A baseline assessment of water quality in the River Chess

Authors: Prof Kate Heppell, Chilterns Chalk Streams Project with maps produced by Dr Wendy Morrison, Chilterns Conservation Board.
Date: January 2022
Version: Draft 1.0

Authorisation and Assurance Record

	Name & Organisation	**Date & Signature**
Prepared by:	Kate Heppell, Chilterns Chalk Streams Project Wendy Morrison, Chilterns Conservation Board	Weds 2 March 2022
Reviewed by:	Rosie Nelson, Thames Water	
Approved by:	SWC Chess SG	22/03/22

Baseline assessment report structure

Table of Contents

List of Figures

List of Tables

Executive Summary

The Chess Smarter Water Catchments (SWC) strategy is a system-based approach to management of the River Chess, designed to address multiple catchment challenges and co-deliver solutions using a partnership approach. One of the objectives of the strategy is to improve river water quality. This report brings together all the pre-existing water quality data from the partner organisations (Environment Agency, Thames Water, Affinity Water, River Chess Association and Chilterns Chalk Streams Project) to assess: (i) current threats to the water quality of the River Chess; along with (ii) opportunities for action. The findings from this baseline assessment underpin the Year 2 water quality actions, along with subsequent monitoring and mitigation plans for the water quality theme.

Preventing future storm tank discharges and reducing inputs of nutrients from Chesham wastewater treatment works (WWTW) are critical actions needed to improve the ecological health of the River Chess. Statutory obligations prescribed by the Environment Agency as part of the current Water Industry National Environment Programme (WINEP, 2020-2025) include an increase in treatment capacity at Chesham wastewater treatment works and reductions in the concentration of reactive phosphorus in final effluent from the works. These measures should help to improve the water quality of the River Chess, but more work is necessary to improve river health. This report identifies key gaps in our datasets, and suggests the following actions for the future:

1. *Reduce phosphate and nitrate concentrations linked to eutrophication*
   Nutrient enrichment from reactive phosphorus and nitrate can result in algal blooms and a reduction in biodiversity. By 2024 reactive phosphorus contributions from Chesham WWTW should decrease from 96% to 75% of the total riverine load (according to Environment Agency SAGIS modelling), but this will not enable the Chess to achieve 'good' phosphorus status. Neither will these measures reduce elevated nitrate concentrations in the River Chess that arise from treated effluent (nitrate concentrations in the River Chess rose markedly in 1985 in response to changes in sewage treatment at Chesham WWTW). This report recommends that action be taken to explore the additional sources of phosphate and nitrate to the river, and that the SWC partnership explores methods to reduce nitrate and reactive phosphorus concentrations in the river to meet 'good' P status.

2. *Measure and reduce fine sediment inputs to the river*
   Fine sediment, and its associated contaminant load, can smother the gravel riverbed, infill gravels, alter oxygen dynamics and prevent salmonids from spawning and their eggs from hatching. Measurements of fine sediment inputs into, and transport through, the River Chess are sparse. Observations from local stakeholders and from the ChessWatch sensors suggest that fine sediment inputs into the Chess are concentrated in the upper catchment, and that pulses of fine sediment enter and move through the river during intense rainfall events. A risk mapping exercise has identified potential sources of sediment to the river including a culverted section of the river, the Vale Brook in Chesham. The risk

maps should be ground-truthed to assess the magnitude of the fine sediment issue in the river, and to develop mitigation options.

3. *Assess the risk from emerging contaminants and plastics to river health*
   A high proportion of river water (40 to 80% depending on baseflow conditions) is sourced from Chesham WWTW and is needed to sustain healthy flows in the river. However, as a result emerging contaminants of concern such as personal care products and pharmaceuticals, along with plastics from domestic activities, may be entering the River Chess. The magnitude of inputs, and the effects of these chemicals on the ecological health of the Chess is not yet known. This report describes the results from preliminary monitoring of emerging contaminants and recommends further monitoring to assess the risk to river ecology using passive and grab water sampling.

Finally, the CaBA Chalk Stream Restoration Strategy 2021 highlights the need to work on water quality, river flows and physical habitat together to improve chalk stream health. The combined impact of abstraction reductions and river restoration activities on water quality in the River Chess should be closely monitored, not least because changes to abstraction have the potential to alter the proportion of baseflow (from groundwater) to treated effluent flows in the river. With regards to treated wastewater effluent, the SWC partnership is well placed to explore the opportunities associated with the Chess being a Flagship Chalk Stream for Restoration, and to create a wastewater treatment works on the River Chess that trials innovative, cost-effective methods to support both clean and resilient flows in our rivers.

1 Introduction

1.1 Smarter Water Catchments Initiative

Smarter Water Catchments is a Thames Water initiative designed to deliver a step change in holistic catchment management. The vision is to build better functioning river catchments with the most effective solutions, without negatively impacting the environment. The initiative is evidence-based and partnership-led and is designed to apply a 'systems thinking' approach to address multiple catchment challenges together.

The River Chess is one of three pilot catchments (Chess, Evenlode and Crane) in the first phase of the Smarter Water Catchments partnership which runs through the Asset Management Plan (AMP) 7 period from 2020-2025. The Chess plan is divided into six key themes: Improving water quality, Managing Flow, Control of invasive non-native species, Improving wildlife corridors, Involving people and Working together. This report is the baseline assessment of water quality in the River Chess that underpins the 'Improving water quality' theme. The report sits beside the 'ChessWatch: scoping future monitoring needs' report created in November 2021, and feeds into the 'River Chess Urban Pollution Study: Phase 1 – Options identification' report produced by Jacobs. The recommendations from this report relating to agricultural activities will also be taken forward by the Chess Valley Farming Officer.

1.2 Purpose of the baseline analysis

The purpose of the report is to:

(i) Review the water quality data currently available to the project partners.
(ii) Highlight critical gaps in the data.
(iii) Summarise threats to water quality in the River Chess.
(iv) Highlight opportunities for actions to address these threats.

Water flow issues are addressed by the 'Managing Flow' theme; however, flow is critical to water quality so an overview of historical and current flows in the Chess is also included here. Similarly, an overview of catchment land use activities is important when considering pressures on chalk streams such as the River Chess, so the report begins with an overview of the catchment.

2 Catchment description

The River Chess is a chalk stream flowing off the dip slope of the Chiltern Chalk escarpment through Buckinghamshire and Hertfordshire for approximately 16 km in a South-Easterly direction into the River Colne at Rickmansworth (*Figure 1*). The size of the topographical catchment is estimated at between 97 and 105 km^2 (Flood Estimation Handbook and CEH Hydrometric register respectively).

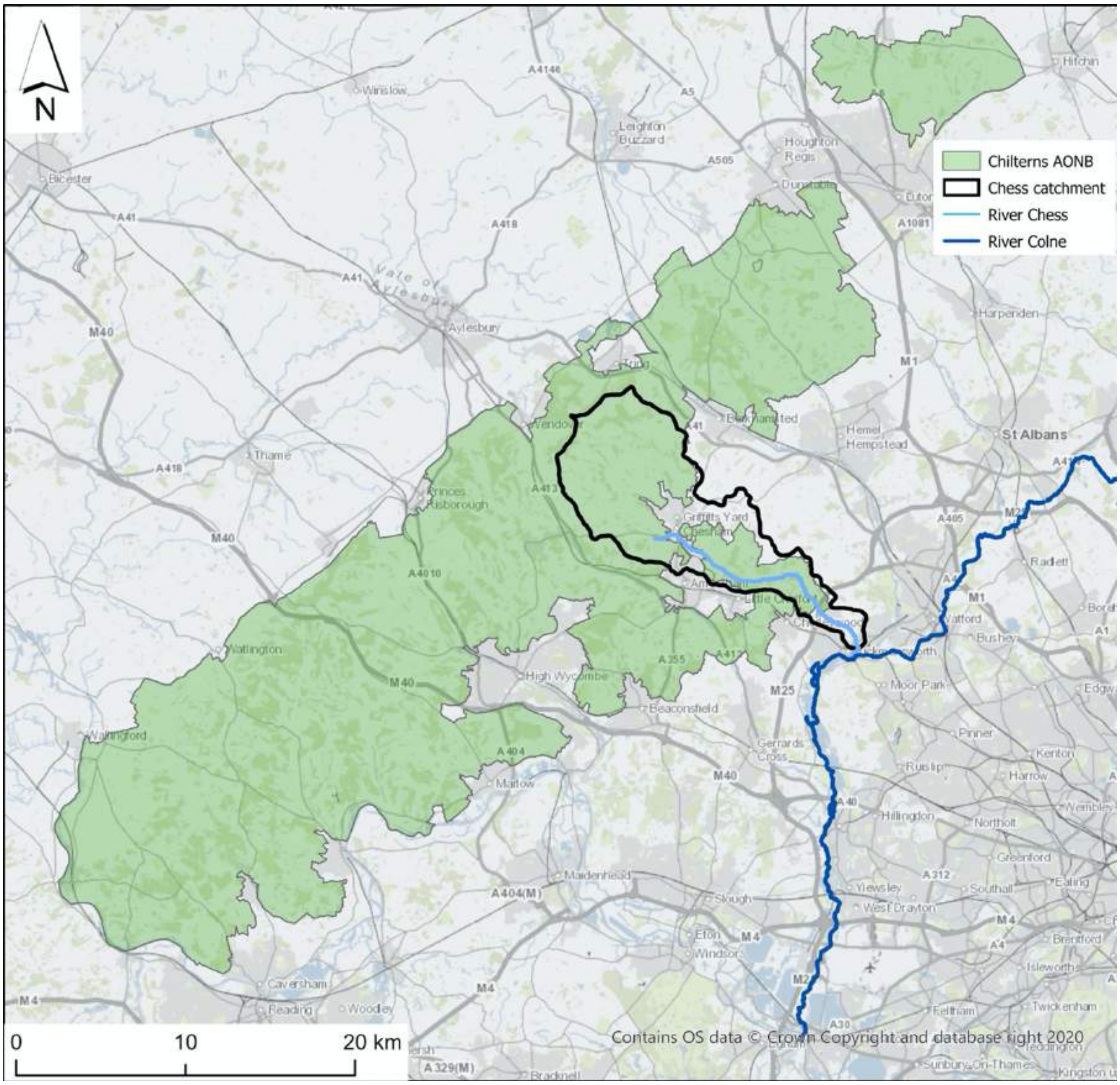


Figure 1 Maps of the River Chess showing location within Chilterns AONB and to the North West of London. Black line indicates topographical catchment. Light blue line indicates River Chess and dark blue line indicates River Colne.

There are three winterbournes (Chesham Vale, Missenden Road and Bury Brook) which flow from separate valleys at the northern end of Chesham, and numerous springs and artesian wells which feed the main river along its length. Discharges from Chesham and Chenies wastewater treatment works (WWTW) also augment river flows throughout the year. The

Chess flows from its urban headwaters in Chesham into a more rural landscape just downstream of Chesham WWTW (*Figure 2*). The river flows through the grounds of Latimer Park House (currently the site of Restore Hope Latimer) on through Latimer Meadows to Chenies and past Frogmore Meadow Nature Reserve. Just after the watercress beds to the northwest of Sarratt Bottom the river turns southwards to flow past Sarratt Mill House and the grounds of Chorleywood Estate. The river then flows under the M25 at Solesbridge Lane, between Loudwater Estate and Rickmansworth, and then past the Royal Masonic School to Scotsbridge Mill. The channel passes under the A412 and the railway line before the Chess flows into the River Colne and Elms Lake at Rickmansworth.

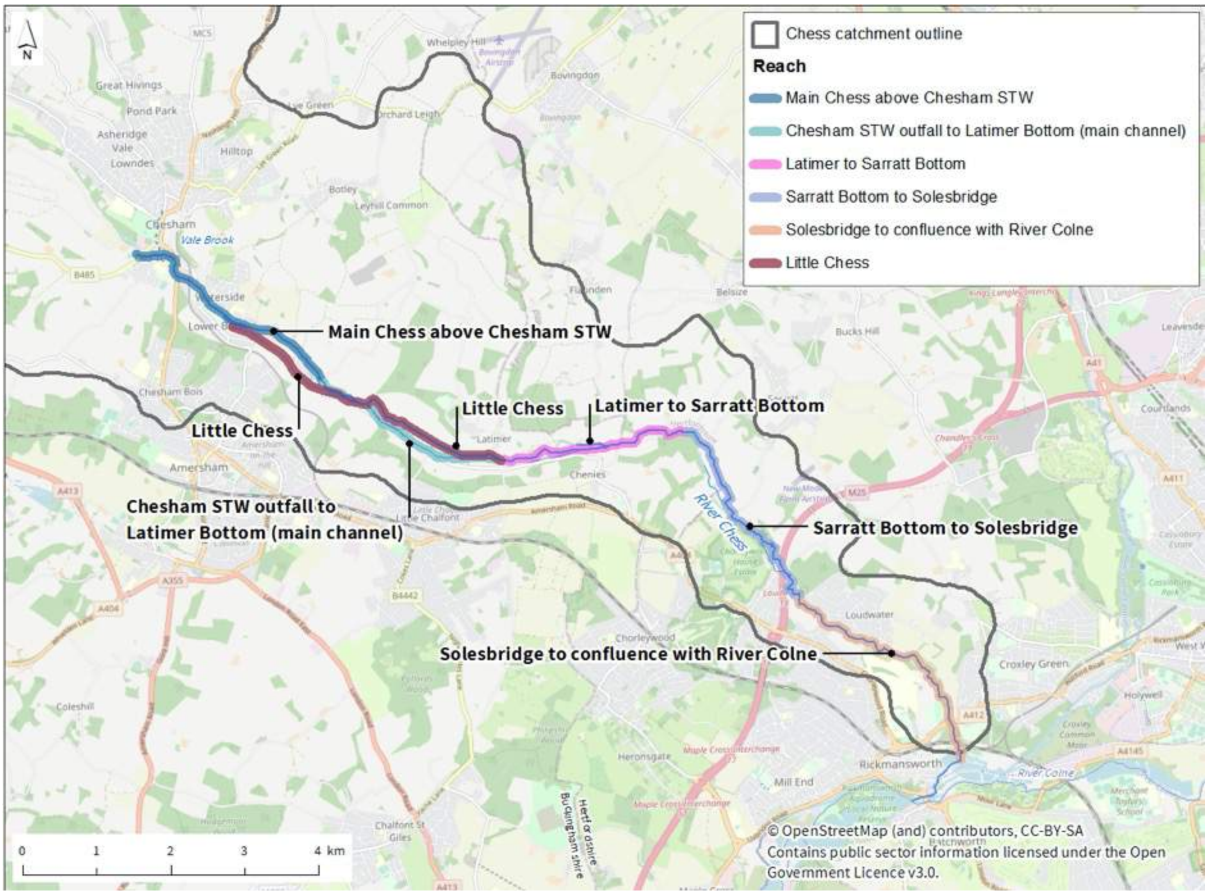


Figure 2 Reaches of the River Chess (as described in the 'ChessWatch: scoping future monitoring needs report')

In the headwaters within Chesham there is a second branch of the river termed the Little Chess which has its source in springs around Weir House Mill, currently owned by Decco. The springs are augmented by an offtake from the River Chess (which is licenced to abstract up to 18.6 ML/day from the river) and artesian wells within the grounds of the Mill. The Little Chess flows along Holloway Lane and Latimer Road before passing under the River Chess in a syphon. It then runs parallel to the Chess, separated only by a berm for a 100 m stretch just south of Bois Mill, before flowing into Great and Lower Water at Latimer Park House. The Little Chess finally joins the Chess immediately above the bridge at Latimer Bottom.

2.1 Superficial and bedrock geology

The catchment is underlain by an extensive unconfined Chalk aquifer (*Figure 3*a). Chalk is a very fine grained limestone of high porosity containing marl bands and flints which is dissected by fractures caused by faults, bedding planes and joints. Much of the fine limestone matrix has been formed from micro-fossils (coccoliths and their debris) and there is also a coarser component of the matrix formed from foraminifera and other shells (Allen et al., 1997).

The majority of the river channel lies within areas of the White Chalk Subgroup (formerly called Middle Chalk) with the lowest reaches around Rickmansworth overlying the Grey Chalk Subgroup (formerly called Lower Chalk). These Chalk Subgroups are overlain by deposits of alluvium and terrace gravels (e.g. Chorleywood and Gerrards Cross gravel formation), with clay-with-flints occupying the higher ground between river channels (termed interfluves) (*Figure 3*b).

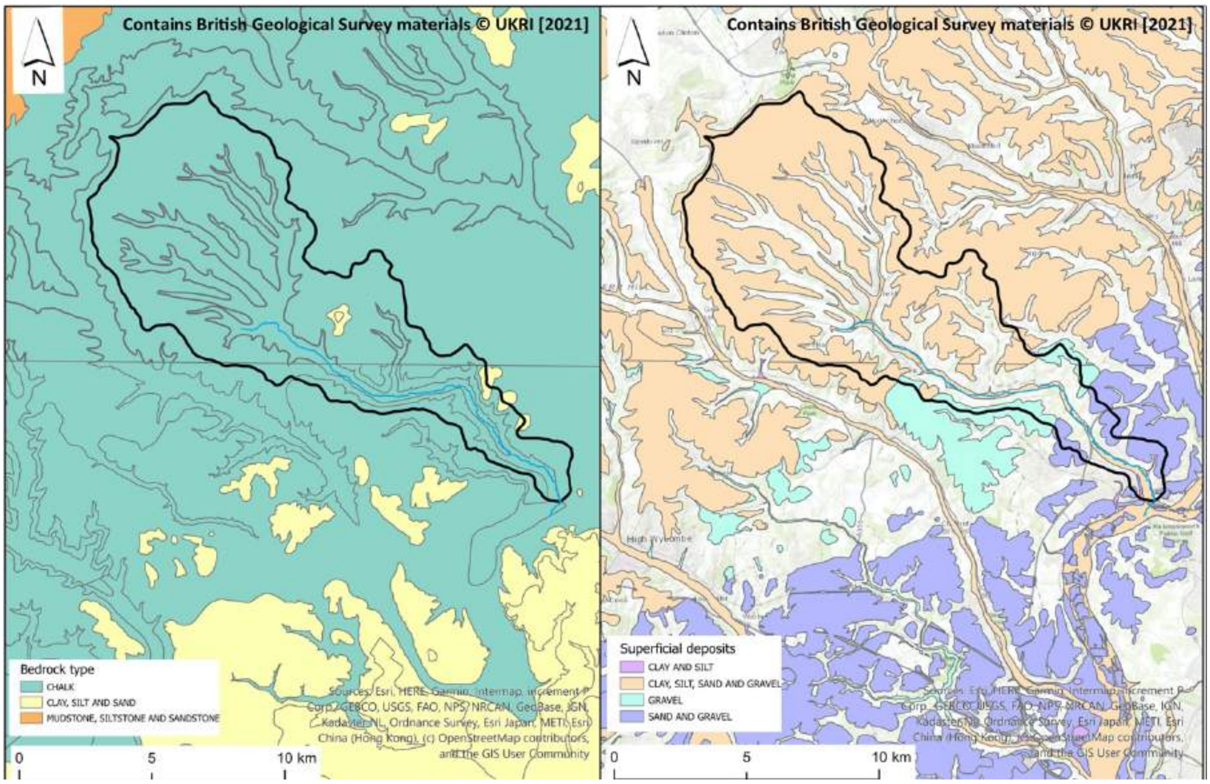


Figure 3 (a) Bedrock and (b) superficial geology of the River Chess catchment

2.2 Soils and land use

Land use in the catchment is predominantly rural with 36% arable/horticultural and 34% grassland. Woodland covers 18% of the catchment and urban areas make up 12% of the land cover (*Figure 4*, UK CEH, 2021).

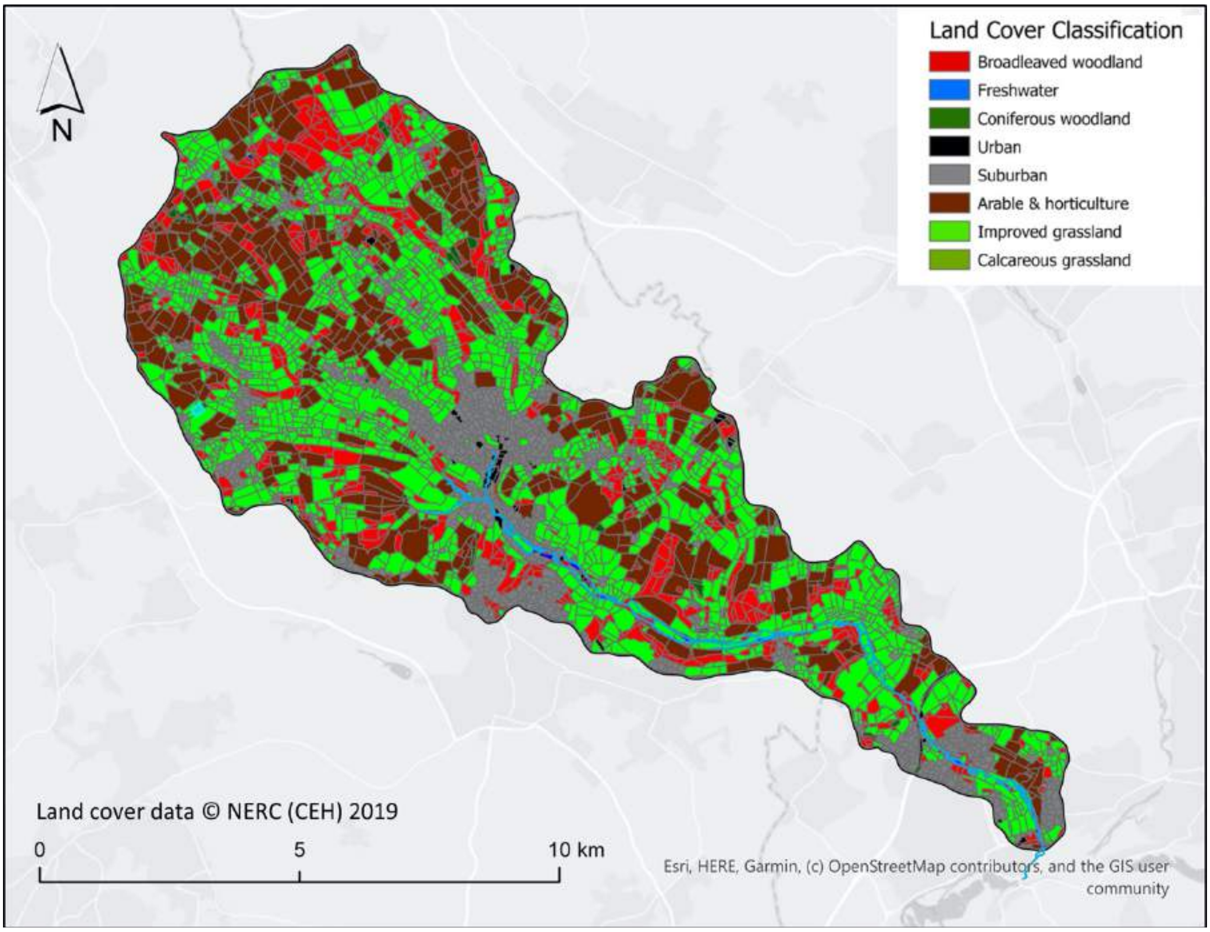


Figure 4 Land use in the River Chess catchment (2019)

On the tops of the Chalk escarpment at the northern end of the catchment, soils are a mixture of slightly acid loams and clay soils with some impeded drainage, and fertility is intermediate. These soils support a mix of pasture, arable farming and woodland. Arable farming for cereals (wheat and barley with some oats) and oilseed rape is concentrated on these slopes in areas where soils are thicker. Field beans are grown as a rotation crop, and food for gamebirds is also grown in small strips in the landscape, next to hedgerows and within fields. *Figure 5* illustrates the spatial distribution of maize, spring and winter arable within the catchment on the basis of satellite imagery (CROME, 2019).

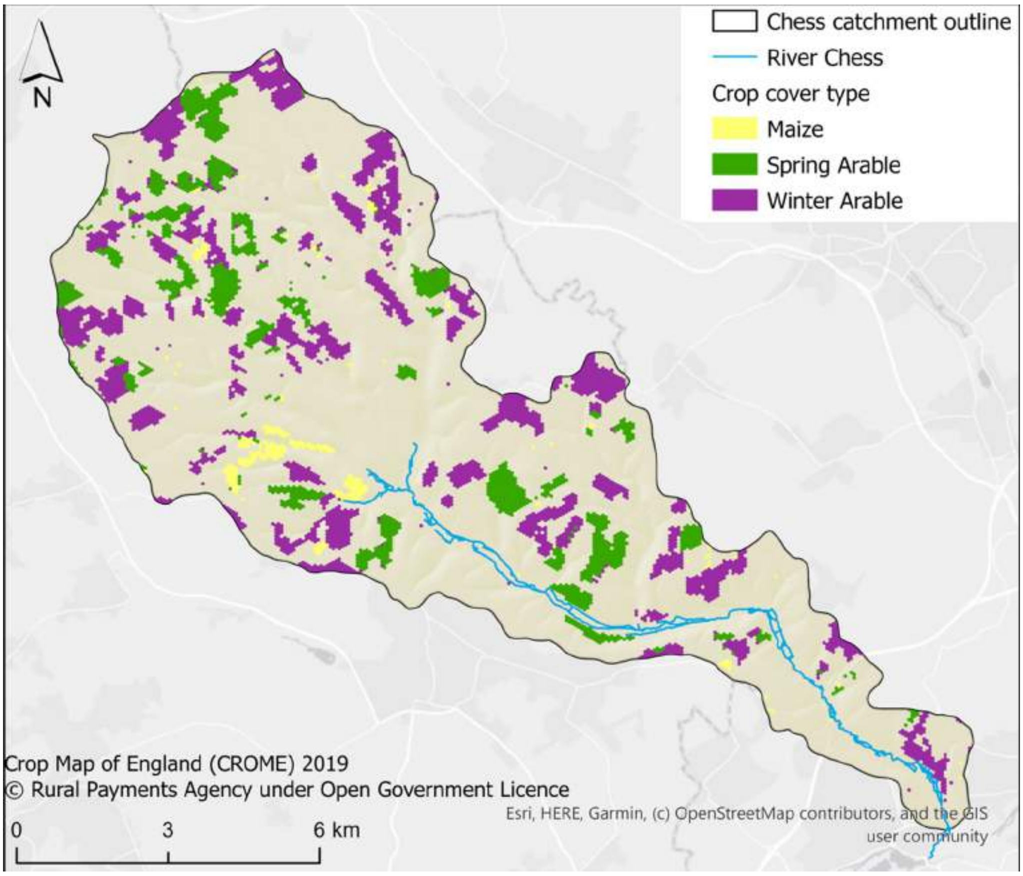


Figure 5 The distribution of maize, spring and winter arable within the catchment on the basis of satellite imagery.

The three valleys around Chesham are characterised by freely draining slightly acid, but base-rich soils of high fertility (*Figure 6*). Downstream from Chesham Bois the free-draining soils become lime-rich and loamy, supporting pasture for sheep and cattle and spring and autumn-sown cereal crops, along with lime-rich deciduous woodland. On the east bank these free-draining lime-rich soils continue to the confluence with the River Colne. On the west side freely draining slightly acid loamy soils predominate with neutral and acid pastureland, and deciduous woodland.

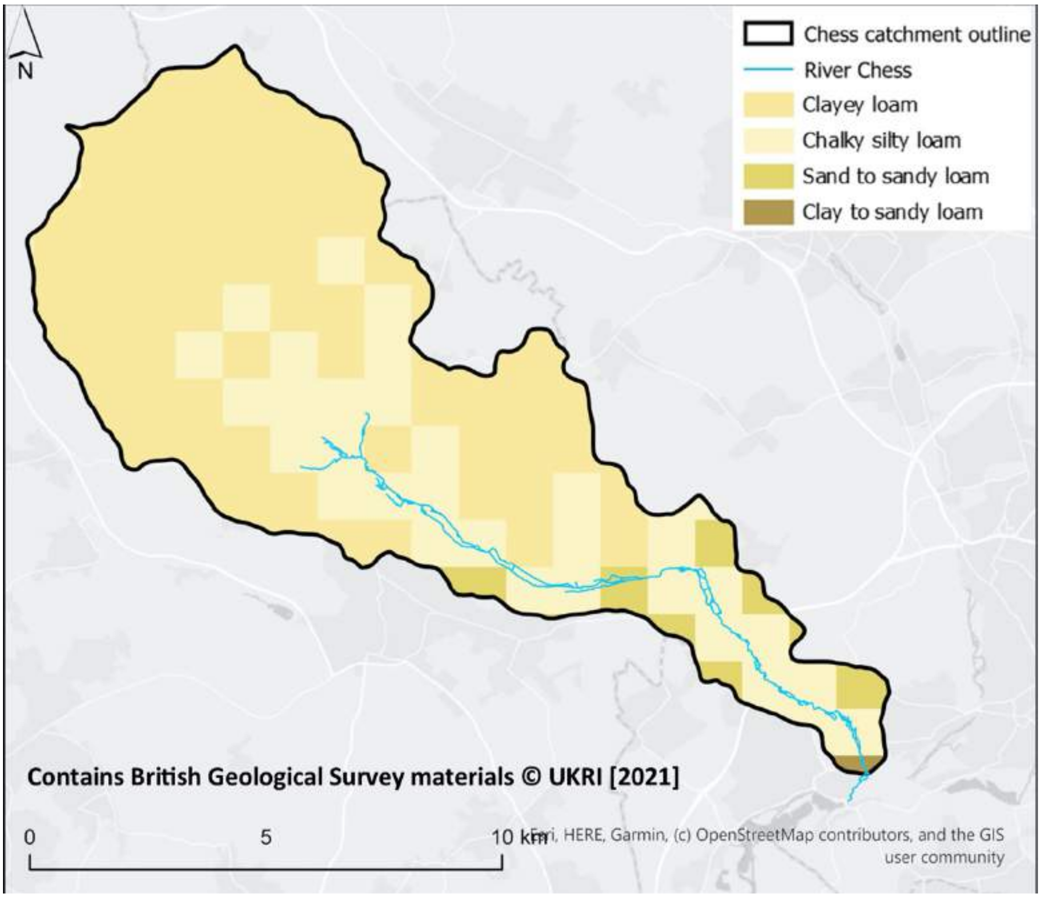


Figure 6 Soil texture of the River Chess catchment

2.3 Landscape Character

Figure 7 shows the Landscape Character Assessment for areas within the Chilterns AONB, with the aim being to conserve, maintain and enhance the features which contribute to the character and distinctiveness of the area. The catchment of the Chess contains both 'Plateau and Dipslope' and 'River Valleys' units.

Dry valleys (known as coombs) are extensive in the northern part of the catchment. These areas are important from an aesthetic viewpoint, providing hidden landscapes (Chilterns Conservation Board, 2014). They are also characterised by steep slopes which could become areas of soil erosion, loss and transport under arable farming activities. Networks of roads and tracks can provide connectivity for water and sediment transport between fields and the river. Valleys that are usually dry may also contain temporarily running water during periods of heavy rainfall due to surface water runoff over impermeable surface such as sunken lanes. With increases in intense rainfall predicted due to climate change, the potential for soil loss (and associated nutrients and plant protection products) from these high gradient areas becomes more marked, particularly when soils are bare. In a feedback loop, soils degraded by loss of topsoil and associated organic matter require more fertiliser and other inputs, which can result in enhanced leaching of agrochemicals to groundwater. This scenario of topsoil and agrochemical loss represents an unwanted economic challenge to the farming community, as well as a potential environmental threat.

Thus, it is more important than ever that the landscape surrounding the identified Chess river valley is recognised as connected to the river system, and contributing to river and groundwater quality and ecosystem diversity and health. The role of this landscape in storing carbon and helping ensure clean supplies of groundwater and surface water should be fully considered in an integrated catchment plan.

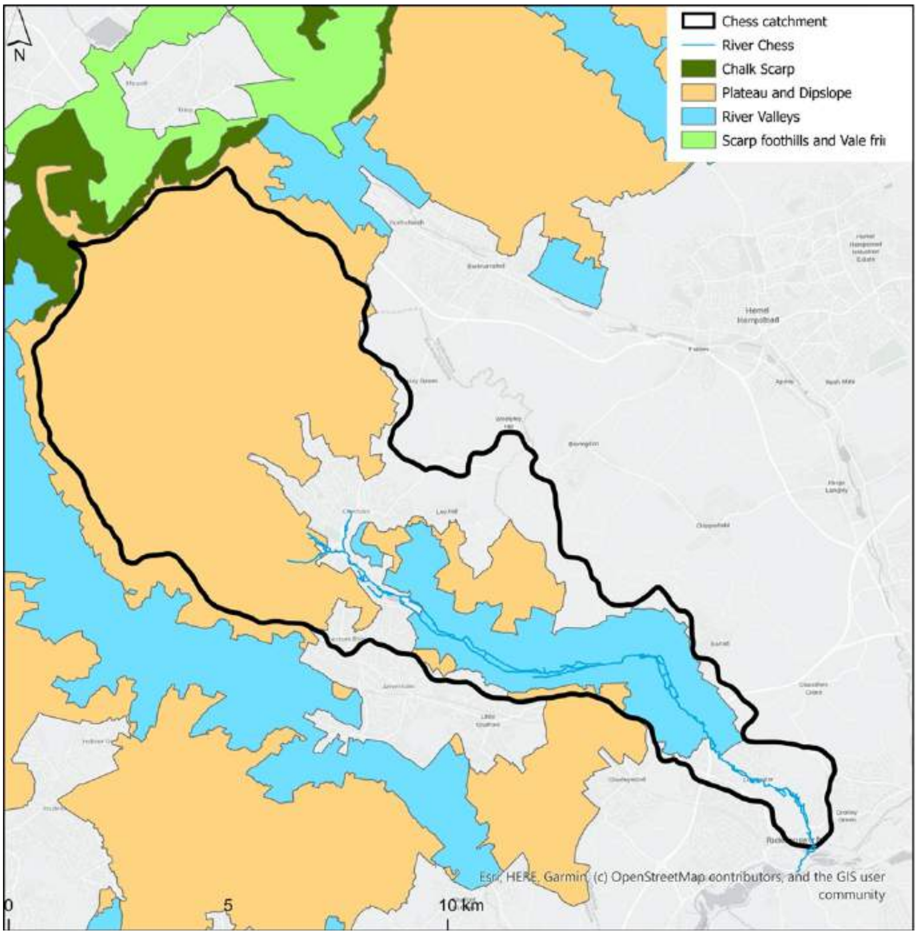


Figure 7 Landscape Character Assessment of the River Chess catchment located within the Chilterns AONB.

2.4 Priority and Designated Habitats

Natural England mapping shows 1612.6 ha of priority habitat in the Chilterns AONB within the Chess catchment including deciduous woodland, lowland calcareous grassland, and traditional orchard. The condition of these habitats is largely unknown as data only exists for priority habitat within SSSIs or Higher-Level Stewardship Schemes.

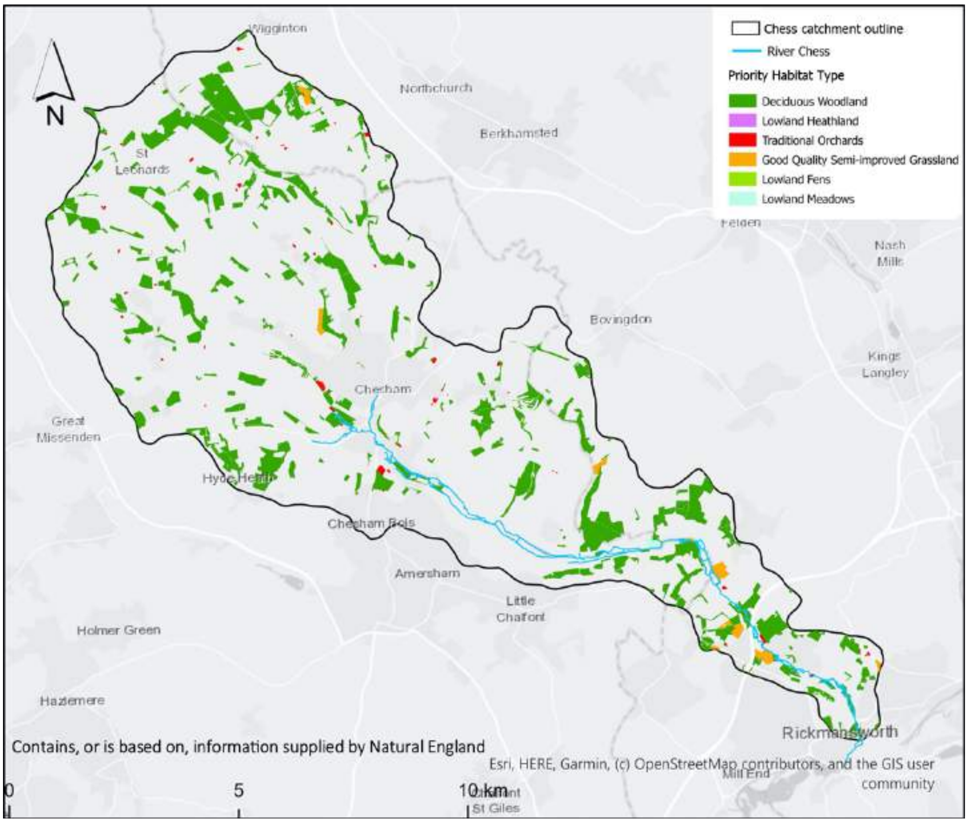


Figure 8 Priority Habitats within the Chess catchment

In an holistic catchment management plan, priority habitats play an important role in providing ecosystem services such as carbon storage and clean water provision. In a groundwater-fed catchment, such as the Chess, the land use activities over the entire catchment area are of importance for provision of clean groundwater. Priority habitats of particular interest located close to the river include lowland fens, wet meadows and floodplain grazing marsh which offer water attenuation and cleansing opportunities. It should be noted, however, that the biodiversity of many of these features depends, in part, on clean sources of water. Diverting nutrient-rich river water through these features may alter their characteristics and degrade ecosystem health. Changing patterns in nutrient, as well as soil moisture status, should be considered in any plans to create or re-create priority habitats in a catchment. Riparian woodland is another valuable habitat that is not currently mapped and needs further consideration, especially with regards to helping provide resilience against increases in river water temperature arising from climate change.

With regards to designated habitats within the Chess catchment (*Figure 9*), there is currently one Local Nature Reserve at Captain's Wood (13.9 ha) and two SSSIs in the river floodplain at Frogmore Meadows (4.6 ha) and Sarratt Bottom (3.2 ha). However, neither of these SSSIs are designated for their aquatic flora and fauna. There are two registered park and gardens at Chenies and Latimer respectively.

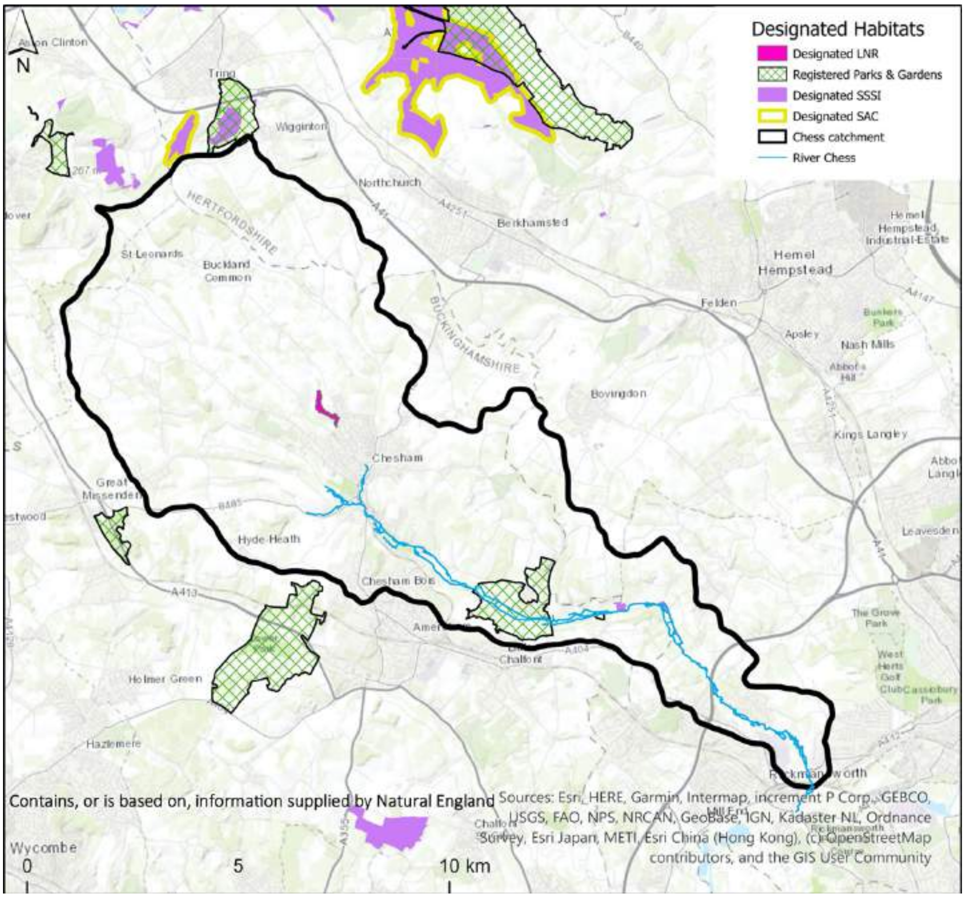


Figure 9 Designated Habitats within the Chess catchment

2.5 Population and infrastructure

The Chess catchment is located to the north-west of London in a commuter belt area which is well served by transport links. The largest local towns are Hemel Hempstead, Watford and High Wycombe (*Figure 10*). Although public transport (Metropolitan Line) enables easy access from London by rail, it is difficult to access the River Chess by public transport from these towns.

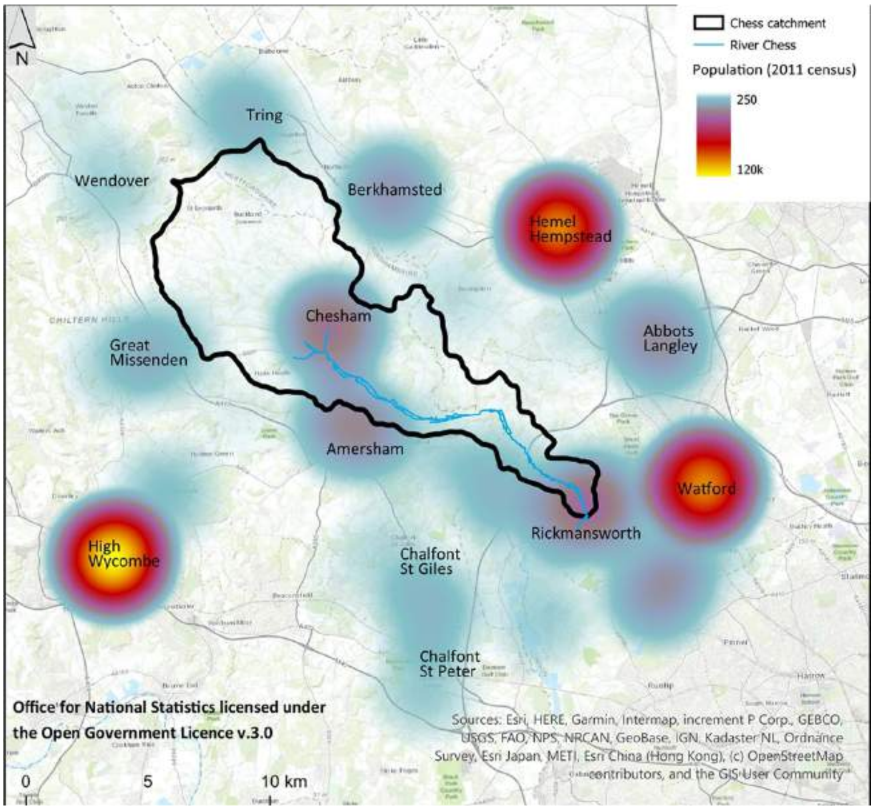


Figure 10 Heat map to illustrate population of towns in and around the River Chess catchment (2011 census data).

2.5.1 Consented discharges including wastewater treatment works

There are two wastewater treatment works (WWTW) at Chesham and Chenies with population equivalents of 37,300 and 150 respectively. Chesham WWTW comprises primary, secondary and tertiary treatment (for additional suspended sediment, ammonium and phosphorus removal) with a permitted dry weather flow (average daily flow during a period without rain) of 14,450 m^3/day. This treated effluent provides between 40 and 80% of water to the river depending on discharge conditions, thus the satisfactory operation of Chesham WWTW is critical to the River Chess ecosystem health. Chenies is a small, rural WWTW with primary and secondary treatment with typical flows of 35 m^3/day comprising < 0.1 - 0.3% of flows in the river (estimated average calculated for 2021).

Figure 11 and *Figure 12* illustrate the location of consented discharges in the River Chess to the river and soil respectively. The latter are important when considering potential routes of chemical and biological contamination to groundwater. The 'River Chess Urban Pollution Study: Phase 1 – Options identification' report produced by Jacobs considers these consented discharges further.

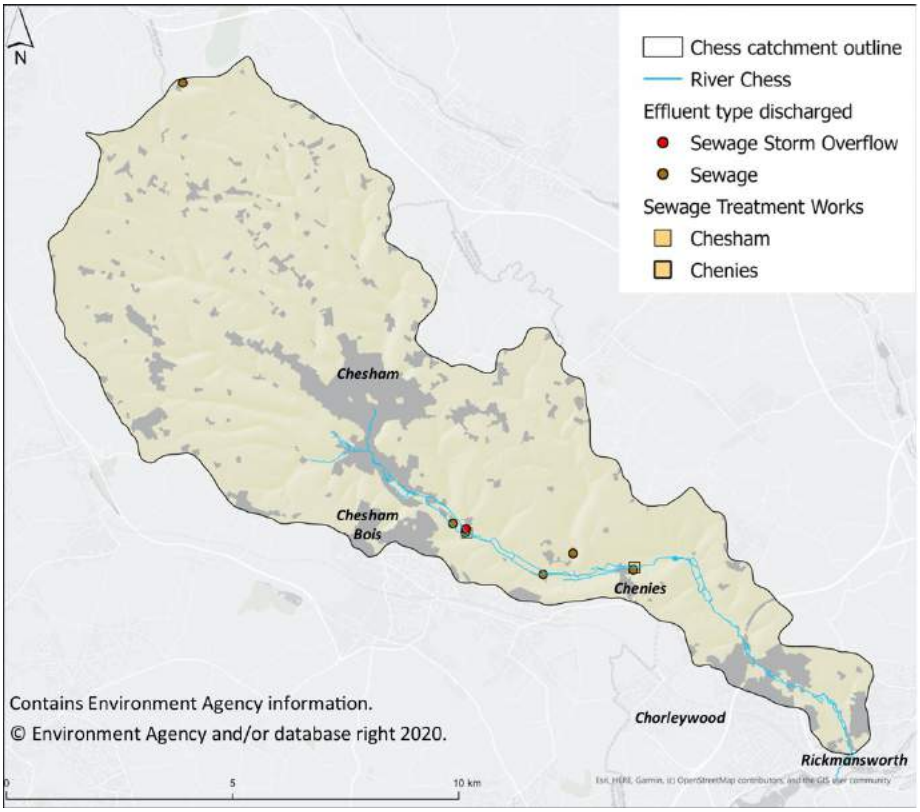


Figure 11 Consented discharges to the river in the River Chess catchment – sewage and sewage storm overflow.

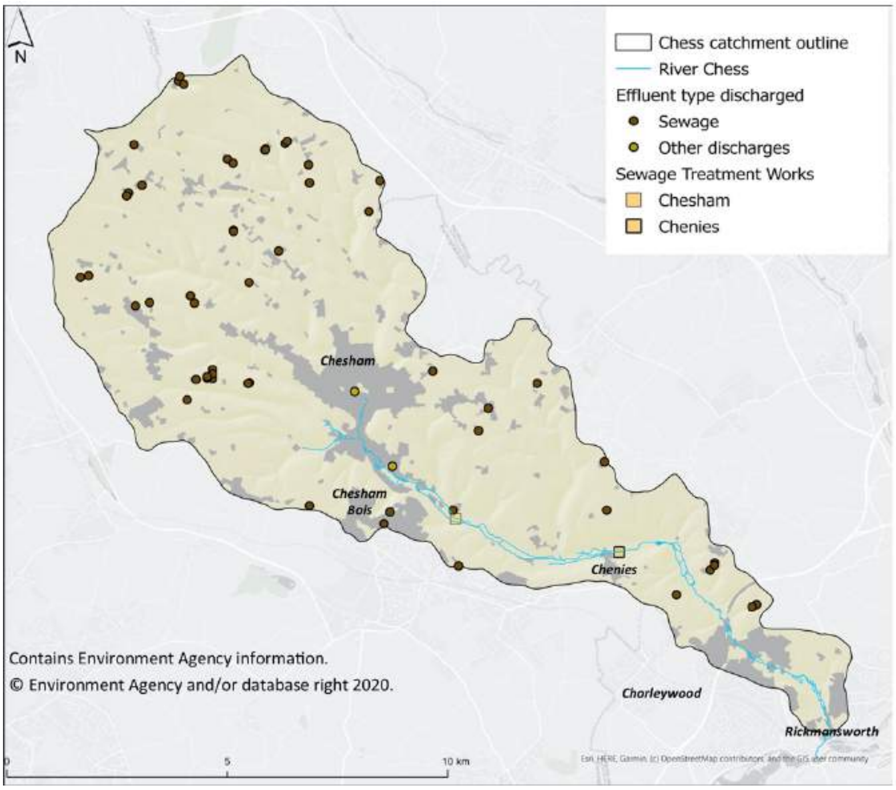


Figure 12 Consented discharges to the soil in the River Chess catchment.

2.5.2 Septic tanks

There are likely to be multiple septic tanks in the River Chess catchment. *Figure 13* indicates postcodes located > 200 m from the sewer network, and therefore the potential location of septic tanks. Septic tanks are used to treat domestic sewage when a house is not connected to the sewer network. They comprise a buried chamber with two tanks designed to remove solids, pathogens and pollutants. Clarified effluent from the septic tank leaches into soils, and the assumption is that the soil will further clean the effluent as it moves into the surrounding environment. However, septic tanks have been shown to be significant sources of P to rivers in some locations in England (May et al., 2015). They can be sources of P (particularly soluble reactive phosphorus) throughout the year; with P seeping to watercourses through the soil in 'treated' effluent from the septic tanks at low rates under low flow and groundwater conditions, or being transported directly from tanks during high groundwater or runoff conditions. There are eleven locations in the catchment where septic tanks may exist and be located close enough to the river (< 100 m from the river) to be identified as 'high risk' in terms of pollution potential.

The risk from a septic tank to the river arises from its location, condition and the way that it is managed. Older septic tanks may be under-sized for modern water usage and may not have been upgraded despite multiple extensions to a house; and they may receive runoff from roofs as well as domestic wastewater. With regards to location, soil hydrology, slope, proximity to the watercourse and depth to water table are all important factors to consider.

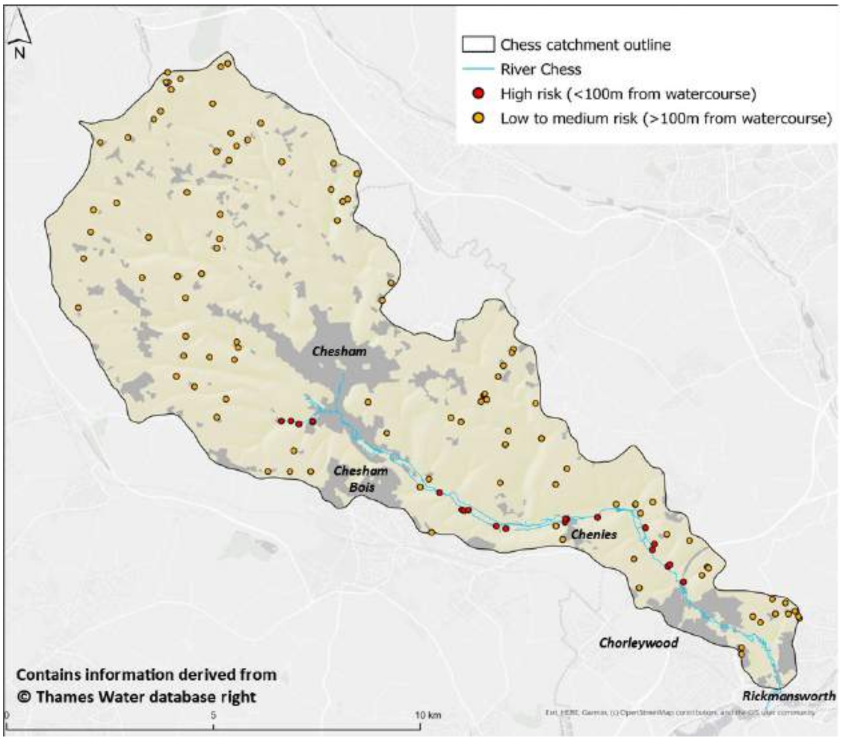


Figure 13 Potential location of septic tanks with risk assessment based on proximity to the River Chess.

The Smarter Water Catchments Initiative offers the opportunity for targeted sampling in the river around potential septic tank locations to determine whether phosphate concentrations increase in the area. This could be accompanied by provision of up-to-date information to the owners of septic tanks regarding their maintenance, operation and risks to the river environment.

2.6 Transport links

The catchment has good public transport links to London via the London underground and Chiltern Railways enabling easy walking access for the public to the Chess Valley Walk. Chesham, Chalfont and Latimer, Chorleywood and Rickmansworth stations are all within a 20-minute walk of the Chess Valley. This is one reason why the Chess Valley Walk is so popular and attracts many visitors each year. The Chess Valley Walk is actively promoted by the Chilterns Society and Chilterns AONB, and advertised by many websites and national newspapers (e.g. Alltrails, LDWA, Time Out, The Guardian).

2.7 Rainfall

Seasonal and annual variations in rainfall are a strong control on groundwater levels in the catchment, and on the magnitude of flows in the River Chess. In this way rainfall patterns also influence water quality. Rainfall events can transport sediment and pollutants from spatially diffuse sources to the river. During drought periods, when groundwater levels are low, there can be less dilution of chemicals arising from point sources, such as the effluent from wastewater treatment plants. Average annual rainfall (1961-1990) for the catchment is 753 mm, with elevated rainfall in the headwaters (+ c. 100 mm/year) compared to the confluence of the Colne.

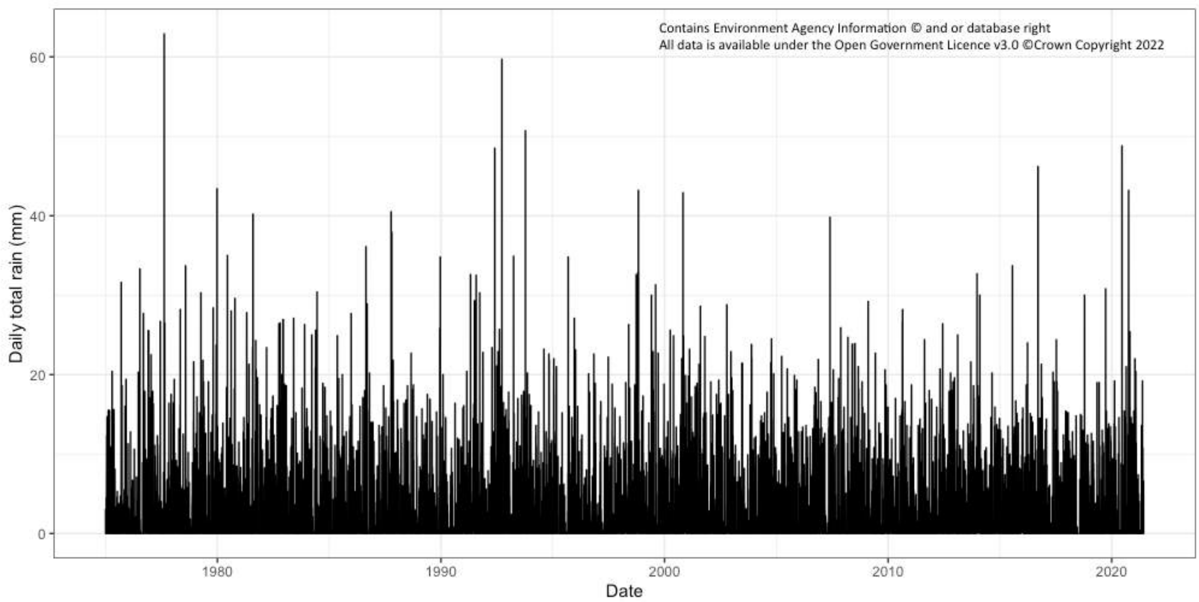


Figure 14 Daily rainfall totals recorded at Chenies raingauge (1975-2021). SOURCE: Environment Agency data.

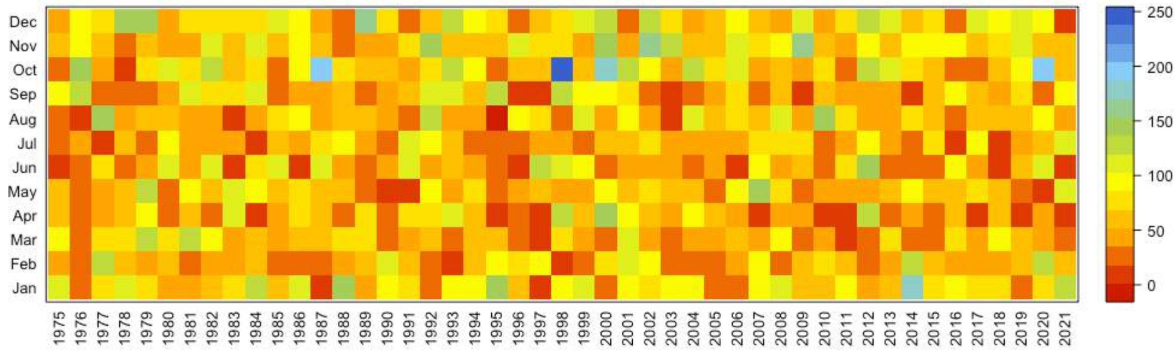


Figure 15 Monthly total rainfall (mm/month) from 1975 – 2021 recorded at Chenies raingauge. SOURCE: Environment Agency data.

The time series of daily rainfall totals (*Figure 14*) highlights days with extreme rainfall totals, whereas the illustration of monthly rainfall totals (*Figure 15*) highlights some periods of particularly high monthly rainfall (e.g. October 1987, 1998, 2000 and 2020 and January 2014) as well as multiple months of low rainfall (e.g. January to August 1976; April to August 1995). However, to fully understand the impacts of changes in rainfall pattern it is useful to use the standardised precipitation index (*Figure 16*).

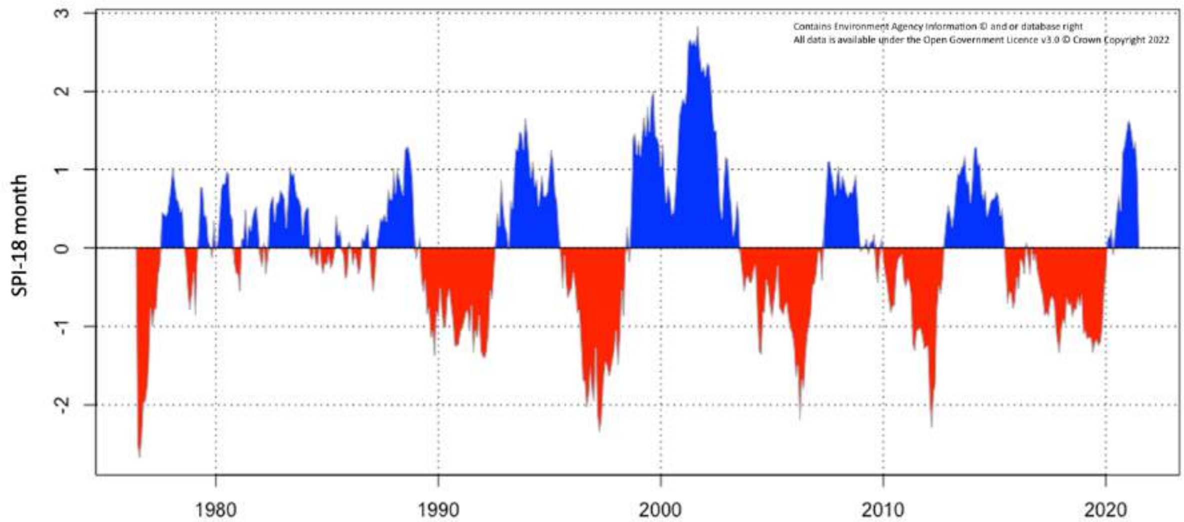


Figure 16 Standardised Precipitation Index (18-month) from 1975 to 2021. SOURCE: Environment Agency data.

Prolonged periods of wet or dry weather are of particular interest because they can give rise to groundwater flooding or drought in the catchment. The standardised precipitation index enables rainfall totals over a selected time period (e.g. 3,6 or 12 months) to be compared to long-term averages to indicate periods of unusually dry or wet weather. It is widely used to characterise meteorological drought, and the SPI value is the number of standard deviations by which the observed anomaly deviates from the long-term mean. *Figure 16* is a time series of standardised precipitation index calculated using an 18-month period and Chenies rainfall dataset (Environment Agency), to enable comparison with groundwater fluctuations reported in Section 3. Areas coloured in red indicate periods of dry weather compared to the long-term mean, whilst areas in blue are periods of wet weather. The dataset starts with the late 1975/early 1976 drought, which is considered the most severe experienced across the UK. The period from 1988 until 1993 was characterised by protracted drought across Europe with very low flows; and loss of aquatic habitat in spring-fed rivers across lowland UK in 1991/1992. A long, hot summer in 1995 was the start of drought conditions until 1998, and the rainfall record also shows that the River Chess was impacted by the 2004/2006 drought. Two periods have also been notable for rapid switches from drought conditions to record rainfall levels; 2010/2012 and again in 2018/2020. The historic drought inventory compiled by Centre for Ecology and Hydrology provides useful national context for these droughts.

3 Hydrogeology and Hydrology

The chalk is an important aquifer in the UK supplying 70% of water for public supply in the South-East of England. The chalk itself is the remains of micro-fossils deposited in the Cretaceous Era (65-100 million years ago). The water is held in both the fractures and matrix of the chalk. The matrix is the pore spaces in-between the micro-fossil fragments and the water stored here is effectively immobile, moving only a few millimetres each year. Fractures occurred originally due to tectonic movements, and by periglacial activity when rapid melting of ice and snow caused runoff to erode chalk weakened by frost action. These fractures can be enlarged over time due to the dissolution of calcium carbonate by acidic water (Bloomfield, 1996; Price et al., 1993). Thus, there is a large range of fracture sizes in the Chalk, which can give rise to a large range in water transport velocity. Larger, enlarged fractures can transport water several hundreds of metres per day, whilst smaller fractures will transport water at much lower velocities of milli-metres per day (Barker, 1993).

The Chalk also contains bands of marl and flint. The marl bands, thought to be of volcanic origin, can be several centimetres thick and extend several hundreds of kilometres. They restrict vertical flow due to their high clay content but are also associated with lateral preferential flow pathways as groundwater is forced to move laterally above the band.

3.1 Groundwater levels

There are two Environment Agency boreholes used for long-term monitoring of groundwater levels: Ashley Green and Wayside. Ashley Green borehole screen is at 100 m depth in the Chalk, whilst the Wayside screen is at 6.6 m depth. Ashley Green is located at a higher elevation relative to sea level (mAOD) than Wayside. Observations in the two groundwater wells are strongly correlated, with no observed difference in this relationship over time (

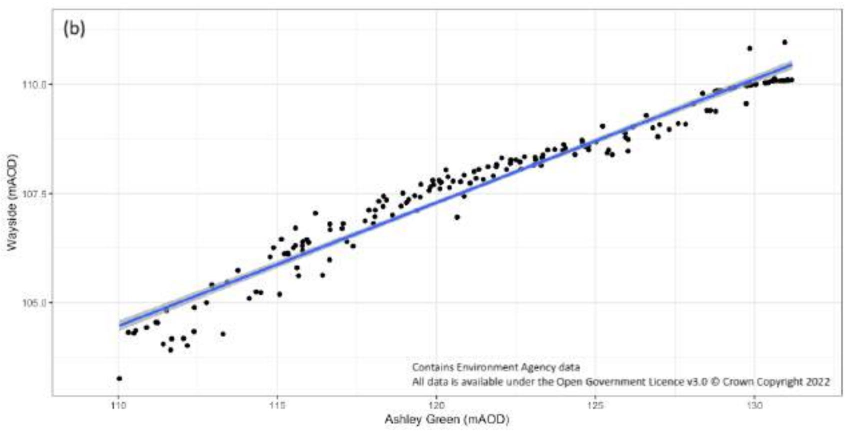
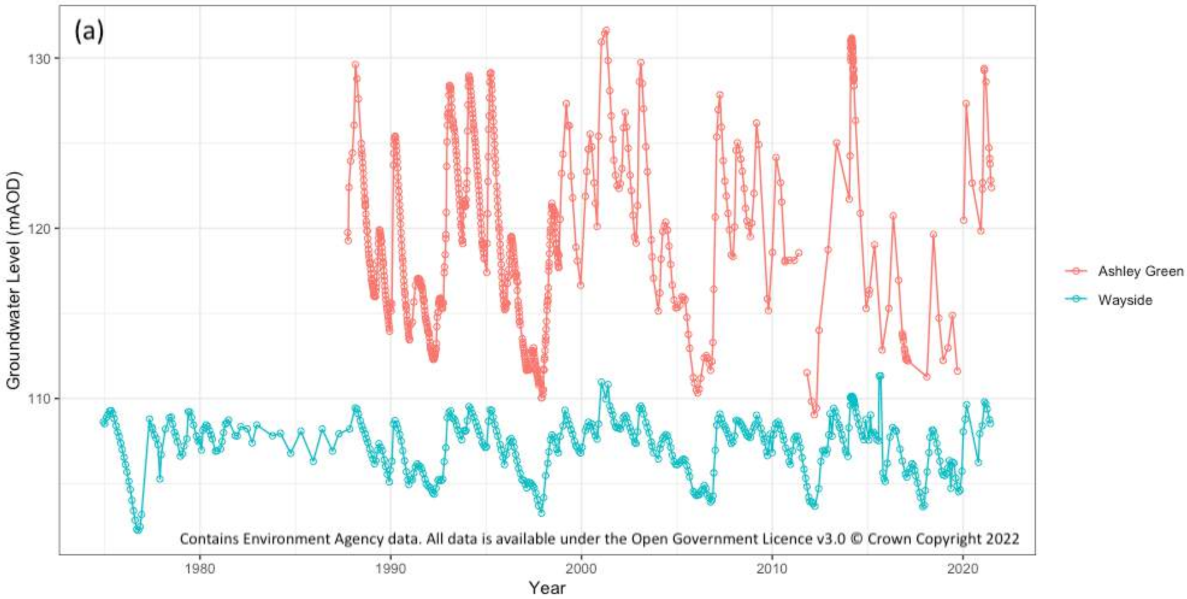


Figure 17). Changing groundwater levels at Wayside correlate well with SPI-18 values calculated with a gamma distribution (*Figure 18*). The 18-month SPI values are used to account for the delay between rain arriving at the soil surface and recharging the uppermost sections of the aquifer.



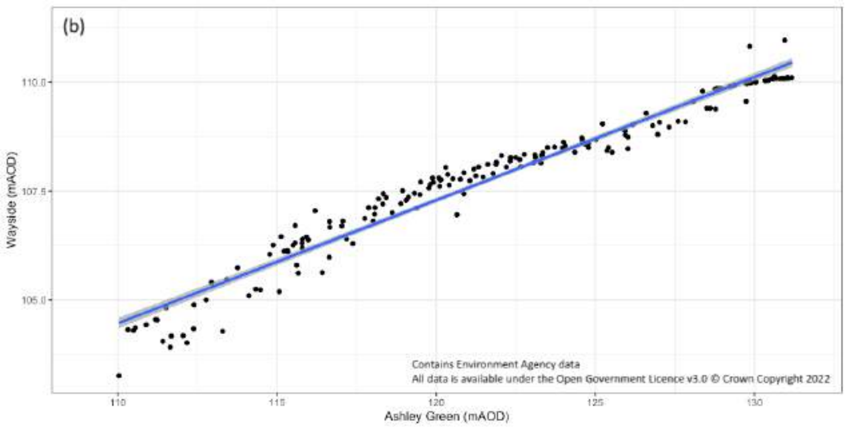


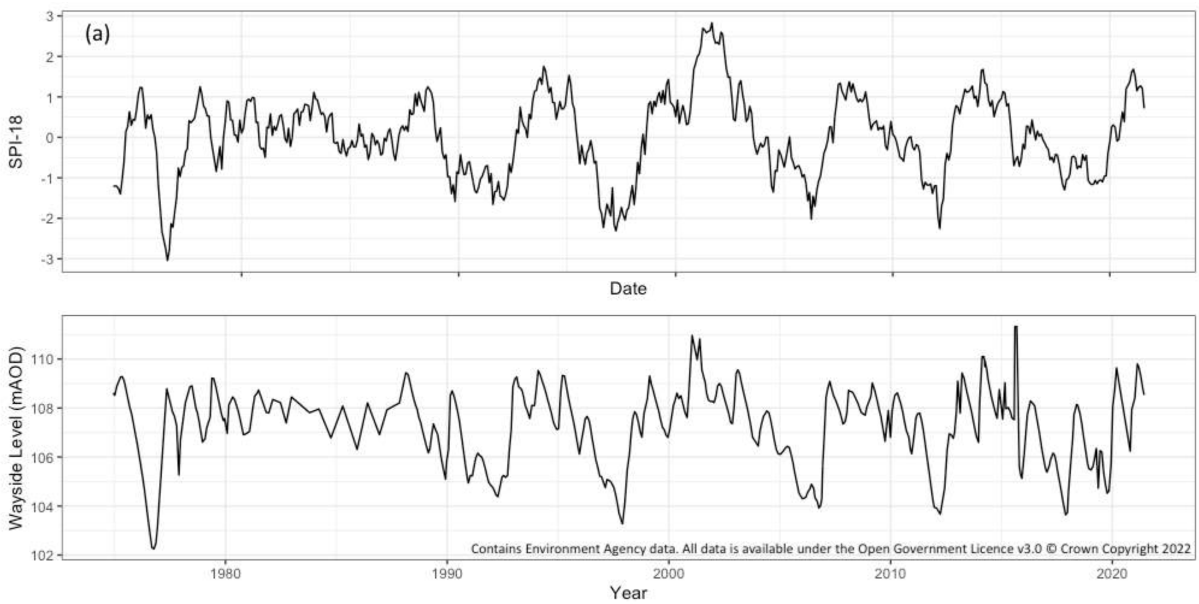
Figure 17 (a) EA observation manual dip data from Ashley Green (1987+) and Wayside (1974+); and (b) Scatter plot of Ashley Green and Wayside levels (mAOD). SOURCE: Environment Agency data

Annual variations in groundwater level are marked due to seasonal patterns in evapotranspiration and rainfall. High temperatures in summer, combined with transpiration of water from plant roots to the atmosphere, cause more evapotranspiration from land surfaces, therefore less rainfall eventually reaches the aquifer to recharge it. In the autumn and winter more rainfall infiltrates through the soil and makes it way to the aquifer. These are the patterns in groundwater that are frequently focused upon, especially in groundwater-fed systems where groundwater level is a strong influence on seasonal river flow.

However, UK Chalk aquifers – in the Chilterns and Cambridgeshire areas in particular – also show marked 7-year (multi-annual) periodicity in levels (Rust et al., 2019). Most UK droughts also coincide with this 7-year cycle observed in groundwater, and this is driven by the North

Atlantic Oscillation (NAO). The NAO is a weather phenomenon whereby changes in atmospheric pressure control the strength and direction of the westerly winds and storms across the North Atlantic Ocean which brings moist air to the UK. Understanding and predicting future groundwater levels on the basis of such connections between meteorology and groundwater levels (and thus groundwater storage) may become important to the success of future adaptive abstraction plans, and to enable water trading between water companies (Rust et al., 2019).

Recent research in the Chilterns area has also revealed the first evidence of the impacts of climate change on groundwater levels, through an increased frequency of groundwater drought due to elevated evapotranspiration – which is associated with higher temperatures (Bloomfield et al., 2019). This means that increases in air temperature due to anthropogenic warming may also have a role to play in controlling future patterns of groundwater drought (defined as mean periods of below-normal groundwater levels) in the River Chess catchment.



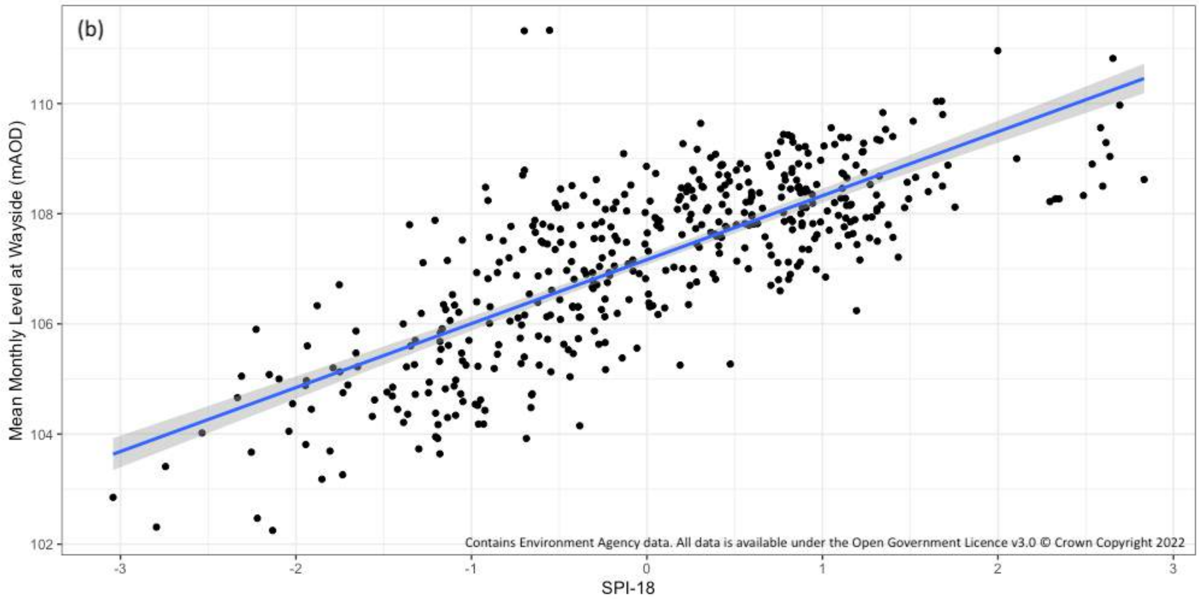


Figure 18 (a) SPI-18, (b) Groundwater level at Wayside, and (c) Scatter plot of SPI-18 vs groundwater levels at Wayside. SOURCE: Environment Agency data

3.2 Linking groundwater levels to the dry/wetting of the riverbed in Chesham

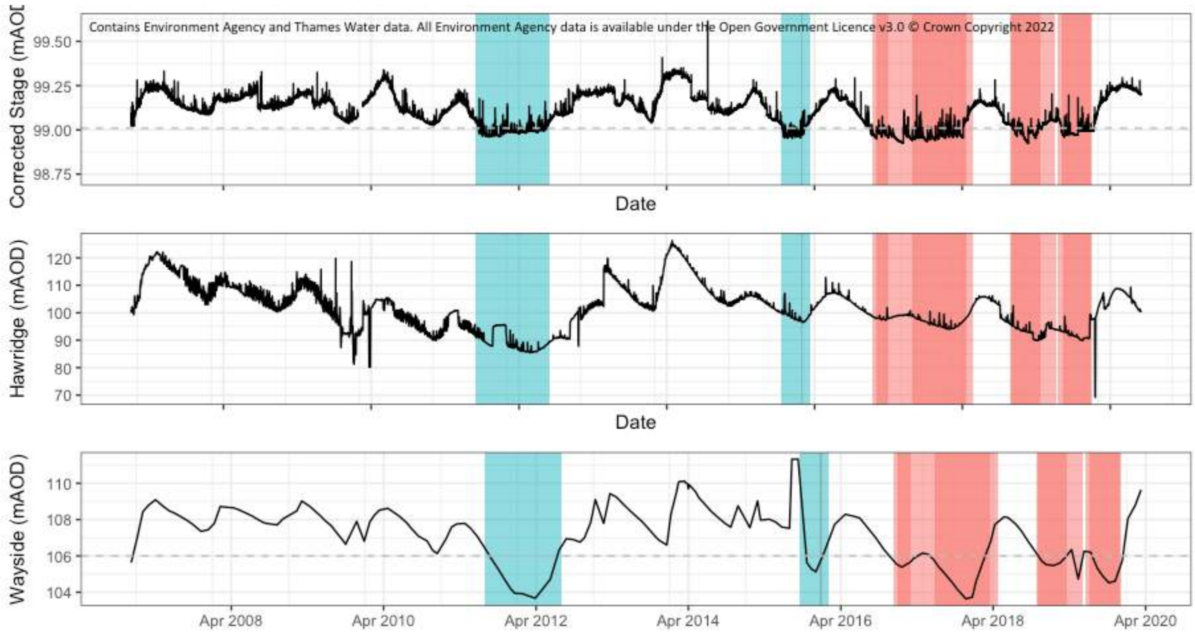


Figure 19 Linking groundwater levels to water levels and flow in the River Chess at Chesham stageboard. Red panels indicate periods during which riverbed was observed to be dry. Blue panels show predicted periods of dry riverbed based on Wayside groundwater levels. SOURCE: Environment Agency and Thames Water data

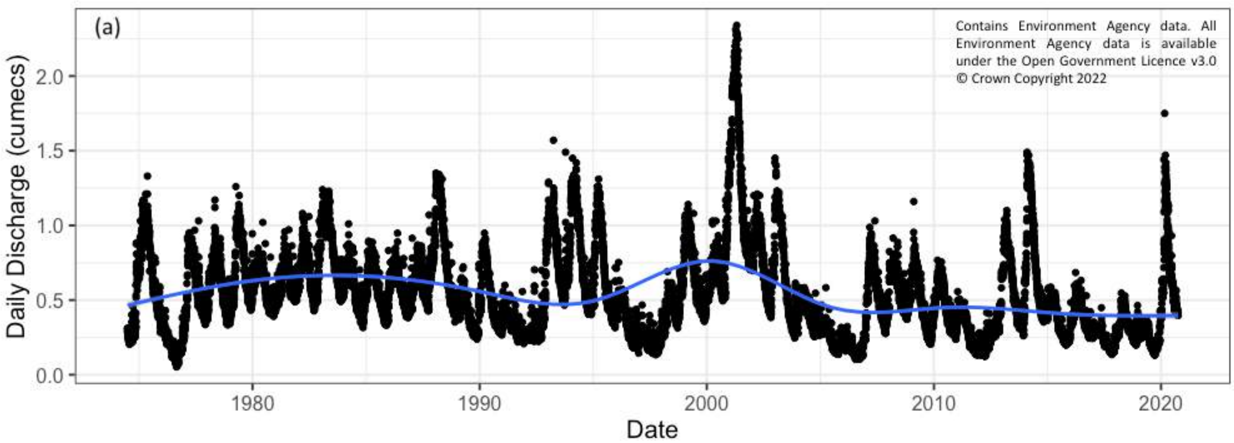
The stageboard in Chesham at Water Lane has been collecting river stage data at 15-mins intervals since 2006, and is a useful source of data in a river reach that is currently ephemeral in nature (*Figure 19*). Both the River Chess Association and Affinity Water have been recording flows on a monthly basis at Water Lane since 2016, and they also record when the channel dries. The red panels in *Figure 19* reflect observations of a dry channel at Water Lane. The stage data looks spikey because it is also influenced by short-term flow in the channel due to surface runoff from rainfall events which reaches the river channel via urban drainage and road runoff in Chesham.

The river flows at Water Lane when groundwater levels at Wayside reach approximately 106 m AOD (denoted by the horizontal grey dotted line). A distinct trigger value using Hawridge data is not so clear, but Hawridge is located up the northern valley at a higher location and the groundwater level data here represents a composite value from several boreholes, with the weighting from each borehole changing over time. By using the Wayside trigger value of 106 m AOD, in conjunction with the stage data, it appears that there were two other periods since 2006 during which the river dried up indicated by the blue panels: (i) July 2011 to July 2012 and (ii) Sept 2015 to Feb 2016.

3.2.1 Temporal variations in discharge

Discharge has been measured at Rickmansworth gauging station since 1974, and this dataset provides a useful long-term record of changes in flow over the last fifty years.

Following the drought of 1976 there was a 20-year period of ‘average’ rainfall conditions in the catchment corresponding to flows at Rickmansworth of c. 0.59 – 0.82 cumecs (i.e. m^3/s) with annual variation in response to seasonal changes in groundwater levels. From 1987 until 2019, however, there has been a general downward trend in flows in the river. This downward trend has been punctuated by inter-annual cycles of higher and lower flows; the latter in response to periods of higher and lower-than-average rainfall lasting several years.



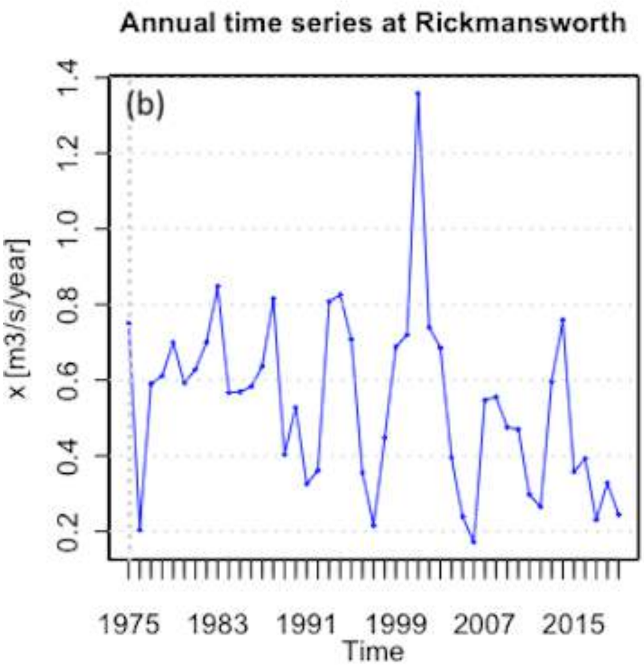


Figure 20 (a) time series of discharge (m3/s) at Rickmansworth gauging station and (b) annual average discharge (m3/s) at Rickmansworth gauging station. SOURCE: Environment Agency data.

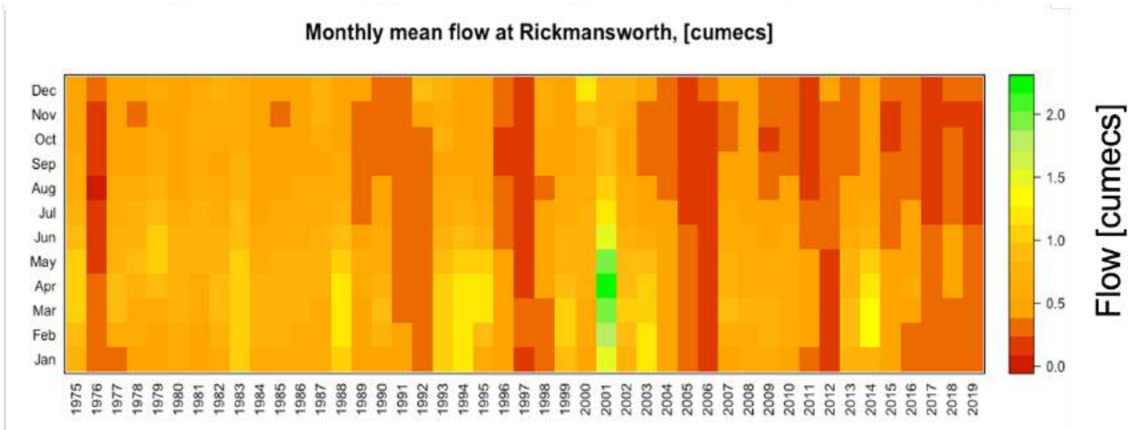


Figure 21 Heat map of mean monthly discharge (m3/s) at Rickmansworth gauging station. SOURCE: Environment Agency data.

The Chess exhibits an annual hydrological regime typical of a chalk stream with mean monthly flows generally highest in March to May and lowest in September to November due to the annual cycle of aquifer recharge.

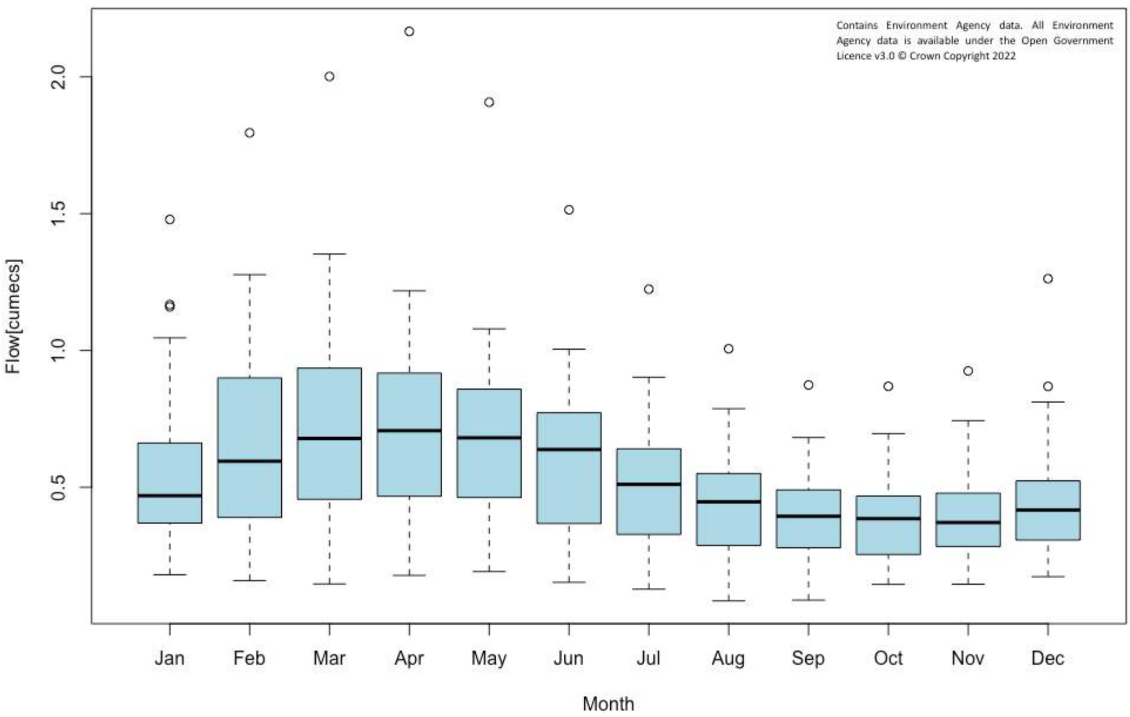


Figure 22 Mean monthly flows (cumecs = m³/s) based on data from Rickmansworth gauging station (1974-2020). Circles are outliers. SOURCE: Environment Agency data.

3.2.2 Spatial variations in discharge in the River Chess

The River Chess is groundwater-fed by a combination of springs and artesian wells. Artesian wells occur when water flows out of the ground under natural pressure without pumping, above the height of the water table. Some of these artesian features in the River Chess may occur naturally (i.e. water flowing via fractures), or they may be boreholes created or augmented by man to provide a reliable source of water to power mills and feed watercress beds. *Figure 23* indicates the location of natural springs and artesian wells in the River Chess.

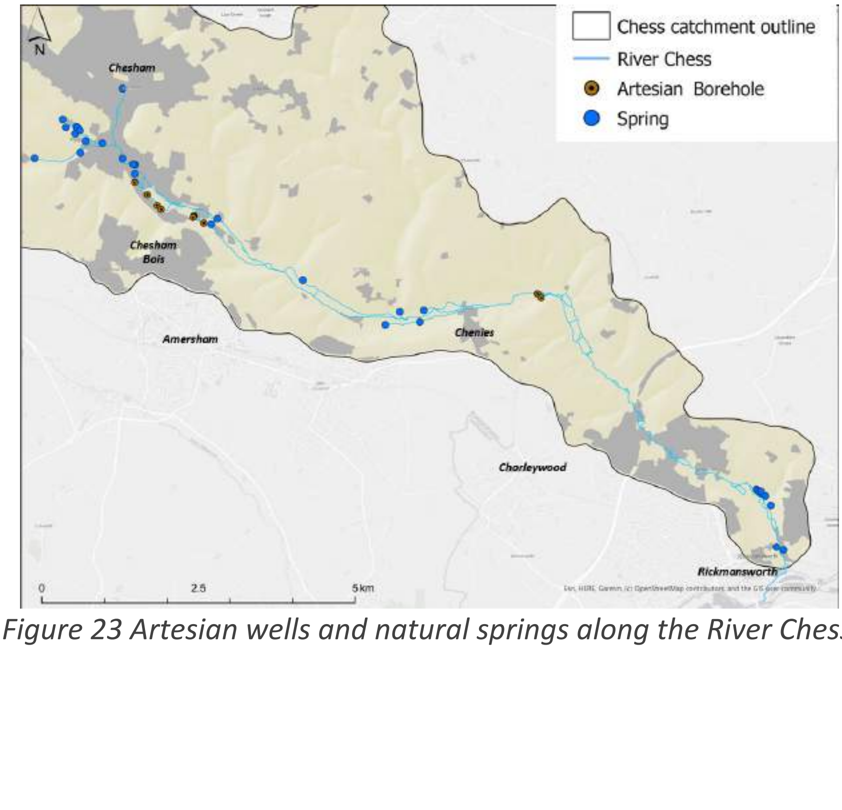


Figure 23 Artesian wells and natural springs along the River Chess

An artesian well at Lords Mill feeds the River Chess all year round and has not, in living memory, been known to dry up. This means that the river is considered to have perennial flow (all year round) from downstream of Lords Mill. Upstream of Lords Mill the river currently ceases to flow during periods of below-average rainfall (Section 3.2) The Little Chess is also fed by several artesian wells and flows throughout the year.

Different sections of chalk streams can be losing or gaining in nature (a losing reach loses water from the riverbed to the aquifer, whereas a gaining reach receives groundwater which adds to the flows). Whether a reach is gaining or losing can depend on a number of factors including topography, nature of the bed material, and in some cases due to abstraction for water supply. A reach can also switch from gaining to losing or vice versa over the year as the groundwater level varies in relation to the height of the riverbed. The Environment Agency have been gauging flows at four sites on the Chess since 2002 (Latimer, Valley Farm Road, Solesbridge and Rickmansworth), and these data can be used to establish whether the reaches between these locations are gaining or losing water. *Figure 24*, *Figure 25* and *Figure 26* show that the river gains water from the ground between Latimer and Valley Farm Road but loses water to the aquifer between Valley Farm Road and Solesbridge. The river is neither net gaining or losing between Solesbridge and Rickmansworth.

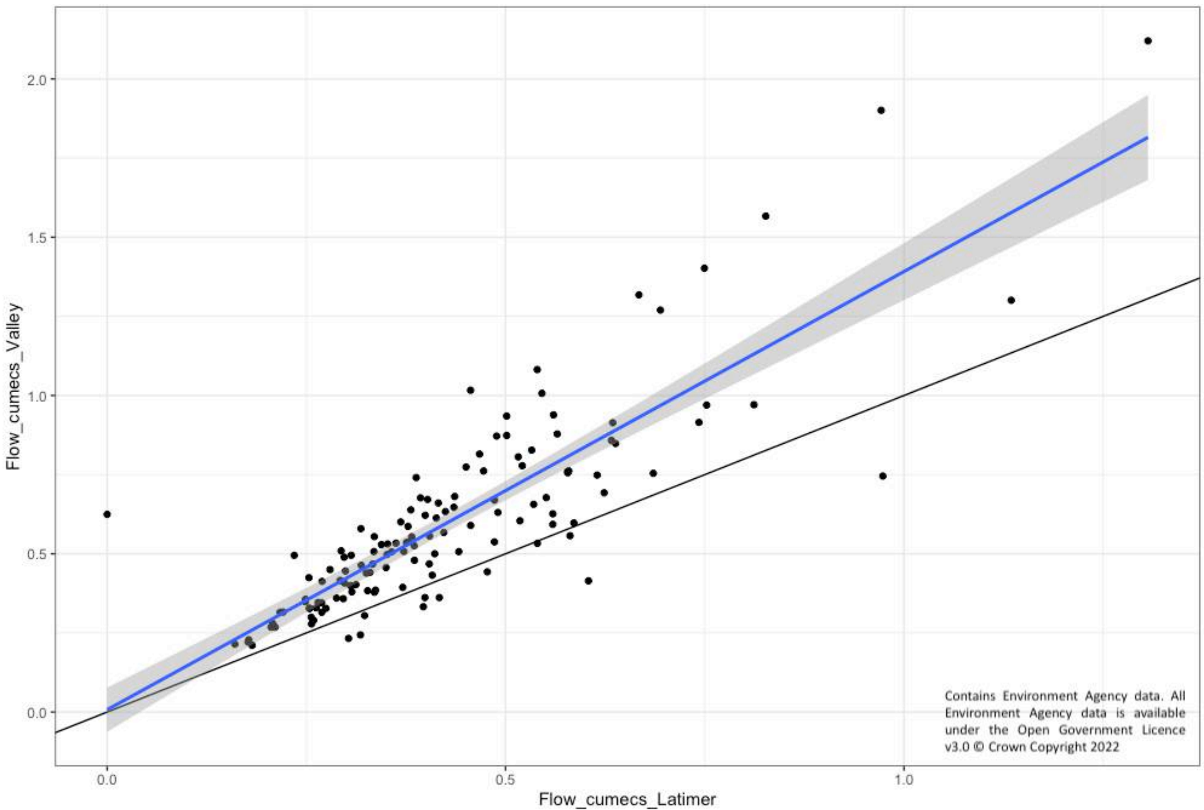


Figure 24 A comparison of gauged flows paired by day for Latimer and Valley Farm Road. The blue line with grey confidence bands indicates the relationship between flows at each site, whilst the solid black line shows a 1:1 relationship. SOURCE: Environment Agency data.

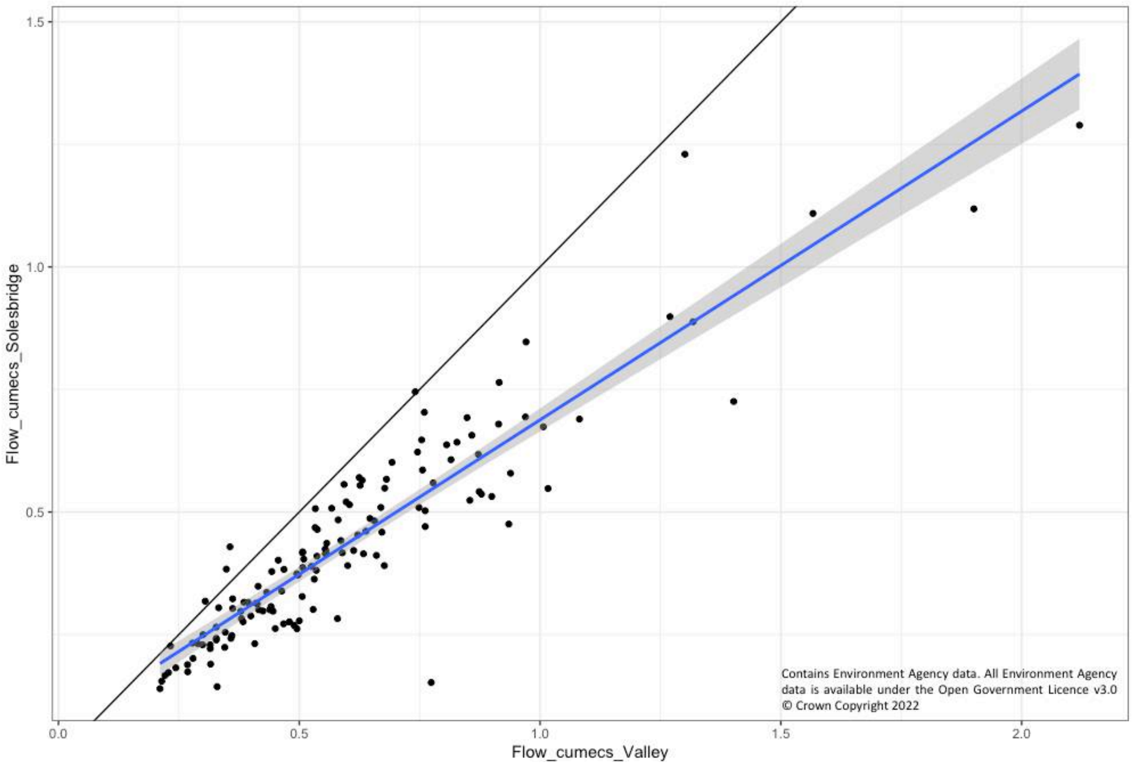


Figure 25 A comparison of gauged flows paired by day for Valley Farm Road and Solesbridge. The blue line with grey confidence bands indicates the relationship between flows at each site, whilst the solid black line shows a 1:1 relationship. SOURCE: Environment Agency data.

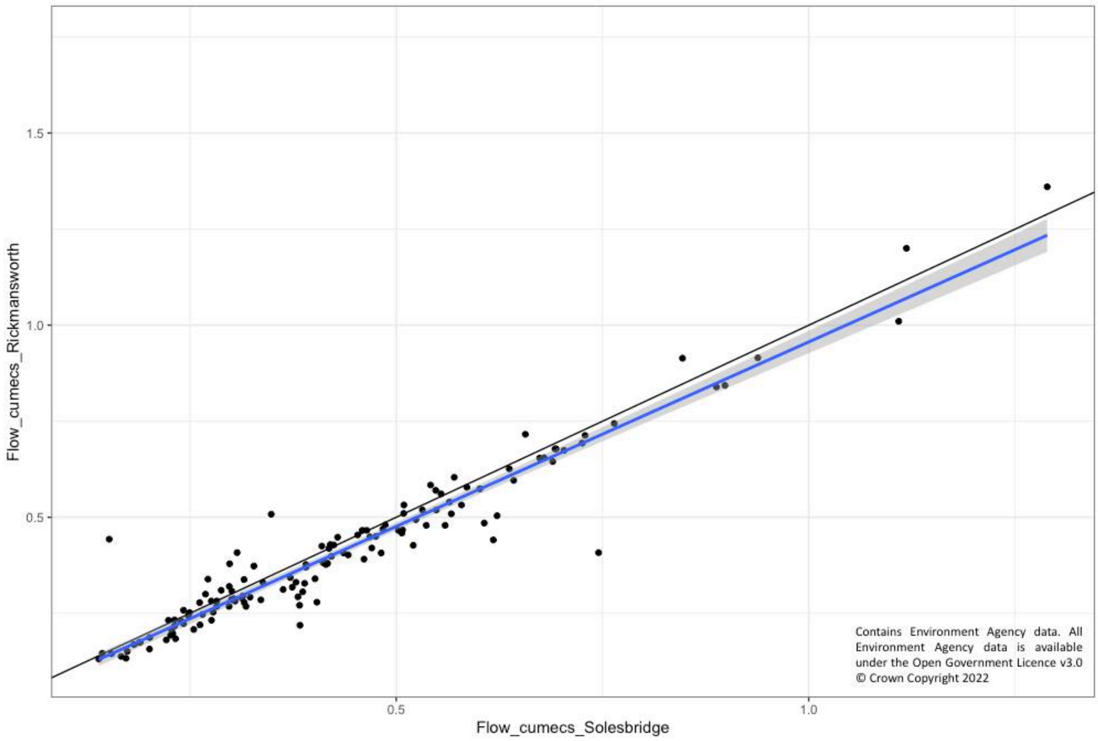


Figure 26 A comparison of gauged flows paired by day for Solesbridge and Rickmansworth. The blue line with grey confidence bands indicates the relationship between flows at each site, whilst the solid black line shows a 1:1 relationship. SOURCE: Environment Agency data.

3.3 Abstraction Management Strategy

There is a long history of water abstraction from the catchment for drinking water supply commencing in the 1880s. The Upper Chess was the focus of an AMP6 low flow investigation by Affinity Water and Thames Water from 2015 to 2020; a requirement which arose from the Environment Agency's National Environment Programme. Under PR19/AMP7 Affinity Water have a statutory obligation to improve the hydrological regime of the Chess through action at Alma Road and Chartridge Road pumping stations. Since publication of the low flow investigation report, Affinity Water have ceased abstraction for drinking water from these two boreholes at the top of the Chess (together comprising c. 7.27 ML/day). One abstraction ceased in January 2018, and the other in August 2020. This cessation of abstraction was announced on 27 September 2020. Consequently, Affinity and Thames Water are monitoring flow and groundwater levels in the upper catchment in order to assess any changes to flows in the River Chess along with changes to the aquifer.

Thames Water have also committed to ceasing abstraction at Hawridge (currently c. 2 ML/day with a current annual licence of 9.09 ML/day); this is part of a large capital programme and is currently planned for delivery by the end of 2024. This is part of the PR19/AMP7 statutory obligations described in Section 5.

There is one further public water supply borehole owned by Affinity Water in the middle reaches of the catchment close to Chorleywood. There are no current plans to cease abstraction from this location.

Boreholes used for public water supply are associated with groundwater protection zones which limit potentially polluting activities surrounding the point of abstraction. *Figure 27* shows the location of the groundwater protection zones in and around the Chess catchment. As can be seen in the map groundwater protection zones are sub-divided into inner and outer areas with their shape and extent based on travel time of a pollutant from activity to the borehole (50 and 400 days respectively for inner and outer zones).

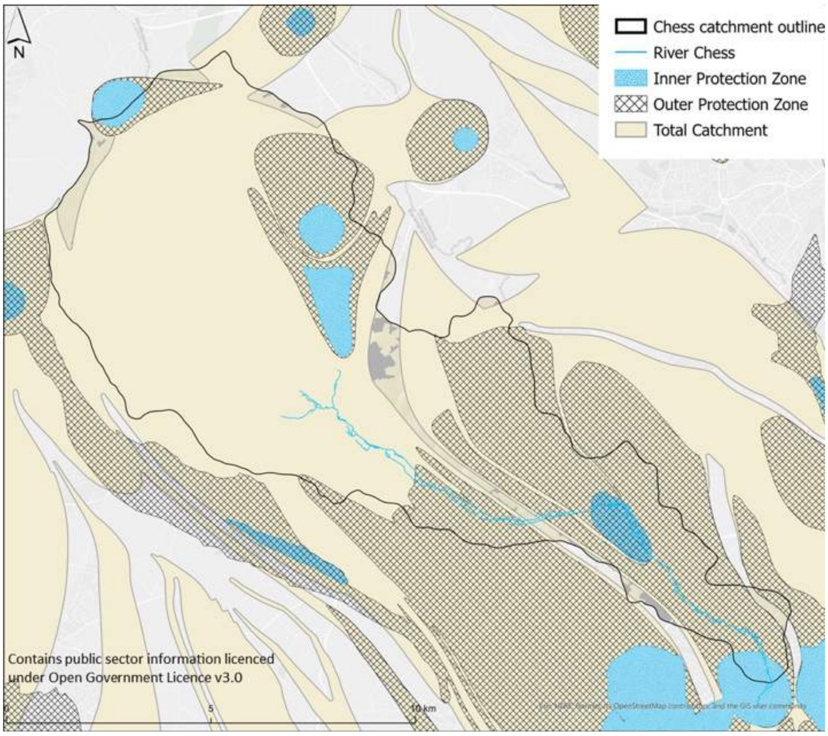


Figure 27 Inner and Outer Groundwater Protection Zones in the River Chess

3.4 Groundwater quality

Figure 28 shows changes to nitrate (mg/L) in groundwater in the Chess catchment from 2001 to the present day showing concentrations in three boreholes of c. 20 mg/L nitrate (= 4.52 mg Nitrate-N/L), with a slight increase in concentration over the 20 years of the record. A fourth borehole shows more elevated and variable concentrations of between 20 and 60 mg/L nitrate. At this borehole nitrate concentrations appear to increase when groundwater levels are high, for example in 2014. During significant flood periods, when the groundwater levels rise into the unsaturated zone and near-surface environment then agrochemicals such as nitrate can be picked up and mobilised through specific, preferential flow pathways. This highlights the importance of controlling nitrate concentrations in groundwater through land use activities, such as following best management practices with regards to fertiliser applications, in the catchment. Similar nitrate mobilisation processes are likely to have been in operation in 2001, but the exact pathways and mechanisms not fully understood.

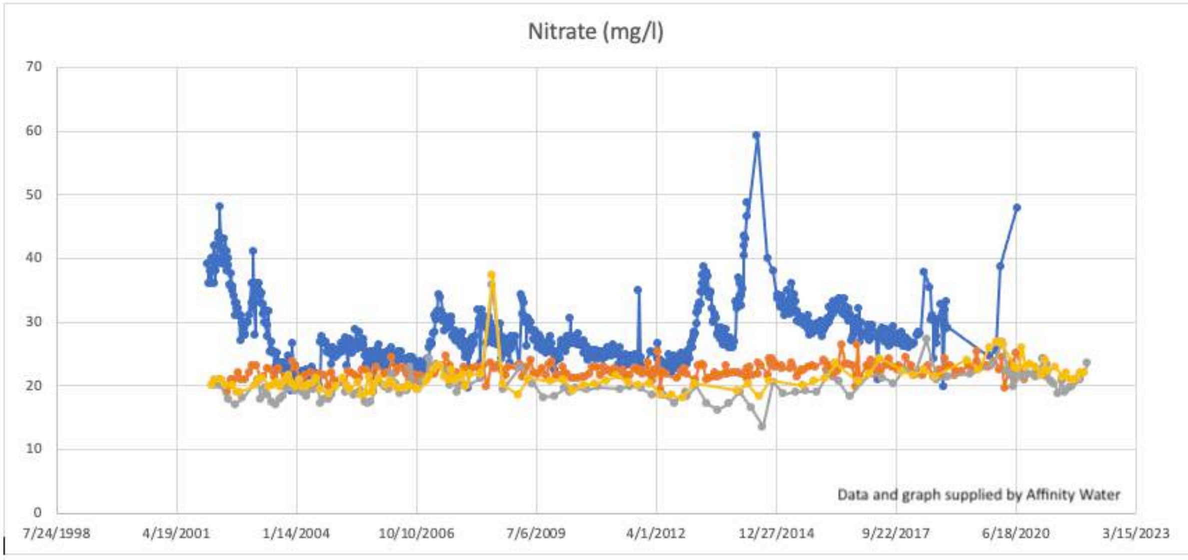


Figure 28 Variations in nitrate concentrations (mg/L) in groundwater in the River Chess catchment. SOURCE: Figure provided by Affinity Water.

Figure 29 shows variations in Phosphorus as P (μg P/L) in groundwater in the River Chess catchment from 2001 to the present time, indicating average concentrations of c. 100 μg P/L with spikes in the data apparent for the same borehole as showed variability in nitrate above. Again this may be due to wet periods which have mobilised flowpaths for local nutrient migration from the near-surface, but the reasons are not fully understood.

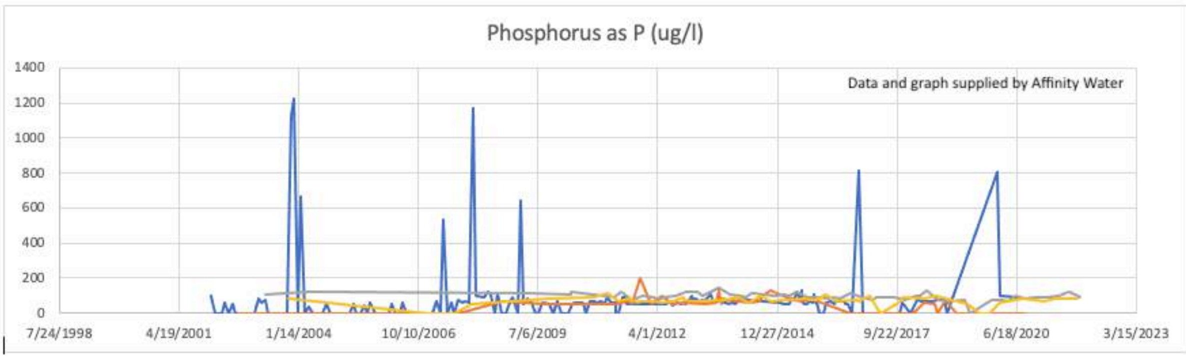


Figure 29 Variations in phosphorus as P concentrations (mg P/L) in groundwater in the River Chess catchment. SOURCE: Figure provided by Affinity Water.

4 Historical and current WFD status

4.1 Context

The Environment Agency currently classifies surface waters from High to Bad Status according to the EU Water Framework Directive (WFD) which came into force in 22 December 2000 and was transposed into UK law. To achieve good ecological status or potential every single element assessed must be at good status or better.

Status	Definition
High	Near natural conditions. No restriction on the beneficial uses of the water body. No impacts on amenity, wildlife or fisheries.
Good	Slight change from natural conditions as a result of human activity. No restriction on the beneficial uses of the water body. No impact on amenity or fisheries. Protects all but the most sensitive wildlife.
Moderate	Moderate change from natural conditions as a result of human activity. Some restriction on the beneficial uses of the water body. No impact on amenity. Some impact on wildlife and fisheries.
Poor	Major change from natural conditions as a result of human activity. Some restrictions on the beneficial uses of the water body. Some impact on amenity. Moderate impact on wildlife and fisheries.
Bad	Severe change from natural conditions as a result of human activity. Significant restriction on the beneficial uses of the water body. Major impact on amenity. Major impact on wildlife and fisheries with many species not present.

Figure 30 Definition of status in the Water Framework Directive. SOURCE: Thames River Basin Management Plan, February 2016.

The initial aim of the WFD was for all surface waters to meet Good Ecological Status by 2015 and plans to improve the status of all water bodies were described in the six-year River Basin Management Plans (RBMP) 2009-2015 (Cycle 1). The target was not met, and two further RBMP cycles were put in place; 2015-2021 (Cycle 2) and 2021-2027. The requirement to develop an RBMP from 2021 to 2027 is set out in domestic law so still applies.

As of 2021 only 14% of assessed rivers in England meet the criteria for good ecological status, and no surface water body meets good chemical status. In 2019 new chemical assessments for ubiquitous, persistent, bioaccumulative and toxic substances, termed uPBTs, were included in the WFD classifications. These substances - such as polybrominated diphenyl ethers (PBDEs) and perfluorooctanesulfonic acid (PFOS) - last a long time in the environment without degrading, and they tend to accumulate in the flesh of fish and other animals (termed bioaccumulation). The EU has derived biota standards to better represent the threats to wildlife from this group of chemicals. The change in classification method in 2019 led to changes in classification criteria for 8 chemicals and chemical groups that were not measured in 2016. If the new assessment for uPBTs is excluded then 93.8 % of rivers would pass the chemical tests, compared to 97% in 2016 (Environment Agency & Natural England, 2021).

4.2 Overview of River Chess WFD status

The Chess is considered under the Colne catchment section of the Thames River Basin Management Plan as Water Body GB106039029870. The river is not designated as artificial or heavily modified. Both overall water body and ecological status were 'Poor' from 2010 until 2012 but have been classified as 'Moderate' since 2013. Chemical status was considered 'Good' until the river failed in 2019 when uPBT analyses were introduced.

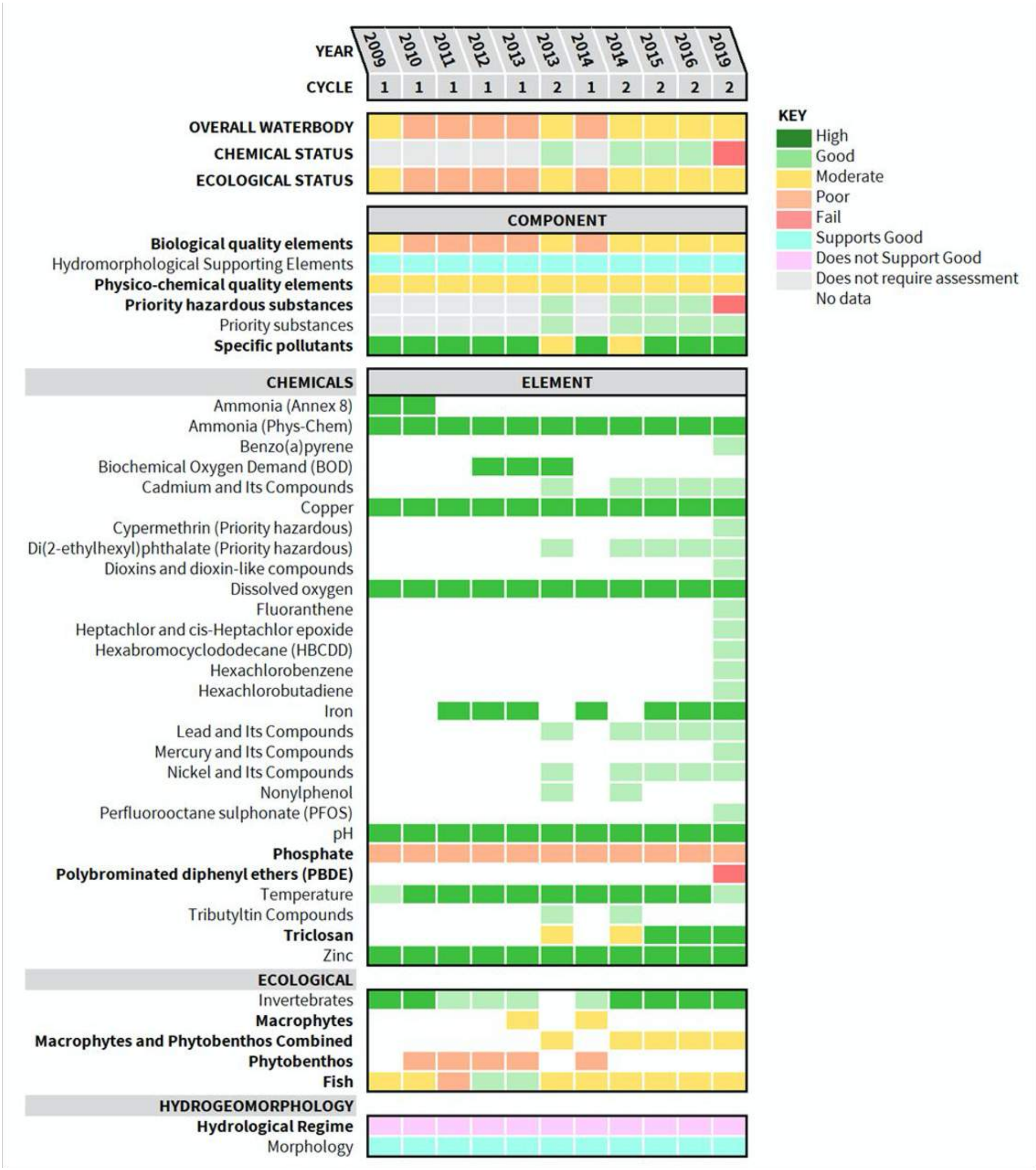


Figure 31 Overall water body WFD status, split into ecological and chemical for first and second cycles. SOURCE: Environment Agency data.

The Chess falls under the remit of the ColneCan catchment partnership, and a stated aim in Thames River Basin Management Plan 2015-2021 was to establish a chalk streams discovery centre on the River Chess to showcase and celebrate the water environment.

Figure 32 shows the locations of the sites used for WFD monitoring. Chemical monitoring for WFD purposes is carried out at five different sites spread out through the river, all downstream of Chesham WWTW. Biological monitoring for macrophytes and invertebrates takes place at four locations marked with green triangles, and fish at three locations marked with a circle and fish symbol. *Table 1* summarises the WFD water quality standards as applied to the River Chess (a Type 7, salmonid river).

In *Figure 31* "Hydrological Regime" means the system whereby the creation, function and health of riverine habitats, as well as the protection of the ecology they support, is regulated using environmental standards (termed Environmental Flow Indicators (EFIs) in England and Wales) that are considered appropriate to support good ecological status under WFD (see the UK Technical Advisory Group on the Water Framework Directive (UKTAG), Reports 2008a and 2008b). If a river Supports 'Good Hydrological Regime' this indicates that flows are compliant with the EFI and supports achieving GES. A 'Does Not Support Good' Hydrological Regime indicates that flows are non-compliant with the EFI, and therefore do not support achieving Good Ecological Status. Hydrological regime is assessed using the Environmental Flow Indicator (EFI), which is a percentage deviation from the natural river flow using a flow duration curve. Continuous discharge is measured at Rickmansworth gauging station, with additional spot flow gauging carried out at points along the river by volunteers.

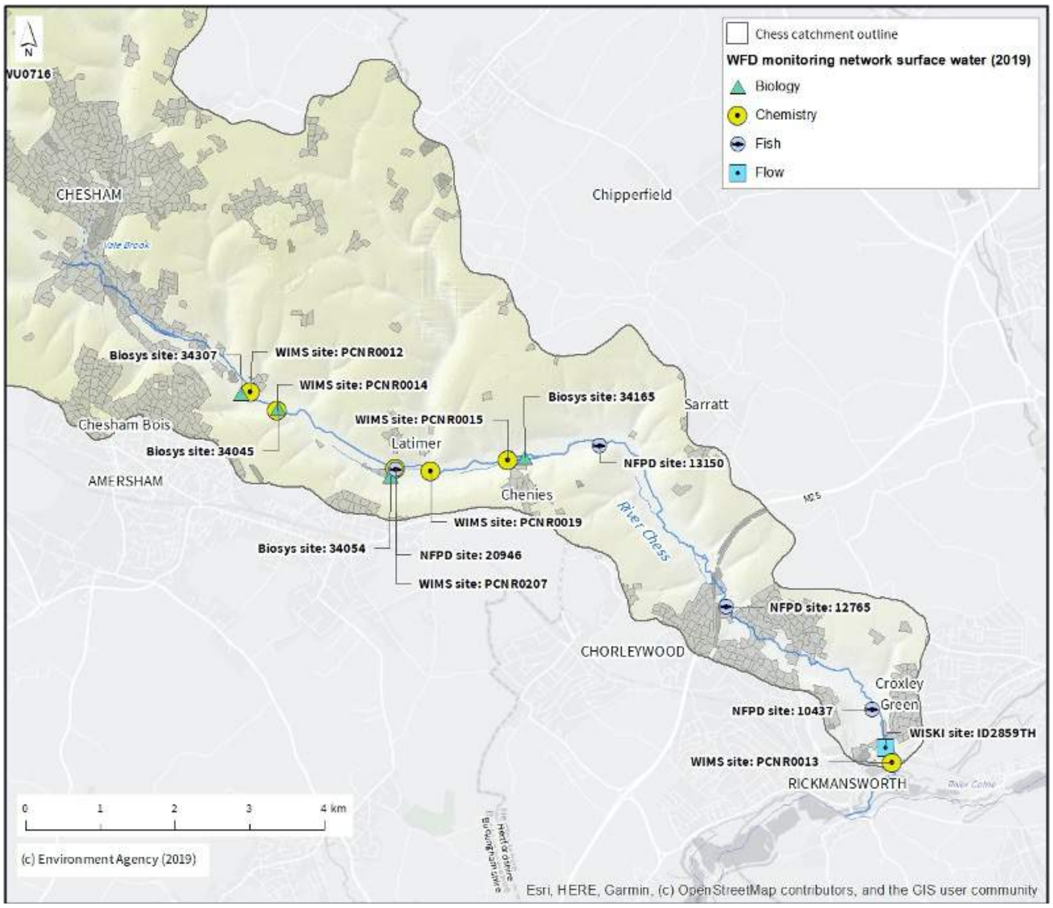


Figure 32 Sites used for WFD classification (2021). SOURCE: Environment Agency data.

Table 1 WFD water quality standards for River Chess (Type 7, salmonid)

Determinand	Method	High	Good	Moderate	Poor
Dissolved Oxygen (%sat)	10th percentile	80	75	64	50
BOD (mg/L)	90th percentile	3	4	6	7.5
Reactive phosphorus (mg/L)	Annual mean	0.042	0.078	0.191	
Temperature (°C)	98th percentile	20	23	28	30
Total Ammonia as N (mg/L)	90th percentile	0.3	0.6	1.1	2.5

4.3 Reasons for not achieving good status

Macrophytes/phytobenthos and fish are classified as'Moderate' status, whilst invertebrates are considered to be 'High' status. All these elements contribute to the 'Moderate' ecological status of the River Chess under the WFD.

Phosphate has been continuously classified as 'Poor' status since the WFD began. The continuous discharge of phosphate arising from treated wastewater effluent has been identified as contributing to the moderate macrophytes/phytobenthos and fish status. Groundwater abstraction is also a confirmed pressure on the river, and according to Cycle 2 analysis the hydrological regime (2013-2019) is not considered to support good overall status. Physical modifications of the river morphology (including for flood protection, operational management and impoundments) are also thought to contribute. Finally sediment from diffuse agricultural sources (riparian and in-river activities including bank erosion) are also thought to contribute to the moderate macrophyte/phytobenthos status.

The river fails for priority hazardous chemical substances due to the failure for poly-brominated diphenyl ethers (PBDEs) in 2019. However, the priority substances class is considered 'Good' and the specific pollutants class is considered 'High'. The reasons for failure for PBDE are considered further in Section 6.11.1.

4.4 Protected areas within the catchment and downstream of the River Chess

The WFD requires that areas which supply drinking water (either from surface or groundwaters) are identified and protected (WFD Article 7.1 and 7.3) to avoid deterioration in water quality. Drinking Water Safeguard Zones identify areas where action is needed to prevent water quality deterioration where a pressure has been identified.

Groundwater Safeguard Zones (SgZs) delineate areas around boreholes or springs used for drinking water supply where there is an issue with groundwater quality which warrants targeted interventions to address the causes of pollution. There are groundwater drinking water safeguard zones in place to the south-east of the River Chess catchment in the Croxley area due to the risk of groundwater pollution by ammoniacal nitrogen (TH025, Eastbury) and metaldehyde (TH026, Tolpits Lane) respectively. The Tolpits Lane metaldehyde issue is now resolved and historical.

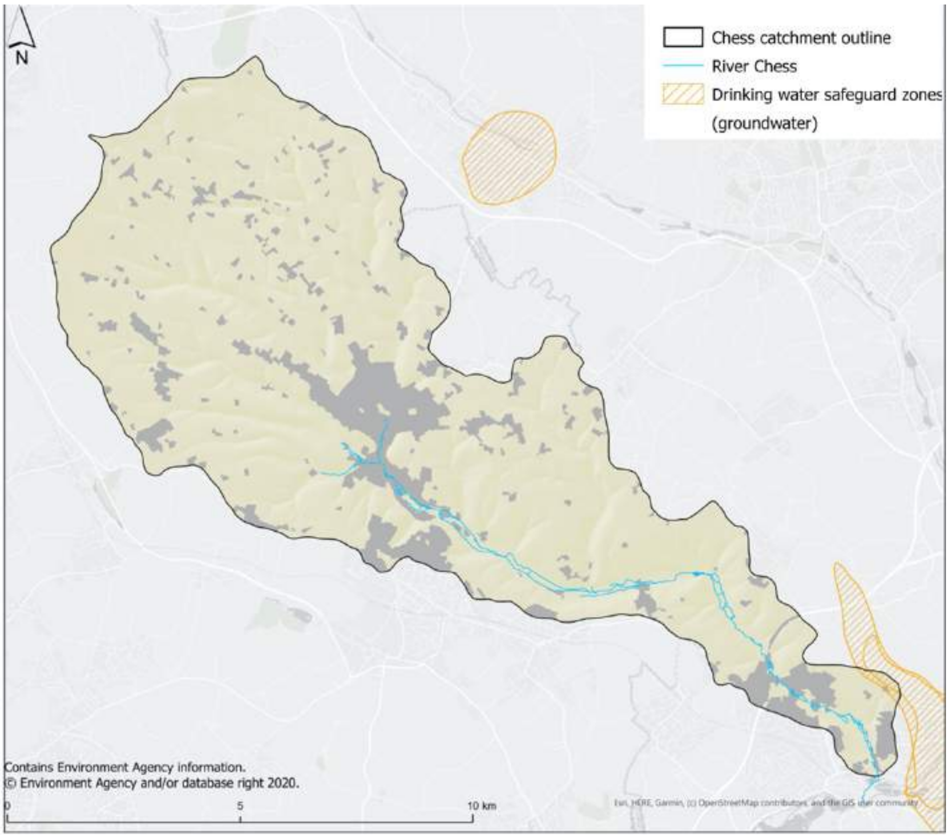


Figure 33 Drinking Water Safeguard Zone (Groundwater) in and around the Chess catchment

Similarly non-statutory Surface Water Safeguard Zones (SgZs) fall within the upstream catchment of a drinking water abstraction location (in this case a river, lake or reservoir) where the surface water is a risk of failing the WFD drinking water objectives. The River Chess is located within the upstream catchment for the Thames Egham-Teddington Drinking Water Protected area; where the Environment Agency, together with Thames Water and Affinity Water have designated the catchment as 'at risk' from the following organic contaminants: propyzamide, carbetamide and metaldehyde. In addition, MCPA, mecoprop and quinmerac are categorised as 'under consideration'.

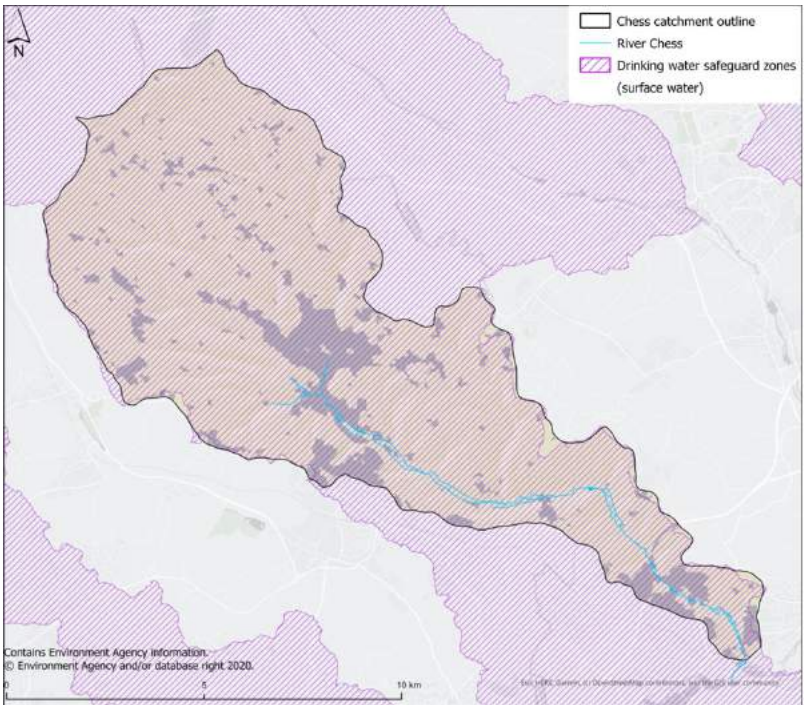


Figure 34 Drinking Water Safeguard Zone (Surface water) in and around the Chess catchment

The area is considered overall of medium priority under the Countryside Stewardship Scheme Water Quality Priority areas (2014 data). With regards to specific water quality parameters it is considered of medium priority for Surface Water Pesticide Issues, but it is not currently prioritised for sediment, phosphate, nitrate or faecal indicator organisms.

5 Review of current regulatory and non-regulatory plans

5.1 Water Industry National Environment Programme (WINEP) and Asset Management Period 7 (AMP7)

The Water Industry National Environment Programme (WINEP) describes the water industry's contribution to delivering objectives for the natural environment as set out in River Basin Management Plans (RBMPs). It comprises a required programme of works for water companies in England to fulfil their obligations arising from environmental legislation and UK government policy. As the WINEP is an important list of obligations used by water companies to develop their business plans, an updated WINEP is required ahead of each five-year price review by Ofwat. We are currently in the Price Review 19 (PR19) period, also known as Asset Management Period 7, which runs from 2019-2024.
Table 2 and *Table 3* summarise the obligations for Thames and Affinity Water (the two water companies operating in the Chess catchment) described under PR19/AMP7.

Affinity Water have a statutory obligation to act at two pumping stations to improve hydrological regime to meet Water Framework Directive objectives related to flow. This has already been actioned as described in Section 3.3. River restoration projects to improve flow and fund work on priority habitat creation are required by 31 March 2025.

Thames Water have a statutory obligation at Chesham wastewater treatment works (WwTW) to (i) install EDMs on storm tank overflows; (ii) investigate whether monitors can be used to measure pass forward flow (PFF) i.e., the instantaneous upstream flow; (iii) increase treatment capacity; and (iv) reduce phosphorus with the aim of meeting Moderate WFD status in the River Chess. The company is also required to act at Hawridge Pumping station to improve hydrological regime in the River Chess and to fund river restoration schemes to improve the environment and create priority habitat.

In *Table 3* FFT means flow to full treatment (the maximum flow a wastewater treatment plant can treat) and Thames Water are obliged to increase treatment capacity at Chesham WWTW to treat peak dry weather flow and additional flows from light rainfall using the equation FFT = 3PG + Imax + 3E where PG is the catchment population (number) multiplied by G (per capita domestic flow in litres/head/day), Imax is the maximum infiltration rate over the year and E is the trade effluent flow (litres/day). Further information can be found here.

Table 2 Summary of WINEP-derived PR19 statutory obligations for Affinity Water in River Chess (from Environment Agency WINEP programme update for 2019).

Unique ID	Scheme Name	Driver (primary)	Driver (secondary)	Driver (tertiary)	Measure type	Completion date
7AF100116	Alma Road pumping station	Action to improve hydrological regime to meet WFD objectives	Change to permit where there is evidence and it contributes towards biodiversity priorities and the NERC Act	Action to prevent deterioration of ecological status from flow pressures	Sustainability Change	22/12/2024
7AF100119	Chartridge pumping station	Action to improve hydrological regime to meet WFD objectives	Change to permit where there is evidence and it contributes towards biodiversity priorities and the NERC Act	Action to prevent deterioration of ecological status from flow pressures	Sustainability Change	22/12/2024
7AF100133	River restoration projects	Action to improve hydrological regime to meet WFD objectives	Allow water companies to fund work on priority habitat creation, restoration, species recovery so as to contribute towards biodiversity priorities and the NERC Act.	Not provided	Adaptive Management	31/03/2025

Table 3 Summary of WINEP-derived PR19 statutory obligations for Thames Water in River Chess (from Environment Agency WINEP programme update for 2019)

Unique ID	Scheme Name	Driver (primary)	Driver (secondary)	Driver (tertiary)	Measure type	Completion date
7TW200 019	Chesham Sewage Treatment Works	Install EDM on WwTW overflows to storm tanks at those WwTW where we can`t use existing monitors to be confident that the permitted FFT setting is being complied with.	Not provided	Not provided	Intermittent discharge	31/03/21
7TW200 054	Chesham Sewage Treatment Works	Investigation to confirm if any existing front end flow monitor or the back end MCERTS flow monitor can be used to measure PFF to full treatment at a WwTW. Existing front end monitors must be considered first and where they can be MCERTS certified to measure PFF they should be used to provide data within AMP7. Where there is no front end monitor or it cannot be MCERTS certified investigate whether the back end flow monitor can be MCERTS certified to measure PFF. If it can, then use it to provide data within AMP7. If neither can be MCERTS certified then a new inlet MCERTS flow monitor will be required under a PR24 driver	Not provided	Not provided	Intermittent discharge	31/03/22
7TW200 084	Chesham Sewage Treatment Works	The WwTW FFT must be increased to 3PG + IMAX + 3E	Not provided	Not provided	Intermittent discharge	31/03/25
7TW200 121	Chesham Sewage Treatment Works	Measures to reduce ammonia, phosphorus, BOD or nitrogen at WWTWs in order to meet WFD standards in rivers, transitional or coastal waters. In this case Phosphorus to Moderate status for the element.	Not provided	Not provided	Continuous discharge	22/12/24
7TW100 044	Hawridge Pumping Station	Action to Improve hydrological regime to meet WFD objectives	Changes to permits or licences, where there is evidence and it contributes towards biodiversity priorities and the NERC Act.	Action to prevent deterioration of ecological status from flow pressures	Sustainability Change	22/12/24
7TW100 064	River Restoration Projects	Action to Improve hydrological regime to meet WFD objectives	Allow water companies to fund work on priority habitat creation, restoration, species recovery, so as to contribute towards biodiversity priorities and the NERC Act. This includes activities on water company owned landholdings or in catchments they influence and operate in when delivering landscape or catchment scale wider benefits and ecosystem services, either in isolation or in partnership.	Not provided	Adaptive Management	31/03/25

The Environment Agency, Defra and Ofwat have planned considerable changes to the WINEP process for the 2024 Price Review (PR24), and these changes are under development. The ambition is to support greater innovation and collaboration through co-design, co-delivery and co-funding of solutions to improve and protect the water environment (Environment Agency, 2021). This new methodology might offer the opportunity for communities and catchment stakeholders to be more involved in catchment planning during AMP8.

5.2 Non-regulatory plans and projects delivering benefits to the River Chess

The Chilterns Society and Chiltern Chalk Stream Projects are working together on a suite of projects as part of the Chalk Streams and Wetland Meadows Project (funded by the Green Recovery Challenge Fund). There are two current river restoration schemes on the River Chess which are part of this project.

The first is a project at Restore Hope Latimer to improve light and flow heterogeneity along a 1.4 km reach aiming for 50:50 light to shade ratio through coppicing and dead wood removal. Wood will be incorporated into berms and deflectors in the channel to improve sinuosity and focus flow allowing greater diversity of in-channel and marginal vegetation. It is hoped that improvements in habitat will encourage the establishment of water vole populations from upstream and downstream of the site (A Porter, pers. comm.). Improvements in vegetation and flow diversity in this stretch of the river could offer enhanced opportunities for nitrate attenuation through plant uptake and an increase in residence time leading to nitrate removal via denitrification.

There is also a second consultation underway to consider re-naturalisation of the channel at Chesham Moor to improve sinuosity, flow heterogeneity and support a greater range of macroinvertebrates and fish (A Porter, pers. comm.). These types of project help with localised oxygenation of river water through increased flow diversity, and can contribute to increasing the overall nitrate removal capacity of the river.

Wilder Chess is a farmer-led initiative in the downstream reaches of the Chess supported by Hertfordshire Wildlife Trust. The idea being for landowners to help identify opportunities in the river valley to improve the habitats present for nature. Hertfordshire Wildlife Trust support the initiative with expertise and land/habitat surveys to help identify the opportunities and questions that farmers raise. There may be opportunities to link with farmers here to discuss soil health, erosion and transport (with associated agrochemicals) within the catchment.

Trout in the Classroom is an annual educational project established by the Chilterns Chalks Streams Project in 2009 to work with local schools to hatch brown trout eggs in tanks and release them to the River Chess. Pupils learn about the life cycle of the fish and develop an interest in their local river, and undertake a site visit to the river. In this way they are also helping to stock trout in the river.

6 Water and sediment quality

This Section describes what is known about the water and sediment quality of the River Chess at the start of the Smarter Water Catchment Initiative. It establishes the 'baseline' water quality in order that monitoring gaps, can be established and opportunities for gap-filling can be identified.

6.1 Measurements of groundwater and surface water quality in the River Chess

Much of this analysis draws on catchment monitoring carried out by the Environment Agency, and is supplemented with data from Thames Water, Affinity Water and from Citizen Science activities (ChessWatch, ARMI Riverfly, flow monitoring) in the catchment.

6.1.1 EA and water company groundwater and surface water quality monitoring

The Environment Agency carry out statutory national surface water quality monitoring for the purposes of the Water Framework Directive, but also for pollution investigations and local monitoring initiatives. *Figure 35* summarises the location of EA surface water quality monitoring sites obtained from the WIMS database where freshwater monitoring has taken place over a number of years. Such sites yield useful data for the purposes of this baseline assessment. Open sites (denoted with a blue circle) are where monitoring is current, and closed sites (denoted with a grey circle) are historical sites where monitoring no longer takes place.

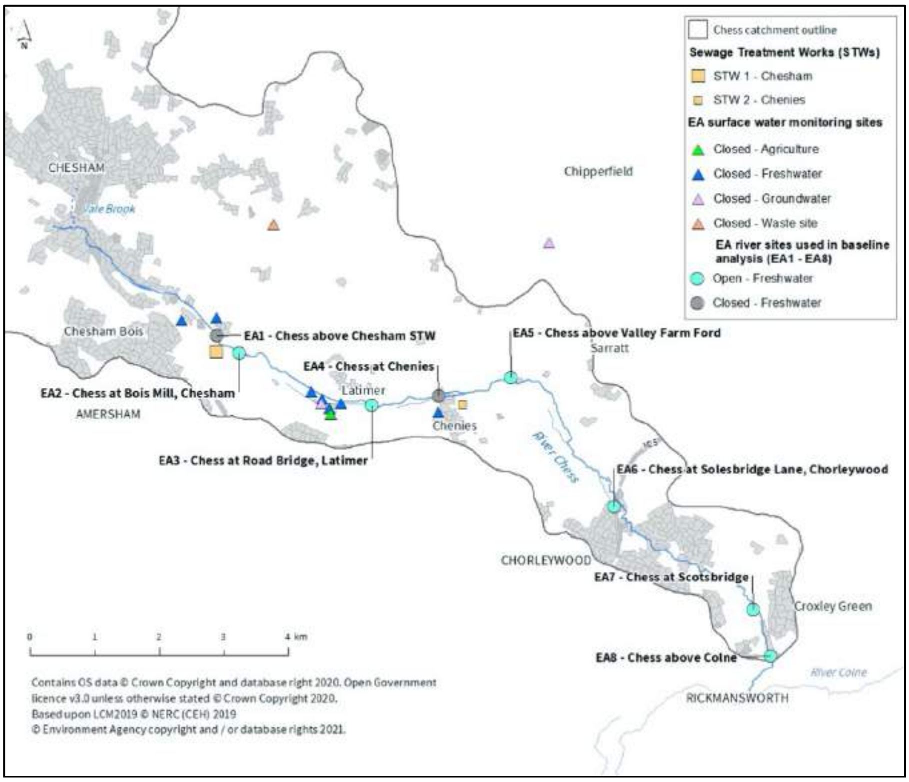


Figure 35 EA surface water quality monitoring sites (open and closed). SOURCE: Environment Agency data.

Table 4 summarises the sites, the status of each site, and the start and end of the sampling window. Although EA1 (Chess above Chesham WWTW) is closed, monitoring at this site recently re-commenced (as of 2022) for local investigations. A new water quality monitoring site was also opened in 2021 at Scotsbridge Mill as a component of the National River Surveillance Network. Grab samples for laboratory analysis are collected at approximately monthly intervals at these sites. With the re-introduction of EA1 there is good coverage of surface water quality monitoring sites along the length of the River Chess, apart from the Little Chess which would benefit from monthly sampling.

Table 4 Environment Agency freshwater monitoring sites and their purpose

Site code	Name	Status	Sample collection dates	Purpose	Comments
EA1	Chess above Chesham WWTW	Closed	2000-2012	Local investigation	Reopened and added to local investigation programme starting 2022
EA2	Chess @ Bois Mill	Open	2000-2021	Local investigation	added to local investigation programme starting 2022
EA3	Chess@Road Bridge Latimer	Open	2000-2021	Area drought plan and water resources monitoring	
EA4	Chess@Chenies	Closed	2000-2013	N/A	
EA5	Chess Above Valley Farm Road	Open	2018-2021	National drought reporting	Long term site
EA6	Chess@Solesbridge Lane	Open	2018-2021	National drought reporting	Long term site
EA7	Chess@Scotsbridge	Open	2021	National (River Surveillance Network) monitoring site	Long term site
EA8	Chess above Colne	Open	2000-2021	Long-term monitoring sites programme	Long term site

There are no Environment Agency groundwater quality monitoring sites in the catchment. Instead the Environment Agency rely on groundwater quality data from the water supply boreholes of the water companies (Affinity and Thames Water). These data are not available to the public for scrutiny.

6.1.2 ChessWatch

Four water quality sondes were installed in the River Chess from April 2019 (*Figure 36*) and have been programmed to take measurements at 15-minute intervals. Each sonde has sensors to measure water level, pH, electrical conductivity, turbidity and dissolved oxygen. They also have rotating wipers to clean the sensors before each measurement, and have been manually cleaned every two weeks by the Citizen Scientist team. The calibration for each sensor has been checked monthly. The ChessWatch programme was designed to investigate water quality in the upper reaches of the River Chess, with the intention to move the sensors downstream over a number of years.

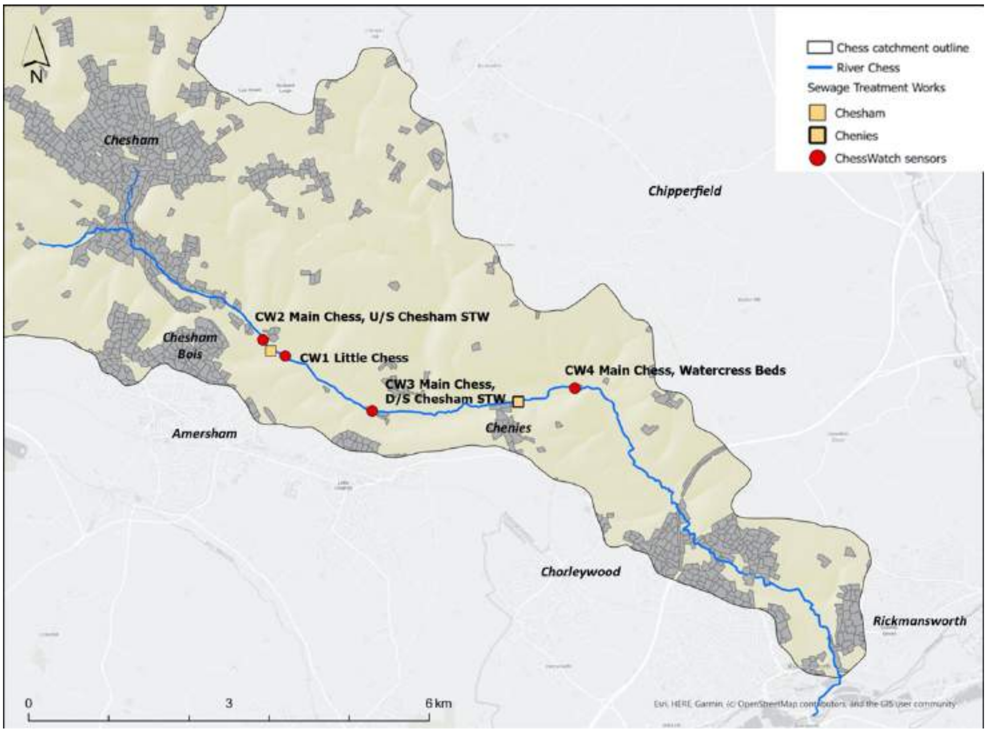


Figure 36 ChessWatch sensor locations.

6.1.3 Riverfly

Citizen Scientists have been collecting ARMI riverfly data in the Chess catchment for over ten years. Selected data are included here when water quality has been shown to impact on river invertebrates.

6.1.4 EarthWatch Freshwater Blitz data for Chesham

Since 2015 Citizen Scientists have been able to analyse water samples for nitrate and phosphate concentrations using colorimetric test kits as part of the Earthwatch Europe Freshwater Watch initiative. The timing of sample collection aligns with the Earthwatch campaigns in Sept/Oct or April/May so does not provide good temporal coverage, but there has been useful sampling activity in Chesham where there is no monitoring by the Environment Agency. The results from these data are considered in Section 6.5.1 and 6.6.2.

6.2 Electrical conductivity

Electrical conductivity measures the ability of the water to conduct electricity, and is a useful surrogate measure of total dissolved solutes. The longer the residence time of water in soils and rocks, the more solutes the water picks up and the higher the electrical conductivity in relation to rainfall; thus groundwater has a higher electrical conductivity than rainwater. The River Chess electrical conductivity values fall within the normal range expected for groundwater-fed rivers in the UK, and the Environment Agency data shows no overall decline or increase in electrical conductivity in the River Chess between 2000 and the current time (*Figure* 37). Mean electrical conductivity (2000-2020) above Chesham WWTW is 578 μS/cm but rises to 741 μS/cm downstream of the outfall as a result of the solute load contributed by the sewage treatment works (*Figure 37*, *Figure 38*). At Latimer Bridge, downstream of Latimer Park Lakes and the confluence of the Little Chess and Main Chess, the mean electrical conductivity (2000-2020) drops to 638 μS/cm due to the dilution of solutes by water from the Little Chess, and then drops further to 624 μS/cm just before the confluence with the Colne.

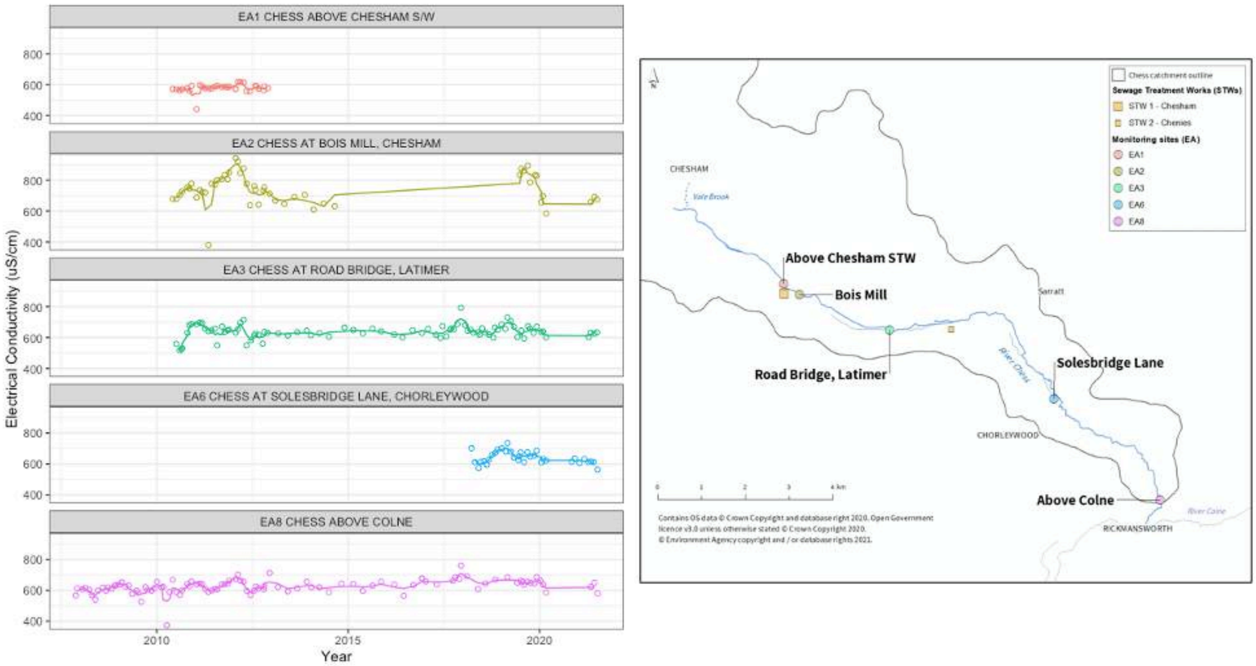


Figure 37 Temporal trends in electrical conductivity in the River Chess since 2000. SOURCE: Environment Agency data.

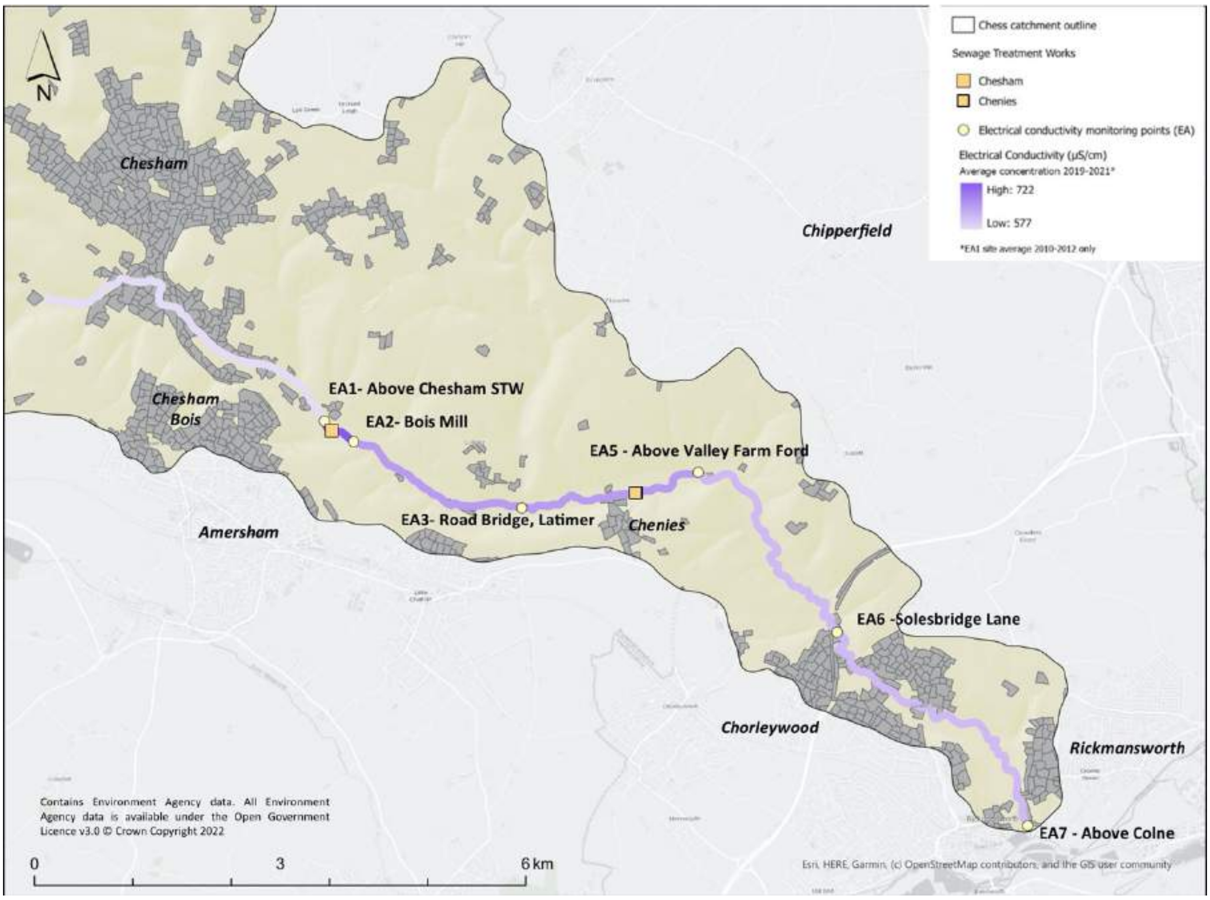


Figure 38 Spatial trend in electrical conductivity in the River Chess (2019-2021). SOURCE: Environment Agency data.

The ChessWatch sensor dataset illustrates how treated effluent from Chesham wastewater treatment works influences electrical conductivity in the River Chess on a daily basis (*Figure 39*). The sewage treatment works has two peaks in effluent outflow – at 13:00 to 14:00 hours GMT and 21:00 to 22:00 GMT corresponding to human domestic activities (along with residence time of effluent in the sewage treatment works). The electrical conductivity signature associated with these activities travels downstream and is observable at Latimer Park and Sarratt. These data can be used to estimate average travel time of water through the River Chess (e.g. 2.5 and 8.5 hours from Chesham WWTW to Latimer Park and Sarratt respectively in August 2019).

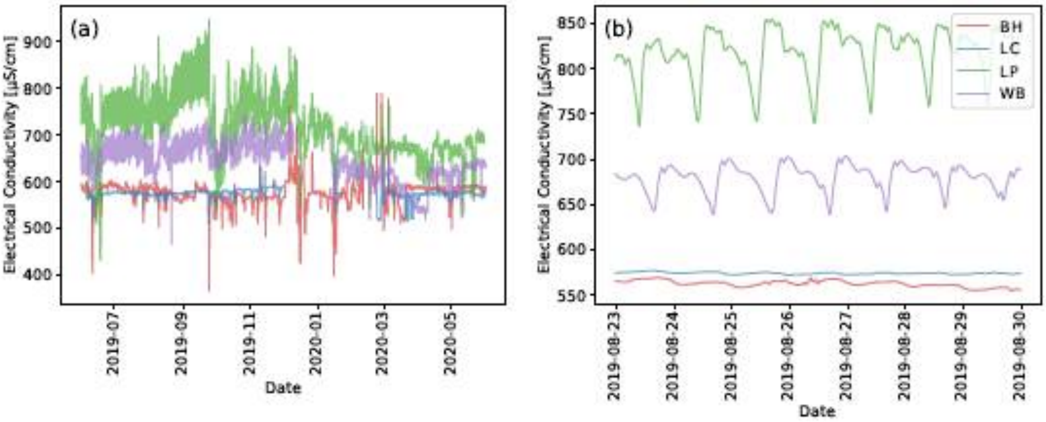


Figure 39 Variations in electrical conductivity (a) June 2019 – May 2020 (b) 23 to 28 August 2019.

Downstream of Chesham, but upstream of Chesham WWTW the electrical conductivity signal is much more stable, with no diurnal patterns. Here changes in electrical conductivity arise due to rainfall events. Urban runoff commonly lowers electrical conductivity, by diluting total dissolved solutes in groundwater. During some rainfall events, however, electrical conductivity is elevated indicating that substances with a higher total solute concentration are moving downstream from Chesham (*Figure 40*). Depending on the nature of the substance, this could indicate some type of polluting event and warrants further investigation. Note, though, that these events are not accompanied by significant changes in dissolved oxygen concentration in the river water.

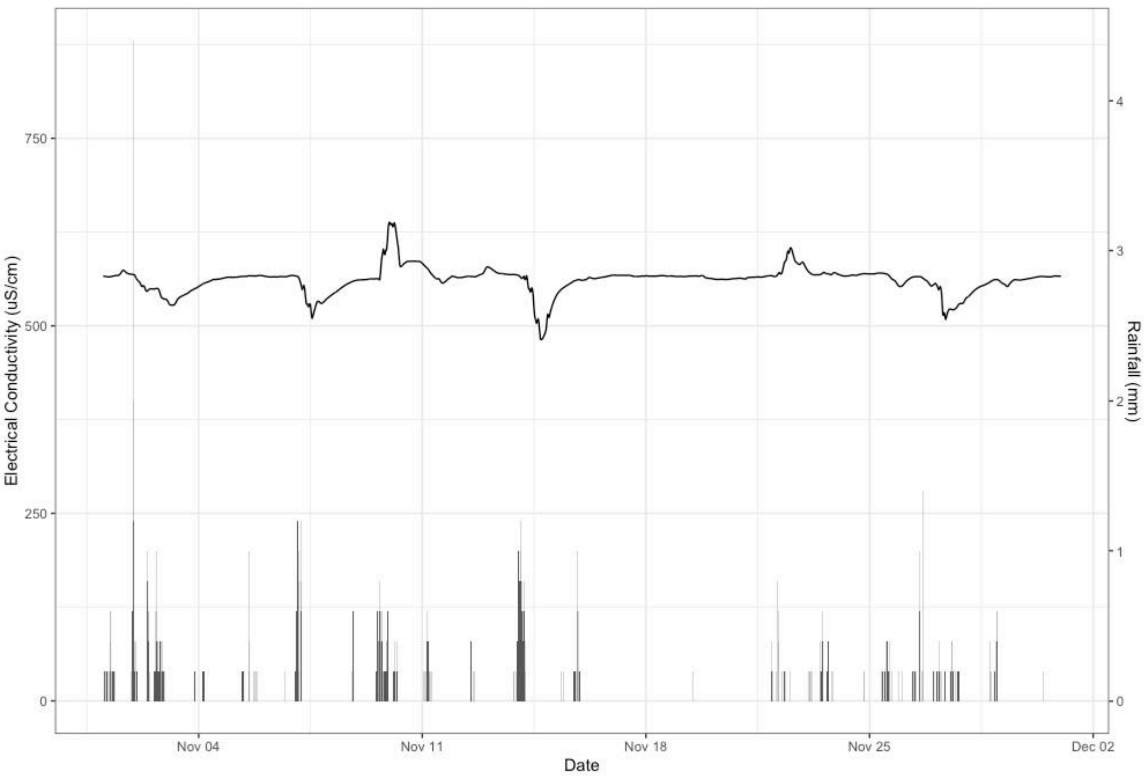


Figure 40 Changes in electrical conductivity in response to rainfall events at CW2 upstream of Chesham WWTW (4 Nov – 2 Dec 2019).

6.3 pH

pH is a measure of the concentration of hydrogen ions in the river water expressed on a logarithmic scale. Chalk streams are characterised by alkaline conditions (pH>7) due to their underlying geology. The Chess is alkaline throughout its length, but there is some spatial variation in pH due to the influence of the treated effluent from Chesham sewage treatment works which lowers the pH by c. 0.18 pH units (*Figure* 41). The continuous contribution of groundwater to the river at various sites downstream of the treated effluent discharge point means that the pH gradually rises with increasing distance downstream. There is no evidence of a long term (2000-2020) change in pH in the river (data not shown).

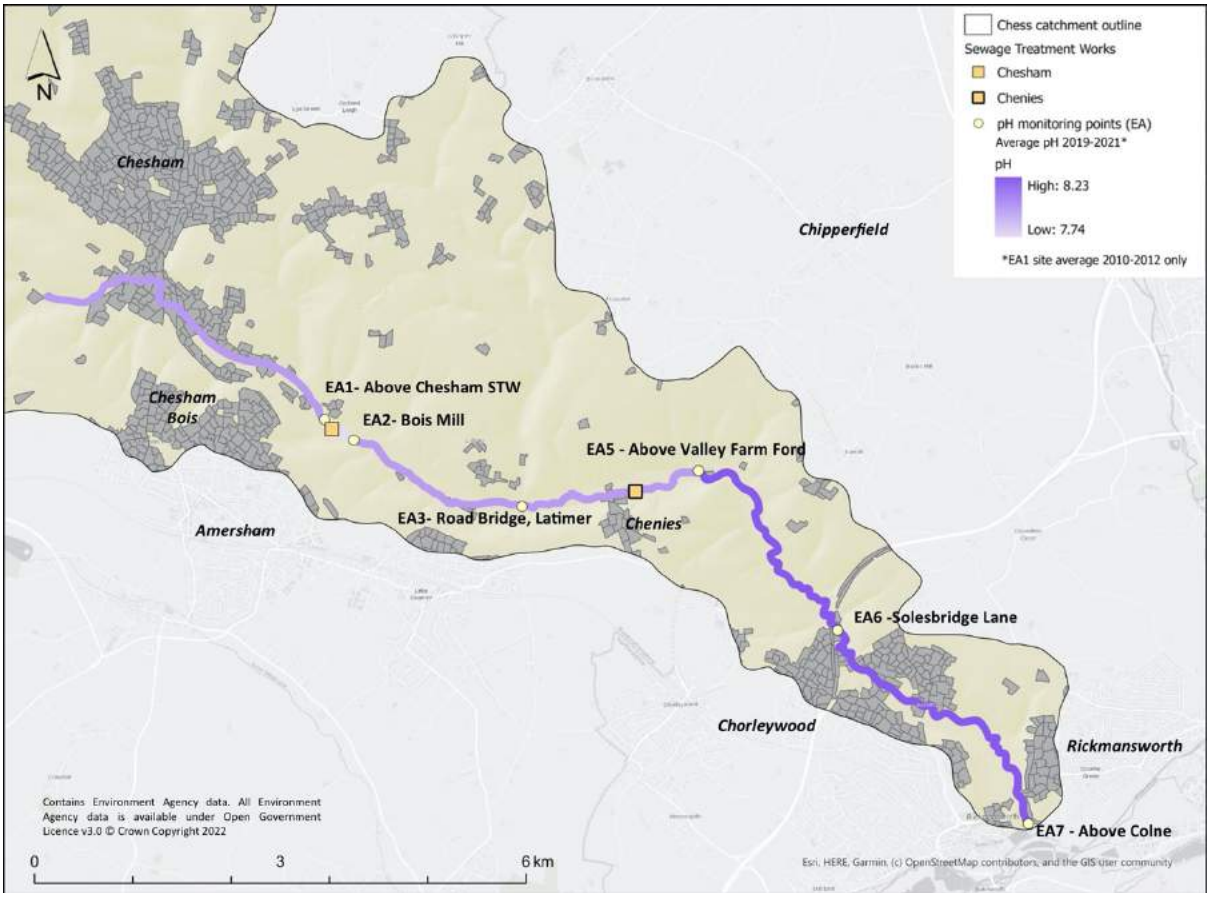


Figure 41 Spatial trend in pH in the River Chess (2019-2021). SOURCE: Environment Agency data.

6.4 Temperature

Water temperature is an important parameter with implications for ecological health of the stream. The water temperature is controlled by external meteorological factors such as air temperature and net radiation, as well as characteristics of the stream such as depth and riparian shading (Caissie, 2006). Anthropogenic activities such as contributions of treated effluent from industrial processes and/or sewage treatment works can also influence river temperatures. Increases in air temperature arising from climate change will lead to elevated water temperatures, and the predicted increased frequency of hotter summer conditions are of particular concern for fish and invertebrate health in a chalk stream context.

Annual average water temperatures in the Chess are highest just downstream of Chesham WWTW; treated effluent from which raises water temperature by c. 1°C (*Figure 42*). Thereafter average temperatures decline until Solesbridge Lane to the Colne. Whilst there is no evidence of a long-term change in water temperature in the River Chess since 1974 (*Figure 43Figure 43*), there were several spells of hot weather in the summer of 2019 under low flow conditions, that saw daytime water temperatures rise above 20°C at Sarratt, a critical temperature for trout and grayling (Basic et al., 2018). Climate change scenarios suggest increasing occurrence of summer heatwaves, so it is important to consider mitigation actions in the Chess for the longer term to keep water cool enough to support healthy fish populations.

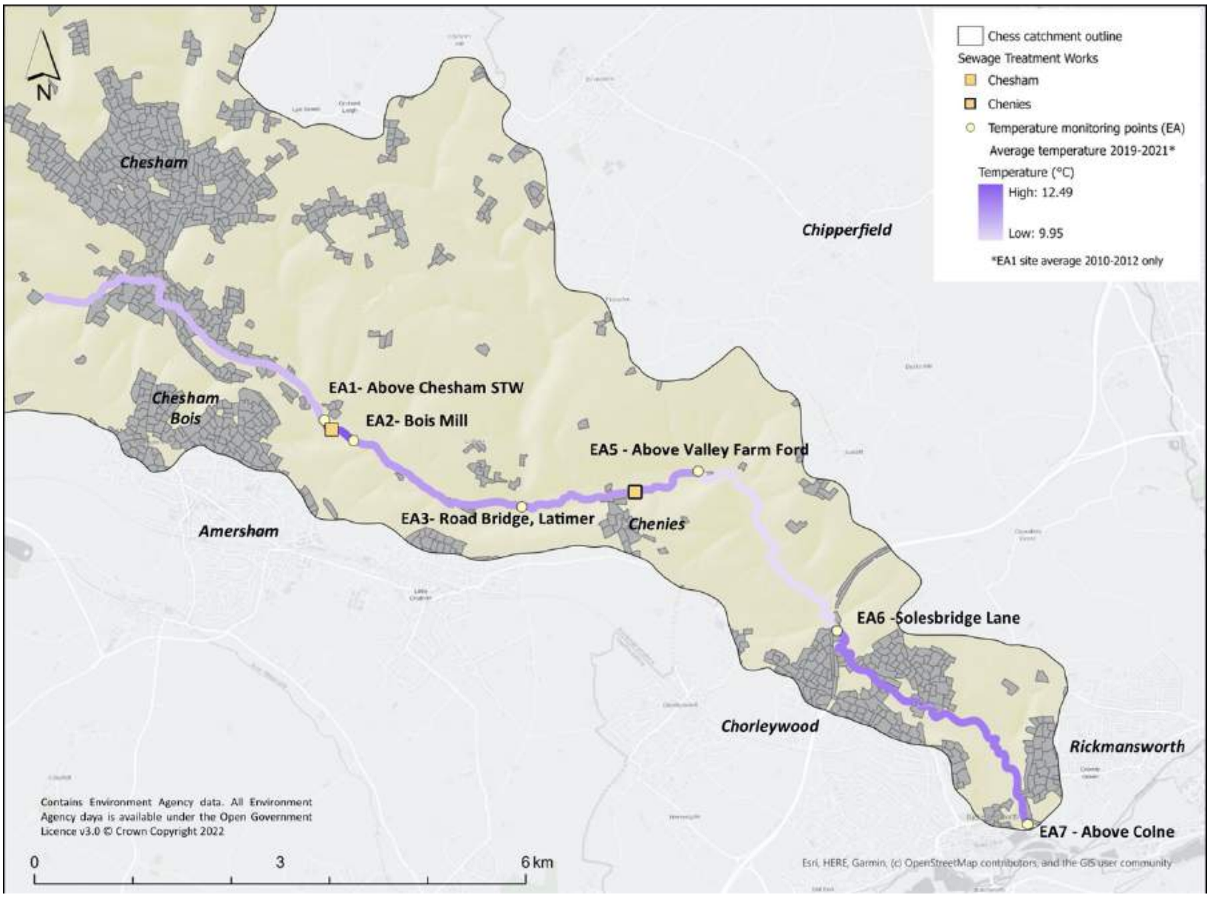


Figure 42 Spatial trend in mean water temperature in the River Chess (2019-2021) derived from Environment Agency data. SOURCE: Environment Agency data.

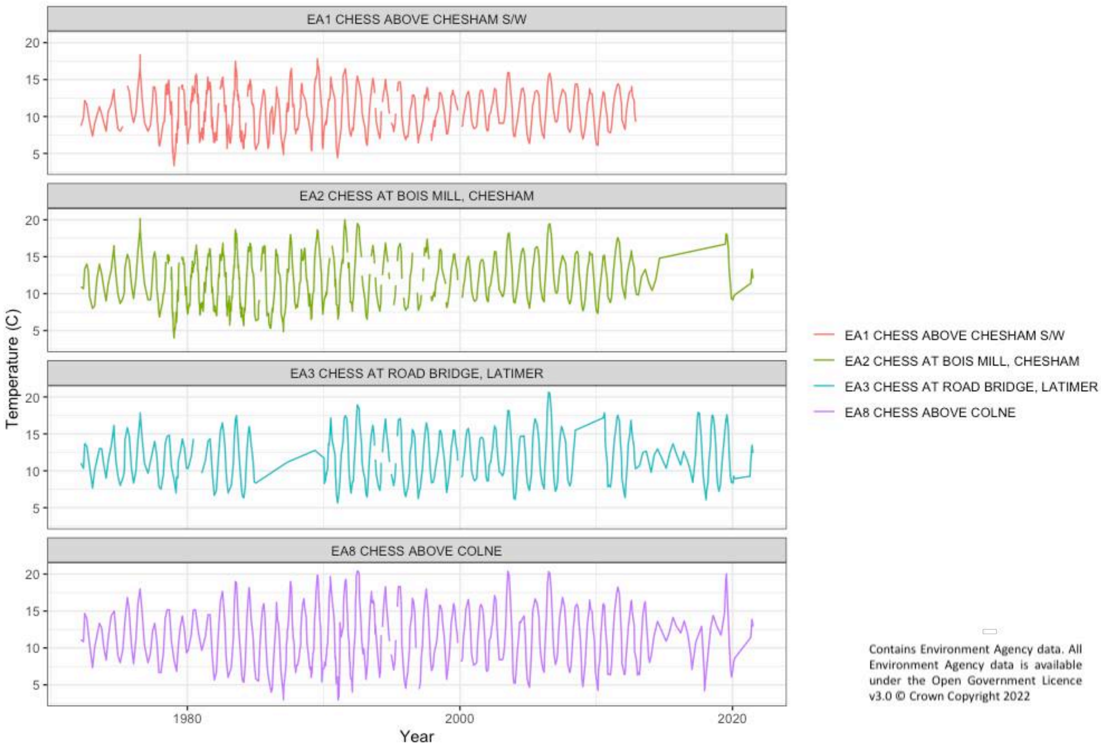


Figure 43 Variations in temperature in the River Chess plotted with 3-point moving average (derived from Environment Agency data).

Figure 44 displays Environment Agency data indicating relative levels of riparian shading derived from satellite imagery. Two areas show relatively less shading than others and could be considered as areas to target ripiarian planting. The Little Chess and Great Lake at Restore Hope Latimer is one such area (*Figure 45Figure 44*) and floodplain around the Royal Masonic School at Rickmansworth is another location (*Figure* 46*Figure 45*).

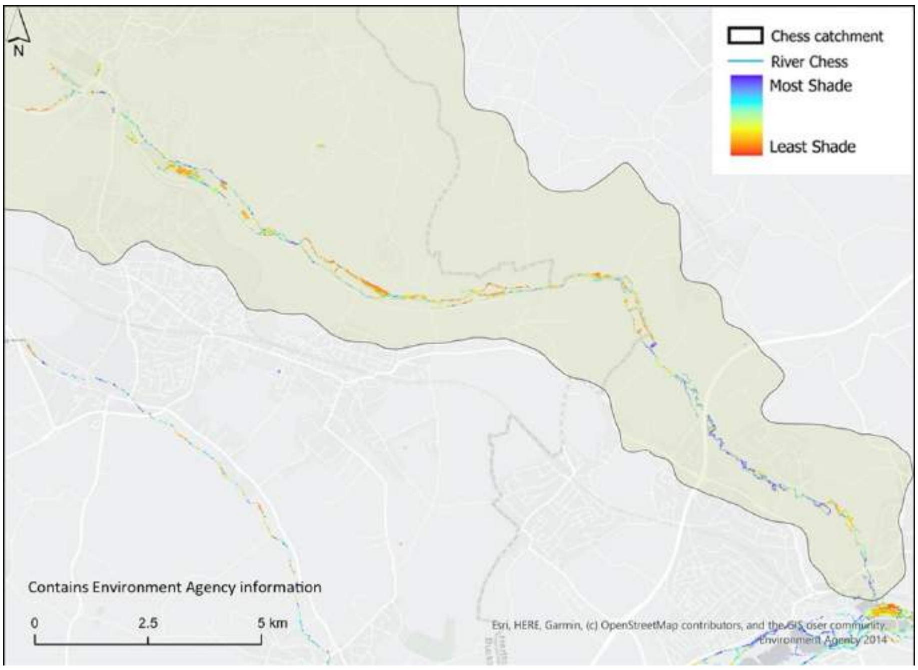


Figure 44 Catchment-scale map of relative levels of current riparian shading with red/orange colours indicating areas of least shade (derived from Environment Agency data).

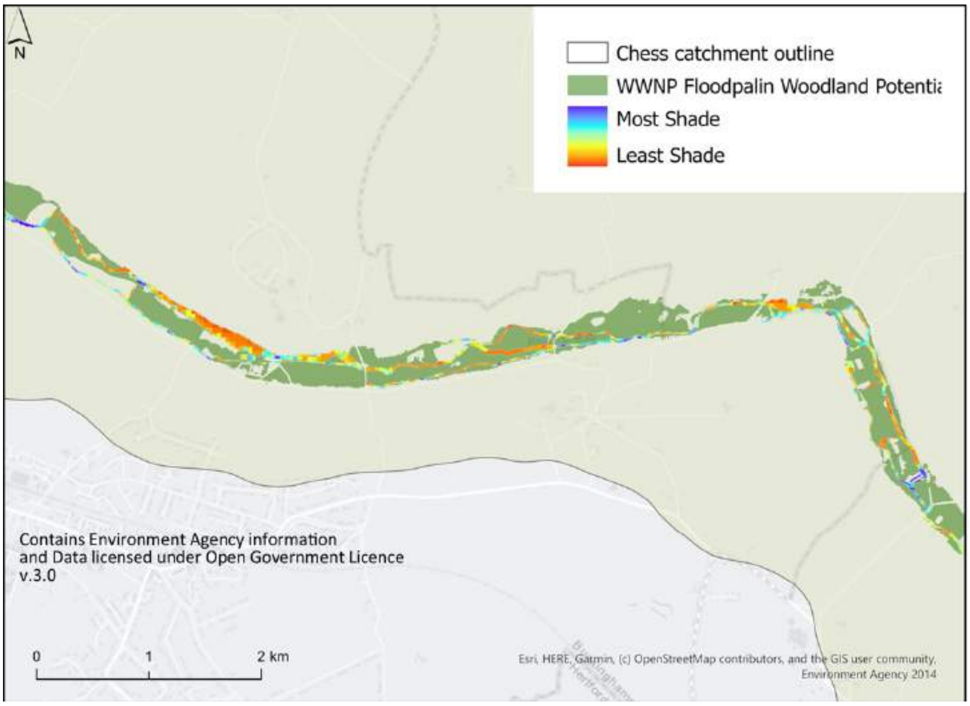


Figure 45 Focus on Latimer to Sarratt with current shade (red/orange equals least shade) combined with Working With Natural Processes opportunity map for riparian woodland/ tree planting.

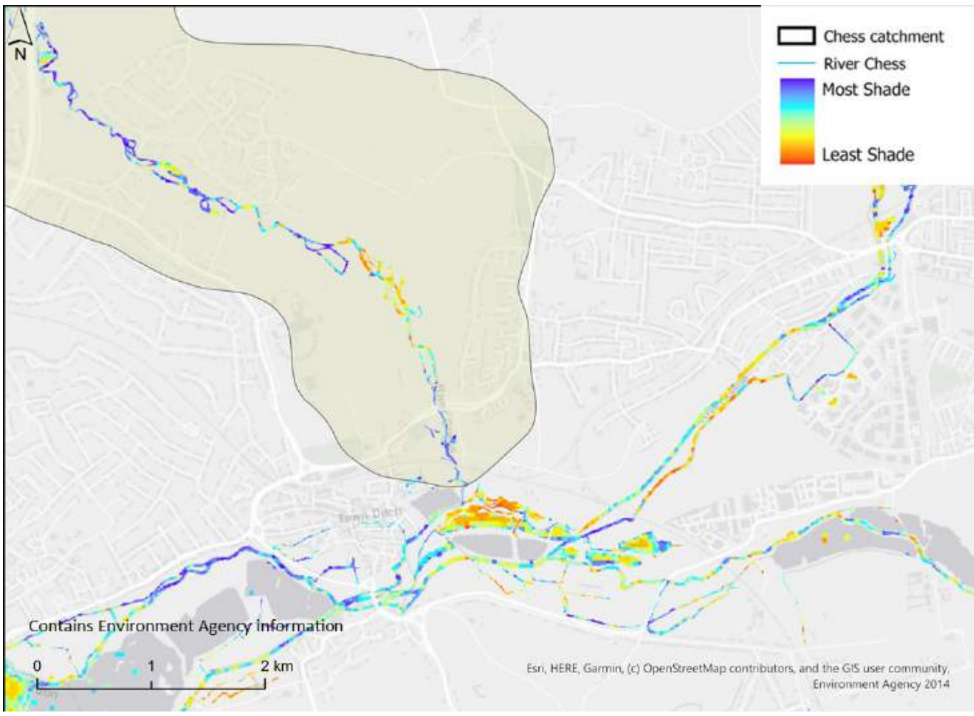


Figure 46 Map of Rickmansworth with relative levels of current riparian shading. Red/orange colours indicating areas of least shade.

Threats:

- Poor recruitment of fish such as trout and grayling as temperatures rise due to climate change.

Opportunities:

- Temperature survey on hot summer day to identify any problem areas; tree planting in selected areas; planting of riparian trees; cooling of effluent water at Chesham WWTW.

6.5 Reactive phosphorus

Phosphorus (P) is a key nutrient involved in eutrophication in freshwaters. Excess phosphorus can cause excessive algal growth which in turn can alter oxygen dynamics in river systems. Eutrophication can cause loss of plants and animals in our rivers, affect recreational activities and increase the cost of water abstraction (Rangeley-Wilson, 2021).

Phosphorus enters our rivers from P-based detergents, through treated and untreated sewage effluent and the use of artificial P fertilisers in farming. Despite reductions in P loading to rivers from agriculture (since the 1980s) and from sewage treatment works (since the 1990s) phosphorus is the most common reason for rivers in England not achieving good ecological status (Environment Agency, 2019b). Nationally, agriculture contributes more P to rivers than sewage treatments works. In densely populated areas, however, the contribution of P from sewage treatment works is more significant than agricultural inputs and this is the case for the River Chess. Source apportionment modelling (SAGIS) by the Environment Agency suggest that in 96% of the reactive phosphorus in the River Chess enters the river from Chesham and Chenies sewage treatment works (*Figure 47*a, as of 2014).

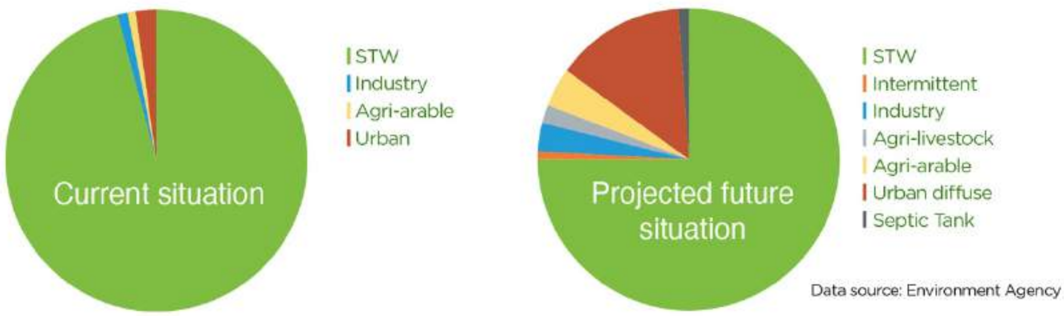


Figure 47 Percentage contribution of different sources of reactive P to the River Chess (a) SAGIS analysis for PR2014; (b) contribution of different sources of P following 2024 permit change (SAGIS modelled prediction).

Long-term records since 1974 show that ortho-phosphate concentrations in the River Chess decreased following the introduction at Chesham WWTW of a permitted discharge consent in April 2006 of 2 mg/L P in final treated effluent (*Figure 48*). Whereas in some catchments timescales over which P improvements are seen can be lengthy (for example where there is a legacy soil issue and/or sediment P loadings are high) the historical dataset shows that the

Chess could respond rapidly to a further decrease in P in treated effluent from Chesham WWTW.

The current WINEP has introduced a permit change to 0.25 mg/L P by 2024 (this is the Technically Achievable Limit for P reduction agreed by the Environment Agency and water companies for PR19). SAGIS modelling suggests that thereafter the sewage treatment works will contribute 75% of the P load (*Figure 47*b), with urban diffuse pollution the second largest contributor (14%). The Environment Agency predict that this permit change should enable the River Chess to reach moderate P status (< 0.191 mg P/L).

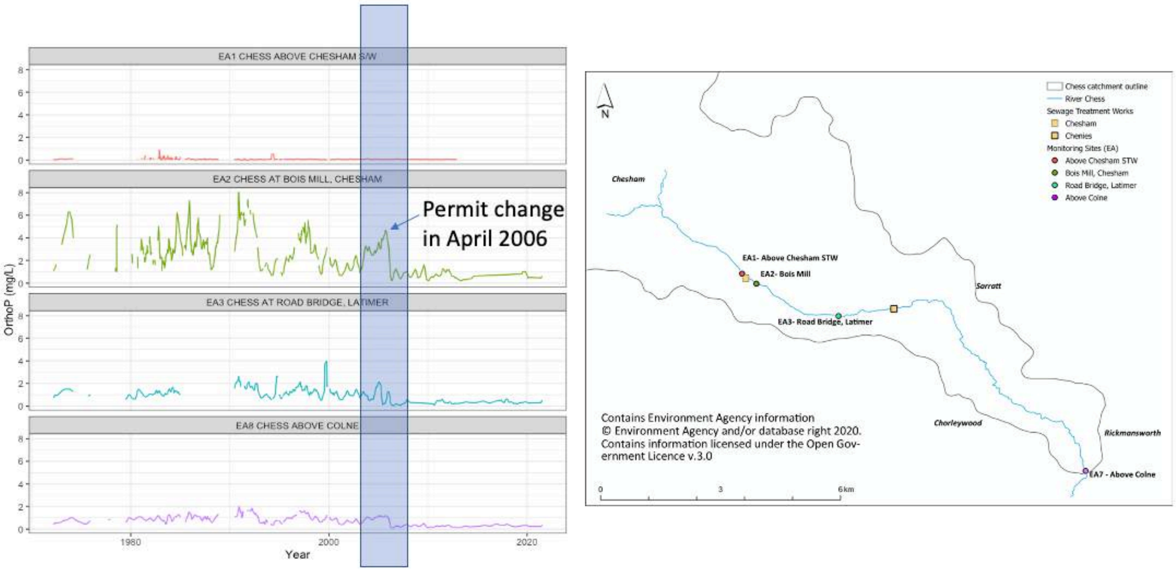


Figure 48 Temporal trends in orthophosphate since water quality records began for River Chess (1974-present).

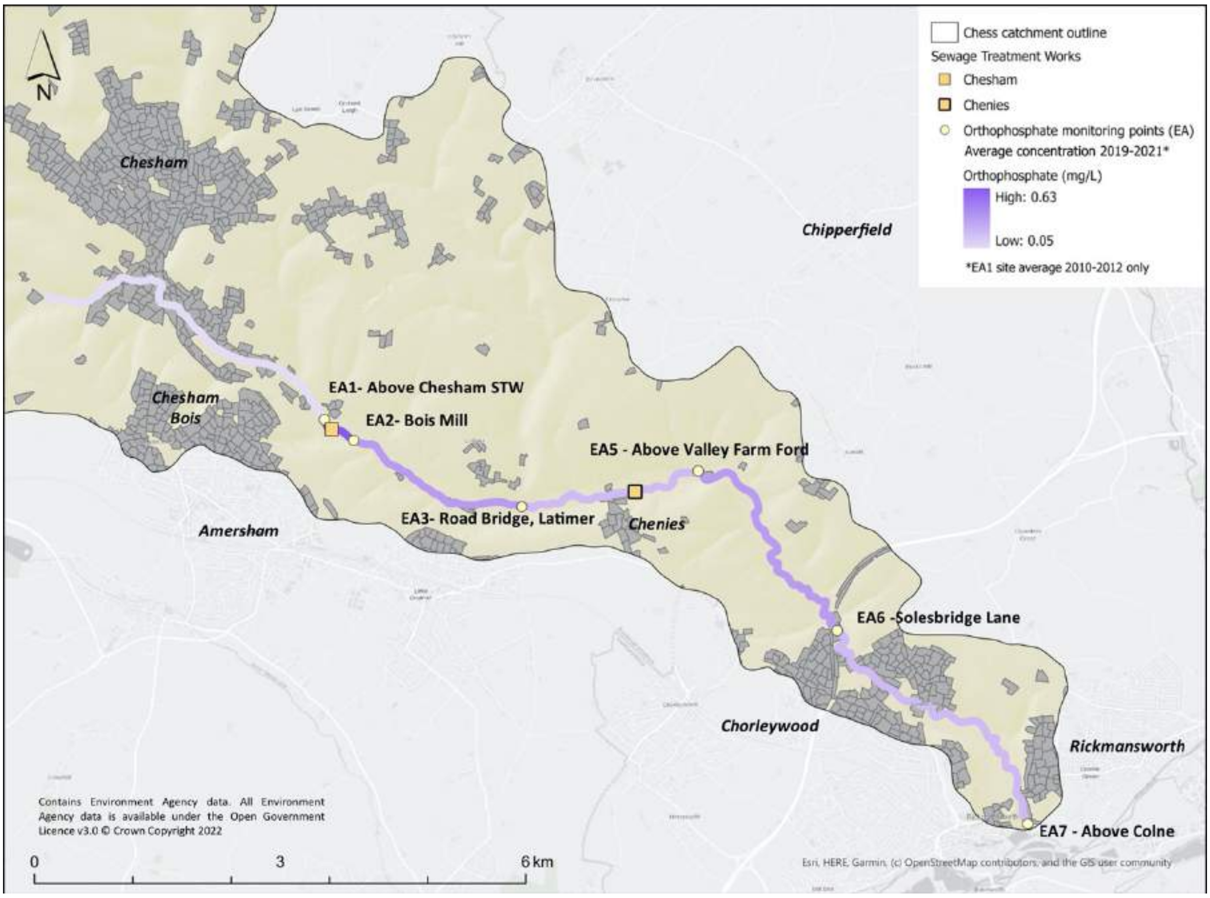


Figure 49 Spatial trend in orthophosphate in the River Chess (2019-2021).

Figure 49 shows the spatial pattern of orthophosphate concentrations in the catchment using data collected between 2019 and 2021, highlighting the decrease in orthophosphate with increasing distance downstream of Chesham WWTW. The data suggest an additional un-identified source of orthophosphate between Valley Farm Road and Solesbridge Lane. This reach does contain a cluster of postcodes which may have septic tanks (*Figure 50*). Detailed monitoring along this reach could help determine the source of this additional orthophosphate.

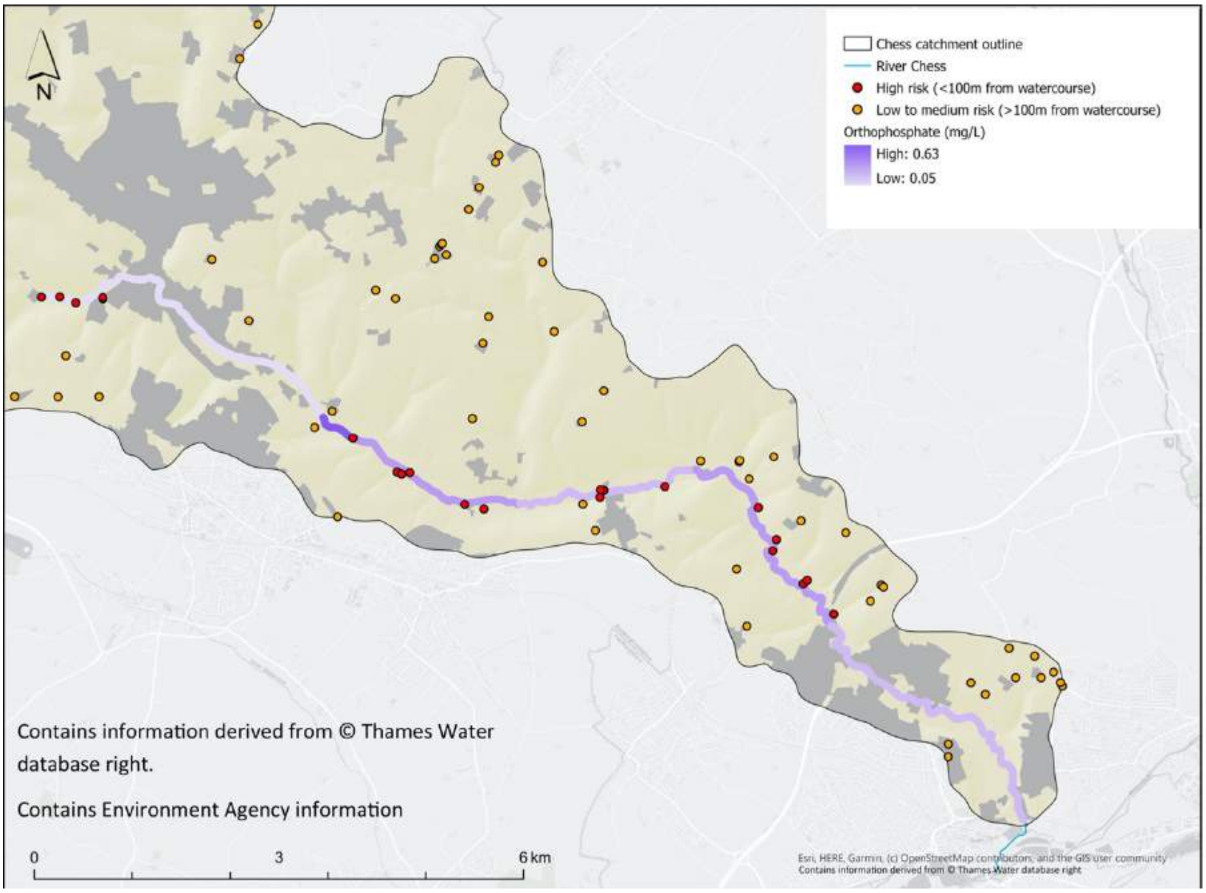


Figure 50 Potential septic tanks with spatial trend in orthophosphate concentrations.

6.5.1 Orthophosphate concentrations in and around Chesham

The time series plot of orthophosphate concentrations at the Environment Agency site just upstream of Chesham WWTW (*Figure 51*) show occasions between 1974 and 2012 during which concentrations were elevated compared to the long-term average of 0.05 mg P/L (comparable to the concentrations of P in groundwater in the Chilterns). These spikes may be indicative of urban sources of phosphate, but it is difficult to determine where in Chesham these inputs might arise from.

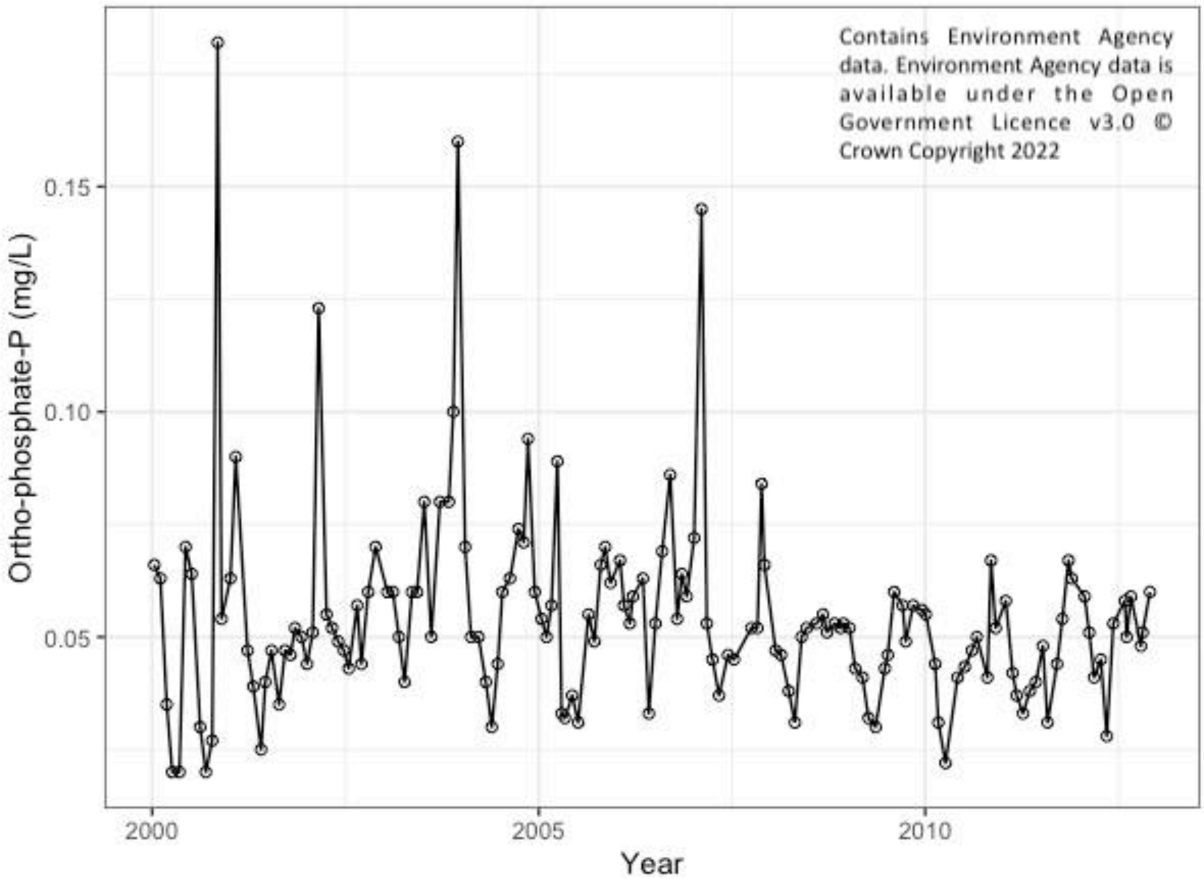


Figure 51 Orthophosphate-P concentration in River Chess above Chesham WWTW (Environment Agency data, PCNR0012).

The Citizen Science data collected as part of the EarthWatch initiative (2015-2021) suggests that orthophosphate concentrations in the River Chess around Chesham are still comparable to the average values recorded from 2000 to 2012 by the Environment Agency (*Figure* 52).

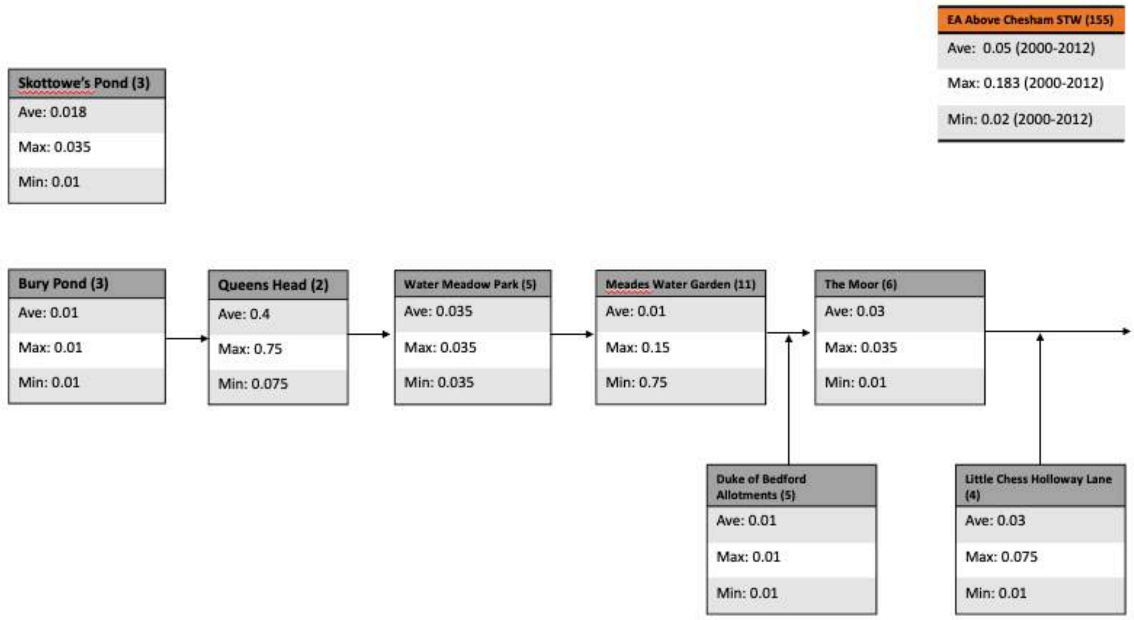


Figure 52 Phosphate concentrations (mg-P/L) in water samples from Chesham collected by Citizen Scientists as part of the EarthWatch Freshwater Blitz (2015-2021). Orange table represents annual average for EA site PCNR0012 in 2012, located upstream of Chesham WWTW, for comparison. Number in brackets = number of samples.

6.5.2 Orthophosphate from water infrastructure

As the proportional loading of P from the WWTW decreases post-2024 then any urban diffuse pollution sources from Chesham will become relatively more important to tackle. Sources of P in urban areas can include sewer misconnections and mains water leakage. 22.8 ML/day was lost from Affinity Water's Misbourne supply area in 2018/19 which includes the River Chess catchment. If leakage rates are assumed equal across the Misbourne area that suggests 4.8 ML/ day of mains water could be lost from the Chess catchment. Mains water is dosed with phosphate, to 1-2 mg P/L to prevent calcite precipitation in the network, and reduce Pb and Cu concentrations in drinking water. Recent research suggests that mains leakage should be considered as a source of phosphate in groundwater in urban areas (Gooddy et al., 2017).

Water quality monitoring of storm tank overflows is not common practice. A trial of a real-time water quality monitoring sensor on 28th April 2021 provided the opportunity to take some river water samples during a storm tank overflow period driven by groundwater ingress. The sampling indicated that soluble reactive phosphate concentrations in the river at Latimer Park rose from 0.23 mg P/L to 0.34 mg P/L during the event, demonstrating how storm tank overflow events increase the loading of orthophosphate to the River Chess.

6.5.3 Orthophosphate from farming activities

Whilst farming activities do not appear to be a major contributor to P loads in the River Chess at the current time, the following points should be considered as best management practices:

Catchment-sensitive farming measures to reduce runoff and diffuse pollution: Preventing soil erosion and runoff from arable fields will help reduce the transport of P to the River Chess. P travels to rivers in runoff in soluble form, and also bound to sediment. Once runoff has entered the river a proportion of the sediment-bound P will be released into the river water and available to cause eutrophication.

Action to improve soil health for water quality: Check arable and pasture soils are not being over-fertilised above the agronomic optimum. Over-fertilisation will lead to P being leached into groundwater and may cause an issue in the River Chess over decades. Over-fertilisation is both financially and environmentally costly, and will cause more P to be lost in rapid runoff pathways over the surface and through soils to the river. Greater livestock density can also raise the P content of soil. Preventing poaching by livestock helps reduce P loss from soil to the river.

Action to reduce connection between runoff and the river: Preventing runoff from reaching the river is critical and can be achieved in part by managing riparian land to create buffer strips and wildlife corridors.

Landowners can consider mechanisms to prevent agricultural diffuse pollution under the new environmental land management schemes (ELMS) and the current Farming in Protected Landscapes (FIPL) programme within the Chilterns AONB. Further advice is also available under Natural England's Catchment Sensitive Farming (CSF) scheme.

Threats:

- There have been no detailed spatial or temporal investigations of orthophosphate concentrations in either the Little Chess or the main river upstream of Chesham WWTW since 2012. This is problematic for source apportionment.

- There is a slight increase in orthophosphate concentrations (+0.03 mg P/L) between Valley Farm Road and Solesbridge Lane. The reason for this increase should be investigated – overlaying the sewer network with these data suggest that there may be septic tanks in this area. Alternative sources of phosphate may be road runoff or agricultural activity.

- Population growth and urbanisation in Chesham and climate change both threaten measures that are currently being put into place to reduce P concentrations in the River Chess. Population growth will increase the proportion of treated effluent to groundwater flowing through the River Chess, and treated effluent is the critical source of phosphate. Under climate change scenarios, reduced summer flows may increase the proportion of treated effluent in the river leading to higher reactive P concentrations. Periods of intense precipitation result in overland flow and soil erosion, and can transport valuable P with topsoil from arable fields to the river.

Opportunities:

- The partnership should consider high resolution ortho-phosphate monitoring (i) around Chesham to assess any contributing areas (e.g. Vale Brook); and (ii) between Valley Farm Road and Solesbridge Lane to identify potential reason for increase in P concentration.

- Chesham WWTW will remain the major contributor of reactive P to the River Chess following changes to the permit in 2024. Chesham WWTW could be considered as a suitable treatment works at which to pilot new technologies for reducing P concentrations below current 'technically achievable limits' under AMP8.

- Preventing storm tank overflows will reduce the load of orthophosphate entering the River Chess.

6.6 Nitrogen

A significant increase in the use of fertilisers since the 1990s has led to a global increase in reactive nitrogen in groundwater and rivers. This reactive nitrogen can take several forms, including nitrate, ammonia and ammonium chemical species – all of which are of interest here. In the environment bacteria can transform these chemicals from one form to another, for example ammonium can be transformed into nitrate by a process called nitrification. High levels of nitrate and ammonia/ammonium are both of concern in our freshwater environments, but for different reasons (*Table 5Table 4*).

Table 5 Threats to the environment arising from nitrogen species, nitrate and ammonia.

Nitrate	Risk to human health from drinking groundwater or surface water with elevated nitrate concentrations. WHO standard = 11.5 mg-N/L at tap. Risk of eutrophication to lowland surface waters, estuaries and coasts Impacts on Groundwater Dependent Terrestrial ecosystems
Ammonia	Direct toxicity to surface and groundwater organisms

Concentrations of nitrate in rivers are higher in central and eastern areas of England compared to other areas due predominantly to more arable agriculture and a drier climate (therefore less dilution of runoff). On a national basis 70% of nitrate is sourced from arable agriculture, and sewage effluent contributes 25-30% (due to the nitrogen-rich compounds in urine and faecal matter). However, in urban areas such as the Thames region, sewage effluent can be the major contributor to the nitrate load in a river (Environment Agency 2019c).

In permeable, chalk catchments such as found in the Chilterns AONB the concentration of nitrate in groundwater will also be a critical factor in determining concentrations in the river water. Because it can take rainwater decades to reach groundwater there is generally a significant lag-time between changes in farming practice and observed changes in regional groundwater concentrations; and the nitrate concentrations observed in groundwater today can reflect land use activities many decades ago (Ascott et al., 2021). Nitrate concentrations in groundwater are highest in the southern and eastern areas of England where groundwater is used for public water supply.

The Environment Agency designate areas as Nitrate Vulnerable Zones if nitrate concentrations in groundwater and rivers are elevated to c.11.5 mg-N/L. If an area is designated as an NVZ then specific farming management activities must be followed, however, the Chess catchment is not currently designated as an NVZ (*Figure 53*).

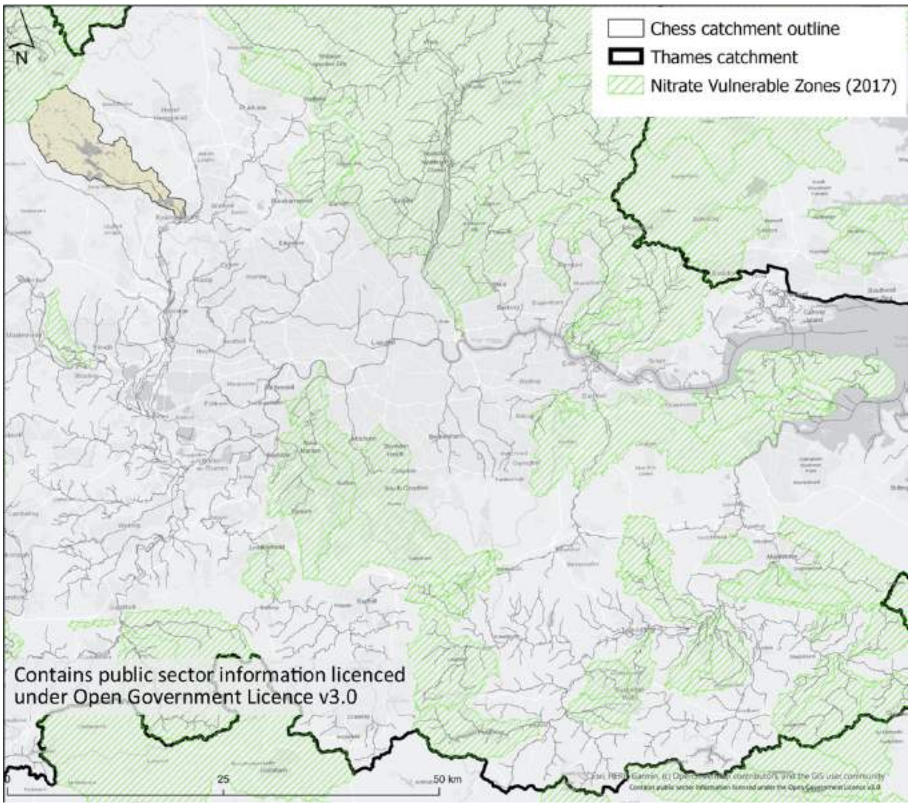


Figure 53 Designation of Nitrate Vulnerable Zones around the River Chess catchment.

Ammonia can enter rivers from wastewater treatment plants, septic tanks and from animal waste (e.g. slurry) via runoff. Ammonia is directly toxic to aquatic organisms and builds up in their internal tissues and blood eventually leading to death. pH and temperature influence the form of the chemical species in water (either ammonia or ammonium) with the ammonia form being toxic.

6.6.1 Total Ammonia as Nitrogen (TAN)

The WFD requires measurement of total ammonia as nitrogen (TAN, i.e. the sum of ammonia and ammonium) in a water body. *Figure 54* shows the abrupt reduction in TAN concentrations in the River Chess in response to a permit change at Chesham WWTW in 1985 (to 4 mg N/L). This would have represented a major improvement in water quality for the River Chess given that under the WFD concentrations of > 2.5 mg N/L for TAN indicate 'Poor' status. *Figure 55* shows the TAN concentration in treated effluent from Chesham

WWTW along with the revised permit requirements (currently 1 mg N/L) since 2000. The River Chess is currently designated as being of 'High' TAN status under the WFD.

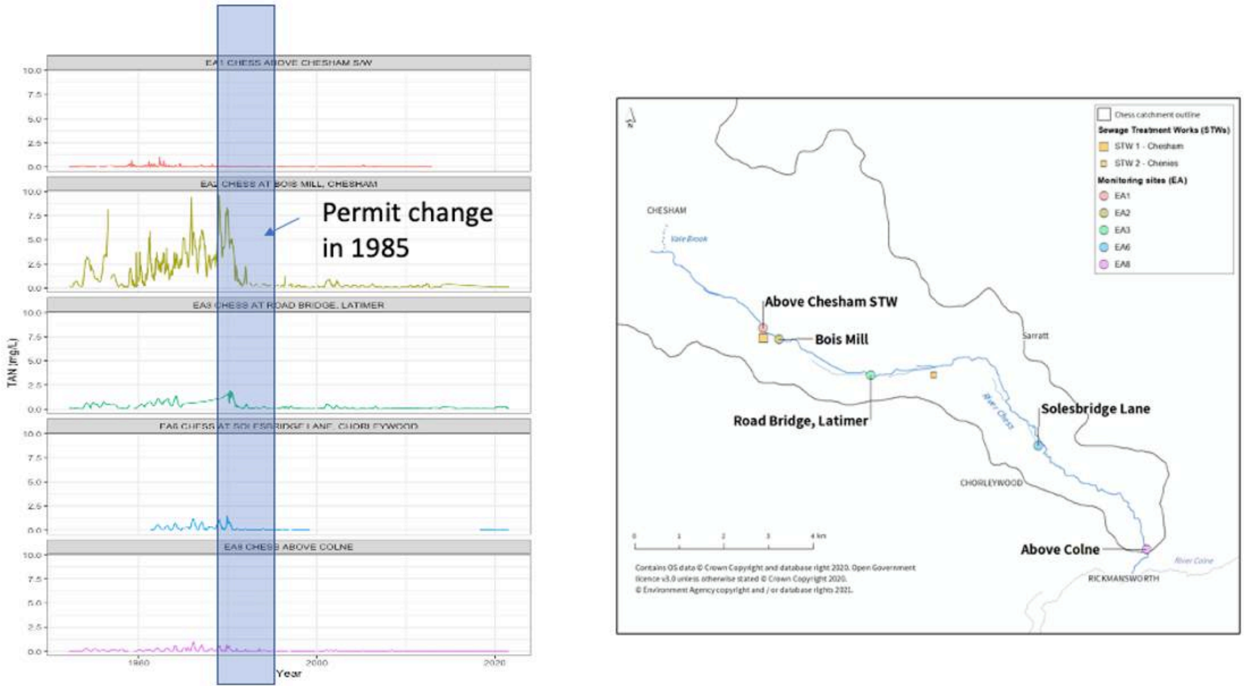


Figure 54 Temporal variations in total ammonia as nitrogen (TAN) in the River Chess (1974-2020) using Environment Agency data.

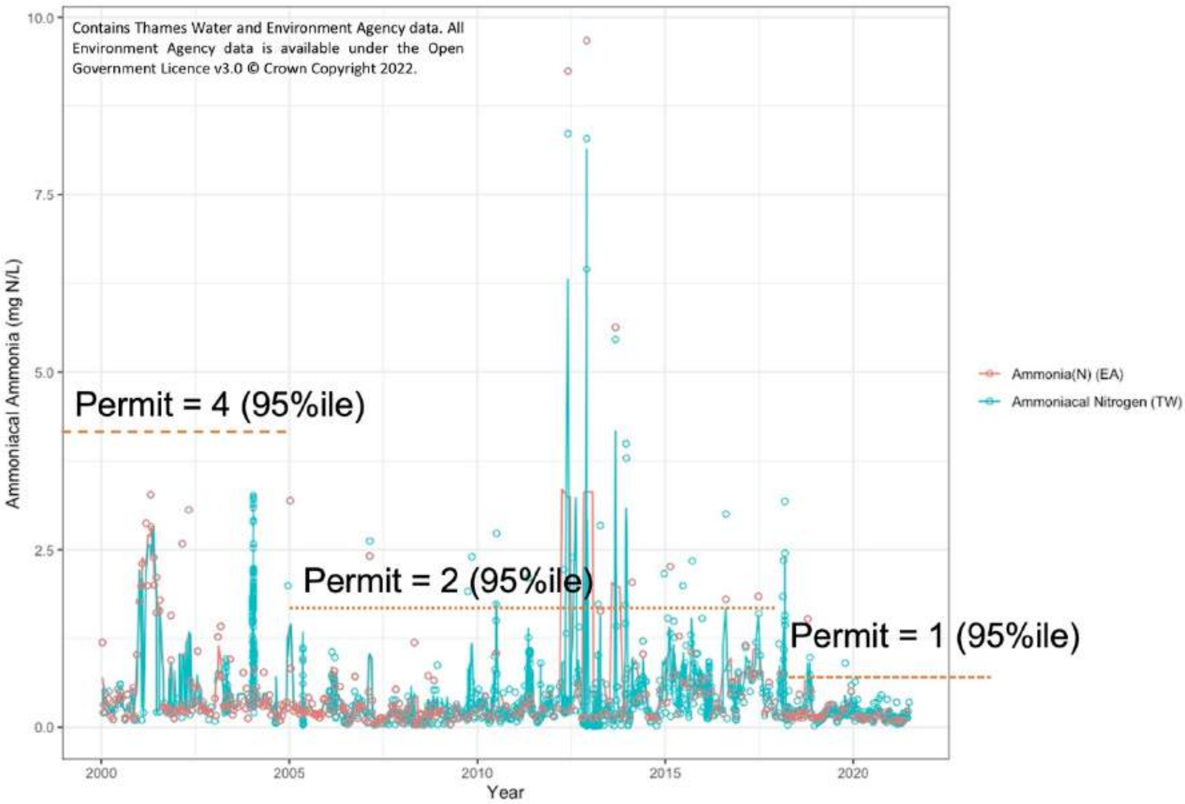


Figure 55 Time series plot of total ammoniacal nitrogen concentrations in the effluent from Chesham WWTW from 2000 to present showing permit changes from 4 to 1 mg/L TAN. Note that the permit value is expressed as a 95%ile.

The Environment Agency deployed EXO multi-parameter sondes logging at 30-mins intervals upstream and downstream of Chesham WWTW from April to July 2021 in response to storm tank flows from Chesham WWTW. The sondes were fitted with ion-selective electrodes for ammonium. These sensors are subject to interferences from cations (particularly potassium) so absolute values, especially when concentrations exceed 10 mg/L ammonium, should be treated with caution. However, the sensors do give a useful picture of overall patterns in ammonium during the monitoring campaign.

The data indicate that there are some sources of ammonium to the river upstream of Chesham WWT albeit causing low level changes in ammonium concentration of the order of 0.1 to 0.6 mg/L ammonium. Peaks in ammonium in *Figure 56* are associated with rainfall events which may wash ammonium into the river from the surrounding catchment. Of particular interest is a series of daily repeating ammonium spikes in mid-May potentially indicative of contribution from some unidentified infrastructure linked to the river. Note that the changes in ammonium during this period are not caused by rainfall events. Another feature of note here is that the peaks in ammonium (whether associated with rainfall or not) are generally not co-incident with drops in oxygen (with the exception of the storm event in mid-June) which is unusual for sewage-based discharges.

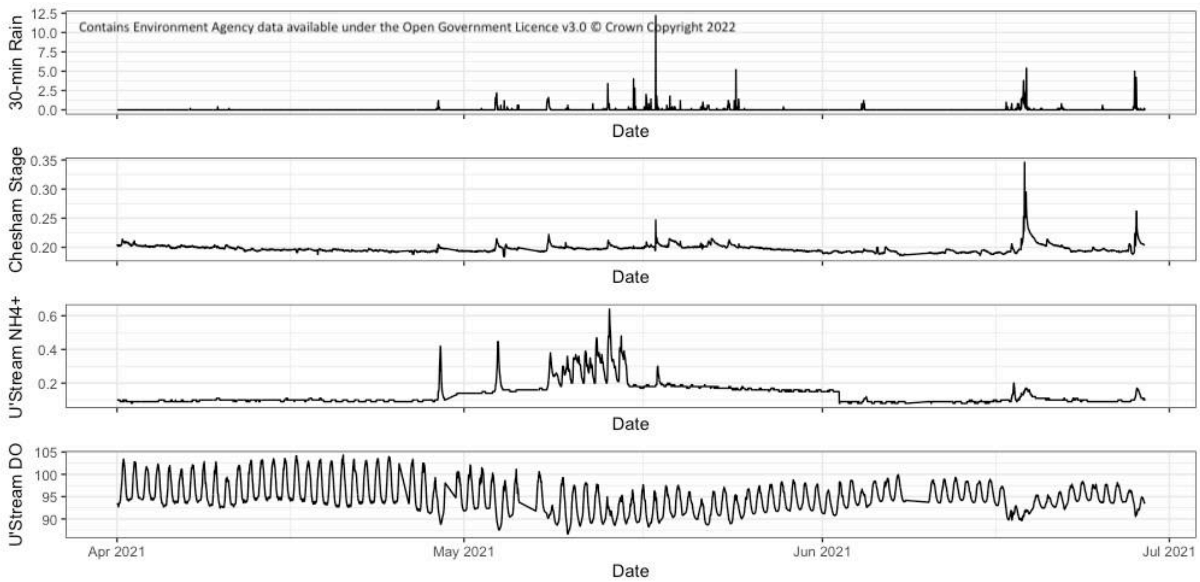


Figure 56 Time series of ammonium and dissolved oxygen concentrations in the River Chesham upstream of Chesham WWTW (Data from Environment Agency).

Figure 57 illustrates the data from the sensor installed downstream of Chesham WWTW. The pink lines represent the periods during which Chesham WTWW storm tanks were operating (using EDM data from Thames Water). Note the order of magnitude difference in ammonium concentration at this location compared with the upstream sensor during periods when the storm tanks were operating. Ammonium concentrations reduce rapidly once storm water tanks cease discharging whereas oxygen levels in the water are depressed for longer timer periods potentially due to enhanced oxygen demand from organic particulate material deposited on the riverbed by the storm tanks. Grab samples taken at Latimer Park on 28 April 2021 during a period of storm tank overflow due to groundwater ingress indicated that total ammoniacal nitrogen concentrations rose from < 0.03 mg N/L before the event to 1.36 mg N/L at peak flow. Overall, these data indicate that when the storm tanks are operating they comprise a significant source of ammonium to the river in the reach below Chesham WWTW.

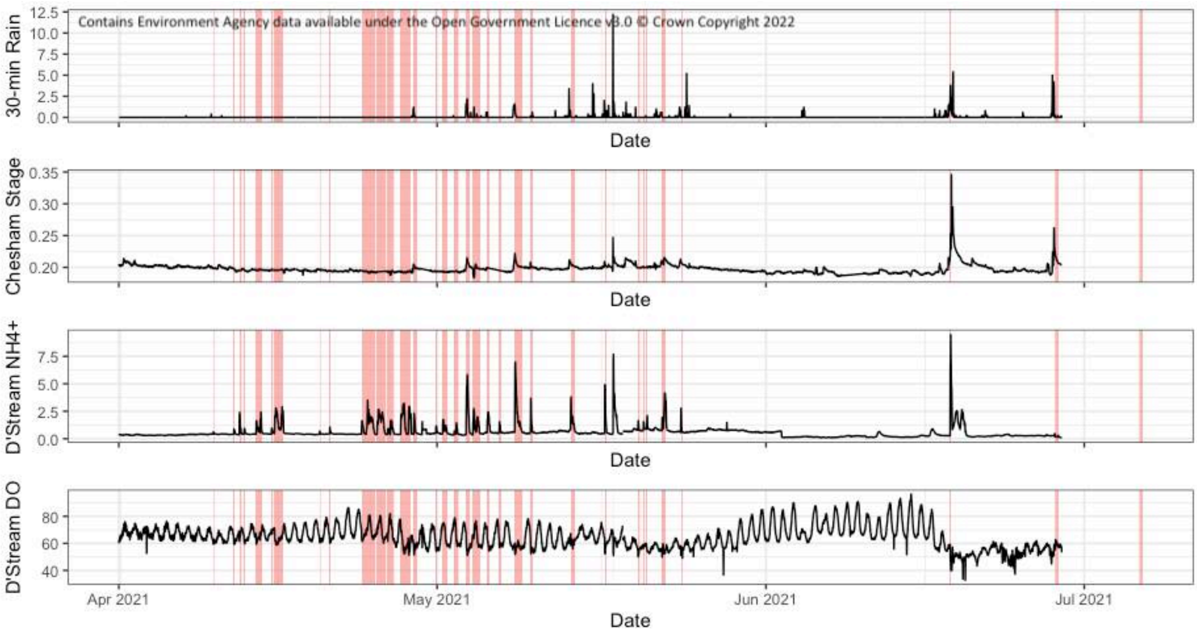


Figure 57 Time series of ammonium and dissolved oxygen concentrations in the River Chesham downstream of Chesham WWTW (Data from Environment Agency).

6.6.2 Total oxidisable nitrogen / nitrate

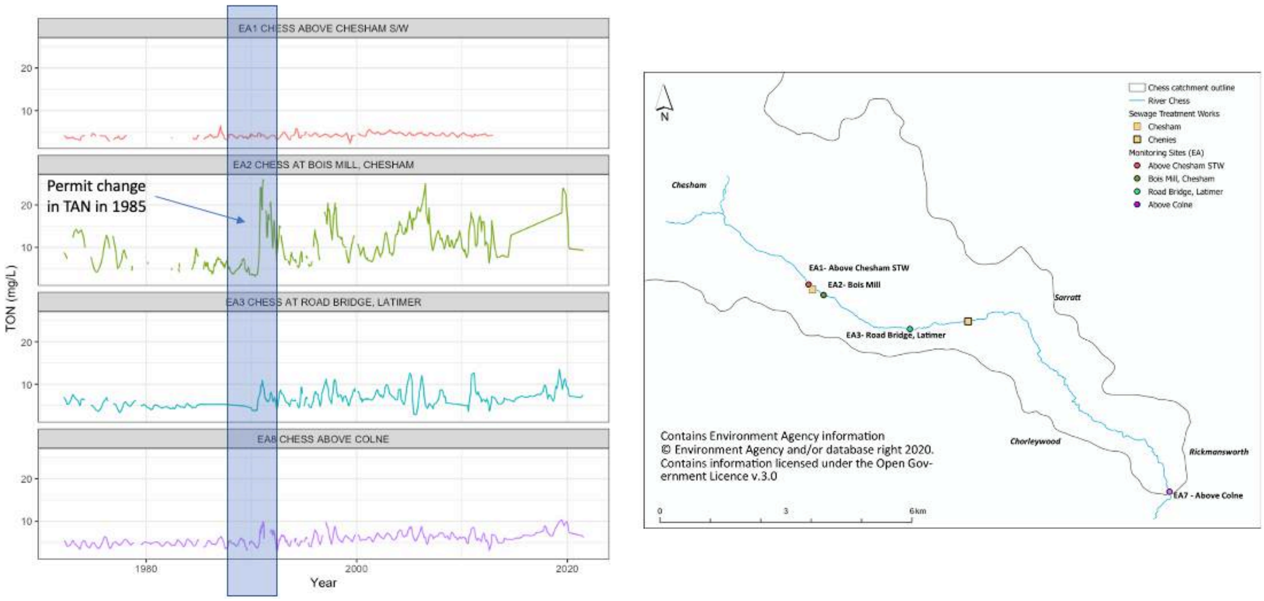


Figure 58 Temporal trends in total oxidisable nitrogen (TON) since water quality records began for River Chess (1974-present).

Long-term Environment Agency monitoring since 1974 shows that nitrate concentrations in the River Chess rose sharply following a change in the total ammoniacal nitrogen permit in

1985 (*Figure 58*). This is most probably due to the enhanced nitrification of nitrogen-rich effluent at the sewage treatment works. Nitrate can be reduced to harmless nitrogen gas via denitrification at sewage treatment works, but this would require the introduction of an anoxic (oxygen-free) treatment process, potentially accompanied by supplementary carbon dosing.

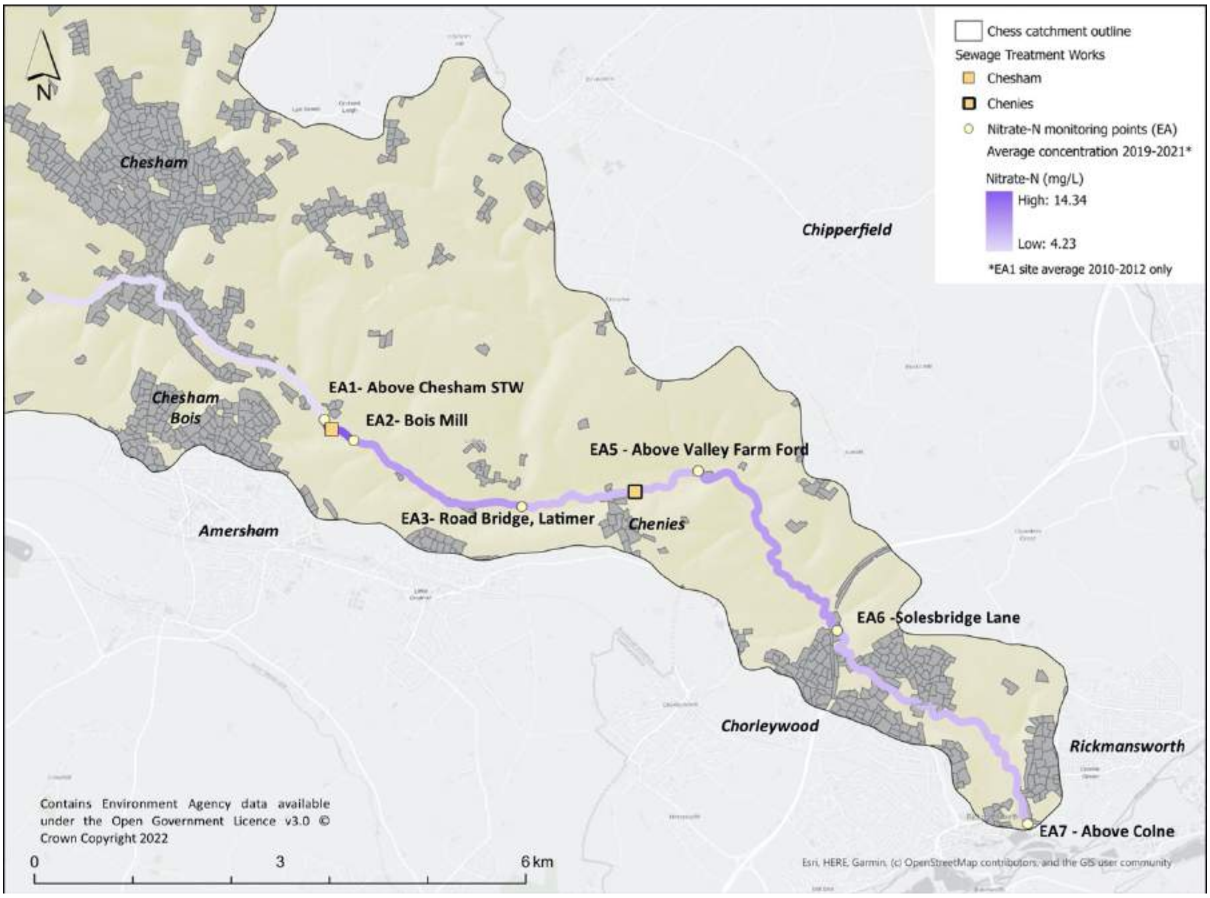


Figure 59 Spatial trend in nitrate-N in the River Chess (2019-2021).

Figure 59 shows the spatial pattern of nitrate concentrations in the catchment using data collected between 2019 and 2021, highlighting the decrease on nitrate with increasing distance downstream of Chesham WWTW. The data suggest an additional un-identified source of nitrate between Valley Farm Road and Solesbridge Lane (as was the case for ortho-phosphate).

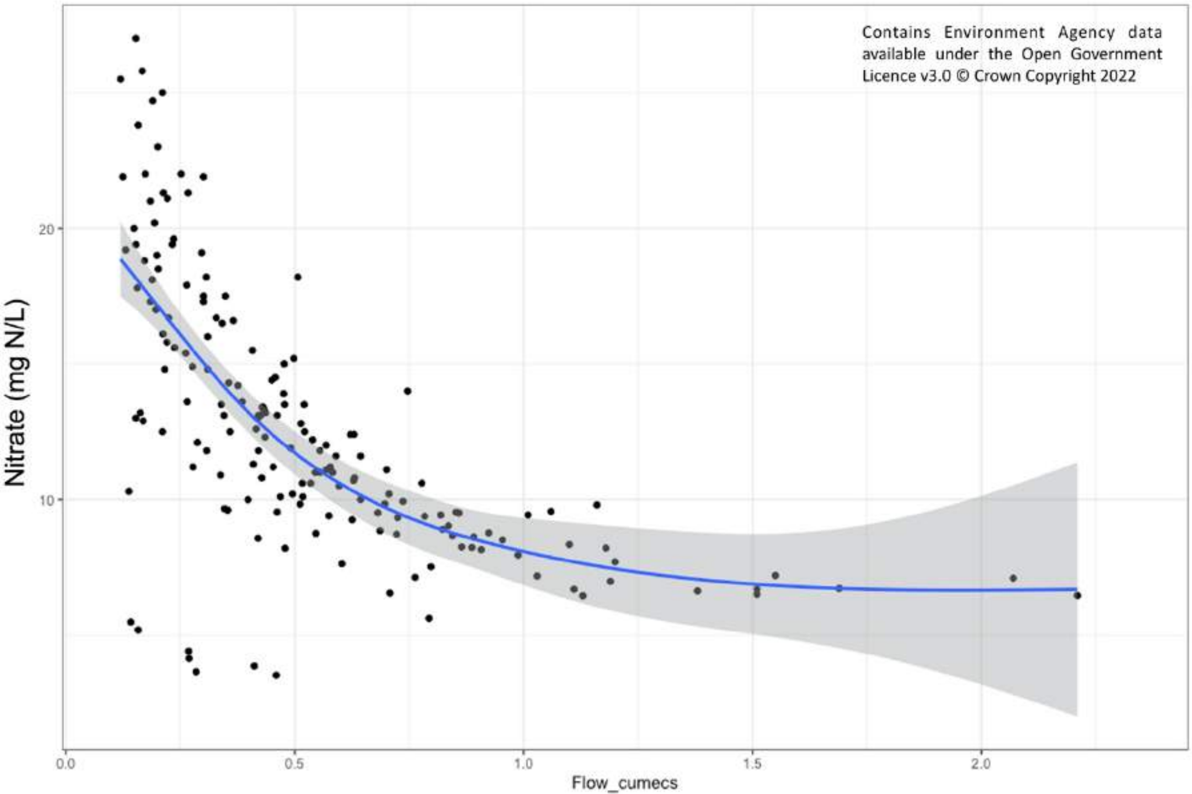


Figure 60 Relationship between nitrate concentration and discharge (post-1990). SOURCE: Environment Agency data.

Figure 60 shows the strong relationship between discharge at Rickmansworth and nitrate concentration in the River Chess as recorded at Bois Mill. At low flows there is a high contribution of TON from treated effluent. As flows increase there is a higher proportion of groundwater to dilute the TON from the sewage treatment works.

The time series plot of nitrate concentrations at the Environment Agency site just upstream of Chesham WWTW show a steady decline in nitrate concentrations between 2004 and 2012 (*Figure 61*). The reason for this decline is not known (the pattern does not reflect changes in groundwater level), nor whether the decline has continued since 2012.

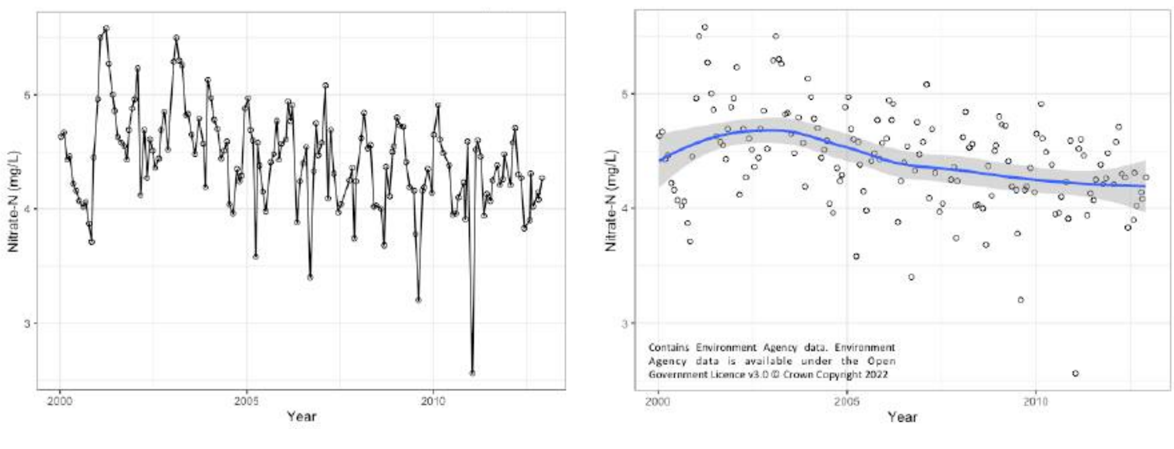


Figure 61 Nitrate concentration in River Chess (a) above Chesham WWTW (Environment Agency data, PCNR0012) and (b) with smooth function to show long-term trend to 2012.

The Citizen Science data collected as part of the EarthWatch initiative (2015-2021) suggests that nitrate concentrations in the River Chess around Chesham have not declined further (*Figure 62*), and are still comparable to the average values recorded from 2000 to 2012 by the Environment Agency; but more samples should be taken to confirm this.

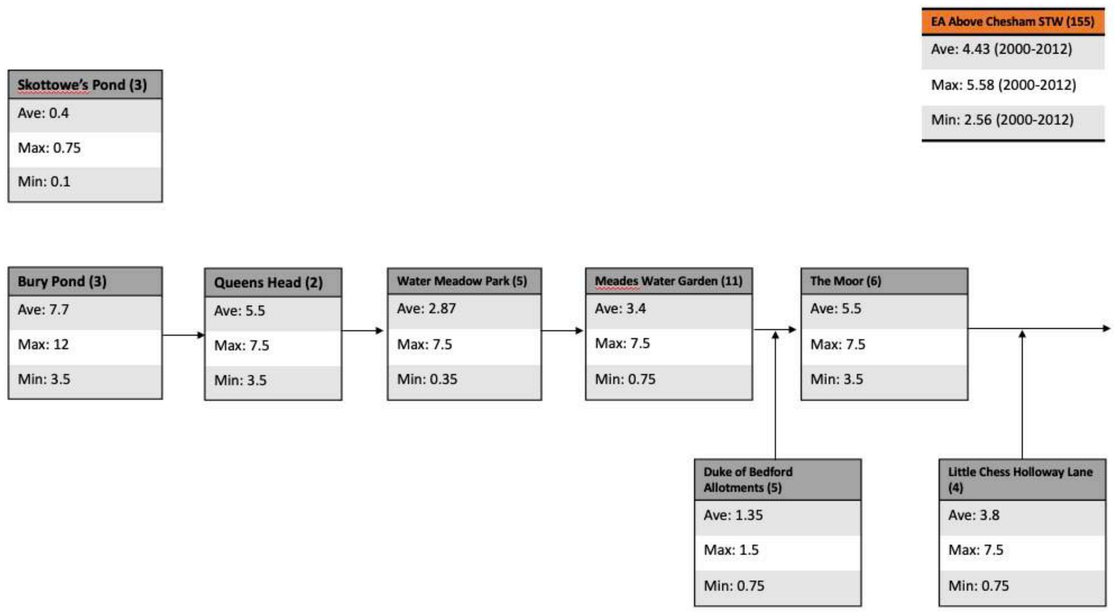


Figure 62 Nitrate concentrations (mg-N/L) in water samples from Chesham collected by Citizen Scientists as part of the EarthWatch Freshwater Blitz (2015-2021). Orange table represents annual average for EA site PCNR0012 in 2012, located upstream of Chesham WWTW, for comparison. Number in brackets = number of samples.

6.6.3 Source apportionment of nitrate

There are no SAGIS results available from the Environment Agency for nitrate. The annual loading from Chesham WWTW should be calculated and compared to the annual nitrate load at Rickmansworth in order to approximate the contribution of Chesham WWTW to total nitrate load passing through the Chess.

6.7 Combined assessment of N,P and C limitation in the River Chess

The Nutrient Limitation Assessment methodology of Jarvie et al. (2018) has been applied to the River Chess to explore the prioritisation of nutrient remediation in the catchment. This methodology assesses both relative nutrient depletion (based on nutrient ratios) and absolute nutrient limitation (based on comparison to absolute limiting concentration thresholds). The analysis uses reactive phosphorus (ortho-phosphate), TON (total oxidisable nitrogen) and DIC (calculated based on alkalinity, pH and temperature) concentrations from the EA WIMS dataset.

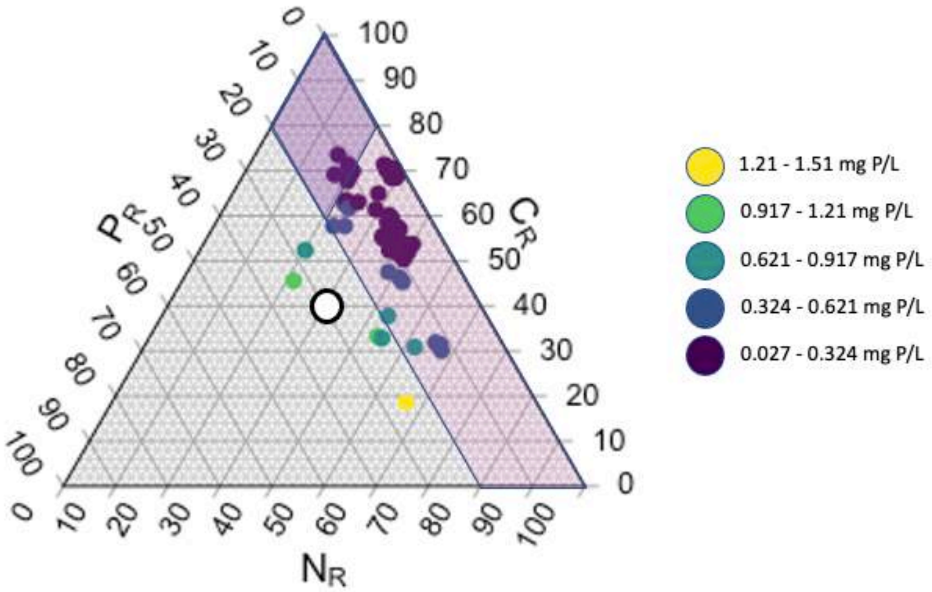


Figure 63 The relationship between P,N and C concentrations in the River Chess for 2012. Samples are colour-coded to indicate their absolute reactive phosphorus concentration. Triangles in (a) indicate samples from an EA site upstream of Chesham Sewage Treatment Works. The open circle at the centre represents the Redfield ratio (106C:16N:1P). Data points falling in the pink shaded area indicated in (c) suggest P-depletion relative to N and/or C and data points falling in the purple shaded area indicate P and N co-depletion relative to C.

The results indicate that much of the Chess shows phosphorus depletion relative to carbon and nitrogen, and sometimes phosphorus and nitrogen are co-depleted relative to carbon (*Figure 63*). Below Chesham WWTW both phosphorus and nitrogen concentrations exceed the upper thresholds for limiting nutrient concentrations of 0.05 mg-P/L and 0.4 mg-N/L.

In 2012 P concentrations above Chesham WWTW indicated the potential for partial P limitation; with concentrations around the upper breakpoint for P limitation of 0.05 mg-P/L. N concentrations above Chesham WWTW, however, were 10 x higher than the upper concentration threshold of 0.4 mg-N/L. The concentrations in the river above Chesham WWTW are comparable to groundwater concentrations in the locality, so may reflect the minimum concentrations achievable in this groundwater-fed river if all current anthropogenic sources of phosphorus and nitrogen were removed. It is important to understand whether P and N conditions in the headwaters have deteriorated since 2012, but there is sparse data with which to carry out these analyses.

Overall this analysis indicates that mitigation measures aimed at reducing phosphorus concentrations are those likely to reduce algal growth within the River Chess. Given current average concentrations of TON in groundwater, it may be impossible to reduce TON to an ecologically-relevant threshold in the river. However, P concentrations will need to be reduced below 0.05 mg P/L in areas downstream of Chesham WWTW to reach partial nutrient limitation, and the current change in permit under AMP7 will only achieve moderate P status and an estimated average concentration < 0.191 mg P/L so further remedial measures should be considered. This is all the more important in the light of climate change scenarios which predict reduced summer baseflows in chalk rivers, and therefore a reduced capacity for dilution of treated effluents.

Whilst it may be impracticable to reduce TON concentrations to ecologically-relevant concentrations in the Chess, the value of reducing TON loads from Chesham WWTW should not be ignored. The Chess is a tributary of the River Colne which in turn flows to the River Thames, and eventually to the North Sea. Therefore, the Chess is contributing to the net export of nitrogen to sensitive coastal waters which are nitrogen-limited. Reducing nitrogen in headwater catchments is important for downstream freshwater ecosystems, and for the future health of our coastal environment. Harmful algal blooms occurring in the North Sea and English channel have been tracked by satellite monitoring since 2016, and are estimated to carry an annual cost of over 900 million euros to tourism and fishing industries in Europe.

6.8 Dissolved oxygen, BOD, COD

Dissolved oxygen status of the River Chess is classified 'High' on the basis of the Water Framework Directive assessment (> 80% as 10th percentile), and this has been the case since WFD analysis began in 2009. Monthly monitoring by the Environment Agency since 1976 indicates no overall decline in the dissolved oxygen status of the river since these records began (*Figure 64*). There is, however, a distinctive spatial pattern in dissolved oxygen concentrations, with dissolved oxygen levels significantly lower at EA2 and EA3 downstream of Chesham WWTW. The supressing effect of the treatment works on dissolved oxygen dynamics in the river can be observed in the long-term record at Latimer Bridge prior to 2000. The monitoring also reveals the effect of effluent discharges from Chesham WWTW on dissolved oxygen in the river further upstream at Bois Mill with dissolved oxygen content of < 55% recorded on two occasions in the late 1970s and mid-1980s.

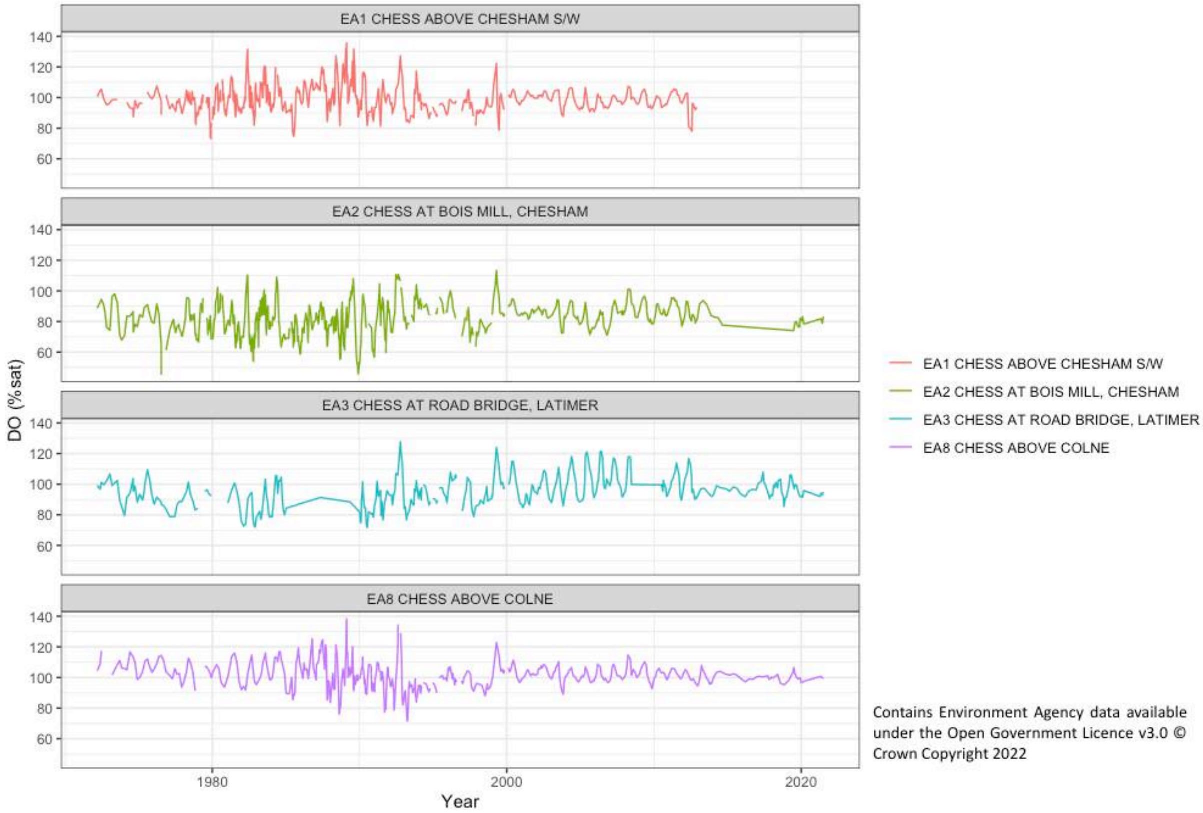


Figure 64 Time series of dissolved oxygen status in River Chess since records began in 1976.

Long-term monthly monitoring is extremely valuable in order to understand temporal trends in water quality arising from land use change and seasonality, but monthly grab samples can miss important event-based dynamics due to rainfall, road and agricultural runoff and storm tank discharges from sewage treatment works

6.8.1 Changes in dissolved oxygen recorded by the ChessWatch sensors

ChessWatch sensor data also illustrate that dissolved oxygen concentrations are lower below Chesham WWTW outfall compared to upstream, but recover further downstream at Sarratt watercress beds where oxygen status is good. The oxygen data from the sensors enable us to consider changes in the daily oxygen cycles across the seasons. We can also use data from the sensors to examine (i) the influence of rainfall events; and (ii) the effects of storm tank overflows from Chesham WWTW on dissolved oxygen status in the river.

Diurnal and seasonal patterns in dissolved oxygen are explored on our ChessWatch water quality dashboard. Here the focus is on the influence of storm tank overflow from Chesham WWTW on dissolved oxygen status in the river. In 2020/2021 storm tank overflow occurred at Chesham WWTW for three reasons:

1. Rainfall events that exceeded both treatment and storm tank capacity of Chesham WWTW.
2. Groundwater ingress into the sewer network.
3. Rainfall events occurring during periods of groundwater ingress.

In 2019 a change in rainfall patterns led to increased groundwater levels in the Chess catchment. In Chesham the groundwater rose to the near-surface and reached the sewer network, leading to ingress of groundwater via joints and cracks in the sewer pipes. Subsequent investigations by Thames Water found that 25.5% of the sewer network surveyed in Chesham had evidence of groundwater infiltration, and they identified 30 groundwater infiltration locations in the sewers and 9 locations at manholes. Further details of the investigations can be found here.

Groundwater entering the sewer network was then transported to Chesham WWTW along with wastewater from domestic and commercial properties. Under these conditions the volume of flow entering the WWTW exceeds the treatment capacity of the works, and the storm tanks begin to fill with a mix of untreated wastewater and groundwater. These storm tanks are designed to collect untreated wastewater when influent flows temporarily exceed treatment capacity due to high-intensity/long duration rainfall events. However, in this case, with a continuous inflow of water the storm tanks eventually fill up and discharge untreated wastewater to the river.

The orange panels in *Figure 65* illustrate periods of storm tank overflow using data from the Event Duration Monitors (EDMs) located at the storm tanks in Chesham WWTW. Thames Water were not able to provide data prior to 15th April 2020 due to incorrect installation of the EDMs. Therefore, the periods of storm tank discharge occurring before 15th April 2020 are based on visual observations from the River Chess Association. The 2021 EDM data is unverified and unvalidated. *Figure 65* also illustrates the concept of a 'trigger level' at which groundwater ingress into the sewer network occurred in 2020 and 2021.

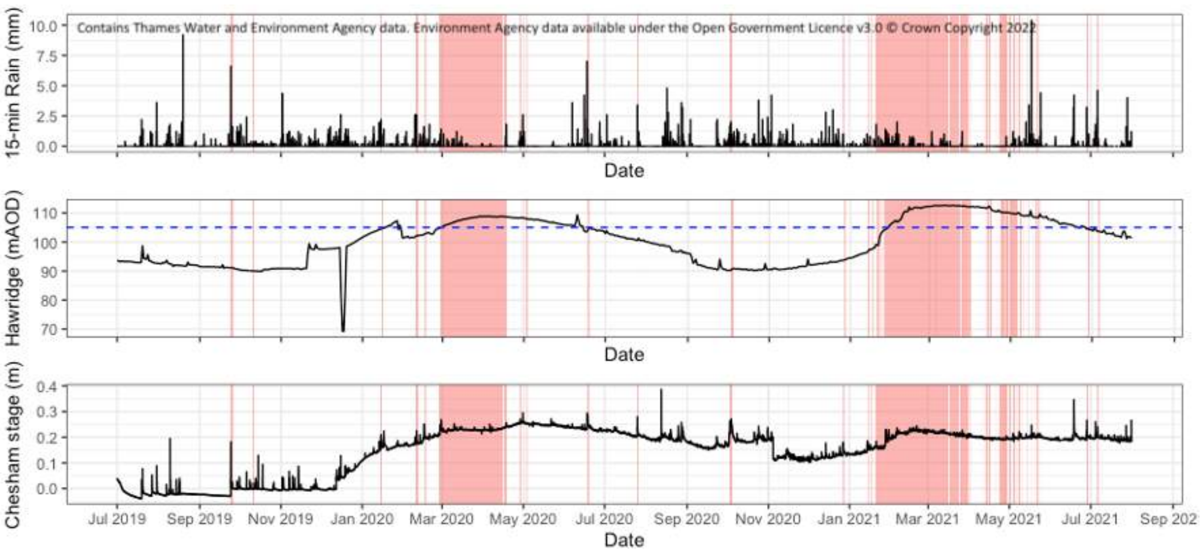


Figure 65 Rainfall, groundwater levels and stage at Chesham. Orange panels indicate time periods when Chesham storm tanks were discharging. Dotted blue line indicates composite groundwater height at Hawridge when treatment and storm tank capacity at Chesham was exceeded.

Figure 66 illustrates the periods of storm tank discharge plotted alongside the dissolved oxygen data from the Chesswatch sensors located upstream and downstream of Chesham

WWTW outfall. Storm tank discharges, irrespective of cause, occurred for a total of 2010.6 hours or 83.8 days from 15th April 2020 to 6th July 2021 (Thames Water EDM data).

Upstream of Chesham WWTW dissolved oxygen levels exceed the WFD good dissolved oxygen status for Type 7, salmonid rivers. Approximately 2 km downstream of the outfall there are periods during which dissolved oxygen levels drop below 75% saturation. Storm tank discharge from Chesham WWTW caused the greatest variations in dissolved oxygen concentration observed in the River Chess during the two years of monitoring. Intense rainfall events can cause storm tank discharge events lasting c. 24 hours in duration (such as in late October 2020) which give rise to transient drops in dissolved oxygen to moderate values (64-75%). Of greatest concern are the lengthy periods of groundwater ingress and groundwater ingress with rainfall causing extended storm tank discharges which occurred late February to late April in 2020 (c. 2 months) and mid-January to the end of April (c. 3.5 months) in 2021. These caused prolonged periods of moderate to poor dissolved oxygen status in the reach between the outfall and Latimer Park, and the distance these conditions extended downstream is not known. The timing of such events in relation to life stages of invertebrates and fish (spawning, egg and fry development) in the river is critical to determining the likely effects on ecosystem health.

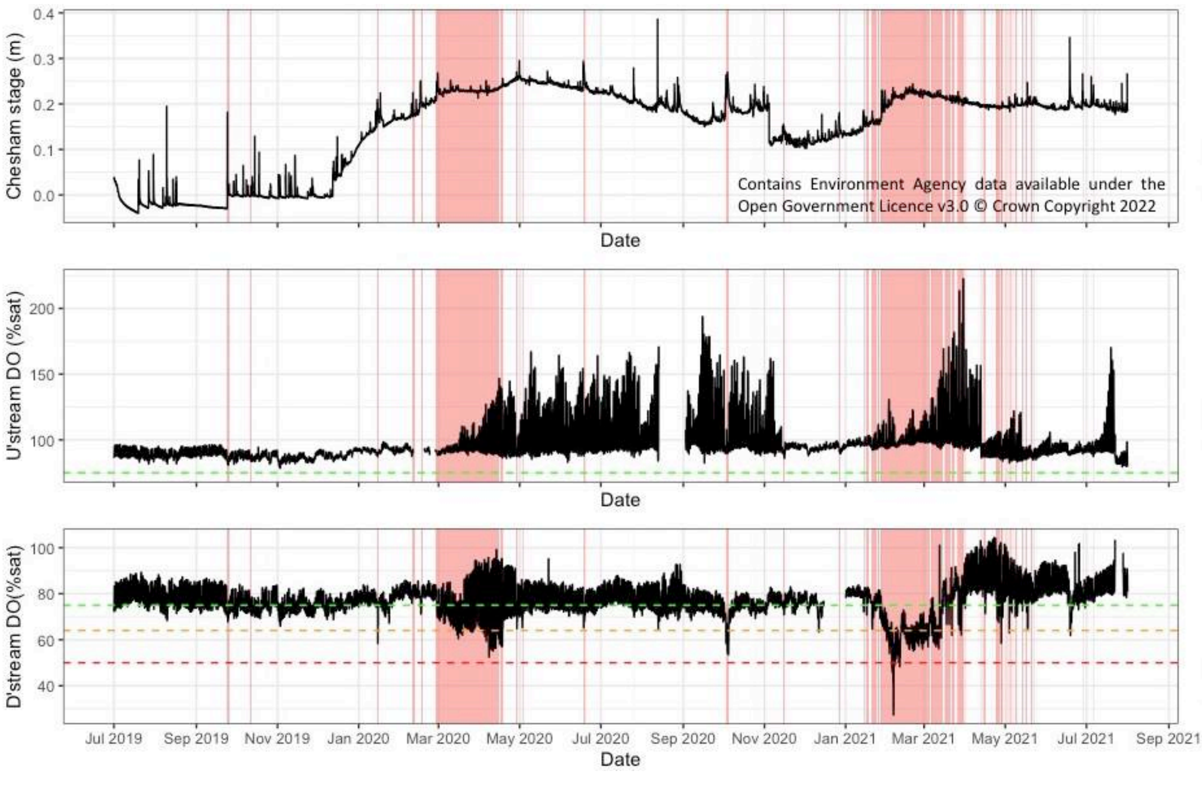


Figure 66 Time series of stage at Chesham plotted with dissolved oxygen levels from the ChessWatch sensors. Orange panels indicate time period during which Chesham WWTW storm tanks were discharging. Green dotted line = Good DO status (> 75%); Orange dotted line = Moderate DO status (64-75%); Red dotted line = Poor DO status (<50%).

Threats:

- The River Chess is classified as 'High' dissolved oxygen status under the WFD and ChessWatch monitoring supports this. However, there are a number of areas where monitoring gaps exist:
  - i) Very little is known about dissolved oxygen levels in Chesham or Rickmansworth areas where sewer mis-connections may occur.
  - ii) Real-time monitoring in the lower reaches of the River Chess would also be advisable to check for any intermittent issues associated with road runoff that have not been picked up by Environment Agency grab sampling.

- Storm tank discharge from Chesham WWTW due to high rainfall causes transient (hours), supressed dissolved oxygen levels in the upstream stretch of the river between the outfall and Sarratt. Storm tank discharge due to groundwater ingress can cause prolonged (months) periods of poor dissolved oxygen concentration in these stretches. It is possible that the dissolved oxygen levels improve at the confluence of the Little Chess and main Chess in Latimer due to mixing of the two sources of water, and this could be explored further by the group.

Opportunities:

- Planned increases in treatment capacity under AMP7 should reduce the frequency and duration of storm tank discharge, but in the longer term population growth and climate change may offset these gains. There is a need for the partnership to better understand Thames Water's forecasting of the frequency and duration of storm tank discharges in response to both rainfall events and groundwater ingress in order to help shape the future direction of investment in Chesham WWTW under AMP8.
- Thames Water have created a Groundwater Impacted System Management Plan for Chesham to address the issue of groundwater infiltration. These plans be found here.

6.9 Sediment

Sediment is a natural component of the riverine ecosystem but can become problematic when supply from the catchment due to human activity exceeds the ability for the river to transport the sediment. Fine sediment can smother the river bed and deteriorate habitat for fish and invertebrates, preventing spawning and egg hatch in salmonid rivers such as the Chess (Wharton et al., 2017). The composition of the sediment is also important. Sediment comprises both organic and inorganic components, and can carry with it nutrients, metals and oils and greases which can be released from the sediment during and after transport to cause harmful effects in the river. Typical sources of sediment in rivers arise from soil erosion from agricultural areas and footpaths, bankside erosion (both natural and livestock poaching), urban runoff and storm tank discharges (Environment Agency, 2019d). There are no river sediment standards and sediment is not routinely monitored by the Environment Agency, so limited data is available from national databases.

6.9.1 Temporal trends in suspended sediment

Figure 67 highlights the infrequent nature of suspended sediment monitoring in the River Chess since 2000. In chalk streams fine sediment is usually mobilised and transported into and through the river during storm events, when flows are higher and stream power is elevated. As a result monthly sampling is not such a useful indicator of sediment transport.

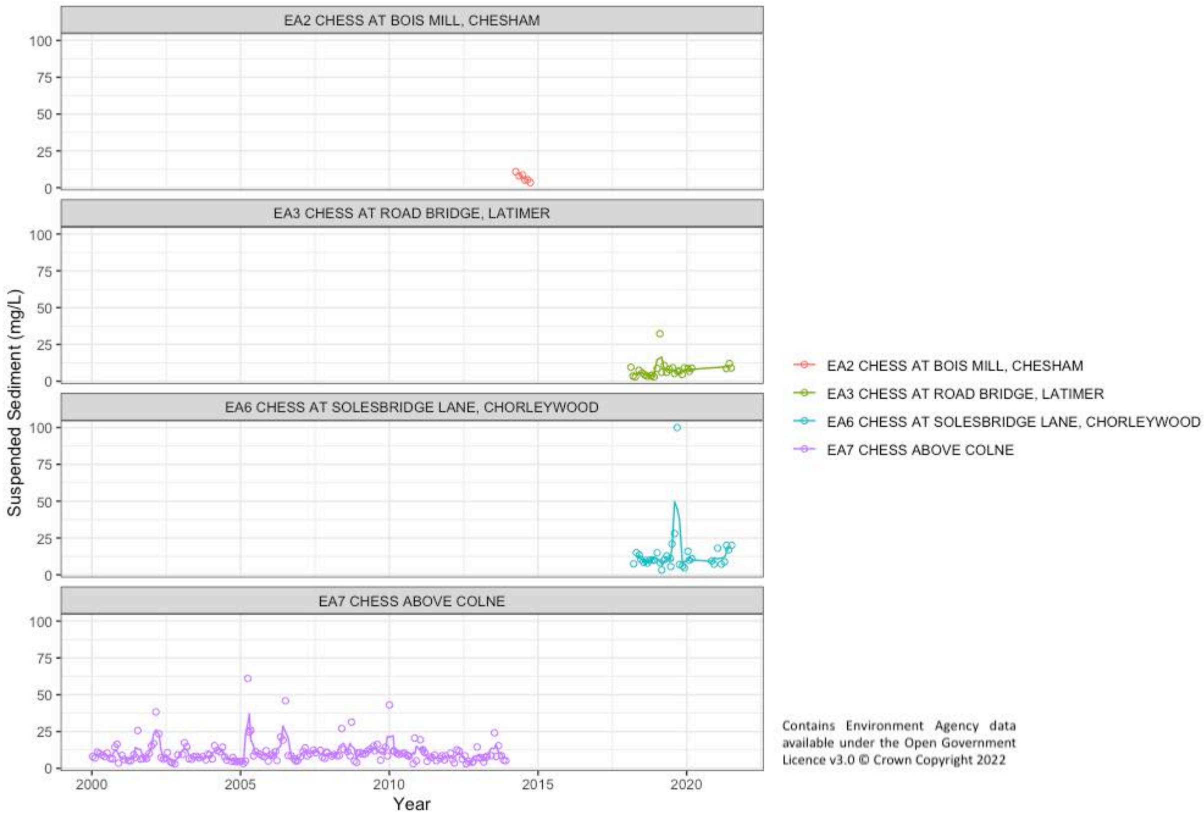


Figure 67 Suspended Sediment concentrations in the River Chess as measured by monthly grab samples (Environment Agency data).

6.9.2 Spatial trends in suspended sediment

A systematic survey of fine sediment inputs into the River Chess has not yet been carried out but there is good local knowledge of sources from local interest groups around the Chesham area (e.g. Impress the Chess, River Chess Association). There are three locations in the upper catchment where sediment inputs to the river are a repeat occurrence during intense rainfall: (a) Vale Brook, (b) Blackwell Hall and (c) Bell Lane (*Figure 68*, *Figure 69*, *Figure 70*) The magnitude and frequency of sediment input at these locations is not known, but Section 6.10 describes the results of analysing metal content in bed sediments at these locations.

Figure 68 Vale Brook at (a) and (b) Townsend Road, 12 November 2021 (SOURCE: Kate Heppell).

Figure 69 Soil erosion and transport along Blackwell Hall Lane, 18 Oct 2018 (SOURCE: Paul Jennings, River Chess Association).

Figure 70 Overland flow and sediment transport at Bell Lane, and subsequent input to River Chess, 1 Feb 2015 (SOURCE: Paul Jennings, River Chess Association).

6.9.3 SCIMAP

SCIMAP is a digital mapping tool created by Durham University which can be used to identify areas in the landscape where there is a risk of soil erosion and sediment transport (https://scimap.org.uk/). SCIMAP works by using land use data and a digital elevation model to identify critical source areas in the catchment where soil erosion might occur, and whether there is an available pathway by which this soil might be transported to the river network via overland flow. Land under arable and horticultural use are considered most at risk because these land use types are often left without plant cover at critical times of the year.

SCIMAP uses topographical information to derive a wetness index when considering water flow pathways. The approach does not take into account the location of roads and footpaths in the catchment, neither will it account for groundwater flooding. The on-line version of SCIMAP uses CEH land cover data from 2007 which may not reflect current land use. SCIMAP is a useful tool to derive risk maps for surface runoff arising from rainfall events, to inform more detailed investigation and should be used in conjunction with local knowledge and ground-truthing (Reaney et al., 2019).

The basic on-line version of SCIMAP was run on 21 Dec 2021 to obtain maps of erosion risk potential, hydrological connectivity and channel accumulated risk for the catchment (*Figure 71*). These model runs used LIDAR, land cover, rainfall and river information provided by the University of Durham in the on-line version of SCIMAP.

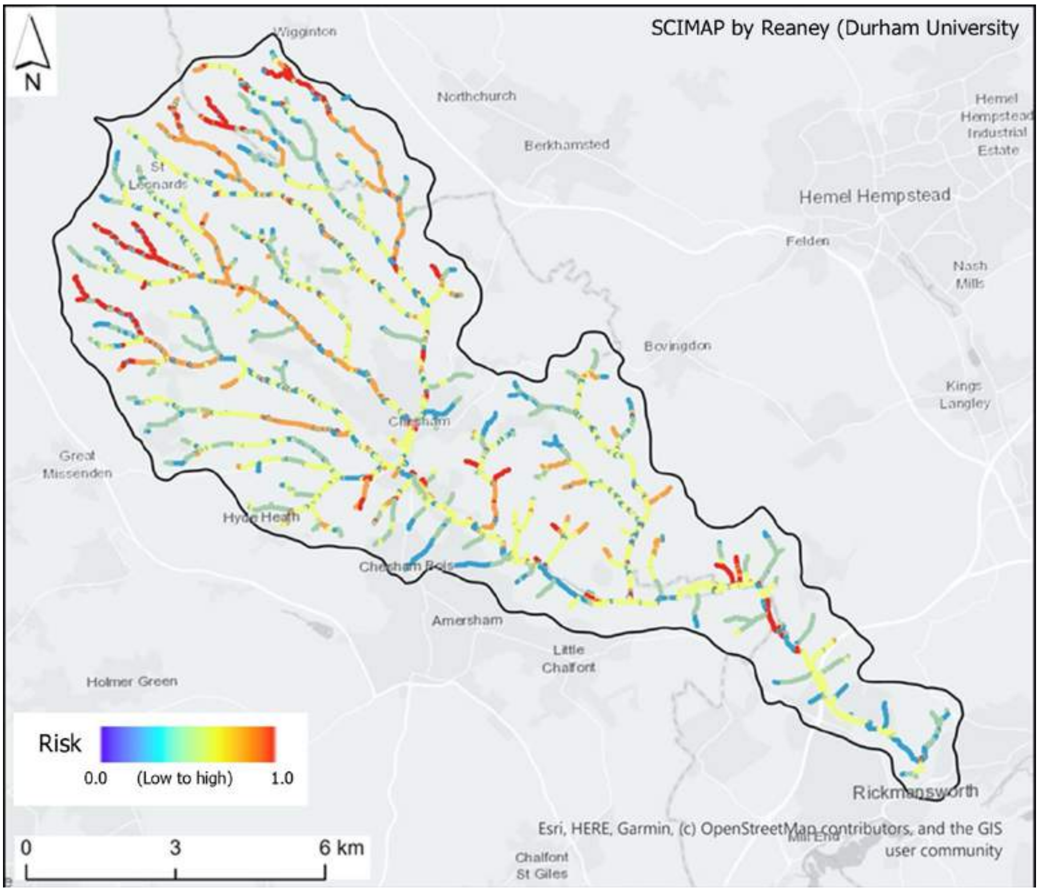


Figure 71 The accumulated risk potential of sediment input to the river channel derived using SCIMAP (2021). Areas highlighted in red are at highest theoretical risk of sediment input to the channel (based on land use and topography) for the catchment.

The River Chess catchment has many dry valleys which SCIMAP considers at risk of overland flow on the basis of land use and topography (*Figure 71*). These are areas where localised soil erosion and sediment transport may occur due to a combination of steep elevation and bare soils at critical times of the year. Such information is useful for assessing catchment-wide risk to soil health, so these areas have been retained to give an overall catchment perspective. It should be noted, however, that in many cases these dry valleys are not permanently connected to the river itself, but may become connected during intense or extreme rainfall. For example there is local knowledge of sediment transport from the Wigginton area (Area A, *Figure 72Figure 72*) to the Vale Brook via the road network, so potential hydrological pathways (based on topography) in this area have been left on the map.

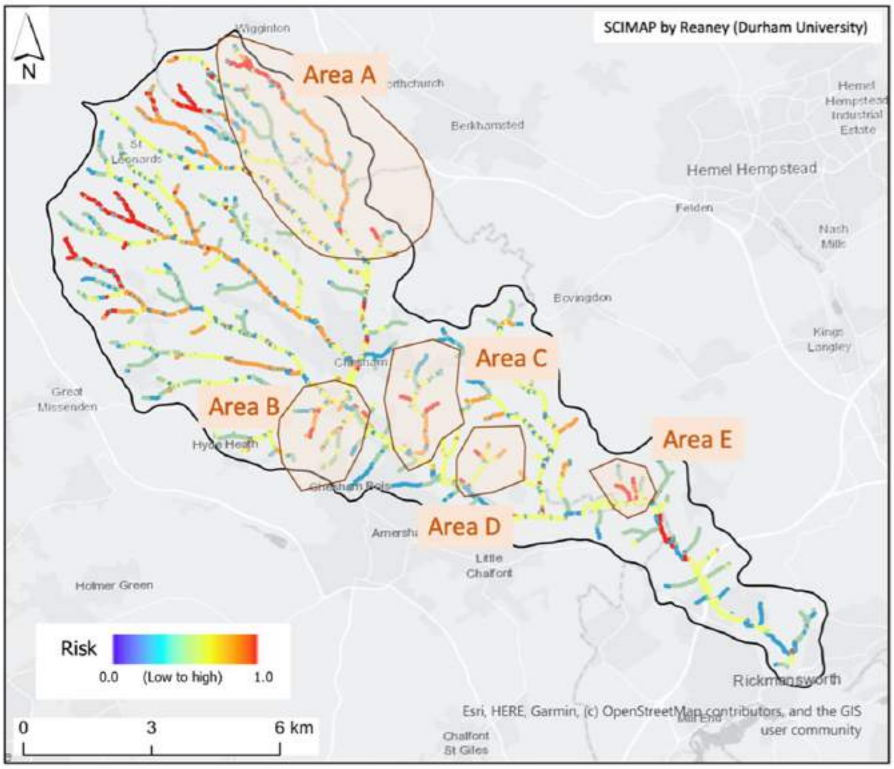


Figure 72 SCIMAP-derived channel network with dry valleys. Areas of potential high risk of sediment input to the channel are highlighted. Note the risk mapping is based on topography and land use cover.

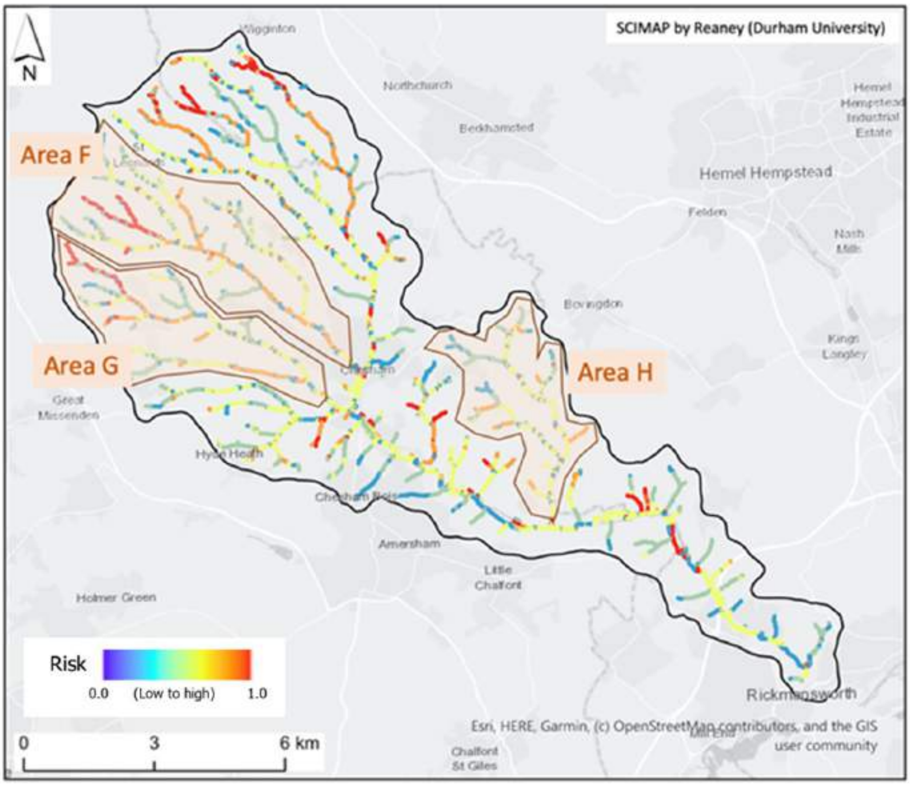


Figure 73 SCIMAP-derived channel network with dry valleys. Areas of potential high risk of sediment input to the channel are highlighted. Note the risk mapping is based on topography and land use cover.

Table 6 along with *Figure 72* and *Figure 73* summarise the sub-catchments of the river channel which have been highlighted as 'at risk' from sediment inputs either/and because of SCIMAP mapping, or from local knowledge. The sub-catchments are labelled in ordered of potential importance based on local knowledge, with Area A being the sub-catchment in which to focus initial ground-truthing investigations.

Table 6 Summary of sub-catchments of the River Chess which are at risk from sediment inputs, and where sediment transport has previously been observed.

Location	Theoretical risk identified	Observation
Wigginton to south of Hawridge (potential connection with Vale Brook)	SCIMAP (Area A on *Figure 72*)	Video of road runoff on Wigginton Road (Year)
Nashleigh Hill & White Hill	-	Road runoff (pers. comm.)
Missenden Road / Fullers Hill	Missenden Road - SCIMAP (Area B on *Figure 72*)	Fullers Hill (pers. comm.) – erosion of roadside bank Missenden Road
North side of Latimer Road by Bottom Lane	SCIMAP (Area C on *Figure 72*)	Canon Hill Avenue (pers. comm.) Road drains contribute to river & receive sediment from upslope
Blackwell Hall Lane	-	Photographs & pers. comm.
North side of Chess at Frith Wood	SCIMAP (Area D on *Figure 72*)	-
Bell Lane Slopes to west of Holloway Lane at Sarratt	- SCIMAP (Area E on *Figure 72*)	Photographs & pers. comm.
Asheridge	SCIMAP (Area F on *Figure* 73)	Surface runoff observed during extreme events (pers. comm.)
Pednor Mead End	SCIMAP (Area G on *Figure 73*)	Surface runoff observed during extreme events at Frogmoor (pers. comm.)
Flaunden Bottom	SCIMAP (Area H on *Figure* 73)	Ponding is observed at base of hill at Latimer during heavy rain (pers. comm.)

6.9.4 Real-time Sensor data

Whist the ChessWatch sensors do not measure suspended sediment directly, turbidity data enables a comparison of temporal variations in water clarity at different locations in the river. The cloudiness of water can be caused by both inorganic and organic suspended particles such as clays, chemical precipitates such as calcium carbonate, plant debris and organisms. Turbidity is measured in Nephelometric Turbidity Units (NTU) with 0 NTU being clear water. Water is visibly cloudy at 4 NTU and opaque at around 250 NTU although the cloudiness will vary according to the composition of the sediment. Typical average turbidity values in the River Chess during periods of baseflow in 2019 to 2021 were 7 to 8 NTU at all sensor sites with little difference observed between locations reflecting transport of biomass past the sensors. However, there are marked changes in turbidity during and following rainfall events due to transport of sediment.

Figure 74 highlights the higher turbidity observed upstream of Chesham WWTW compared to at Sarratt during rainfall events in 2019 when Chesham WWTW storm tanks were not operating. There is no significant change to dissolved oxygen levels in the river during this rainfall event.

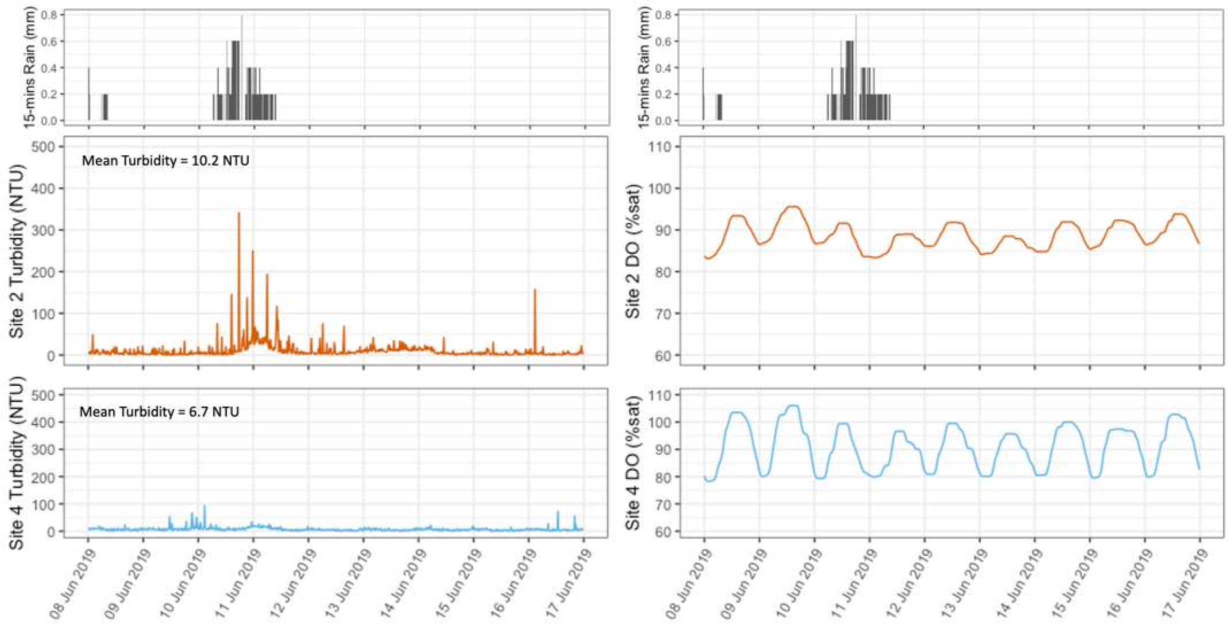


Figure 74 Changes in turbidity and dissolved oxygen upstream of Chesham WWTW and at Sarratt watercress beds during a 25 mm rainfall event in June 2019. Mean turbidity is calculated for the whole time period plotted.

Figure 75 illustrates variations in turbidity and dissolved oxygen levels during rainfall events in November 2019. Whilst the preceding events (1.8 and 4 mm of rainfall respectively) are not accompanied by significant changes in turbidity, the 15.6 mm event on 14 Nov 2019 transports sediment in both the Little Chess (Site 1) and main Chess upstream of Chesham WWTW. Turbidity at Latimer Park peaks more rapidly than the sites further upstream suggesting a localised source of material entering the river just upstream of the sensor. As previously, turbidity at the watercress beds in Sarratt (Site 4) is lower suggesting that the upper reaches of the Chess in and around Chesham are important sources of sediment. Once again there are no significant changes to dissolved oxygen levels in the river during these rainfall event.

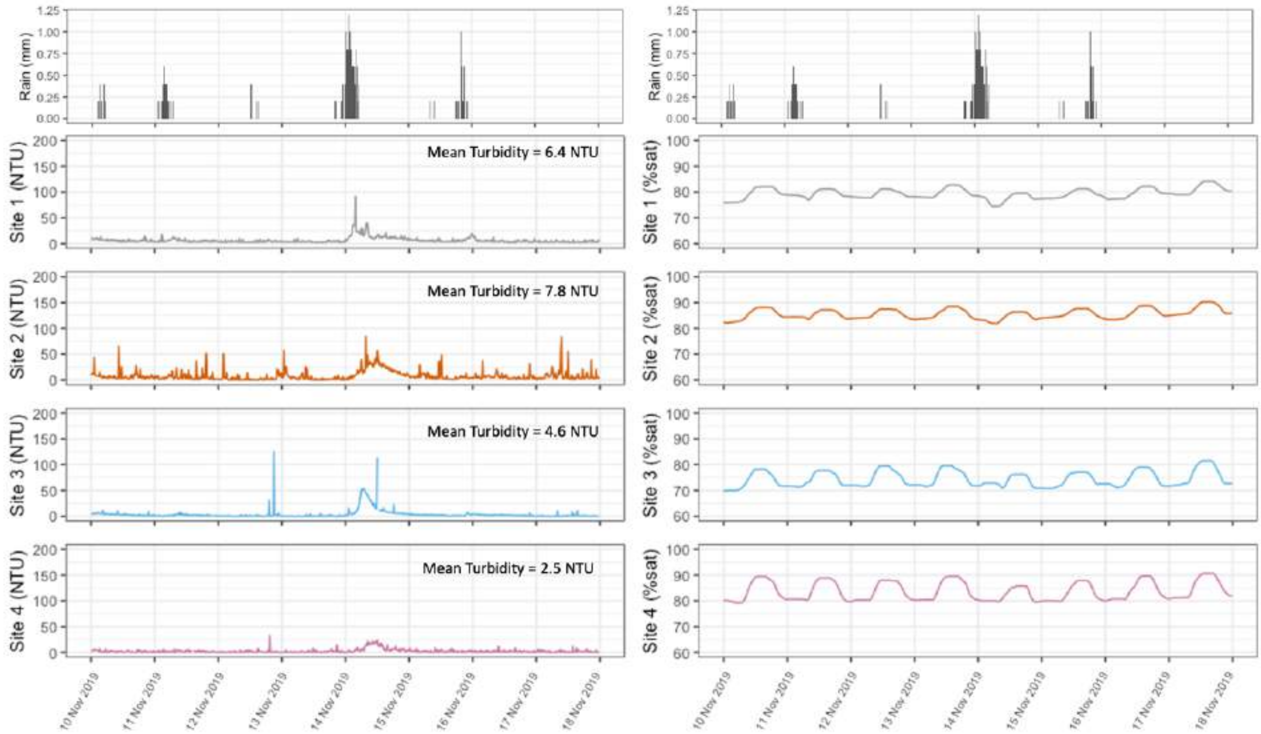


Figure 75 Variations in turbidity and dissolved oxygen at four ChessWatch sensor sites from 10 to 18 Nov 2019. Mean turbidity is calculated for the whole time period plotted. Site 1 = Little Chess, Site 2 = Upstream of Chesham WWTW, Site 3 = Latimer Park, Site 4 = Watercress beds at Sarratt.

Figure 76 shows the change in turbidity and dissolved oxygen at three sensor sites when sewage discharge from the storm tanks at Chesham WWTW was occurring. Turbidity is still highest at Site 2 upstream of Chesham WWTW, however, there is a marked transient drop in dissolved oxygen concentration approximately 2 km downstream of the WWTW indicative of the oxygen demand associated with gross pollution. Such events may cause changes to biochemical oxygen demand in the river gravels causing low oxygen condition for salmonid eggs and invertebrates.

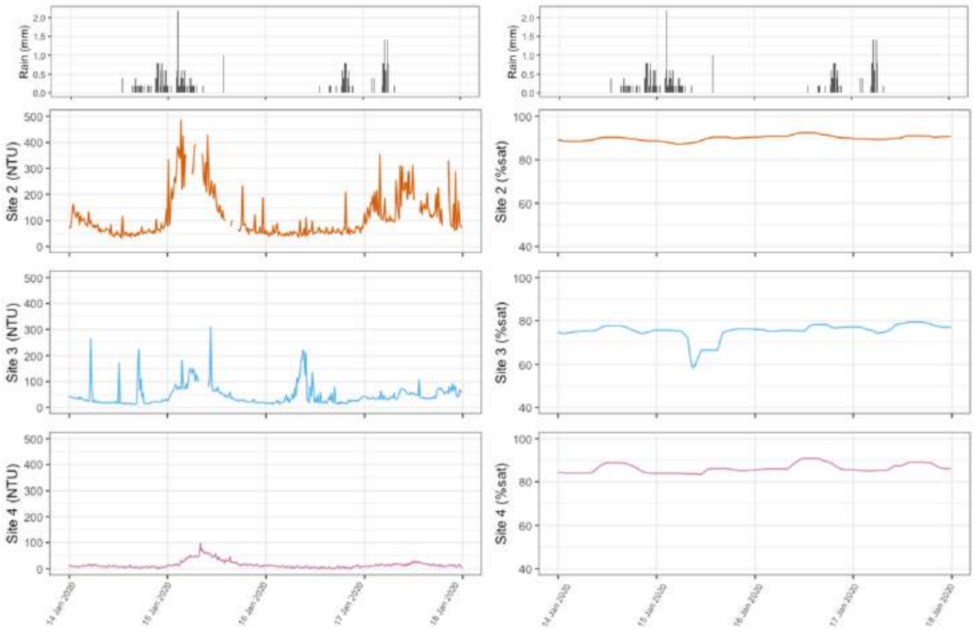


Figure 76 Variations in turbidity and dissolved oxygen in the River Chess in response to a X mm rainfall event during which Chesham WWTW storm tanks were discharged. Site 2 = Upstream of Chesham WWTW, Site 3 = Latimer Park, Site 4 = Watercress beds at Sarratt.

The composition of this fine sediment will vary according to whether Chesham WWTW storm tanks are operating. Urban road runoff material is likely to be dominated by inorganic material such as sand and grit with sediment-associated metals and hydrocarbons. Road runoff from agricultural parts of the catchment may incorporate soil from eroded roadside verges and topsoil from agricultural land. The storm tank discharges will be high in particulate organic matter from faeces and fibres from toilet paper and sanitary products. If polluted, such sediment can act as a source of contaminants to the water column – particularly with regards to coliform bacteria, and to the release of phosphorus and metals. For example, as phosphorus levels are decreased in the river these reservoirs of fine sediment can switch from being a sink for pollutants to a source which can challenge attempts to improve water quality.

Irrespective of origin or composition, the fine sediment will move down the river and settle in areas of low flow, such as in and around macrophyte stands, at the river margins and behind infrastructure such as weirs and barriers. In some places on the Chess (such as Dodds Mill at Latimer) metres of sediment have built up over the years behind impoundments such as weirs. Gravels may become clogged and infilled (termed colmation) as a result of the deposition of transported sediment in the river. Mapping bed sediments at regular intervals (using survey techniques such as Modular River Survey, and using invertebrate health metrics such as PSI (as incorporated in SmartRivers initiative) should help determine the extent of the problem in the Chess, and whether sediment deposition is threatening invertebrates numbers and diversity in the river.

Threats:

- Sediment input to the River Chess via the Vale Brook
- Sediment input to the Chess arising from soil loss from steep slopes under arable agriculture during heavy rains, with subsequent transport down tracks and roads to the River Chess.
- Sediment delivered from un-metalled urban roads in the catchment to the river.

Opportunities:

- Use MudSpotter Citizen Science method to identify locations where sediment reaches the river channel.
- Quantify mass of fine sediment moving through the River Chess as suspended sediment using Philips samplers.
- Ground-truth the SCIMAP risk maps and MudSpotter output using walkover surveys.
- Introduce measures to prevent soil erosion from eroding road verges where appropriate.
- Introduction of swales and sediment retention features to prevent road runoff entering Chess outside urban areas (recommendations for urban areas are included in a separate report being prepared by Jacobs).
- Work with farming community in targeted areas to find solutions to prevent any identified soil erosion and loss of topsoil with associated carbon and nutrients.
- Use of a sediment-sensitive macro-invertebrate metric (such as PSI, Proportion of Sediment-sensitive Invertebrates) together with habitat assessments such as Modular River Survey to assess the threats arising from sediment deposition and transport in the River Chess.

6.10 Metals

Dissolved Cadmium, Lead, Mercury and Nickel and their associated compounds are defined as priority substances under the Water Framework Directive. Samples have been collected by the Environment Agency at EA2 Bois Mill site to test for dissolved metal concentrations in the River Chess. Lead, Mercury and Nickel were analysed at this site on a monthly basis from April 2014 to March 2015. Dissolved mercury concentrations were below limits of detection in every sample collected. *Figure 77*a and c show that, whilst dissolved lead and nickel were detectable, they fall below the Environmental Quality Standards (expressed as an Annual Average) of the Water Framework Directive. Dissolved cadmium concentrations are also an order of magnitude below the AA-EQS for Class 5 rivers with high alkalinity (*Figure 77*b). The Environment Agency have continued to monitor Cadmium concentrations at Bois Mill until 2020.

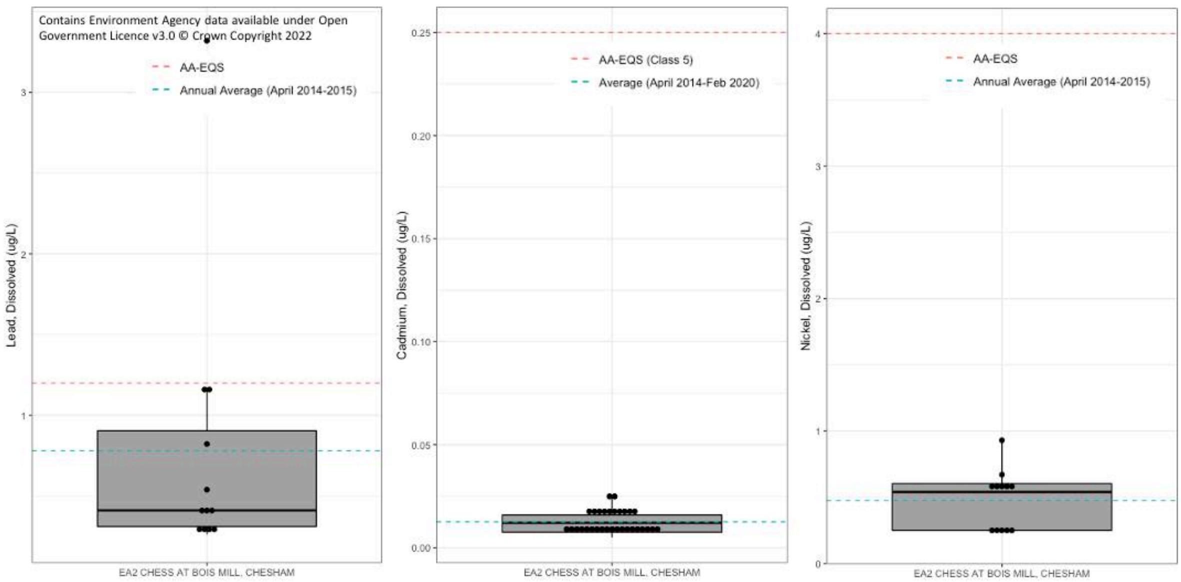


Figure 77 Dissolved metal concentration in water; (a) Lead, (b) Cadmium and (c) Nickel at EA2. AA-EQS is Environmental Quality Standard assessed by Annual Average Concentration.

The Environment Agency have also analysed water samples for other metals not designated as priority substances under the WFD. Environment Agency monitoring from 2000 to 2008 has also indicated that Total Arsenic and Vanadium concentrations in surface water were below levels of detection (< 1 and 2 mg/L respectively).

6.9.2 Metals in bed sediments

Two bed sediment samples (A and B) were taken from Meades Water Gardens in 2006 prior to restoration of the site. Lead concentrations were 252 and 536 mg/kg in samples A and B respectively. Sample B breached Soil Guidelines Values from the Contaminated Land Environmental Assessment model (CLEA) for lead for soils with residential use with and without plant uptake and for allotments. This sample also breached Waste Acceptance Criteria thresholds for Hazardous Waste (total organic carbon, dry weight) and Inert Waste (total organic carbon, mineral oil C10-40 and Polyaromatic Hydrocarbons).

Table 7 Metal and hydrocarbon content in bed sediments.

Determinand	Sediment content (mg/kg)
Hydrocarbons C10-40, dry weight	4000
PAHs EPA 16 total, dry weight	116
Lead, dry weight	536

Below are the US-EPA consensus-based freshwater sediment quality guidelines for Pb for comparison with sediment Pb contents measured in the River Chess.

Table 8 US-EPA Consensus-based sediment quality guidelines for Pb (McDonald et al., 2000)

	Threshold Effect Concentration[a] (mg/kg)	Probable Effect Concentration[b] (mg/kg)
Lead (Pb)	35.8	91.3

[a]Threshold Effect Concentration is the contaminant concentration below which harmful effects on sediment-dwelling organisms are not expected.
[b]Probable Effect Concentrations are the contaminant concentrations above which harmful effects on sediment-dwelling organisms are expected to occur frequently.

The original analyses in 2006 at Meades Water Gardens prompted two further investigations of metal concentrations in sediments around Chesham in 2010 (QMUL undergraduate dissertation) and 2019 (QMUL postgraduate dissertation).

In 2010 fine bed sediment was collected from three sites on the River Chess and analysed by ICP-OES (< 2mm fraction, 69% nitric acid extraction) for metal content. 15 sediment samples were collected from each site; five from unvegetated sediment, five from submerged vegetation and five from emergent vegetation. *Table 9* shows average metal content with standard error of the fifteen samples at each site. The Moor site yielded the highest Pb content, followed by Meades Water Gardens and lowest Pb content in bed sediment was found at Chorleywood House Estate. Pb content in bed sediment at Meades Water Gardens were considerably lower than recorded in 2006 (pre-restoration).

Table 9 Average metal content in fine sediments of the River Chess (2010) at Site (1) Meades Water Gardens; Site (2) The Moor recreation area; and Site (3) Chorleywood House Estate. The error bars represent standard error of n=15 samples.

Site	Average Pb content (mg/kg)	Standard Error (n)
Site 1 Meades Water Gardens	33	5 (15)
Site 2 The Moor	65	15 (15)
Site 3 Chorleywood House Estate	8	1 (15)

In 2019 a fine sediment survey was carried out which focused on metal content in bed sediment downstream of Chesham, and sediment sourcing around sites of known sediment input to the upper river (*Figure 78*). Samples were analysed by ICP-OES (< 63 um fraction, aqua regia extraction) for metal content. Rows shaded in grey in *Table 10* exceed the US-EPA Probable Effect Concentrations for lead in freshwater sediments.

Table 10 Pb content in bed sediment at selected sites (2019).

Reach	Location	Average Pb content (mg/kg)	Standard Error (n)
Pednor to Queens Head	1a Pednor Bottom	38.6	1.0 (4)
	1b Bury Pond	< dl	0.0 (4)
	1c Pednormead End	77.1	4.2 (5)
	1d Queens Head	100.4	14.1 (5)
Vale Brook to Meades Water Gardens	2a D'stream Vale Brook	96.2	15.0 (5)
	2b U'stream Vale Brook	81.6	9.5 (4)

	2c Meades Water Garden	94.2	4.0 (4)
Blackwell Hall Lane	3a Soil in field	60.6	16.9 (5)
	3b Sediment on road	36.7	5.5 (5)
	3c U'stream of Blackwell Hall Lane	84.6	12.0 (4)
	3d D'stream of Blackwell Hall Lane	71.5	5.7 (5)
Latimer and Bell Lane	4a Top of Bell Lane	117.6	12.4 (4)
	4b U'stream Bell Lane	36.3	3.7 (5)
	4c D'stream Bell Lane	34.7	1.9 (5)

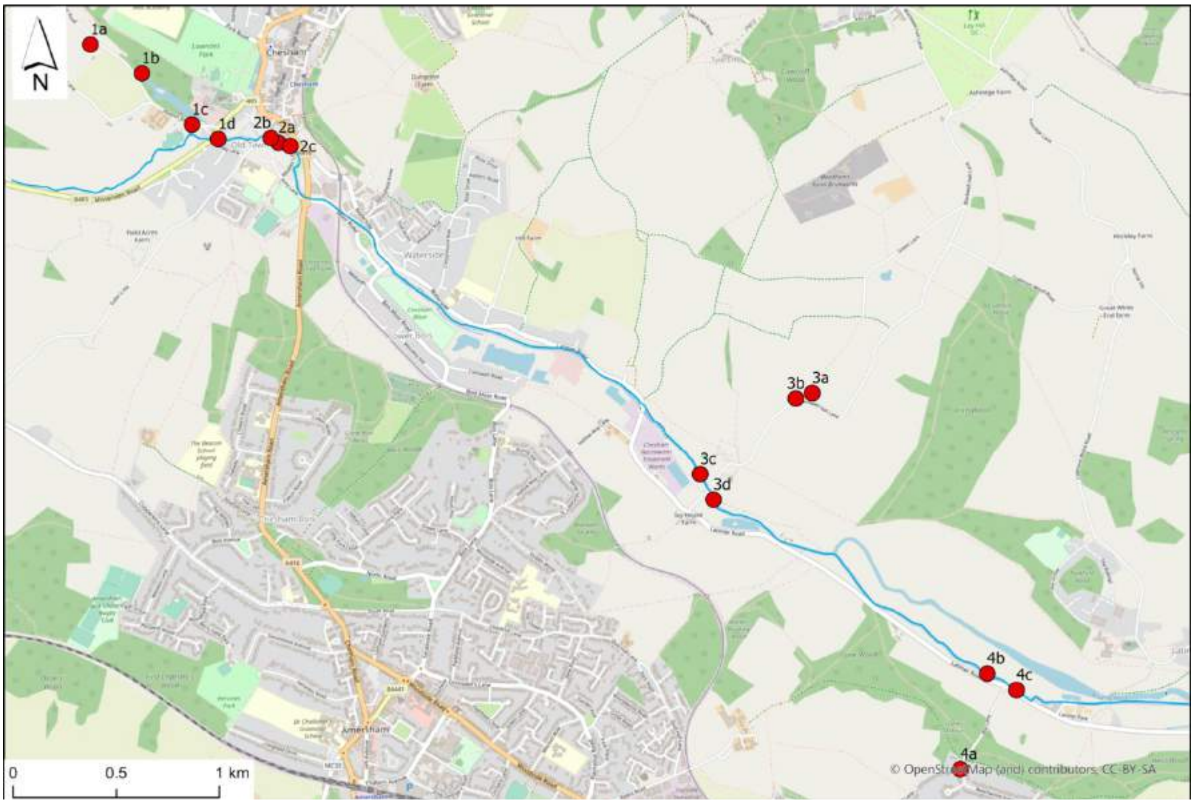


Figure 78 Sampling sites to assess metal content in sediments (2019).

Taken together these analyses suggest that (i) there may be a source of Pb entering the River Chess around the Vale Brook area and that the Pb-content of this sediment has declined since the early 2000s; and (ii) road runoff may be a source of Pb to the River Chess.

Threats:

- Pb levels in riverbed sediments exceed ecological threshold criteria in Chesham.
- Analysis in 2006 suggested that PAH levels in sediment exceeded waste disposal criteria.

- Exact sources of these sediments are not known, but this contamination potentially arises from a combination of road runoff and from the culverted Vale Brook.

Opportunities:

- Analyse fine sediments and gravels for Pb and PAH levels in an accredited laboratory to determine the severity of the risk.
- Create a risk map of sediment inputs to the River Chess in Chesham and surrounding areas using SCIMAP.
- Ground-truth SCIMAP using walkovers by Citizen Scientists.
- Explore mechanisms by which fine sediments can be prevented from reaching the River Chess in Chesham, and via road runoff in other locations (including Rickmansworth where no previous analyses have been carried out).
- Explore the contribution of the Vale Brook to sediment load in the River Chess.

6.11 Organic contaminants

Organic chemicals are used in all aspects of our society and are found throughout our global environment. In this instance the term ‘organic’ is used to describe a chemical with a molecular skeleton containing carbon and hydrogen atoms, with carbon atoms bound to one another with covalent bonds. Example uses of organic chemicals include in personal care products, pharmaceuticals, domestic cleaning products, pesticides used in agriculture and our urban environment, in industrial process such as dry cleaning, and in flame retardants. The chemical group are often referred to as organic ‘contaminants’ rather than pollutants because they are present and detectable in water, but they may not cause harm to human health or wildlife at the observed concentrations.

‘Priority substances’ are chemicals (inorganic and organic) known to cause harm in the aquatic environment when present at concentrations above the Environmental Quality Standard threshold. Under the WFD good chemical status is achieved if the concentrations of all priority substances are below their Environmental Quality Standard thresholds. ‘Priority hazardous substances’ are a subset of priority substances considered to be extremely harmful for which the aim is to cease or phase out all emissions (Environment Agency, 2020). The River Chess currently fails chemical status due to the failure for a priority hazardous substance called PBDE; a flame retardant which is now banned but is persistent (does not degrade readily) in the aquatic environment. All other priority and priority hazardous substances are at concentrations below their EQS threshold.

‘Specific pollutants’ are pollutants released in significant quantities to UK waters. If the concentrations of these substances exceed their EQS then the water body does not achieve good ecological (rather than chemical) status. In 2013 and 2014 aa specific pollutant called triclosan was found at concentrations indicative of moderate status in the River Chess, but since this time monitoring has not found elevated concentrations. Triclosan is an anti-bacterial chemical used in personal care products.

There are c. 150,000 chemicals in everyday use in society, and new chemicals are developed for our use. We do not yet fully understand the risks to aquatic organisms from long-term exposure to mixtures of these chemicals, and to some chemicals currently in use. Under the WFD there is a watch list of chemicals that should be monitored to determine the risk they pose to the aquatic environment. The list is reviewed every two years and enables scientists and regulators to better assess risks from chemicals found in surface waters. The Environment Agency also collaborate with European organisations to keep track of 'chemicals of emerging concern', some of which are on the EU Watch List. These chemicals do not have formal threshold values or statutory EQS but are considered of international concern.

6.11.1 Priority organic contaminants

The River Chess fails the WFD for priority hazardous chemical substances due to the failure for poly-brominated diphenyl ethers (PBDEs) in 2019 when monitoring protocols were altered, and water-column based standards (0.0005 mg/L in freshwater) were replaced by those related to the concentration of PBDEs in fish (0.0085 mg/kg), crayfish and mussels.

It should be noted that all water bodies (freshwater, estuaries and coastal waters) in England currently fail the PBDE standard. The biota monitoring network is not large enough to measure biota from all rivers, and in many locations the data are extrapolated from one river to represent a larger geographical area. For example nationally freshwater fish biota data were collected at 79 sites for compliance assessment compared to c. 1800 sites locations for water samples. For the River Chess it is likely that samples from the larger river basin district was used to inform the PBDE classification.

PBDEs are organo-bromine chemicals which were used as flame retardants in electrical and electronic equipment, textiles and foams. This is a family of 209 different chemicals, with three available commercially; penta-, octa- and deca-BDE (Environment Agency, 2015).

Their use peaked in the UK in the early 1990s, and declined until 2004 when the production and use of penta-BDE and octa-BDE was banned in the UK; and imports have subsequently ceased. Deca-BDE is restricted for use, but still used as a flame retardant in textiles and some polymers. In March 2019 the EU implemented measures to regulate Deca-BDE to < 0.1% by weight for its use in mixtures, as a constituent of substances or articles under Annex XVII of the 'Registration, Evaluation, Authorisation of Chemicals' (REACH) regulation.

Penta-BDE and octa-BDE are classified as persistent organic pollutants under the Stockholm Convention, and designated priority hazardous substances under the amended EQS directive (EQSD, 2013/39/EU). Deca-BDE may be transformed by microbial action into octa- and penta-BDE in the river environment, and many studies have shown that water, sediment and biota samples from rivers are now dominated by Deca-BDE.

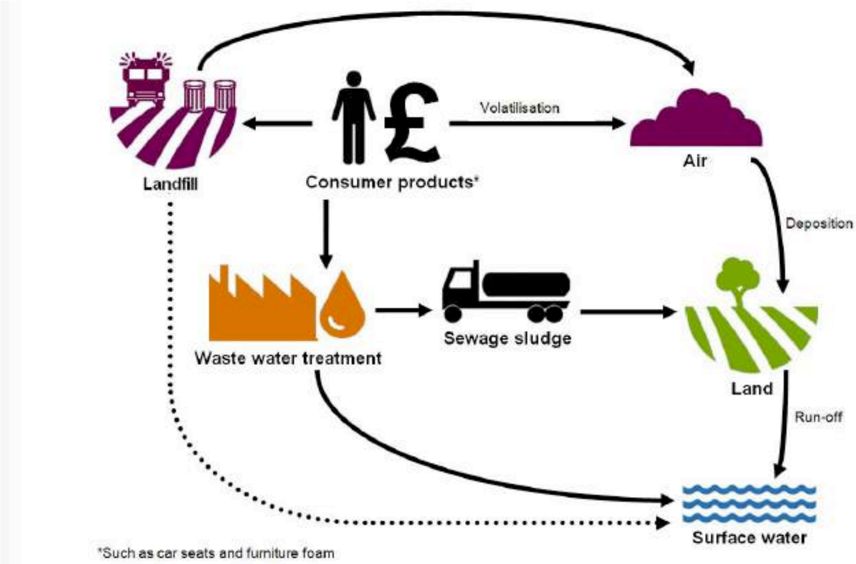


Figure 79 Sources and pathways of PBDEs into the environment. SOURCE: Environment Agency, 2015.

Domestic wastewaters are the critical source of PBDEs to rivers, and whilst removal of these substances during sewage treatment is good (estimated at 85% removal) due to sorption to sewage sludge, there are low level concentrations of PBDEs in treated effluent from WWTW, and loadings can be significant due to large effluent volumes. This is thought to be the main route by which PBDEs enter rivers and arises from the leaching of these chemicals from household products (*Figure 79*). When storm tanks / combined sewer overflows are operating then the load and concentration of PBDE reaching rivers is likely to increase.

Threat

- PBDEs are toxic, bioaccumulative and persistent chemicals that are being detected nationally in fish at levels exceeding the Environmental Quality Standards (Annual Average) for biota. WWTW are the main route by which these compounds reach freshwaters, and loadings can be significant when treated effluent comprises a high proportion of flow in the river.

Opportunity

- It is unlikely that any fish samples from the River Chess were used directly for the classification for the reasons explained above. The Chess SWC could fund bespoke monitoring of fish in the River Chess to explore the scale of the issue. If this route is explored, then fish populations immediately downstream of Chesham WWTW in the main Chess should be targeted and could be compared to concentrations in fish from the Little Chess.

6.11.2 Emerging organic contaminants

In March 2020 32 grab samples were collected from six locations on the River Chess as shown on *Figure 80*. The purpose of the sampling was to determine (i) whether concentrations of organic contaminants were higher downstream of Chesham WWTW compared to upstream to provide a preliminary understanding of potential sources of organic contaminants to the River Chess; and to determine (ii) whether concentrations of organic contaminants were elevated when storm tanks at Chesham WWTW were operating.

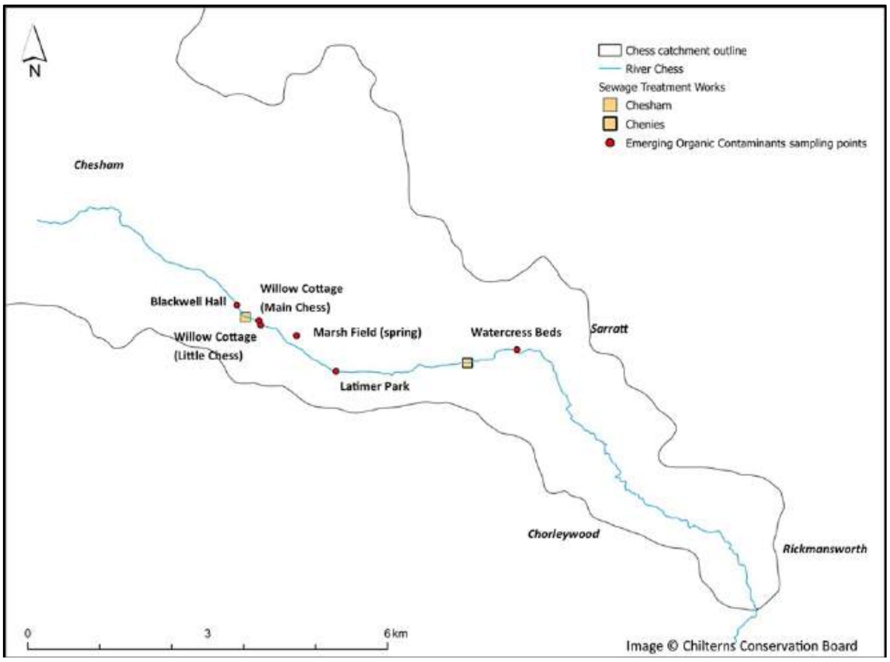


Figure 80 Sampling sites for organic contaminants on 4th and 10th March 2020.

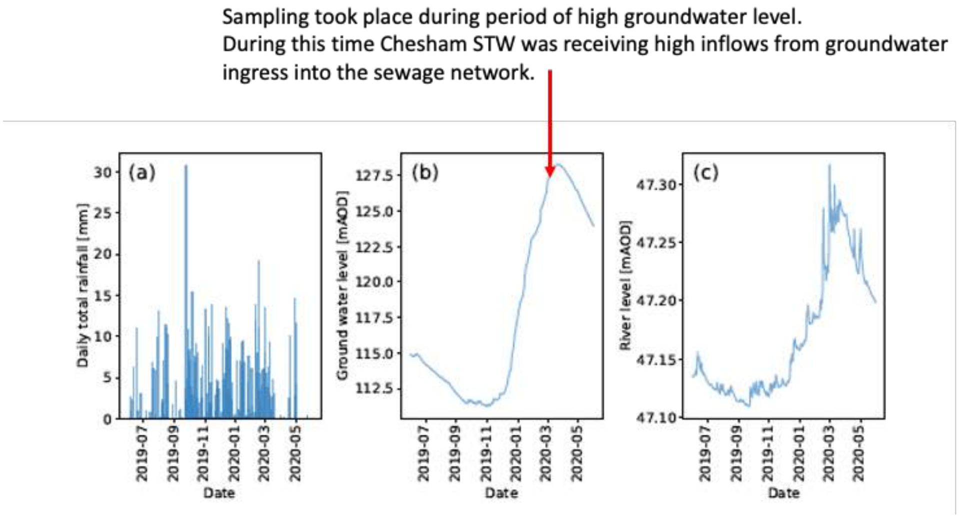


Figure 81 Groundwater conditions during sampling for emerging contaminants.

This was a period during which groundwater levels were high and there was groundwater ingress into the sewer network upstream of Chesham WWTW causing regular storm tank discharges (*Figure 81*). The first set of water samples were taken before and after a 3.8 mm rainfall event on 4th March. The second set of water samples were taken on 10th March (following a 12 mm rainfall event on 9th March) during which time Thames Water sent a text alert to local stakeholders advising of a storm tank discharge from Chesham WWTW. The intention was to continue sampling during Spring 2020 as groundwater flows receded, but Covid-19 restrictions prevented further sample collection.

Grab samples were filtered on site using 0.45 mm cellulose acetate filter papers, frozen at –20°C within two hours of sampling and returned to the laboratories at Imperial College for analysis by direct injection liquid chromatography-tandem mass spectrometry. Chemical risk quotients were calculated by dividing river water concentration by predicted no effect concentrations (PNECs) obtained from the NORMAN ecotoxicology database. In total 35 different organic contaminants were identified, the vast majority with zero or low risk quotients. Four chemicals, however, were identified with medium risk quotients: fenuron, carbamazepine, diclofenac and venlafaxine (*Figure 82*).

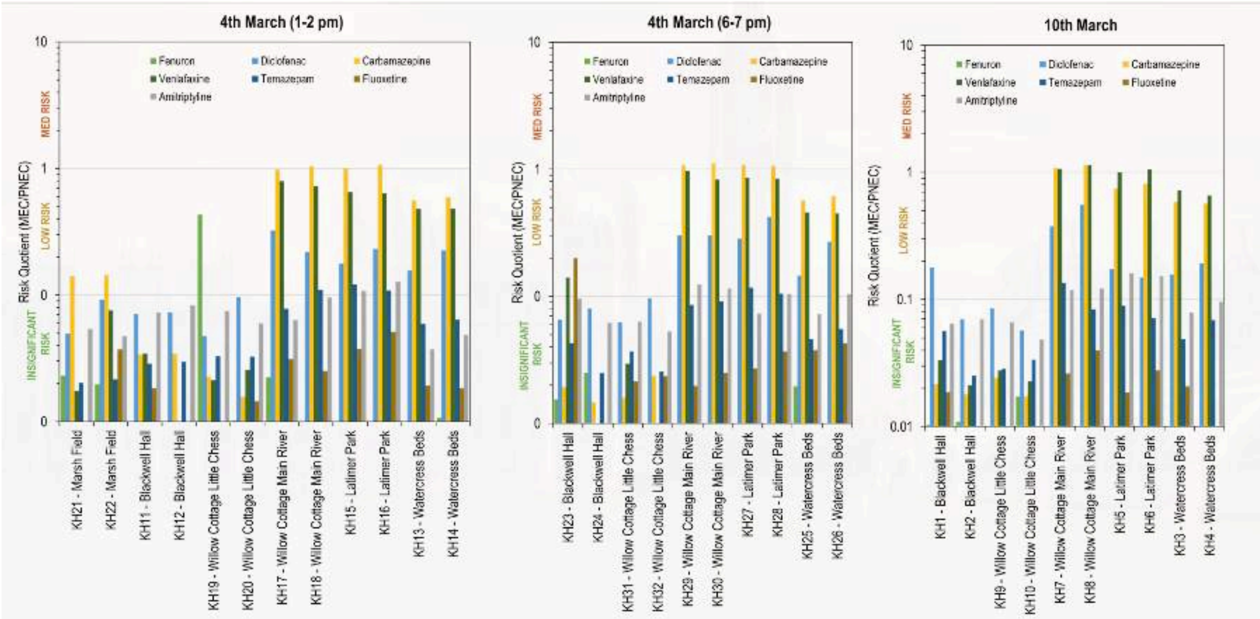


Figure 82 Risk quotients for emerging organic chemicals found in River Chess on 4th and 10th March (SOURCE: Leon Barron, Imperial College).

Fenuron is a phenylurea herbicide no longer approved for use in the UK. This herbicide was used for the control of annual broad-leaved weeds and woody plants in agriculture and amenity settings (i.e. the control of weeds in crops and on hard surfaces in urban areas). Example crops that this herbicide were applied to include spinach, peas and beans, sugar beet and fruit. Fenuron was reported at highest concentrations on the Little Chess, and upstream of Chesham WWTW indicating an urban and/or groundwater source in the Chesham area.

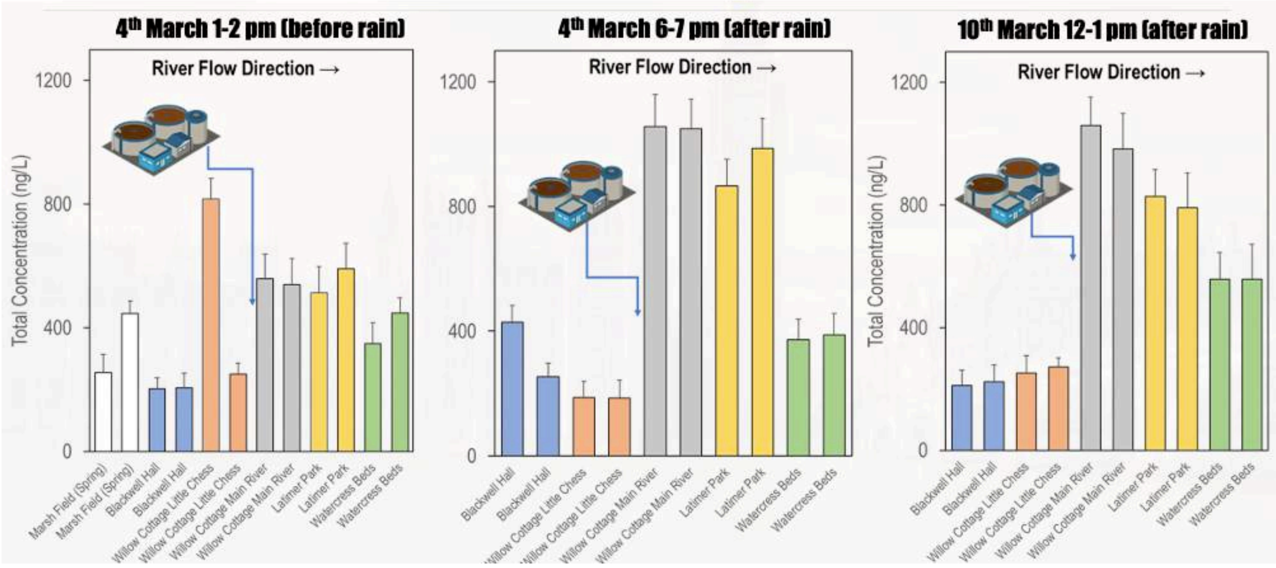


Figure 83 Total measured concentrations of pharmaceuticals, agrochemicals and illicit drug residues detected in all river water grab samples (SOURCE: Leon Barron, Imperial College).

Carbamazepine is a pharmaceutical used for the treatment of epilepsy, bipolar disorder, schizophrenia and neuropathic pain. Diclofenac is another pharmaceutical used to treat inflammation and associated pain which is found in products such as Voltarol. Venlafaxine is an anti-depressant used to treat anxiety, panic attacks and depression. Such chemicals enter the sewage network from day-to-day use in our homes and are likely to reach the River Chess via a combination of sewer misconnections and treated / untreated effluent. Concentrations of these chemicals were highest downstream of Chesham WWTW, and following storm tank discharge (*Figure 83*).

Threats

- This sampling was preliminary in nature, and results are indicative of chemical concentrations in the River Chess under very high groundwater flows prior to and during storm tank discharges from Chesham WWTW which were also affected by groundwater ingress to the sewer system.
- Samples were filtered on-site (with potential for organic contaminants to sorb to the cellulose acetate membranes) and future research should consider alternative filter membranes or grab / passive sampling without filtering.

Opportunities

- The Chess Smarter Water Catchments Action plan outlines R&D to investigate emerging organic contaminants in Years 3 and 4 of the programme. This action should be brought forward to Years 2 and 3 to ensure that findings can feed into proposed solutions for the River Chess where appropriate.
- Brainstorm purpose and nature of sampling with Citizen Scientists (CS) and stakeholders to co-create sampling strategy of interest to the community.
- Use of passive samplers (can be deployed for one week at a time) with CS to explore sources of different groups of emerging organic contaminants to the River Chess.
- Explore use of composite water samplers for water sampling at selected sites such as Bois Mill where both Little Chess and main Chess can be sampled together.

- Sampling of artesian boreholes and springs to determine concentrations of emerging organic contaminants in groundwater contributing to flows in the River Chess.
- Sampling the full length of the River Chess to explore potential sources of emerging organic contaminants downstream of Sarratt.
- Collection of biota to determine which organic contaminants are bio-concentrating and moving through the food chain of the River Chess.
- Investigation of Vale Brook to explore contribution of this culverted winterbourne to emerging organic contaminants in the River Chess.

6.12 Plastics

Understanding the sources and fate of macro- and micro-plastics in rivers is a growing area of research activity due to observations of the large quantity of plastics deposited in riverbed sediment, and the concerns that plastics can negatively impact aquatic ecosystems and human health (Horton et al., 2017). Plastic debris can injure or kill wildlife through physical mechanisms such as entanglement. Micro-plastics (< 5 mm) may cause harm to the aquatic life that ingests them, and there is increasing evidence that micro-plastics can act as vectors for other contaminants that sorb to the plastic surfaces. High quantities of plastic in riverbeds are associated with urbanised areas and can enter a river system via wastewater treatment works, storm tank discharges and via road runoff which contains plastics from the wear and tear of vehicles (Woodward et al., 2021). However, monitoring activities by regulatory agencies and water companies do not currently include plastics.

Threat: The extent of plastic pollution in the River Chess is unknown but the headwaters are under pressure from the human activities associated with high plastic loading (urban runoff, wastewater treatment and storm tank discharges).

Opportunity: There are many universities carrying out research on plastics in rivers at the current time. Collaboration with a university research team may offer the opportunity to carry out a baseline analysis of plastics in the River Chess, identify the relative importance of different plastic sources and assess potential impact on the river ecosystem.

7 Critical threats and opportunities to improve water quality in the River Chess

Table 11 summarises the recommendations for next steps to improve water quality in the River Chess. Some activities are already being undertaken under AMP7, so in this instance the report recommends potential actions that might be explored for AMP8.

7.1 Unresolved water company-related pressures

Environment Agency monitoring shows that Chesham WWTW is the critical control on total ammonia, nitrate and orthophosphate concentrations in the River Chess, currently contributing 96% of reactive phosphorus to the river. ChessWatch data indicates that the WWTW controls daily cycles of electrical conductivity which track patterns of treated effluent discharge. Whilst dissolved oxygen concentrations in the river are generally high, they are lowest immediately downstream of Chesham WWTW.

Storm tank discharges from this WWTW occur in response to intense rainfall and/or to high groundwater levels when groundwater ingresses the sewage network in Chesham. These discharges of untreated effluent occurred for a total of 83.8 days from 15th April 2020 to 6th July 2021 (Thames Water EDM data) when groundwater levels in the catchment were high, and led to extended periods of low dissolved oxygen concentration in upstream reaches of the river. These periods of untreated effluent discharge will also contribute additional ammonia, nitrate, phosphate, bacteria and viruses, organic contaminants and plastics to the river system; the extent of which is largely unknown as there is no monitoring of storm tank water quality or statutory river water sampling during these episodes. Sampling by local volunteers during one event show elevated phosphate concentrations, and Environment Agency monitoring from April to July 2021 indicated elevated ammonium concentrations during a storm tank discharge event arising from high groundwater levels. The volume and nature of the untreated sewage discharges means that, during periods of high groundwater, these storm tank discharges are likely to constitute the greatest identified threat to ecosystem health in the River Chess.

Preventing future storm tank discharges and reducing inputs of nutrients to the river from Chesham WWTW are fundamental issues to address in order to improve river health. Under AMP7 (the funded 5-year period of the Chess SWC) Thames Water are undertaking the following actions:

- Reducing total phosphorus concentration in treated effluent from 2 mg/L to a maximum of 0.25 mg/L to help the River Chess achieve 'moderate' phosphorus status
- Increasing treatment capacity at Chesham WWTW from 240 L/s to 335 L/s to meet the new AMP7 WINEP 2023 'flow to full treatment' permit based on population growth predicted for 2026

Thames Water are also piloting a 'Green Recovery' project in Chesham in order to reduce storm tank discharges into the River Chess; this will provide supporting evidence for expanding the approach for inclusion as part of investment in PR24 for delivery in AMP8 onwards. The Green Recovery project includes the following measures:

- Lining the sewer network in Chesham to reduce or eliminate groundwater infiltration
- Replacing and sealing manhole covers to reduce or eliminate surface water inundation into the sewer network
- Finding and correcting surface water to foul misconnections.

These measures will go some way to improving the water quality of the River Chess, but they will not enable the Chess to achieve 'good' phosphorus status, in order to prevent eutrophication. Neither will these measures reduce the elevated nitrate concentrations that arise from treated effluent; nitrate concentrations in the River Chess rose markedly in 1985 in response to changes in sewage treatment at Chesham WWTW. The River Chess is a headwater catchment which contributes freshwater to the Colne and the Thames; as such the downstream export of sewage-derived chemicals (such as nitrate, and contaminants of emerging concern including plastics) should be considered as part of holistic catchment management.

7.2 Unresolved pressures arising from agricultural activity and road runoff

Data on suspended sediment concentration in the River Chess is sparse. Turbidity data from the ChessWatch sensors indicate that pulses of fine sediment enter and move through the river during intense rainfall and storm tank discharge events. Observations by local stakeholders indicate that this sediment may be sourced from a combination of agricultural activities, erosion from road verges and urban runoff, but the relative importance of each source is unknown. Observations of sediment transport to the river are focused around the upper catchment and theoretical risk mapping shows elevated relative risk in these same areas where steep slopes and arable agricultural activities combine. Field observations suggest that footpath and road network provide connectivity between sediment sources and inputs to the river at critical locations. Fine sediment that enters the river accumulates upstream of infrastructure such as weirs and old mill leats and ponds.

The Vale Brook in Chesham is a notable source of sediment to the river system and should be a focus of future mitigation activity, however in general the locations, magnitude and sources of sediment to the Chess are not fully understood. Potential risk mapping should be ground-truthed, and mitigation activities explored in partnership with local stakeholders so that sources and pathways of sediment transport to the river can be identified and prevented.

Further downstream, around the Rickmansworth area, the threats to water quality in the River Chess are less clear. Environment Agency monitoring suggests a slight increase in nitrate and phosphate concentrations in the river between Valley Farm Road and Solesbridge Lane which warrants further investigation. There has been no continuous, real-time monitoring in these downstream reaches so the influence of rainfall events on water quality (e.g. via road runoff) is not known and should be explored.

7.3 Population and climate change

Population growth in the catchment, and climate change will both impact water quality of the River Chess in the future. Population growth will lead to a need for increased treatment capacity at Chesham WWTW, and there will be an increase in flow and chemical load (such as nutrients) in influent and treated effluent at the works. An increased proportion of treated wastewater compared to groundwater in the river downstream of Chesham WWTW will have a negative effect on river water quality (e.g. elevated concentrations of nitrate/phosphate/down-the-drain chemicals) unless treatment is improved. The SWC initiative offers the opportunity for Thames Water to work in partnership with local communities on AMP8 plans to shape future wastewater treatment scenarios, and clarify decision-making in order to ensure a resilient water infrastructure for the future.

Two meteorological aspects of climate change may threaten future water quality in the River Chess:

- Increased frequency of high intensity rainfall events
- Elevated air temperatures leading to reduced groundwater recharge and increased water temperatures.

High intensity rainfall has the energy to detach soil particles, causing soil erosion and transport of sediment to the river, if pathways such as the road network allow. For this reason, fine sediment transport may become more marked with climate change. This adds impetus to the need to design and implement mitigation measures (such as sustainable urban drainage systems and improved land management practices) to minimise soil erosion, surface runoff and sediment transport in the Chess catchment.

Water temperature monitoring has revealed that, in some locations, river water temperatures are already exceeding 20^{o}C during hot summers when baseflow is low. These temperatures are problematic for river ecosystem health, therefore, it is recommended that a survey of river water temperatures is carried out during the summer to identify areas most at risk. In this way opportunities to provide shading through riparian planting can be fully assessed.

Reduced groundwater recharge may lead to lower baseflows in goundwater-fed rivers, and consequently reduced flow to dilute treated effluent. Consequently, concentrations of wastewater-derived chemicals may increase in those chalk streams receiving high proportions of treated effluent, such as the River Chess. Future infrastructure planning needs to take these climate-induced changes in water quality into account.

Table 11 Summary of Recommendations for Next Steps by Issue and Location

Issue	Evidence base	Location	Proposed methodology / recommendations
Wastewater			
Chesham WWTW treated effluent: *phosphate, nitrate, PBDE and emerging chemicals*	Environment Agency Harmonised Monitoring Dataset, WFD Classification, CS activities	Downstream of Chesham WWTW	Under AMP7 phosphate will be reduced to attain moderate status. Explore further reductions to phosphate and inclusion of nitrate for AMP8. Explore role of Chesham WWTW in PBDE failure for River Chess.
Chesham WWTW storm tank overflow: *dissolved oxygen with potential for faecal contamination and other chemicals*	CS monitoring (dissolved oxygen and emerging chemicals monitoring, riverfly), CS activities	Downstream of Chesham WWTW	Under AMP7 treatment capacity at Chesham WWTW will be increased by 39%. Explore how frequently STOs will occur after AMP7 modifications, quantify their associated pollutant loading with different scenarios of changing rainfall pattern and population growth.
Sewer mis-connections: *faecal contamination, low dissolved oxygen levels, high ammonium, phosphate*	EA real-time monitoring (ammonium), CS activities (electrical conductivity during high rainfall)	Chesham and Rickmansworth urban areas	Thames Water investigation combined with expanded Outfall Safari; real-time monitoring of ortho-phosphate around Chesham to identify any storm-driven flushes of P
Sediment transport to river			
Inputs of sediment through road runoff*: suspended sediment, bed sediment and associated contamination by metals and hydrocarbons*	Local stakeholder and CCSP / RCA observations. MSc dissertations.	Blackwell Hall Lane Bell Lane Plus areas mapped by Jacobs options report using local knowledge.	Trial investigation by volunteers using MudSpotter with data from SCIMAP to identify all sediment inputs. Link to urban runoff mitigation optioneering commissioned by Buckinghamshire Council.
Soil erosion from agricultural fields and transport to river*: suspended sediment and nutrient (N,P) load*	Local stakeholder and CCSP /RCA observations.	Areas of high risk mapped using SCIMAP and included in Section 6.9.3. Also included in Jacobs options report.	Risk maps ground-truthed by Chess Valley Farming Officer to identify mitigation options. Assess relative magnitude of sediment entering river as a result of agricultural activity.
Nutrients – unknown origin			
Elevated nitrate and phosphate downstream of Valley Farm Road	Environment Agency Harmonised Monitoring Dataset	Between EA5 (Valley Farm Road) and EA6 (Solesbridge Lane)	Water sampling campaign to assess spatial variations in phosphate and nitrate within the reach (focusing on potential locations of septic tanks)

Additional recommendations arising from gap analysis

Issue	Evidence base	Location	Proposed methodology / recommendations
An indication of elevated water temperatures (>20^{o}C) during heatwaves exceeding tolerances for fish	ChessWatch sensors	Sarratt	Temperature survey during summer to assess critical locations in the Chess
Extent of sedimentation in the river, and threats to wildlife	Very limited survey data from Modular River Survey in 2020	Along entire river	Modular River Survey in conjunction with sediment-specific invertebrate matrix such as used in SmartRiver to assess extent of threat
There is little data on the influence of rainfall events on water quality in the downstream reaches of the River Chess below Sarratt Watercress beds.	Environment Agency Harmonised Monitoring Dataset	Between EA5 (Valley Farm Road) and EA8 (Chess above Colne)	Real-time monitoring (turbidity, dissolved oxygen, pH) downstream of locations at which M25 and A412 crosses the River Chess.
There is sparse data on risks from EU Watch List and chemicals of emerging concern.	CS monitoring	-	Action R&D into chemicals of emerging concern to help determine risks quotients and associated critical catchment activities.
There is no data on plastics in the River Chess and any impacts.	-	-	Consider R&D into extent of plastics pollution and mitigation measures at Chesham WWTW.

References

Allen DJ, Brewerton LJ, Coleby LM, Gibbs BR, Lewis MA, MacDonald AM, Wagstaff SJ & Williams AT (1997) The physical properties of major aquifers in England and Wales. British Geological Survey Technical Report WD/97/34, 312pp, Environment Agency R&D Publication 8.

Ascott MJ, Gooddy DC, Fenton O, Vero S, Ward RS, Basu N, Worrall F, Van Meter K & Surridge BWJ (2021) The need to integrate legacy nitrogen storage dynamics and time lags into policy and practice. https://doi.org/10.1016/j.scitotenv.2021.146698

Barker JA (1993) Modelling of flow and transport in the chalk. In: RA Downing, M Price & GP Jones (eds) The Hydrogeology of the Chalk of North-West Europe, Clarendon Press, Oxford. pp 35-38.

Basic T, Britton JR, Cove RJ, Ibbotson AT, Gregory SD (2018) Roles of discharge and temperature in recruitment of a cold-water fish, the European grayling *Thymallus thymallus*, near its southern range limit. https://doi.org/10.1111/eff.12405

Bloomfield J (1996) Characterisation of hydrogeologically significant fracture distributions in the Chalk: an example from the Upper Chalk of southern England. Journal of Hydrology 184, 355-379.

Bloomfield JP, Marchant BP & McKenzie AA (2019) Changes in groundwater drought associated with anthropogenic warming. https://doi.org/10.5194/hess-23-1393-2019

Caissie (2006) The thermal regime of rivers: a review. Freshwater Biology, 51(8), 1389-1406.

Rangeley-Wilson C (2021) Catchment Based Approach Chalk Stream Restoration Strategy Main Report.

Chilterns Conservation Board (2014) Chilterns Area of Outstanding Natural Beauty Management Plan, 2014-2019.

CROME (2019) Crop Map of England, Rural Payment Agency https://data.catchmentbasedapproach.org/datasets/theriverstrust::crop-map-of-england-2019-rpa/about

Environment Agency (2021) Draft water industry national environment programme (WINEP) methodology. https://consult.environment-agency.gov.uk/environment-and-business/review-of-the-winep/user_uploads/draft-water-industry-national-environment-programme-methodology.pdf, Accessed 2 Feb 2022.

Environment Agency & Natural England (2021) State of the water environmental indicator B3: supporting evidence. https://www.gov.uk/government/publications/state-of-the-water-environment-indicator-b3-supporting-evidence

River Chess SWC Baseline assessment of water quality

Environment Agency (2020) Statutory Assessment and Reporting Guide to WFD chemicals classification in surface waters.

Environment Agency (2019a) Chemicals in the Water Environment Challenge, River Basin Management Plans 2021.

Environment Agency (2019b) Phosphorus and Freshwater Eutrophication Pressure Narrative, River Basin Management Plans 2021.

Environment Agency (2019c) Nitrate Pressure Narrative, River Basin Management Plans 2021.

Environment Agency (2019d) Fine Sediment Pressure Narrative, River Basin Management Plans 2021.

Environment Agency (2015) Polybrominated diphenyl ethers (PBDEs); background data and predicted future emissions.

Environment Agency (2014) Thames River Basin District Water Framework Directive Investigation.

Gooddy DC, Ascott MJ, Lapworth DJ, Ward RS, Jarvie HP, Bowes MJ, Tipping E, Dils R & Surridge BWJ (2017) Mains water leakage: Implications for phosphorus source apportionment and policy responses in catchments. https://doi.org/10.1016/j.scitotenv.2016.11.038

Horton AA & Dixon SJ (2017) Microplastics: An introduction to environmental transport processes. https://doi.org/10.1002/wat2.1268

Jarvie HP, Smith DR, Norton LR, Edwards FK, Bowes MJ, King SM, Scarlett P, Davies S, Dils R & Bachiller-Jareno N (2018) Phosphorus and nitrogen limitation and impairment of headwater streams relative to rivers in Great Britain: A national perspective on eutrophication. https://doi.org/10.1016/j.scitotenv.2017.11.128

May L, Place C, O'Malley M & Spears B (2015) The impact of phosphorus inputs from small discharges on designated freshwater sites. Natural England Commissioned Reports, Number 170.

Price M, Downing R & Edmunds W (1993) The chalk as an aquifer. In: RA Downing, M Price & GP Jones (eds) The Hydrogeology of the Chalk of North-West Europe, Clarendon Press, Oxford. pp 35-58.

Reaney SM, Mackay EB, Haygarth PM, Fisher M, Molineux A, Potts MC & Benskin McWH (2019) Identifying critical source areas using multiple methods for effective diffuse pollution mitigation. https://doi.org/10.1016/j.jenvman.2019.109366

Rust W, Holman I, Bloomfield J, Cuthbert M & Corstanje R (2019) Understanding the potential of climate teleconnections to project future groundwater drought. https://doi.org/10.5194/hess-23-3233-2019

UK CEH (2021) https://nrfa.ceh.ac.uk/data/station/spatial/39088 Accessed 22 Oct 2021.

Wharton G, Mohajeri SH & Righetti M (2017) The pernicious problem of streambed colmation: a multi-disciplinary reflection on the mechanisms, causes, impacts and management challenges. WIRES Water 4:e1231. doi:10.1002/wat2.1231.

Woodward J, Li J, Rothwell J & Hurley R (2021) Acute riverine microplastic contamination due to avoidable releases of untreated wastewater. https://www.nature.com/articles/s41893-021-00718-2