001	10	49.2	4.92	8
	23/04/2002	12	67.6	5.63	7.9
	10/07/2002	15	67.1	4.47	6.69
	16/10/2002	12	51.5	4.29	6.6
	11/04/2003	22	103.3	4.7	7
	27/08/2003	18	78.5	4.36	6.73
	05/11/2003	13	51.7	3.98	6.7
	20/01/2004	15	63.9	4.26	6.36
	09/04/2004	19	99.2	5.22	6.79
	06/07/2004	14	62.2	4.44	6.73
	11/04/2005	20	93.9	4.7	6.65
	05/06/2006	17	67.7	3.98	6.23
	20/10/2010	15	50.2	3.35	6
95241	10/07/2002	22	107.3	4.88	6.79
	16/10/2002	24	113.4	4.73	6.5
	27/08/2003	32	162	5.06	6.65
	05/11/2003	26	133	5.12	6.73
95243	10/07/2002	13	53.2	4.09	6.55

SITE_ID	SAMPLE_DATE	WHPT_N_TAXA	WHPT_TOTAL	WHPT_ASPT	LIFE_FAMILY_INDEX
	16/10/2002	17	72.8	4.28	6.67
	27/08/2003	22	87.8	3.99	6.22
	05/11/2003	15	56.5	3.77	6.38
95452	11/04/2003	12	60.4	5.03	7.3
	09/04/2004	10	46	4.6	6.5
	30/03/2010	12	64.8	5.4	6.8
96641	11/04/2003	24	136.9	5.7	7.29
	20/01/2004	19	88.4	4.65	6.07
	09/04/2004	17	87.5	5.15	7.23
	06/07/2004	20	103.7	5.19	7.2
	05/06/2006	14	73.1	5.22	7.23
	17/04/2007	22	131.4	5.97	7.33
	31/10/2007	19	97.3	5.12	7
	04/11/2008	29	151.7	5.23	7.23
	20/05/2009	27	147.8	5.47	7.22
	12/10/2009	7	31.1	4.44	6.67
	30/03/2010	25	143.2	5.73	7.33
96645	11/04/2003	10	62.5	6.25	7.88
	09/04/2004	14	76	5.43	7.6
	06/07/2004	10	45.9	4.59	7.56
	11/04/2005	17	83.8	4.93	6.69
	17/04/2007	13	67.7	5.21	6.9
	20/05/2009	12	71.9	5.99	7.2
	30/03/2010	11	65.2	5.93	7.88
156030	19/10/2010	19	88.5	4.66	6.53
156031	19/10/2010	21	109.2	5.2	6.79

Appendix C. Photos for 2021 fish surveys undertaken by the Environment Agency

Photos courtesy of Nick Rule, FotE.

Mill Meadows survey in progress

Mill Meadows adult brown trout

Mill Meadows 2nd year trout – possibly pre-smolt

Mill Meadows adult eel

Mill Meadows juvenile brown trout

Deep Springs survey in progress

Deep Springs pike

Deep Springs nine-spined stickleback

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