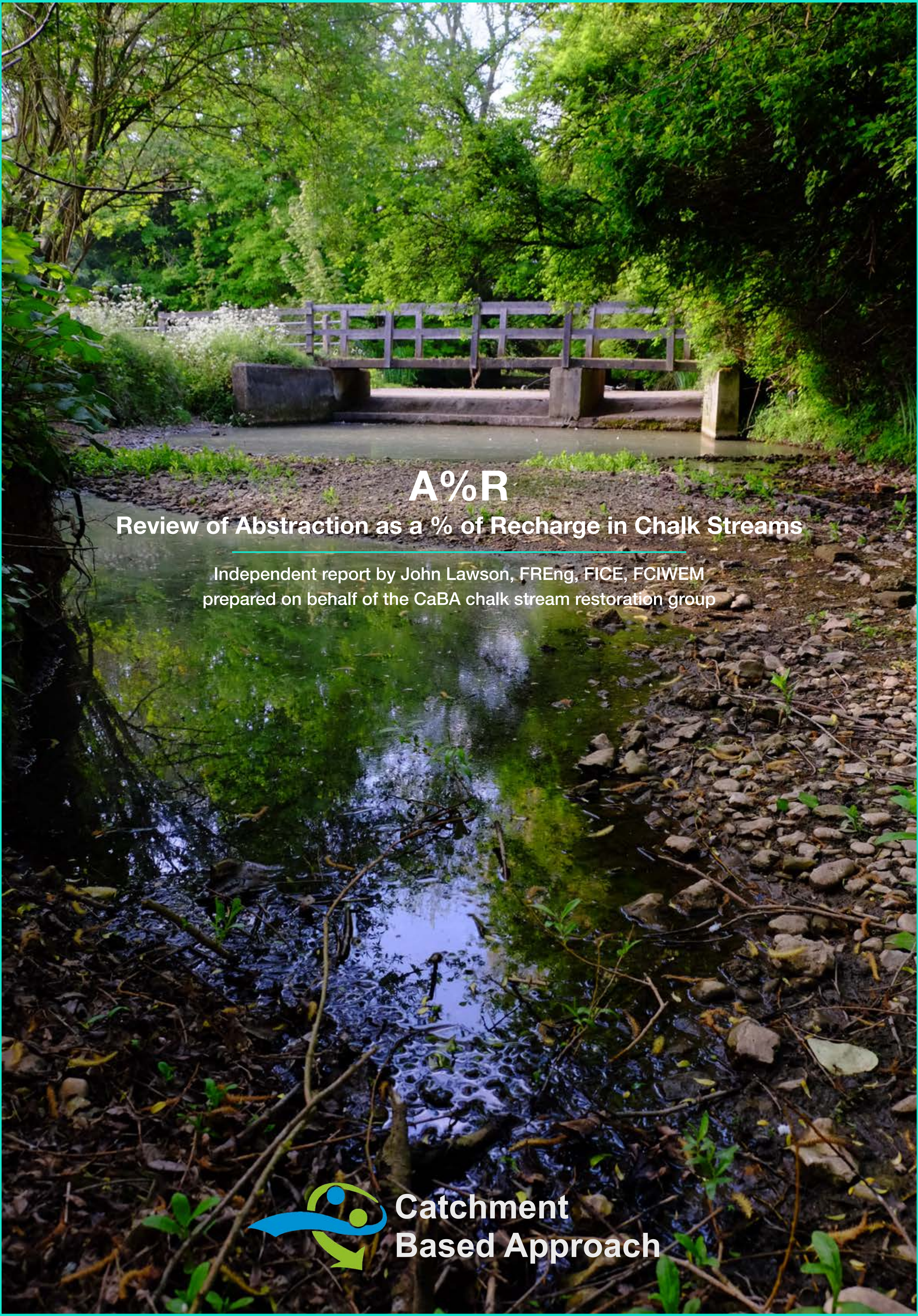

A%R

Review of Abstraction as a % of Recharge in Chalk Streams

Independent report by John Lawson, FREng, FICE, FCIWEM
prepared on behalf of the CaBA chalk stream restoration group

Catchment
Based Approach

A%R

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Commissioned February 2021
First draft September 2021
Revised following Defra / EA feedback December 2021*

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*The author would like to thank the Environment Agency and Defra for their valuable assistance in preparing this report, which nevertheless remains the independent work of the author prepared on behalf of the CaBA chalk stream restoration group

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Cover image: a dry River Beane at Walkern in May 2017 © Charles Rangeley-Wilson

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*** Qube acknowledgement: all calculations of recharge shown in the above figures and tables, and elsewhere in this report, use effective rainfall provided by Qube using Qube methodology and data, Wallingford HydroSolutions Ltd, 2021.**

Summary

Background

River flows in chalk streams come mainly from groundwater, discharging through springs into river beds, river banks and valley sides. A chalk stream's flow rate is largely dependent on groundwater levels in the chalk aquifer. Groundwater levels go up and down depending on the relationship between recharge and discharge. When recharge exceeds discharge, groundwater levels rise and vice versa.

Generally speaking groundwater levels rise during the winter and early spring when most rainfall sinks into the ground and reaches the water table. This type of rainfall is called 'effective rain' and largely determines the recharge of the aquifer. Groundwater levels generally fall during the summer and autumn, when evapotranspiration accounts for most of the rainfall and so greatly reduces effective rain, while the aquifer continues to discharge into the river and via underground flow, known as aquifer through-flow.

Another significant form of discharge from chalk aquifers is groundwater abstraction for water supplies. Since discharge forms a net loss to groundwater levels it follows that if a large proportion of the aquifer recharge is abstracted for water supplies, groundwater levels will be lowered more than they would otherwise be, and consequently chalk stream flows are reduced relative to their natural state.

Abstraction as a percentage of groundwater aquifer recharge, abbreviated to A%R, has been proposed as an easily derived and comprehensible way to assess the relative amounts of chalk groundwater abstraction in different catchments and chalk regions and its likely impacts on flows.

At present, the Environment Agency (EA) assesses chalk abstraction acceptability using Environmental Flow Indicators (EFIs). Compliance with EFIs is measured using regional groundwater models and then requires further modelling to determine the abstraction reductions needed to comply with the EFIs. However, the results of this complex process are only made available to the public as either 'does' or 'does not support good ecological status'.

The A%R method has the potential to be a more accessible and readily understandable measure of abstraction acceptability that can inform the debate between stakeholders, regulators and industry on abstraction sustainability and reductions.

This report has been commissioned by Defra and the CaBA chalk stream restoration group as part of the work contributing to a national strategy for improving chalk streams. The objectives are:

1. To help understand the scale of over-abstraction of chalk aquifers and chalk streams in southern and eastern England.

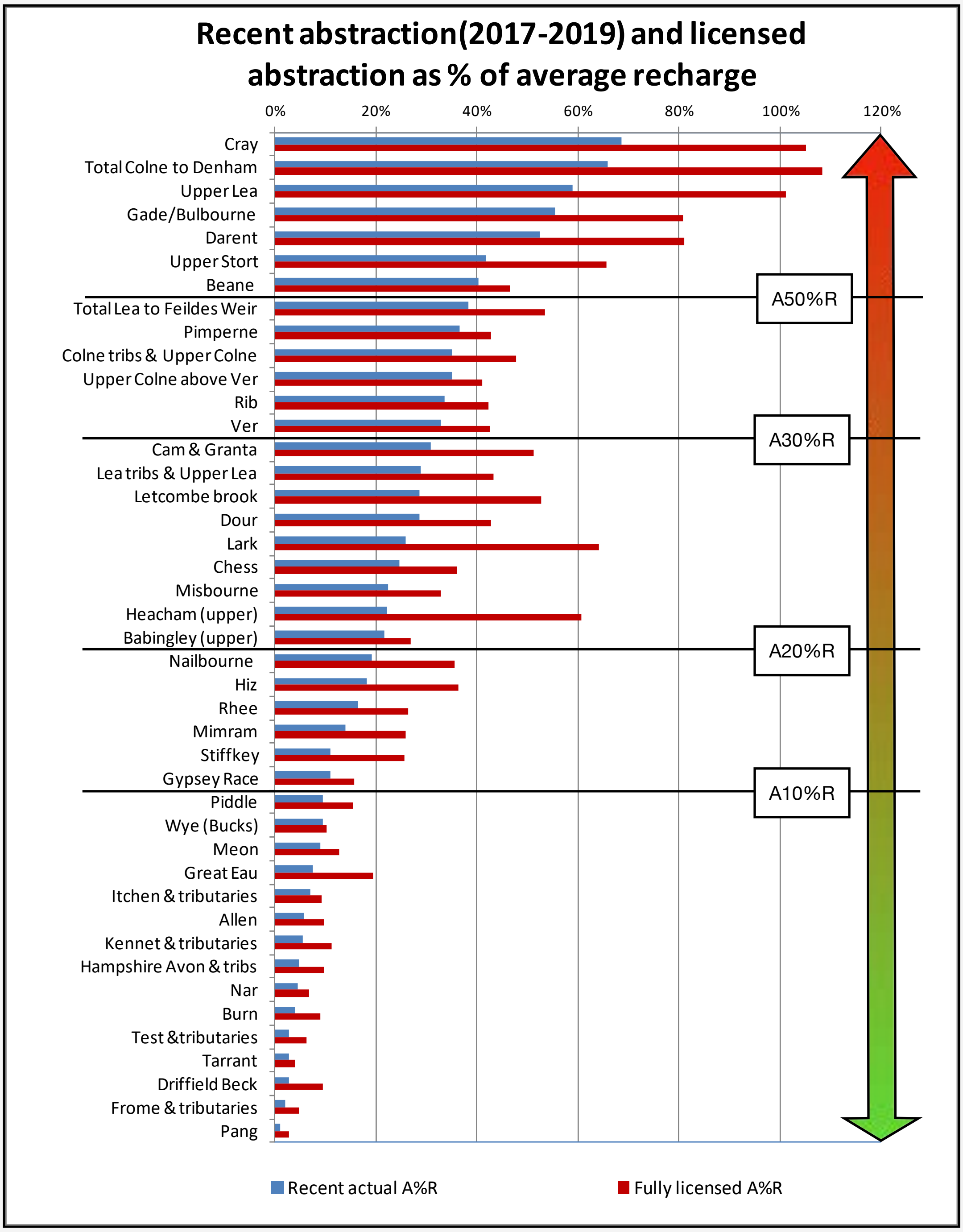
2. To investigate "abstraction as a % of aquifer recharge" (A%R) as a simple and accessible method for determining acceptable levels of abstraction in chalk catchments and prioritising action, not as an alternative to use of environmental flow indicators (EFI), but as a means of independent evaluation.

A%R is defined as the average annual abstraction in a chalk river valley divided by the average annual recharge in the valley, expressed as a percentage. The average annual recharge is the depth of average annual effective rain, ie. rain percolating to the aquifer, multiplied by the valley's surface catchment area. It should be noted that the groundwater divide between adjacent chalk valleys can differ from the surface topographic divide and can vary year to year and even through the year.

The analysis of A%R and associated abstraction reductions for about 55 named rivers and tributaries for this report, covering most (but not all) of the country's well known chalk streams, has entailed only a few weeks' work, including the preparation of the report. This has demonstrated the simplicity of the process in comparison with the approach using Environmental Flow Indicators.

Assessed and target values of A%R.

The assessed values of A%R for recent and licensed abstraction are shown below:

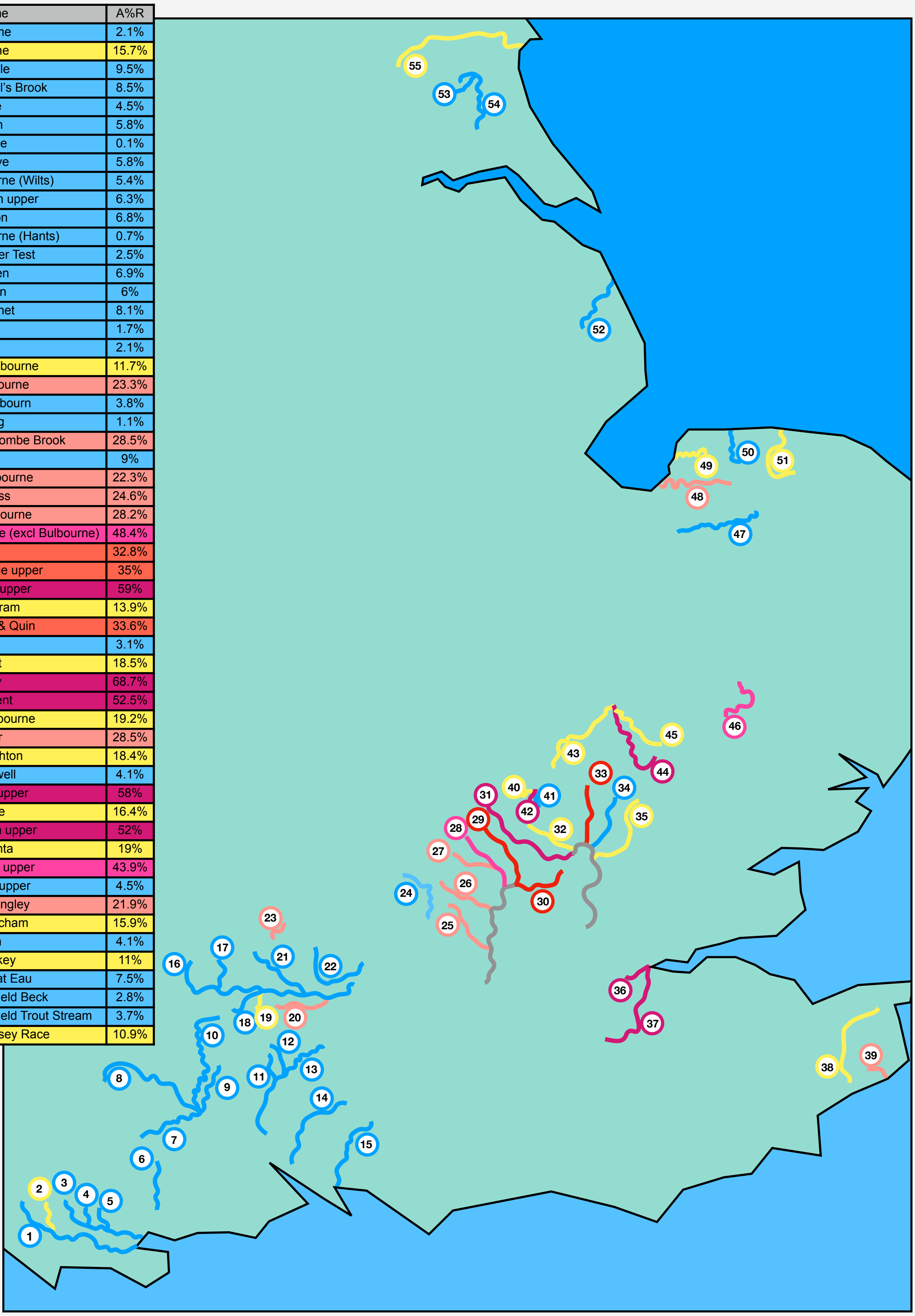


The EA's environmental flow indicator (EFI) targets for the most sensitive chalk streams (abstraction sensitivity band ASB3) allow no more than a 10% reduction at times of low river flow and 15-20% at higher flows. Independent modelling of abstraction impacts in the River Ver* suggests that these targets would be broadly achieved if groundwater abstraction is limited to 10% of average recharge. This is suggested as an initial, pragmatic target if A%R is used as an indicator of acceptable abstraction in chalk streams. Limiting abstraction to 10% of average annual recharge – ie A10%R – would be a target roughly equivalent to the Environment Agency's EFI target of 10% flow reduction at low river flows.

* Abstraction Impacts in the River Ver Catchment – Comparison of EA and CSF modelling. John Lawson. Report to EA and Defra, 11.4.2021 https://chalkstreams.org/abstraction-impacts-on-the-river-ver-catchment/

The geographic distribution of recent actual A%R values is shown on the map below:

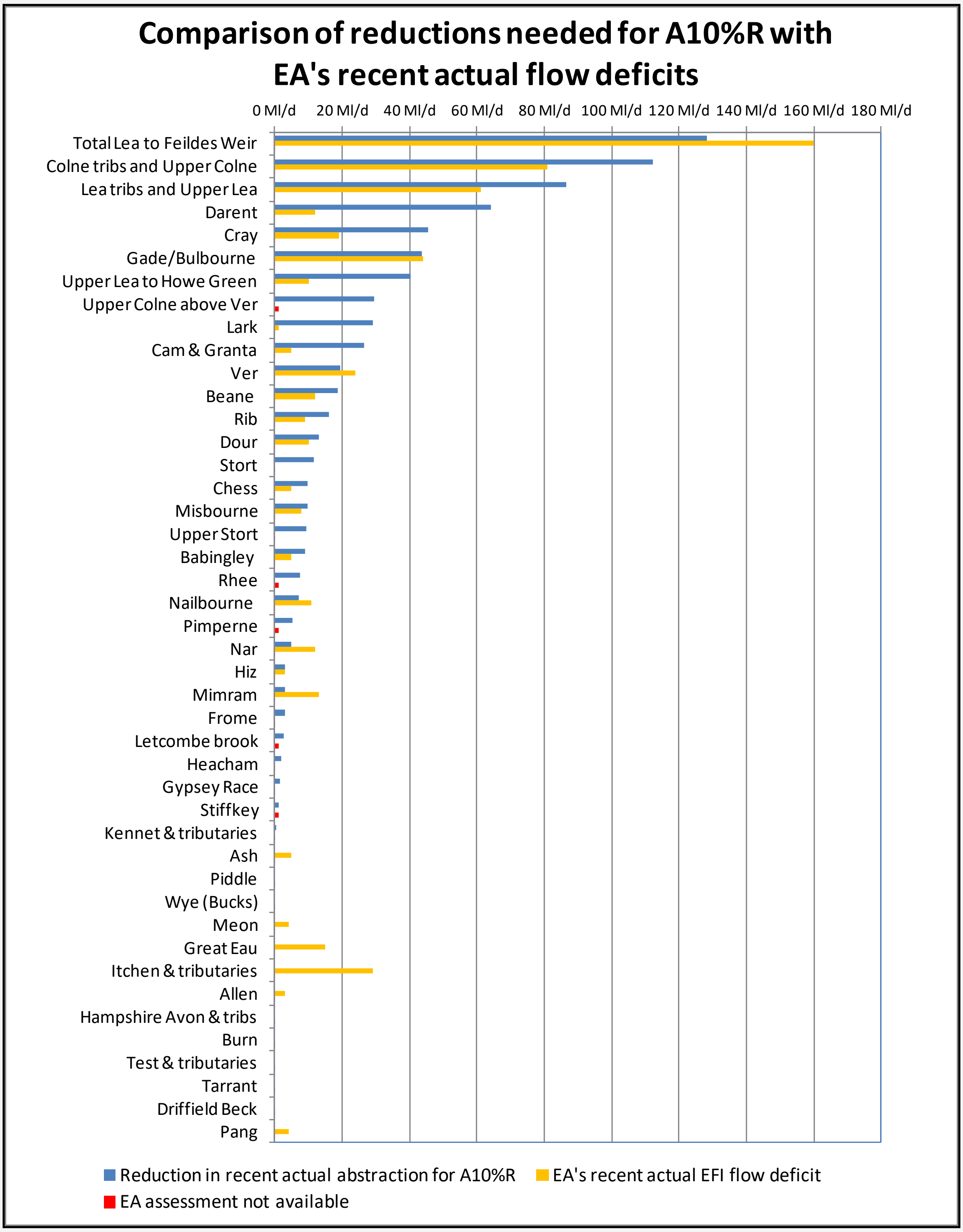
No	Name	A%R
1	Frome	2.1%
2	Cerne	15.7%
3	Piddle	9.5%
4	Devil's Brook	8.5%
5	Bere	4.5%
6	Allen	5.8%
7	Ebble	0.1%
8	Wylye	5.8%
9	Bourne (Wilts)	5.4%
10	Avon upper	6.3%
11	Anton	6.8%
12	Bourne (Hants)	0.7%
13	Upper Test	2.5%
14	Itchen	6.9%
15	Meon	6%
16	Kennet	8.1%
17	Og	1.7%
18	Dun	2.1%
19	Shalbourne	11.7%
20	Enbourne	23.3%
21	Lambourn	3.8%
22	Pang	1.1%
23	Letcombe Brook	28.5%
24	Wye	9%
25	Misbourne	22.3%
26	Chess	24.6%
27	Bulbourne	28.2%
28	Gade (excl Bulbourne)	48.4%
29	Ver	32.8%
30	Colne upper	35%
31	Lea upper	59%
32	Mimram	13.9%
33	Rib & Quin	33.6%
34	Ash	3.1%
35	Stort	18.5%
36	Cray	68.7%
37	Darent	52.5%
38	Nailbourne	19.2%
39	Dour	28.5%
40	Oughton	18.4%
41	Purwell	4.1%
42	Hiz upper	58%
43	Rhee	16.4%
44	Cam upper	52%
45	Granta	19%
46	Lark upper	43.9%
47	Nar upper	4.5%
48	Babingley	21.9%
49	Heacham	15.9%
50	Burn	4.1%
51	Stiffkey	11%
52	Great Eau	7.5%
53	Driffield Beck	2.8%
54	Driffield Trout Stream	3.7%
55	Gypsey Race	10.9%



This shows that the chalk streams with the highest A%R are mostly around the fringes of London and Cambridge. The EA's EFI assessment shows a similar picture. The 'classic' southern and Wessex chalk streams and the north-east chalk streams are generally within the band of rivers with abstraction less than 10% of recharge (A10%R).

Abstraction reductions needed to achieve A10%R

The reductions in recent abstractions needed to comply with the suggested A10%R target are shown below and compared with the EA's assessed flow deficits relative to EFIs:



It should noted that the abstraction reductions needed to achieve A10%R are not directly comparable with the EA's EFI flow deficits where the abstraction reductions needed for EFI compliance will be somewhat larger than the EFI flow deficits themselves (because there is not a direct 1:1 relationship between abstraction reduction and flow-recovery). Nevertheless, the required A10%R reductions and the

EA's flow deficits present a broadly similar picture – major deficits around London and mostly compliance elsewhere.

The A10%R and EFI deficits for the tributary chalk streams in the Colne and Lea catchments are generally very similar. However, there are some substantial differences elsewhere, usually because:

• the EFI deficits allow for sewage effluent returns and the A%R assessments do not

• the EFI deficits include surface water abstractions and the A%R assessments do not

• the EFI deficits are capped when the deficit exceeds the natural Q95 flow. However, this has only applied to the Darent and Cray catchments, where abstraction has exceeded recharge in dry years, even after some abstraction reductions.

Allowing for the sewage effluent returns when determining acceptable chalk stream flows may not truly reflect the flow status of reaches upstream of the STW discharge. Also, in droughts, the river flow may comprise largely treated sewage effluent. This applies particularly in the upper Lea, Stort, Cam and Lark.

Prioritisation of chalk stream abstraction reductions

The total of the significant reductions in abstraction needed in the assessed rivers to achieve A10%R is 410 Ml/d, excluding the lower Colne and lower Lea groundwater abstractions. If these are included, the total rises to about 610 Ml/d. However, the lower Rivers Colne and Lea are heavily modified, winding between gravel pits and sharing their courses with canals. Therefore, reducing abstraction in the lower rivers could arguably be considered a lower priority than the well publicised problems in the ecologically sensitive chalk tributaries and upper reaches.

If the abstraction reductions in the Colne and Lea catchments are prioritised to the 'classic' upper reaches and tributaries, the total reduction for the Colne and Lea would be 131 Ml/d. The chalk streams improved would form a continuous band in the Chilterns chalk from the Misbourne to the Quin, with no gaps and no possibility that reductions in one tributary could be replaced by additional abstraction in an adjacent tributary, nullifying the benefit. This would also eliminate concerns that topographic catchments assumed in calculating A%R may not align with groundwater catchments – abstraction would be reduced to 10% of recharge over the full width of the upper Colne and Lea catchments. For example, there would be no concern about whether or not the large abstraction in the upper Lea catchment at Luton affects the adjacent Rivers Ver and Mimram.

The total reduction in abstraction to achieve A10%R in the Darent/Cray catchment is 104 Ml/d. However, most of the existing abstraction is in the lower Darent and Cray catchments. In the most ecologically sensitive part of the Darent catchment, the AONB upstream of Farningham, a reduction of 28 Ml/d would achieve A10%R. The Cray catchment is heavily urbanised and could arguably be considered a lower priority than the upper Darent. However, there could be concerns that continuing high abstraction in the Cray, and in the Darent catchment downstream of Farningham, will still lower the regional water table and affect the upper Darent. If the Darent/Cray system is considered a high priority there could be a case for reduction to A10%R throughout, but this would entail the much larger abstraction reduction.

There could be similar prioritisation in the Cam and Lark catchments. The total reduction in recent abstraction to achieve A10%R in the Cam/Rhee catchment is 34 Ml/d, but only 14 Ml/d reduction is needed in the ecologically sensitive upper Cam above Audley End. The required reduction in the Lark catchment is 29 Ml/d, of which 10 Ml/d is in the 'classic' chalk stream section upstream of Bury St Edmunds.

Arguably, a prioritisation of the order with which we address abstraction deficits is needed according to their significance in terms of chalk stream ecology. Large deficits have been identified by the EA and are currently being considered in regional water resource plans. The regional planners are required to identify the water resources options that give best value to customers, society and the environment, rather than simply focusing on the lowest cost. However, cost will come into the equation, so the EA requires regional planners to ensure that the ecologically essential reaches of chalk streams benefit from the scale of abstraction reductions needed to properly facilitate their recovery (in conjunction with measures to address water quality and physical habitat).

If the reductions in all the assessed chalk streams are prioritised to the 'classic' chalk streams, typically tributaries of the larger chalk streams and their upper reaches, where abstraction exceeds 20% of recharge, top priorities could be:

High priority abstraction reductions		
Chalk stream	**Recent A%R**	**Required reduction**
Misbourne	22%	10 Ml/d
Chess	25%	10 Ml/d
Upper Bulbourne	28%	6 Ml/d
Upper Gade	48%	10 Ml/d
Ver	33%	20 Ml/d
Total Colne catchment		**55 Ml/d**
Upper Lea to Luton Hoo	92%	29 Ml/d
Beane	40%	19 Ml/d
Rib/Quin	34%	16 Ml/d
Upper Stort	42%	9 Ml/d
Total Lea catchment		**73 Ml/d**
Upper Darent	39%	26 Ml/d
Upper Cam	52%	12 Ml/d
Upper Lark	44%	8 Ml/d
Kennett/Lea Brook	20%	4 Ml/d
Upper Babingley	54%	9 Ml/d
Upper Hiz	58%	4 Ml/d
Total reduction in recent abstraction		**188 Ml/d**

Suggested priorities for reductions in recent actual abstraction

Note: the Mimram is not in this list because recent abstraction is only 14% of recharge

These reductions would cover the sensitive upper reaches of the chalk streams, so would also benefit the river reaches downstream. The list covers most of the rivers which have been the subject of long running local concerns about over-abstraction. Many of these rivers are in urbanised areas, so abstraction reduction at this scale could cause problems with high groundwater levels and local flooding.

If recent actual abstraction was increased to fully licensed amounts, A%R failures would be a lot larger and more widespread. However, boreholes are often unable to deliver licensed quantities in droughts and water companies may not be planning to make full use of their licences.

1. Introduction

1.1 Scope of work

This report has been commissioned by the CaBA chalk stream restoration group in consultation with Defra as part of the work contributing to a national strategy for improving chalk streams. The scope of work is given in Appendix A. The objectives are:

1. To help understand the scale of abstraction and over-abstraction of chalk aquifers and chalk streams in southern and eastern England.

2. To investigate "abstraction as a % of aquifer recharge" (A%R) as a simple and accessible method for determining acceptable levels of abstraction in chalk catchments and a tool for prioritising action, not as an alternative to use of environmental flow indicators (EFI), but as a means of independent evaluation.

To enable this work, the Environment Agency (EA) has supplied three sets of data and has helpfully responded to queries and requests for clarification:

• monthly abstraction data, 1999 to 2019, for all licensed abstractions in about 40 chalk catchments

• monthly effective rainfall data for the selected catchments

• the EA's own analysis of flow deficits in the selected catchments

The work was commissioned in late February 2021. The EA supplied the abstraction data in late March and the effective rainfall data in late May and June. The data for the EA's own deficit analysis was supplied in mid-July. The analysis of the data has been undertaken gradually as the data became available and has entailed about six weeks work overall, including the preparation of this report.

1.2 Use of A%R as a measure of abstraction impact

Assessing groundwater abstraction as a % of the annual recharge (A%R) of the aquifer – ie. groundwater abstraction as a % of the amount of 'effective' rainfall that sinks down into the ground to drive base-flows in the river – is a simple and easily comprehensible way to assess the level of groundwater abstraction in a given catchment.

As such A%R is a potentially useful tool for assessing and comparing the likely scale of abstraction impacts on flows, the extent and geographical distribution of groundwater abstraction pressure. It also provides a way of enabling stakeholders to contribute to and understand the process of strategising how to address those pressures over time.

Until now accessible information, such as it is, has confined stakeholder knowledge to a binary assessment of whether flows do or do not support good ecological status. The degree to which flows do not support good status is not readily available. The methodology for making the assessment, the EFI, is relatively complex, and relies on recorded flow data, including sewer discharges, combined with extensive computer modelling of groundwater levels and river flows.

A%R may not capture all the complexities of groundwater behaviour or the fact that subterranean catchments are not always or at all times the same size as surface catchments, or that aquifers can be layered, but these points notwithstanding it does give a basic idea of the level of abstraction as a % of the water balance in a given catchment or even across a set of neighbouring catchments.

Moreover, because A%R quantifies the % of the catchment water-balance taken by groundwater abstraction and is not based on flow data at a fixed assessment point, it inherently assesses the likely impact of groundwater abstraction on the whole catchment, including the ecologically valuable headwater and ephemeral reaches of chalk streams, reaches that might not be assessed by a fixed assessment point some way down the valley or downstream of a sewer discharge. A%R simply assesses the proportion of water taken by groundwater abstraction and as such it gives an indication of the likely degree of impact of that abstraction on flows.

This concept has been seen to be valid in lumped parameter models in the Ver and Kennet catchments which show that historic groundwater and river flows can be well predicted from historic records of abstraction and effective rain, assuming recharge to be simply '*effective rain x surface catchment area*'.

The only variable input data for this modelling are the daily effective rain and monthly abstraction data. The relatively simple 'lumped parameter' modelling of the catchment water-balance has produced close fits between modelled and observed GWLs and river flows.

Examples of this for the River Ver in the Chilterns are shown in Figure 1. In particular, it can be seen that the modelling showed good fits for the periods of unnatural drying of the Ver at Redbourn. The model equations calculating daily river flow are related to Kinsbourne Green groundwater levels, which are determined from the daily catchment water-balance: change in GWL is proportional to catchment inflows (ie recharge) less catchment outflows via the river and abstraction. The prediction of periods of historic river drying at Redbourn, as shown in the lower plot in Figure 1, is a lot better than the prediction of drying from the Hertfordshire Regional Groundwater Model, for example.*

The good validation of modelled historic flows in the Ver and Kennet catchments, using lumped parameter models based on catchment water balances, provides some evidence that A%R could be an effective measure for determining acceptable abstraction in chalk streams, including winterbourne stretches.

* Abstraction Impacts in the River Ver Catchment – Comparison of EA and CSF modelling. John Lawson. Report to EA and Defra, 11.4.2021 https://chalkstreams.org/abstraction-impacts-on-the-river-ver-catchment/

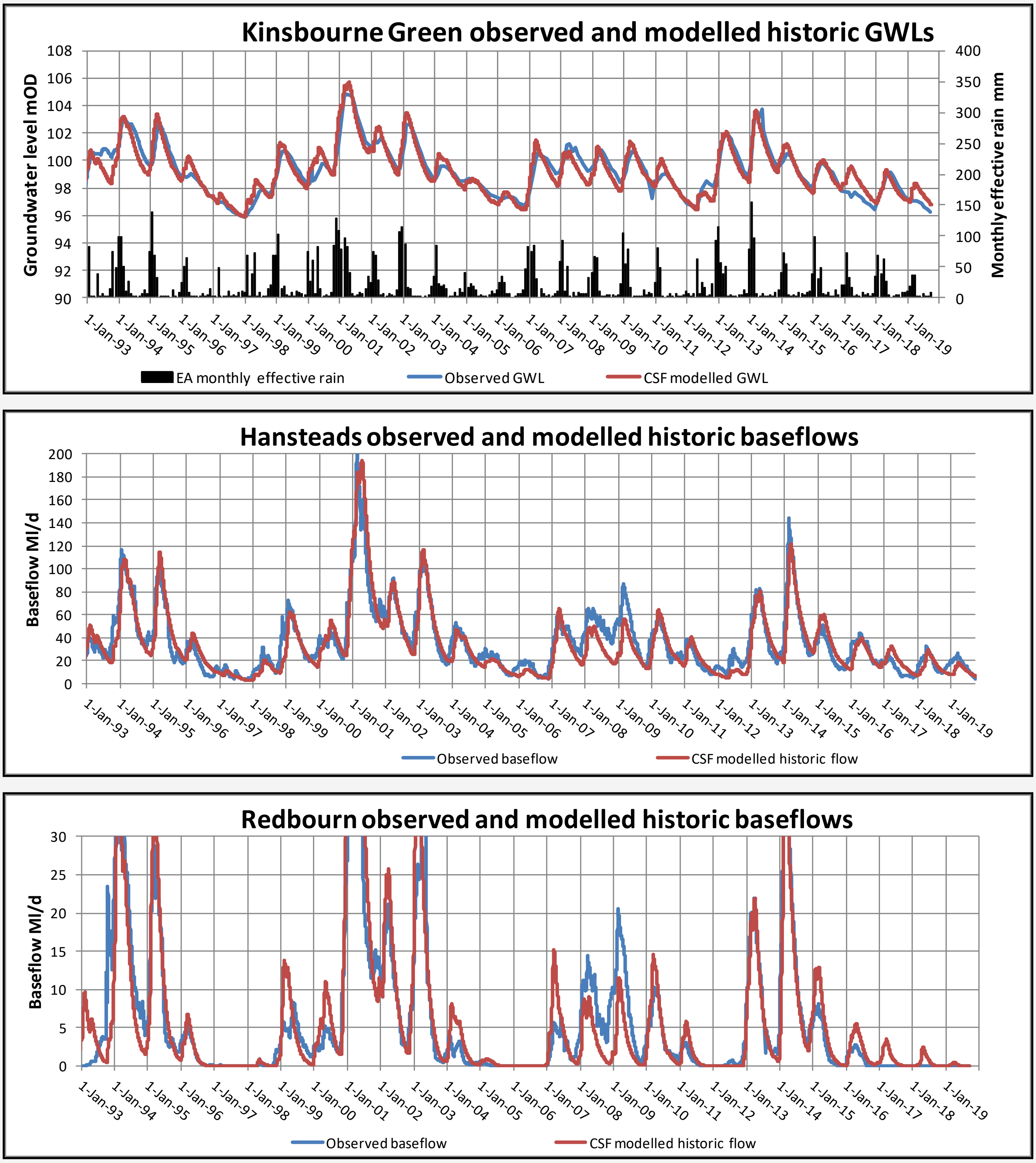
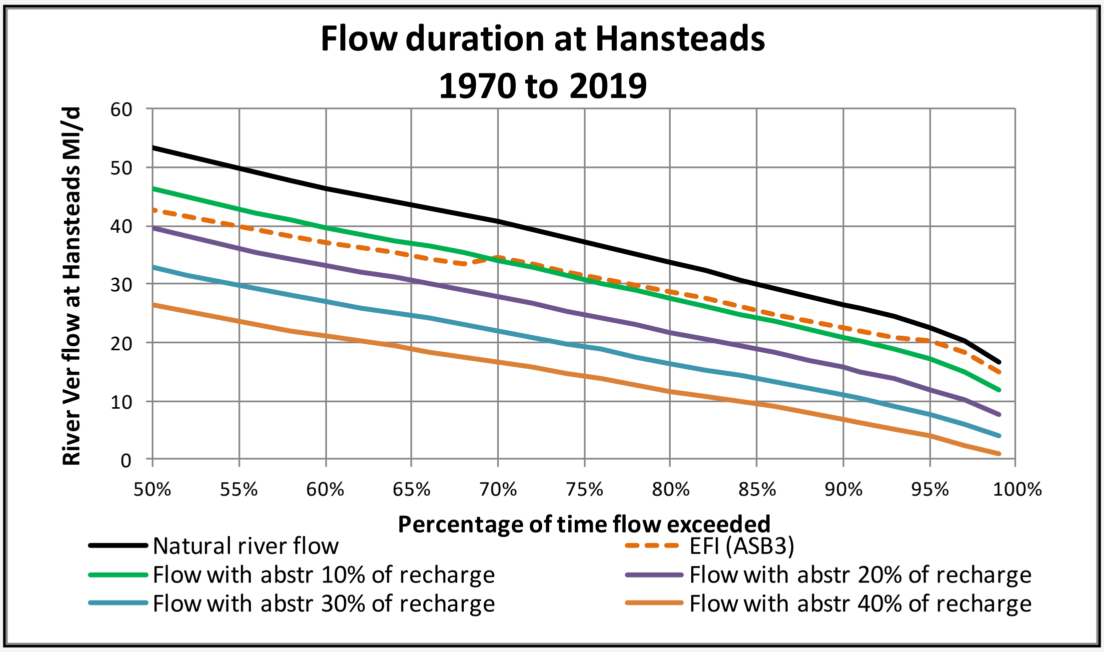


Figure 1 - Examples of close-fit CSF-modelled groundwater levels and river flows against historic records of recharge and abstraction in the River Ver catchment

• Kinsbourne Green is an observation borehole in the upper Ver catchment, Hansteads is a gauging station just above the Ver confluence with the Colne and Redbourn is a gauging station at the lower end of the winterbourne section of the Ver

• The CSF (Chalk Streams First) model is a lumped parameter model developed by John Lawson

The two charts on the following Figure 2 show modelled flow durations under various amounts of abstraction at Redbourn and Hansteads on the River Ver. The River Ver is about 22 km long. Redbourn is 10 km from the source near Kensworth Lynch, while Hansteads is close to the downstream confluence of the Ver with the Colne (locations can be seen on the map in Figure 9).



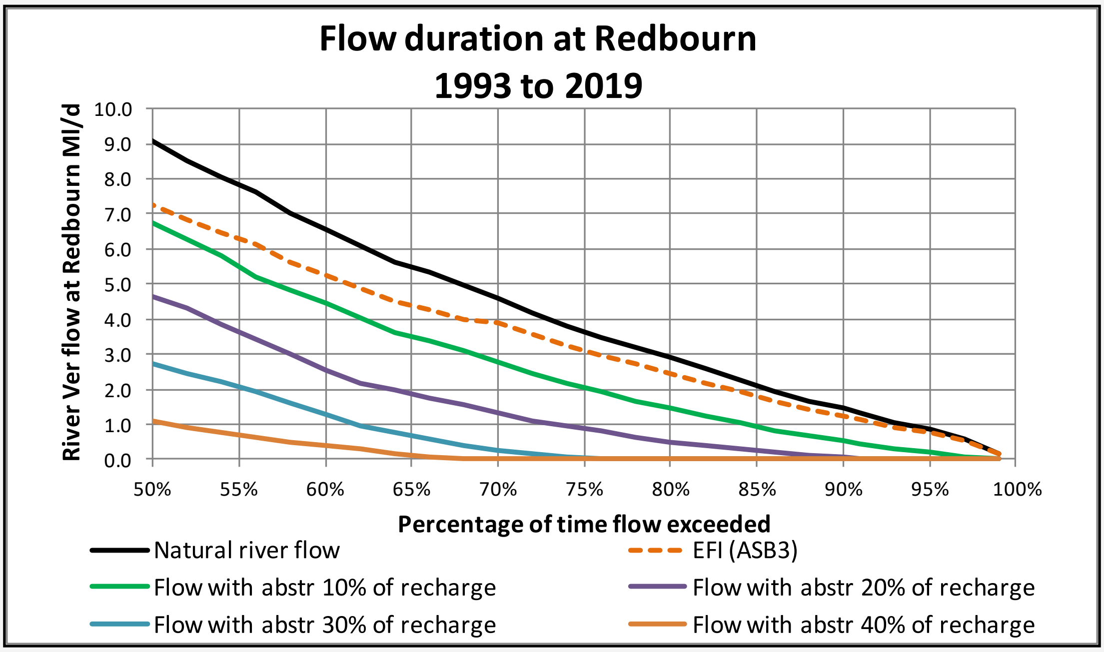


Figure 2 - Modelled flow durations at varying A%R in the River Ver

• Note: The EFI line is calculated relative to the modelled natural flow

The modelled natural flow in the Ver is shown in black. The EA's EFI flow (shown as if for an Abstraction Sensitivity Band 3 (ASB3) river, although in fact the Ver is ASB2) is shown in dotted brown. This is the deviation from natural flow considered by the EA to still be capable of supporting good ecological status. Modelled flows under four levels of abstraction as a % of annual catchment recharge are shown by the coloured lines.

The recent actual abstraction of the River Ver is about 28% of average annual recharge (A28%R): therefore close to the pale blue A30%R line. Historically abstraction has been much higher, but abstraction reductions have been made on the River Ver in recent years. As can be seen, the recent level of abstraction still yields flows that are a long way short of the EFI. At Redbourn A30%R indicates that the river dries for about 25% of the year when otherwise it might not dry at all. Note also that even at A10%R the Redbourn flows are well short of meeting the EFI target of 10% reduction at Qn95. This suggests that the EFI target might not be an appropriate measure for the upper reaches of chalk streams and certainly not for winterbourne reaches where Q95 is zero.

At Hansteads A30%R yields flows at Q95 of 8 Ml/d when naturally they would be about 23 Ml/d. Again note that an A%R of 10% comfortably meets the EFI up to about Q70, is a close match up to Q90, but actually needs to be closer to 5% to meet the EFI at Q95.

Results from this simple form of assessment of the Ver and of other chalk streams suggest that groundwater abstraction should account for no more than between 5% to 10% of catchment recharge if the stream's flows are to meet (or get close to meeting) the EFI at Q95. Note that, although the EFI for ASB3 rivers at Q95 is 10%, for SSSI and SAC rivers, the recommendation is a reduction in flow of no more than 5%, which would suggest a total groundwater abstraction of less than 5% of recharge.

2. Method of analysis

2.1 Selection of chalk streams

The original list of chalk streams for which data were requested from the EA covered about 40 chalk catchments, each a recognised chalk stream in its own right, whilst maintaining separate identities for individually well-known tributaries. The EA provided data for all these catchments in regional groupings, which sometimes included data for additional chalk streams. Some of the additional streams had significant abstraction so were added to the list for A%R analysis.

The main chalk streams were sub-divided into reaches and tributaries, with assessment points mostly chosen to match the assessment points in the EA's analysis of deficits, usually at water body boundaries. In some cases, assessment points were sites of gauging stations shown on the National River Flow Archive. The list of original catchments for which data were requested and the list of those analysed for A%R are shown on Table 1.

In total, the A%R analysis covered about 55 named chalk streams, including most of the well known rivers. Those not covered included the Rivers Loddon, Wey, Kentish Stour and Wensum, and some of the other Norfolk and Lincolnshire chalk streams.

Original list of rivers for which data requested	Additional tributaries or reaches analysed	Number of A%R assessment points
River Frome upper incl Wraxall, Hooke, Sydling and Cerne	South Winterbourn and Frome assessed for 3 reaches	5
River Piddle (incl Devil's Brook and Bere Stream)	Piddle assessed for 3 reaches	5
Not on original list	Tarrant and Pimperne	2
River Allen (incl Gussage and Crichel Streams)		1
River Wylye (incl Till, Chitterne and Heytesbury Stre River Ebble	All upper Hampshire Avon tributaries, including Nadder	6
River Test upper to Anton incl Bourne, Dever, Anton and Pilhill Brook		5
River Itchen upper incl Candover, Cheriton and Alre		2
River Meon	Assessed for 2 reaches	2
River Kennet upper incl Og, Aldbourne, Dun	Shalbourne and Enbourne added, plus 3 Kennet reaches	7
Not on original list	Letcombe Brook added	1
River Pang		1
River Lambourn		1
River Wye (inc Hughenden Stream)	Assessed for 2 reaches	2
River Colne and tributaries		
River Ver	Assessed for 2 reaches	2
River Gade (incl Bulbourne)	Assessed for 3 reaches	3
River Chess		1
River Misbourne		1
River Colne	Assessed for 3 reaches	3
River Lea and tributaries		
Upper River Lea	Added and assessed for 2 reaches	2
River Mimram	Assessed for 2 reaches	2
River Beane	Stevenage Brook added	2
River Rib (incl Quin)	Assessed for 2 reaches	2
River Ash		1
River Stort	Assessed for 3 reaches	3
Lower River Lea		1
River Darent	River Cray, 5 reaches assessed	5
River Dour	Assessed for 2 reaches	2
River Hiz (incl Oughton and Purwell)	Assessed for 3 reaches	5
River Cam and Rhee	Wenden Brook, Granta and 3 Cam reaches	6
River Lark (incl Linnet and Hawkstead)	Lark assessed for 3 reaches	5
River Nar	Assessed for 3 reaches	3
River Babingley	Assessed for 2 reaches	2
River Heacham	Assessed for 2 reaches	2
Not on original list	Stiffkey	3
River Burn	Assessed for 2 reaches	2
Great Eau (incl Burwell Beck)	Assessed for 2 reaches	2
Driffield Beck (incl West Beck, Elmswell, Little Driffield Beck, Eastburn, Southburn and Water	Assessed for 2 reaches	2
Foston Beck		1
Gypsey Race.	Assessed for 2 reaches	2
	Total A%R assessment points	**105**

Table 1 - List of Chalk Rivers and tributaries assessed for A%R

2.2 Analysing abstraction data

The abstraction data were provided by the EA in the files shown in Appendix C, Table C1.

The files labelled ‘act’ in Table C1 contain monthly abstraction data since 1999, include licence number and name, grid references, owner’s name and use descriptions. The files labelled ‘done’ contain licence details including licence number and name, owner, grid references, surface or ground water, dates of issue and expiry, and annual and daily licensed quantities.

The ‘done’ files also include the EA’s assessment of the river catchment affected by some of the abstractions. These were a useful guide to the river catchments affected, but mostly did not sub-divide into river reaches or tributaries. Therefore, the river reach or tributary affected was reassessed for all public water supply and other major abstractions by plotting the locations on OS mapping and application of personal judgement based on topography. This also provided a check on the EA’s assessments of rivers affected, with no major differences found.

The EA’s descriptions of licence use were used to determine whether licences were consumptive or non-consumptive. For example abstractions for cress beds, fish farms and environmental remediation were assumed non-consumptive. Abstractions labelled as ‘public water supply direct’ were assumed fully consumptive, in other words with no allowance for returns via sewage treatment works effluents.

For analysing the abstraction as % of recharge for catchments, reaches and tributaries, the EA’s ‘act’ and ‘done’ files were combined to facilitate the use of Excel ‘Lookup’ functions in the analysis (see files listed in Appendix C, Table C2). The monthly consumptive groundwater abstraction in each reach or tributary was extracted using the Excel ‘Sumproduct’ function, allowing the monthly abstractions to be plotted as time series, as for the example below for the Kennet:

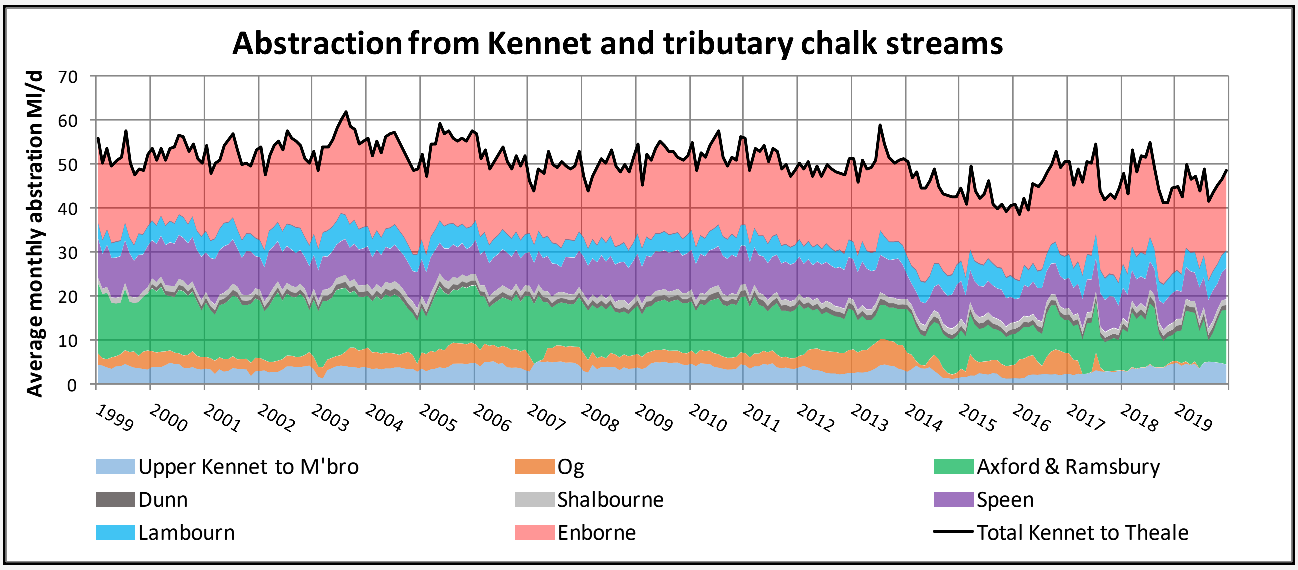


Figure 3 - Example of plot of monthly consumptive abstraction for reaches and tributaries

Plotting in this format allowed a visual sense check of the analysis as well as providing a picture of the changing pattern of abstraction over the past 20 years.

The information provided by the EA on dates of licence issue, revocation or expiry allowed the present day licensed quantities to be determined for each assessment point.

2.3 Analysing recharge

Average annual recharge for catchments, river reaches and tributaries was calculated as *'average annual effective rain x surface catchment area above the assessment point'*.

Surface catchment areas (ie topographic) were taken from the EA's Catchment Explorer web-site (if the assessment point was a waterbody boundary) or from the NRFA web-site (if the assessment point was a flow gauging-station). It should be noted that the groundwater divide between adjacent chalk valleys can differ from the surface topographic divide and can vary year to year.

Average effective rainfall data were mostly derived from Qube data taken from the EA's file *'Copy of Effective Rainfall_ QUBE_1999_2015.xlsx'*, which gave monthly values from October 1998 to December 2015. Following queries based on some inconsistencies of the type described below, the EA provided modified data for the Rivers Frome, Piddle, Allen, Kennet, Darent, Test, Ver, Meon and Babingley.

As a sense check of the validity of the effective rainfall data for calculating A%R, the Qube effective rainfall data were compared with the daily effective rainfall data, 1920-2019, previously supplied by EA for the Berkshire Downs, Colne Chalk and Lea Chalk. Comparisons were also made between Qube data in adjacent catchments. Both comparisons revealed some inconsistencies which raised concerns about the validity of the Qube data for calculating recharge. Examples of the inconsistencies are shown below:

a) Example of poor correlation between Qube effective rain and EA effective rain

a) Example of poor correlation between Qube effective rain in adjacent catchments

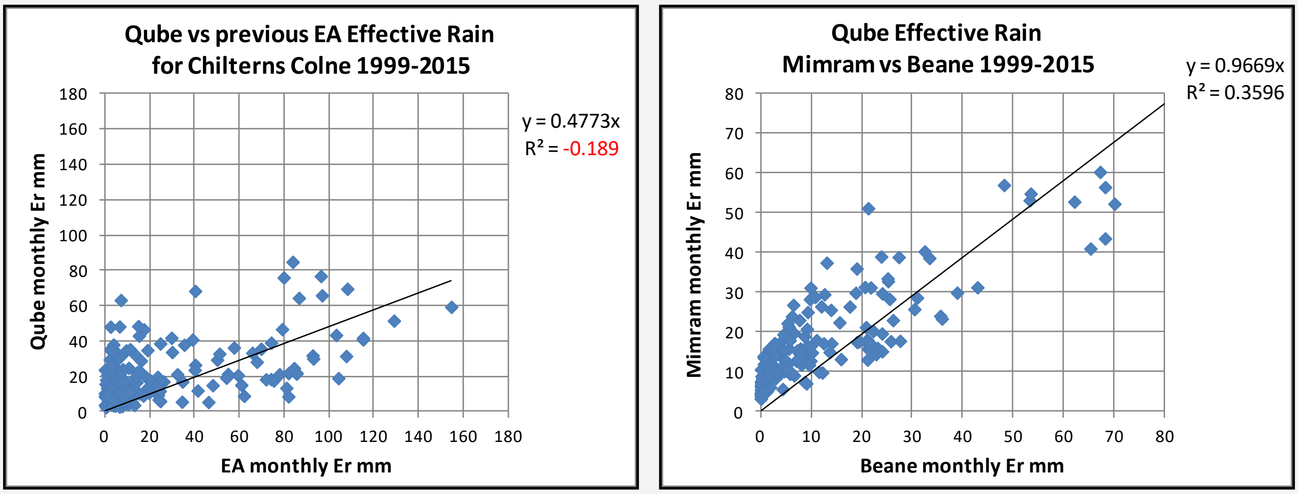


Figure 4 - Examples of inconsistencies between Qube and EA effective rainfall data

The poor correlation between the monthly effective rainfalls provided by the EA and Qube data – see plot a) above – could lead to potentially significant differences in the average annual effective rain used to

Average ER 1999 to 2015 mm/year	Berkshire Downs ER	Chilterns Colne ER	Lea Chalk ER
Qube data	255	241	159
Previous EA data	290	285	212
% difference	-15%	-15%	-25%

Table 2 - Differences in average effective rain between Qube and EA data

All calculations of recharge shown in the above figures and tables, and elsewhere in this report, use effective rainfall provided by Qube using Qube methodology and data, Wallingford HydroSolutions Ltd, 2021 calculate catchment recharge. Average annual effective rain (Er) from the two data sources are compared in Table 2:

The poor correlation between the Qube monthly effective rain in some adjacent catchments is also a concern – see plot b) in Figure 4 – noting that the EA's previous monthly effective rain for the Berkshire Downs, Colne Chalk and Lea Chalk correlated much better (R^2 was 89%-92%). On this evidence, the EA's previously supplied effective rainfall data would have been much preferable to the Qube data for calculating recharge. However, the EA's data were only available for the Berkshire Downs, Colne and Lea.

Therefore, after discussion with EA, it was decided to use the Qube effective rainfall data for all the A%R analysis. This has the advantage of consistency across all the catchment assessments. However, the concerns over the validity of the Qube effective rainfall data remain. The potential significance has been assessed by sensitivity testing of the A%R values for the Colne and Lea catchments, where both EA and Qube data are available (see Section 3.9).

3. Results of A%R analysis

3.1 Summary for rivers assessed

The results of the A%R analysis for individual rivers, sub-divided into tributaries and reaches, are summarised on the table shown in Appendix B. This table is taken from an Excel file which is linked to the 20 Excel data analysis files listed in Appendix C. The data analysis files contain confidential information about the abstracted amounts and licensees.

The values of A%R for the assessed chalk streams and tributaries are shown on Figure 5 (generated from values shown in the summary table in Appendix B):

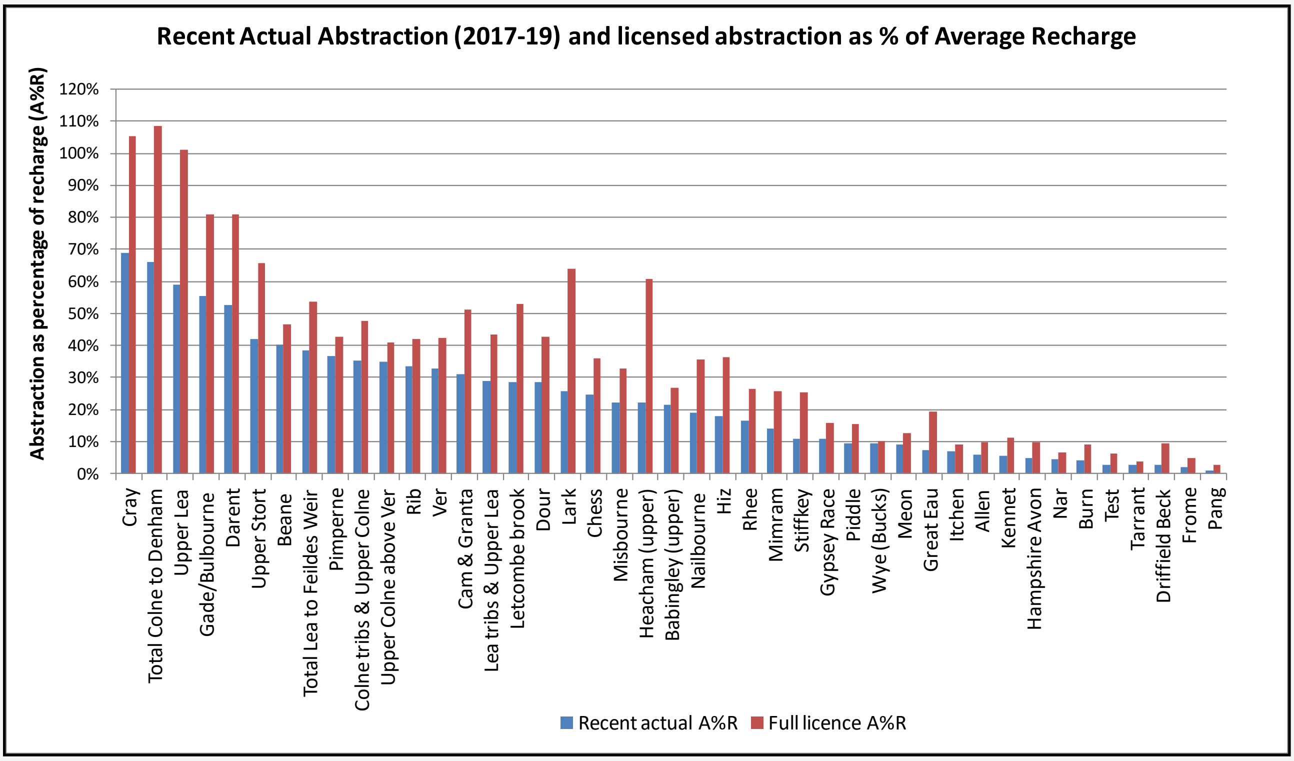


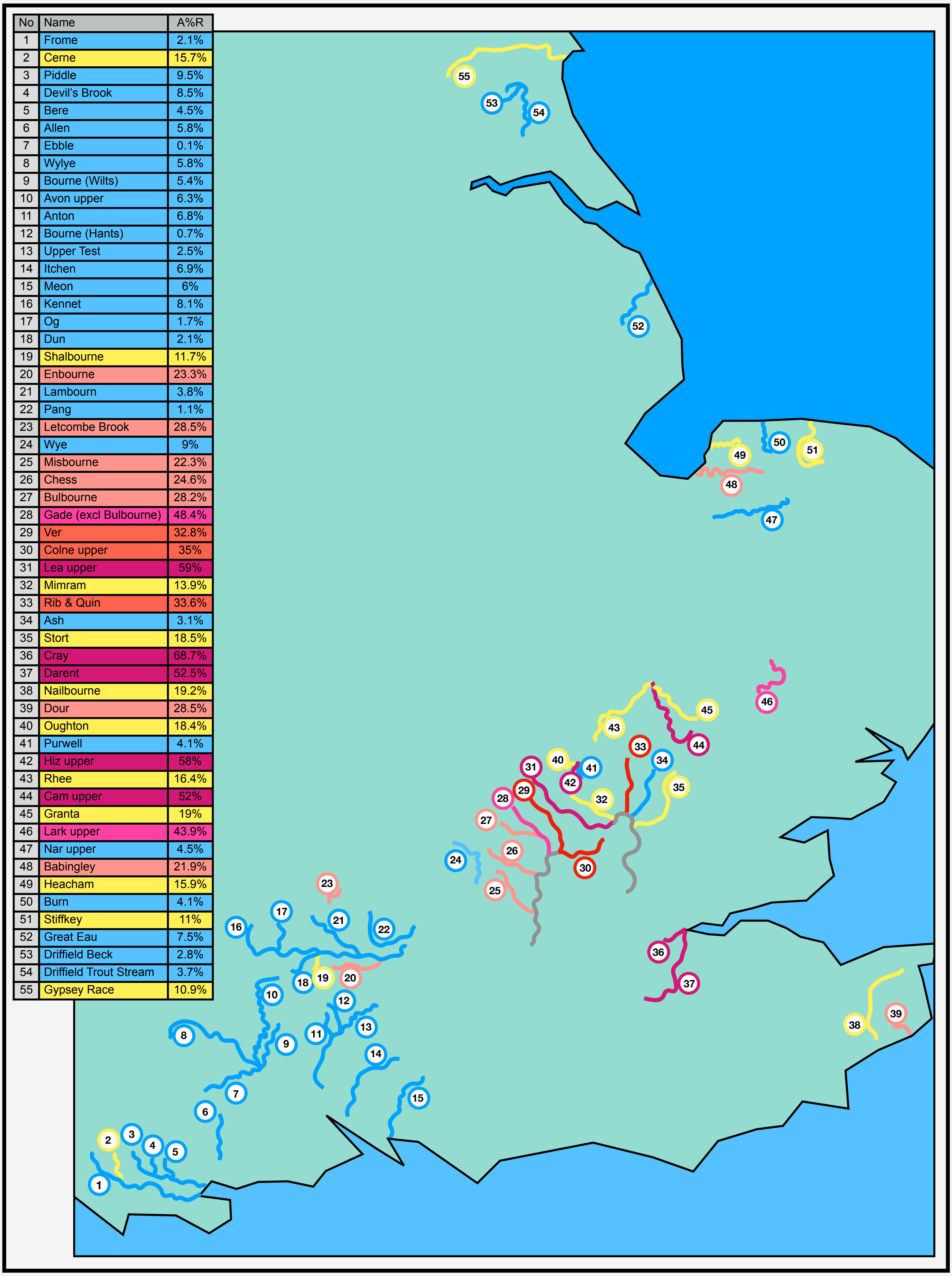
Figure 5 - Values of ‘recent actual’ and licensed A%R for chalk streams and tributaries

Figure 5 shows that in the mostly heavily abstracted chalk streams a high proportion of average aquifer recharge is being abstracted. Often, the licensed abstraction is a lot higher than recent actual abstraction. This suggests that over-abstraction of chalk streams could get a lot worse unless some existing licences are reduced or revoked (see also Section 3.2).

It should be noted that the A%R values are abstraction as a % of average annual recharge, so in dry years a much higher % of the previous year’s recharge has been abstracted. Examples of this for the Rivers Darent, Cam and Lark are shown in Sections 3.5 to 3.7.

The geographic distribution of recent actual A%R values is shown on Figure 6

Figure 6 shows that the chalk streams with the highest proportion of recharge abstracted are mostly around the fringes of London and in East Anglia. In most of the Wessexand the north-eastern chalk streams groundwater abstraction is less than 10% of recharge. However, many of these streams are SSSI or SAC chalk streams (lower Frome, Lambourne, Kennet catchment, Avon catchment (downstream of Upavon), Test catchment, Itchen catchment, Nar, Wensum, Driffield Beck) where the Q95 EFI is more likely to be met with a figure of no more than A5%R.



No	Name	A%R
1	Frome	2.1%
2	Cerne	15.7%
3	Piddle	9.5%
4	Devil's Brook	8.5%
5	Bere	4.5%
6	Allen	5.8%
7	Ebble	0.1%
8	Wylye	5.8%
9	Bourne (Wilts)	5.4%
10	Avon upper	6.3%
11	Anton	6.8%
12	Bourne (Hants)	0.7%
13	Upper Test	2.5%
14	Itchen	6.9%
15	Meon	6%
16	Kennet	8.1%
17	Og	1.7%
18	Dun	2.1%
19	Shalbourne	11.7%
20	Enbourne	23.3%
21	Lambourn	3.8%
22	Pang	1.1%
23	Letcombe Brook	28.5%
24	Wye	9%
25	Misbourne	22.3%
26	Chess	24.6%
27	Bulbourne	28.2%
28	Gade (excl Bulbourne)	48.4%
29	Ver	32.8%
30	Colne upper	35%
31	Lea upper	59%
32	Mimram	13.9%
33	Rib & Quin	33.6%
34	Ash	3.1%
35	Stort	18.5%
36	Cray	68.7%
37	Darent	52.5%
38	Nailbourne	19.2%
39	Dour	28.5%
40	Oughton	18.4%
41	Purwell	4.1%
42	Hiz upper	58%
43	Rhee	16.4%
44	Cam upper	52%
45	Granta	19%
46	Lark upper	43.9%
47	Nar upper	4.5%
48	Babingley	21.9%
49	Heacham	15.9%
50	Burn	4.1%
51	Stiffkey	11%
52	Great Eau	7.5%
53	Driffield Beck	2.8%
54	Driffield Trout Stream	3.7%
55	Gypsey Race	10.9%

Figure 6 - Geographic distribution of chalk stream 'recent actual' A%R values

3.2 Reduction in abstractions needed to achieve A10%R

The EA's environmental flow indicator (EFI) targets for sensitive (ASB3) chalk streams is no more than 10% reduction in the 95%-ile natural flow (Qn95), 15% at Q70 and 20% at Q50. The modelling of the River Ver shown in Figure 2 suggests that these targets would be broadly achieved if abstraction is limited to 10% of recharge. This is suggested as an initial, pragmatic target if A%R is used as an indicator of acceptable abstraction in chalk streams. Limiting abstraction to 10% of average annual recharge – ie A10%R – would be the target equivalent to the EFI 10% maximum flow reduction target.

The reductions in recent actual and licensed abstraction to achieve A10%R are shown in Figure 7:

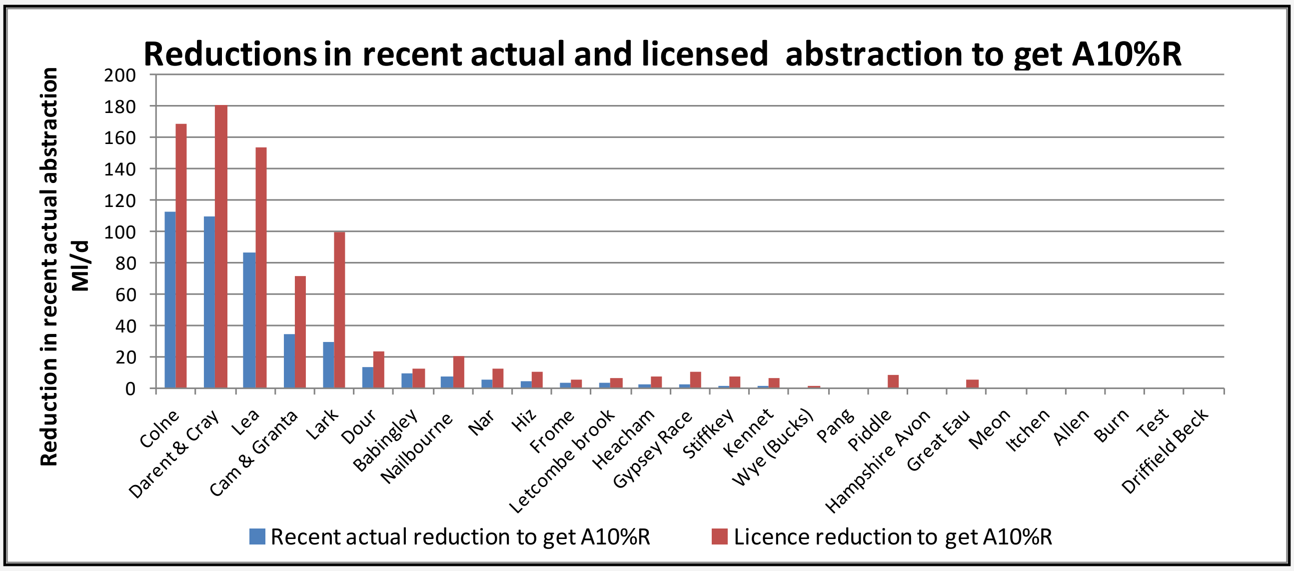


Figure 7 - Reductions in recent actual and licensed abstraction needed to get A10%R

The largest abstraction reductions to achieve A10%R are in the Colne, Lea and Darent /Cray catchments. There are also significant reductions needed in the Cam and Lark catchments.

Figure 7 shows that in most rivers licensed abstractions substantially exceed recent actual abstractions. If existing licences were to be fully used, chalk stream over-abstraction would be much worse than at present.

However, water company Water Resource Management Plans do not always assume that the deployable output of their groundwater sources equate to the total licensed amounts, because boreholes may not be able to deliver the licensed amounts in droughts. An example is shown in Table 3, which is extracted from Affinity Water's current WRMP tables for their Lea supply zone:

Therefore, the threat to chalk streams due to rises in abstraction within existing licences will be less than suggested by the licensed amounts shown in Figure 7, albeit it could still be substantial.

Licence number	Source name	Deployable output (Ml/d)	Annual licensed quantity (Ml/d)	Constraints on deployable output
29/38/01/67	Crescent Rd Group	28.13	28.49	Licence
28/39/28/226	Hatfield Group	21.60	27.28	DAPWL
29/38/01/41	Hyde Group	4.10		DAPWL
28/39/28/130	Kensworth Group	4.30	6.82	Licence
06/33/14/10	Willian Rd Group	10.50	14.77	DAPWL
29/38/03/42	Whitehall Group	4.20	6.55	DAPWL

Table 3 - Example of deployable output of GW sources not matching licensed amounts

3.3 Comparison with Environment Agency's assessed flow deficits

The amounts of reduction in recent actual abstraction needed get to 10% of recharge (A10%R) are compared to the EA's EFI flow deficits in Figure 8:

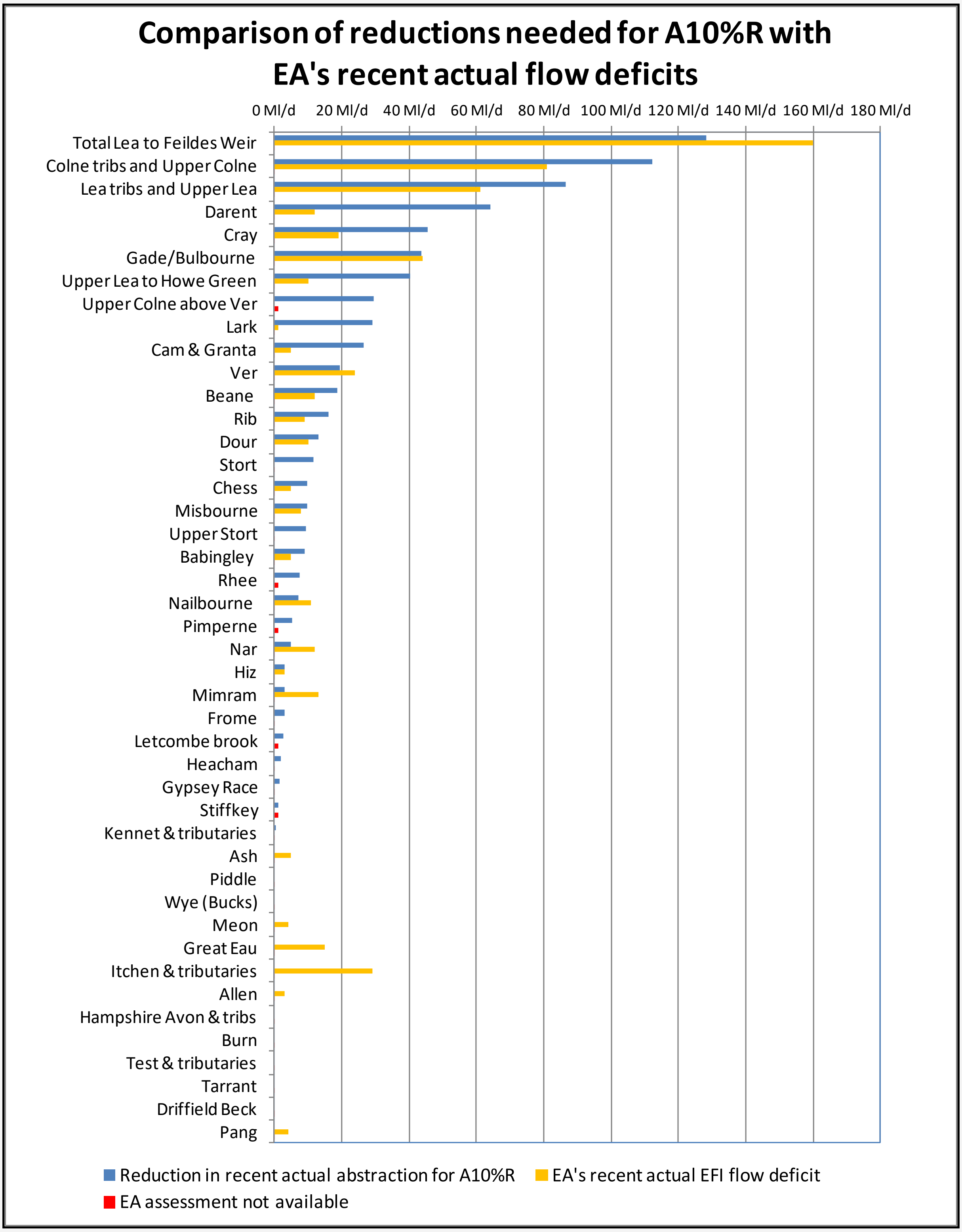


Figure 8 - Comparison of reductions needed for A10%R with EA's EFI deficits

Note: The large total deficits to Lower Colne and Lower Lea are not plotted, but shown in Table 4 below

The EA's flow deficits do not equate to the amount of abstraction reduction needed to eliminate the deficit at Q95 flows. Therefore, in general, the EA's EFI flow deficits can be expected to be somewhat less than the reductions needed to achieve A10%R. This is generally the case for the comparisons shown in Figure 8.

The A10%R reductions and EA EFI deficits show broadly similar pictures – heavy over-abstraction in the chalk streams around London and much less elsewhere. However, there are substantial differences in individual rivers, as further shown on Table 4:

Catchment or river	RA reduction for A10%R	EA EFI flow deficit	Comment
Enbourne	#N/A	#N/A	
Total Colne to Denham	274.1 Ml/d	176.0 Ml/d	EA deficits allow for STW effluent and surface abstraction
Total Lea to Feildes Weir	128.3 Ml/d	160.0 Ml/d	EA deficits allow for STW effluent and surface abstraction
Colne tribs and Upper Colne	112.4 Ml/d	81.0 Ml/d	Broadly similar for Colne and Lea tributaries and upper rivers.
Lea tribs and Upper Lea	86.6 Ml/d	61.0 Ml/d	
Darent	64.2 Ml/d	12.0 Ml/d	EA's deficits cappeded because abstraction exceeds natural Q95
Cray	45.6 Ml/d	19.0 Ml/d	
Gade/Bulbourne	43.8 Ml/d	44.0 Ml/d	EA deficits allow for STW effluent and surface abstraction
Upper Lea to Howe Green	40.2 Ml/d	10.0 Ml/d	EA deficits allow for STW effluents
Upper Colne above Ver	29.6 Ml/d	#N/A	
Lark	29.1 Ml/d	1.0 Ml/d	EA deficits say 'overide' and allow for STW effluents?
Cam & Granta	26.4 Ml/d	5.0 Ml/d	EA deficits allow for STW effluents?
Ver	19.5 Ml/d	24.0 Ml/d	
Beane	18.7 Ml/d	12.0 Ml/d	
Rib	16.1 Ml/d	9.0 Ml/d	
Dour	13.0 Ml/d	10.0 Ml/d	
Stort	11.5 Ml/d	0.0 Ml/d	EA deficits allow for STW effluents?
Chess	9.8 Ml/d	5.0 Ml/d	EA deficits allow for STW effluents?
Misbourne	9.6 Ml/d	8.0 Ml/d	
Upper Stort	9.3 Ml/d	0.0 Ml/d	
Babingley	8.9 Ml/d	5.0 Ml/d	
Rhee	7.4 Ml/d	#N/A	
Nailbourne	7.0 Ml/d	11.0 Ml/d	EA deficits allow for surface water abstractions
Pimperne	5.3 Ml/d	#N/A	
Nar	4.9 Ml/d	12.0 Ml/d	EA deficits allow for surface water abstractions
Hiz	3.1 Ml/d	3.0 Ml/d	
Mimram	2.9 Ml/d	13.0 Ml/d	
Frome	2.8 Ml/d	0.0 Ml/d	
Letcombe brook	2.7 Ml/d	#N/A	
Heacham	2.1 Ml/d	0.0 Ml/d	EFI deficit is EA local over-ride
Gypsey Race	1.6 Ml/d	0.0 Ml/d	
Stiffkey	1.1 Ml/d	#N/A	
Kennet	0.2 Ml/d	0.0 Ml/d	Small A%R deficit for Shalbourne
Ash	0.0 Ml/d	5.0 Ml/d	EA deficit exceeds recent abstraction - to be checked
Piddle	0.0 Ml/d	0.0 Ml/d	
Wye (Bucks)	0.0 Ml/d	0.0 Ml/d	
Meon	0.0 Ml/d	4.0 Ml/d	A10%R just OK, small EFI deficit
Great Eau	0.0 Ml/d	15.0 Ml/d	EA deficits allow for surface water abstractions
Itchen	0.0 Ml/d	29.0 Ml/d	EA deficits allow for surface water abstractions
Allen	0.0 Ml/d	3.0 Ml/d	EA deficits allow for surface water abstractions
Hampshire Avon	0.0 Ml/d	0.0 Ml/d	
Burn	0.0 Ml/d	0.0 Ml/d	
Test	0.0 Ml/d	0.0 Ml/d	
Tarrant	0.0 Ml/d	0.0 Ml/d	
Driffield Beck	0.0 Ml/d	0.0 Ml/d	
Pang	0.0 Ml/d	4.0 Ml/d	EA deficit exceeds recent abstraction - to be checked

Table 4 - Differences in A10%R and EA's EFI deficits, with suggested reasons

Note: EA may have used different periods of recent abstraction for Mimram and Pang

Although the EA's flow deficits are somewhat less than the abstraction reduction that would be needed to address those deficits (and meet the EFI target)*, they might be expected to be broadly similar to the A10%R deficits. There are several reasons for the differences between the required A10R% reductions and the EA's EFI deficits shown in Table 4:

1. The EA's EFI deficits allow for sewage effluent returns and the A%R assessments do not. It is worth noting:

• river flows in the reach upstream of the effluent discharge can be heavily depleted, without being identified as such by the EFI assessment

• in droughts, the river flow can comprise largely STW effluent, with minimal dilution from natural flows

2. The EA's EFI deficits include surface water abstractions and the A%R assessments do not. The A%R assessment methodology is intended primarily for identifying excessive groundwater abstraction in chalk streams, including their headwater tributaries and winterbournes. In these cases, there is rarely any significant surface water abstraction. However, there can be large surface water abstraction in the lower reaches of the chalk streams, where there is substantial perennial flow.

3. The EA's deficits are capped when the deficit exceeds the natural Q95 flow. However, the EA has said this has only applied to the Darent and Cray catchments.

4. In some cases, the EA's initial compliance figures have been over-ridden by assessments from local staff. Details of the changes are not available.

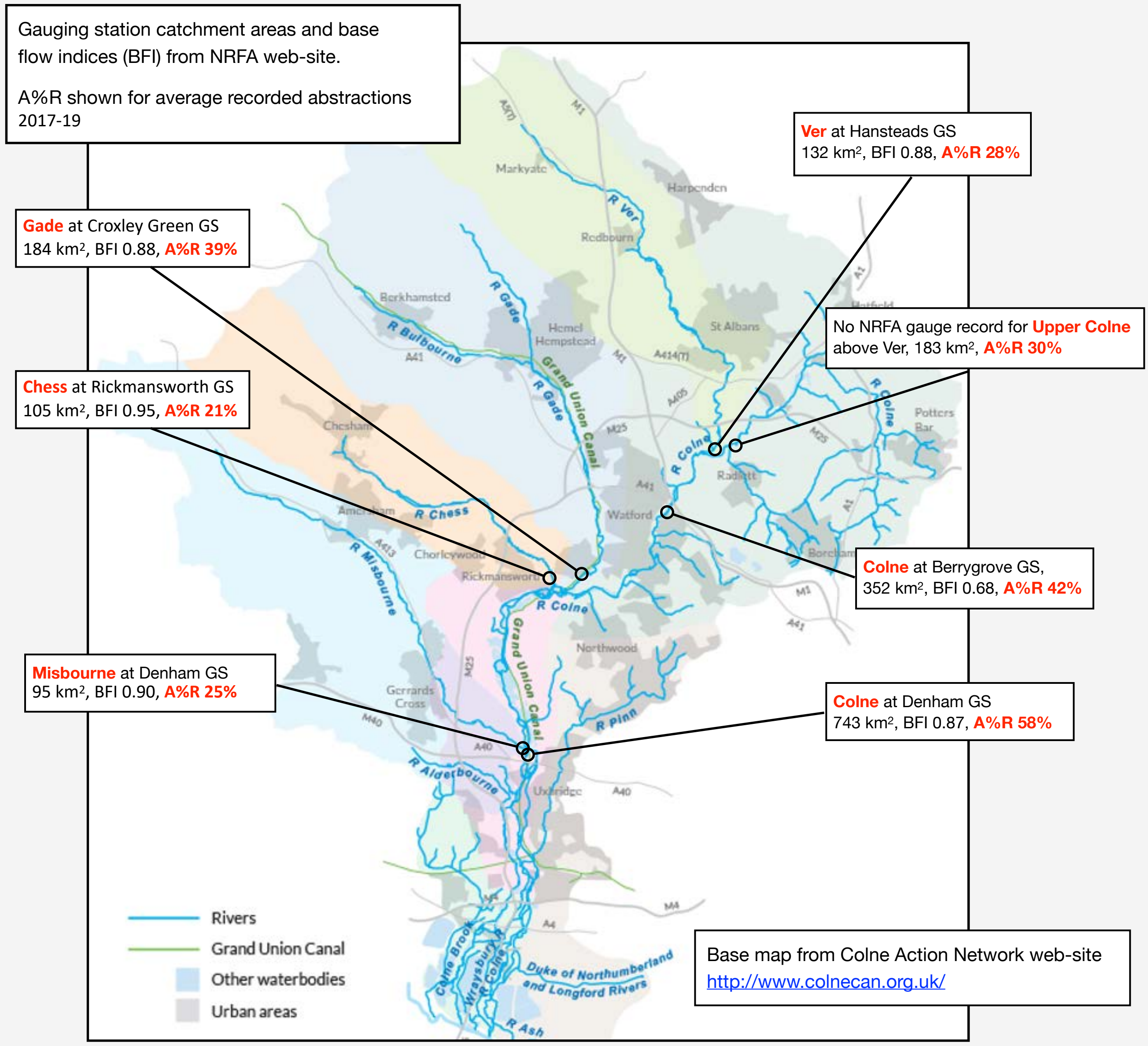
Further comments on individual rivers are given in the following sections.

*This is because there is not a direct 1:1 relationship between reduced abstraction and recovered flow

3.3 The River Colne catchment

The River Colne is the most heavily abstracted catchment both in its upper reaches and tributaries and in the river overall. This is shown by both the A%R assessment and the EA's assessment of EFI deficits.

Figure 9 shows the location of the various A%R assessments for River Colne and its tributaries:



	Misbourne	Chess	Gade/ Bulbourne	Ver	Upper Colne above Ver	Total Colne tributaries (incl Colne above Ver)	Total Colne to Denham
Catchment area km^2	95.0	105	184	132	183	699.0	743
Baseflow index	0.90	0.95	0.88	0.88	#N/A		0.87
Av. annual recharge	78.3 Ml/d	67.3 Ml/d	96.5 Ml/d	85.5 Ml/d	118.5 Ml/d	446.1 Ml/d	489.9 Ml/d
Abstraction in 2017-19	17.5 Ml/d	16.5 Ml/d	53.4 Ml/d	28.1 Ml/d	41.5 Ml/d	157.0 Ml/d	323.1 Ml/d
Abstraction as %recharge	22.3%	24.6%	55.4%	32.8%	35.0%	35.2%	66.0%
Reduction to achieve A10%R	**9.6 Ml/d**	**9.8 Ml/d**	**43.8 Ml/d**	**19.5 Ml/d**	**29.6 Ml/d**	**112.4 Ml/d**	**274.1 Ml/d**
GW consumptive licence total	25.6 Ml/d	24.2 Ml/d	78.0 Ml/d	36.3 Ml/d	48.7 Ml/d	212.8 Ml/d	531.1 Ml/d
Licence A%R	32.7%	36.0%	80.8%	42.4%	41.1%	47.7%	108.4%
Licence reduction for A10%R	**17.8 Ml/d**	**17.5 Ml/d**	**68.3 Ml/d**	**27.7 Ml/d**	**36.9 Ml/d**	**168.2 Ml/d**	**482.1 Ml/d**

Figure 9 - Map of A%R assessment in the Colne catchment

Changes in abstraction and A%R since 1999 are shown in Figure 10:

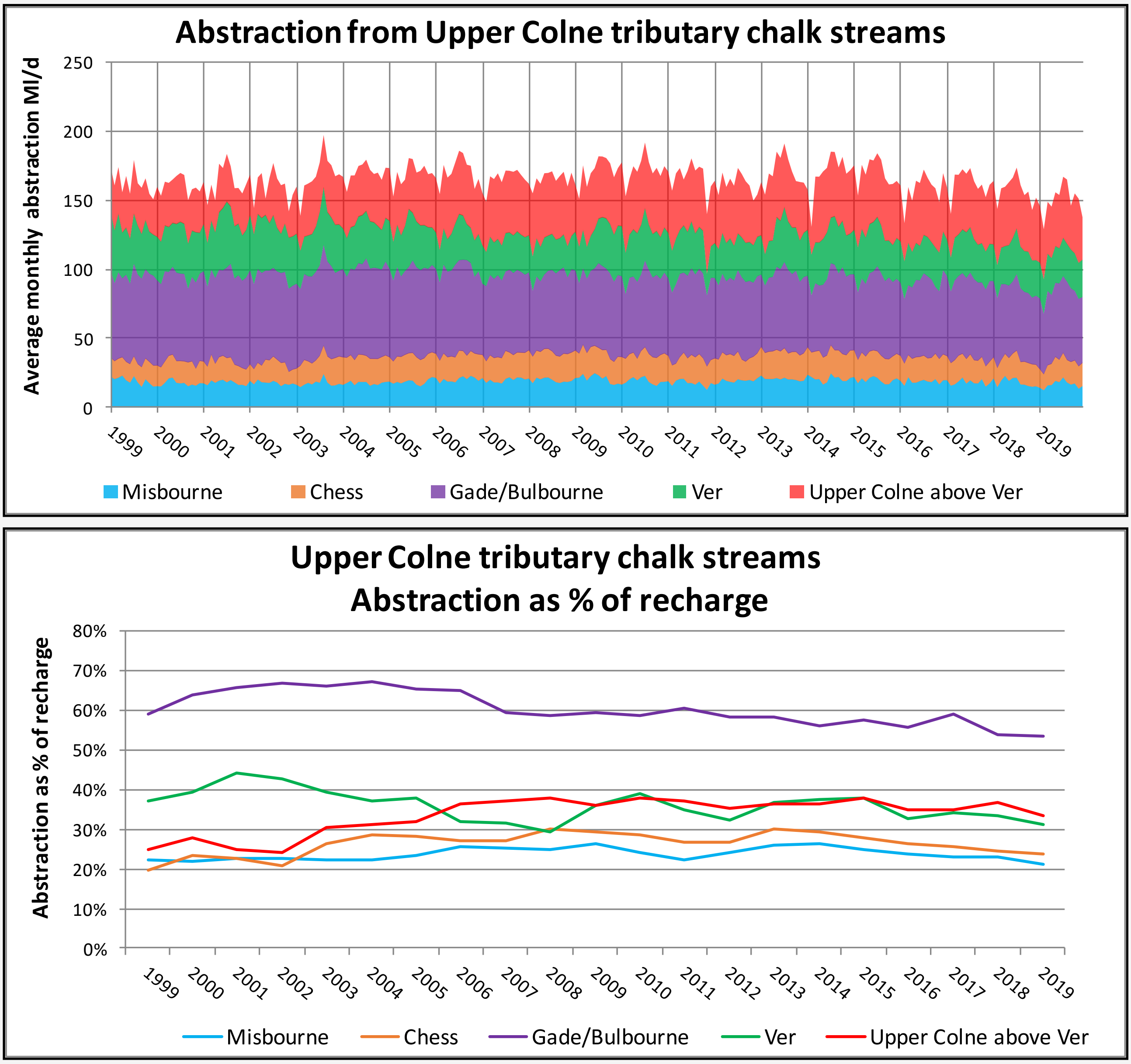


Figure 10 - Changes in abstraction and A%R in main upper Colne tributaries since 1999

Note: each yearly A%R is abstraction ÷ average annual recharge 1920-2019, not recharge for that year

Abstraction as % of recharge in the main chalk tributaries has changed little since about 2006. Overall, there has been minimal reduction in total abstraction from the tributary chalk streams in the Colne catchment in the last 20 years, with reductions in some tributaries offset by increases in others – between 1999 and 2006, the A%Rs for the Ver and Misbourne both fell by about 7-8%, but the reductions were offset by increases in the Chess and Upper Colne catchments.

The approximate locations of the main public water supply abstractions in the Ver and Upper Colne catchments are shown in Figure 11, with recorded abstractions as per August 2018:

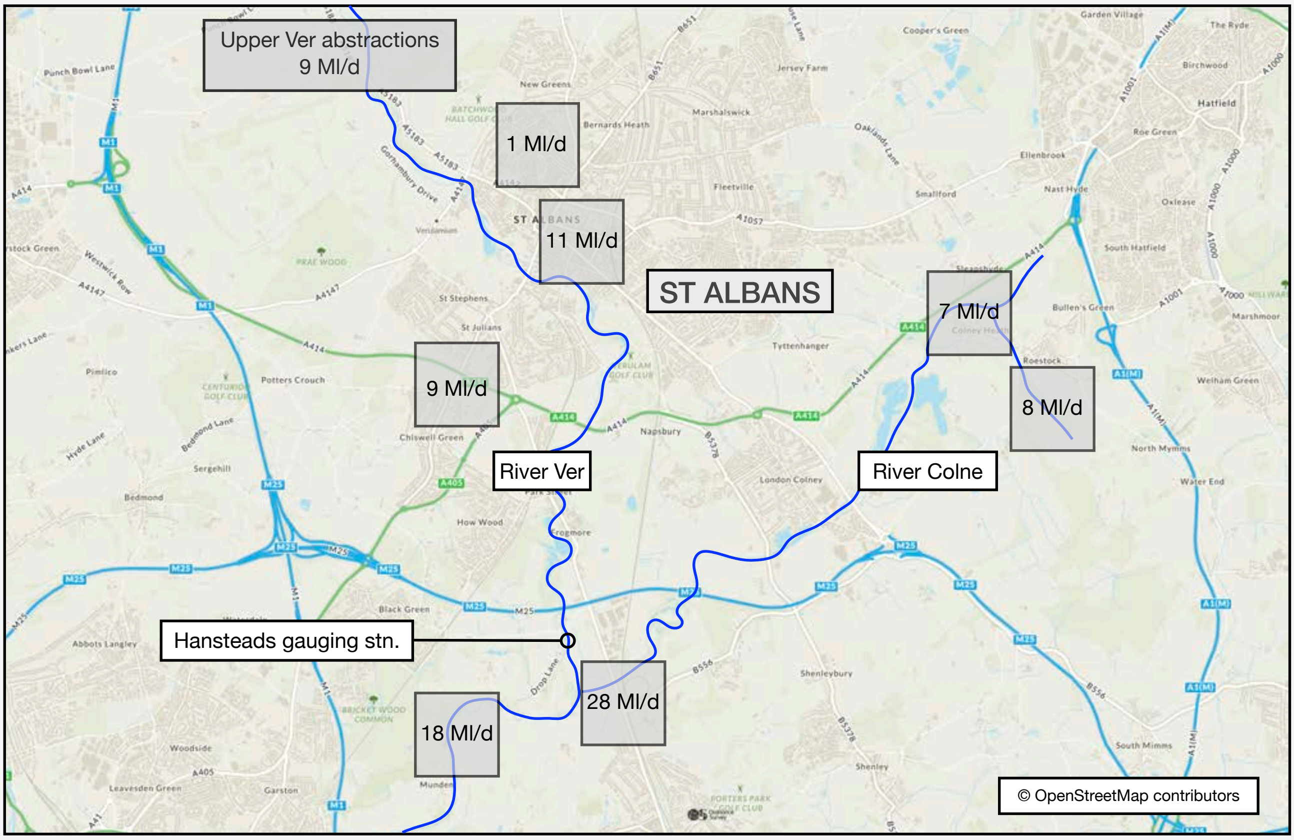


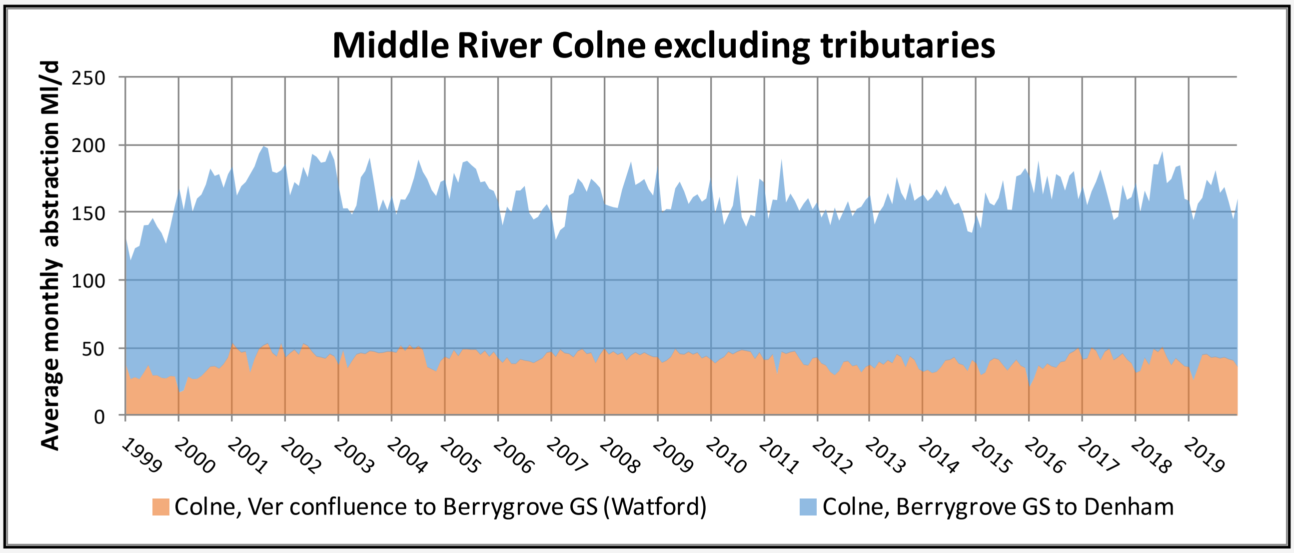
Figure 11 – Approximate location of main abstractions in Upper Colne and Lower Ver

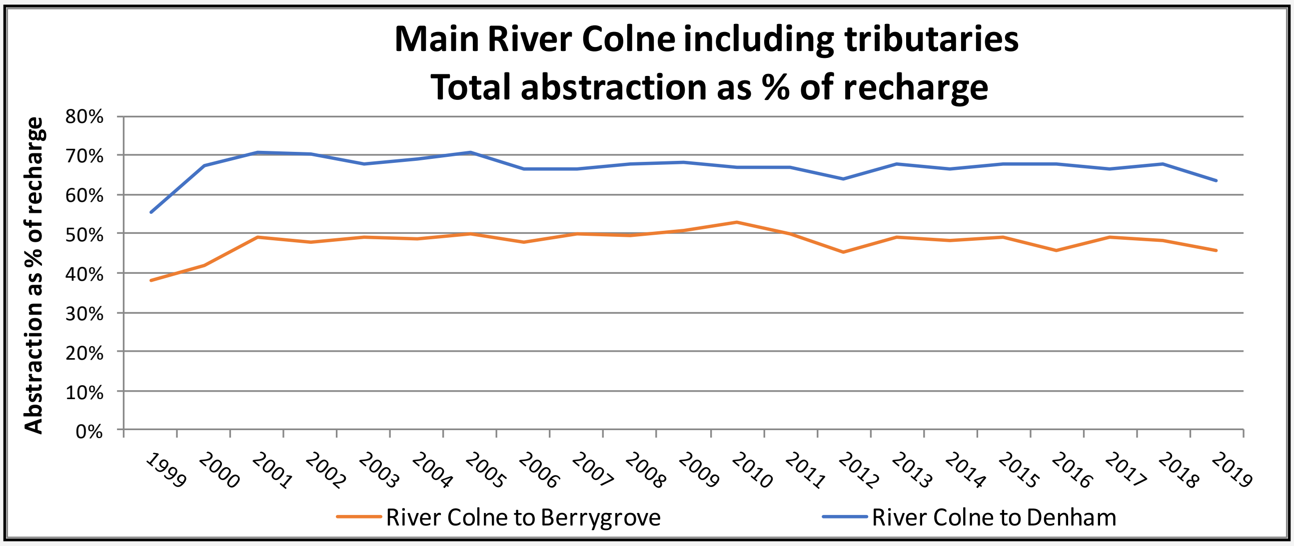
There is no gauging station and no available base-flow index for the Colne above the Ver confluence. The base-flow index further downstream at Berrygrove is 0.68 which in spite of the influence of the Ver is low for what might be considered a true chalk stream (comparable with 0.71 for the mixed-geology headwaters of the upper Avon), rising to 0.87 further downstream of all the chalk tributaries at Denham. Most of the abstraction in the Upper Colne, ie. above the Ver confluence, comes from the large pumping station located above the confluence (the 28 Ml/d abstraction on Figure 11). Apart from this, the 7 Ml/d and 8 Ml/d abstractions about 5-6 km above the Ver confluence are only about 12% of the average recharge for the Upper Colne.

There is also an 18 Ml/d abstraction just downstream of the Colne/Ver confluence.

The reduced groundwater levels around the confluence may well affect flows upstream in the Ver. The combined 2018 abstraction of 46 Ml/d from these two pumping stations is 27% of the combined recharge for the Ver and the Upper Colne. This raises the question – should abstractions just downstream of the main tributary chalk streams be included in the A%R reckoning for the tributaries?

Further down the Colne valley, there are a lot more groundwater abstractions, all located downstream of the Gade, Chess and Misbourne chalk catchments. The changes in these Middle Colne valley abstractions since 1999 are shown in the upper plot in Figure 12. The lower plot shows the total abstractions, including the tributaries, as % of total recharge.





	Total Colne to Berrygrove	Total Colne to Denham
Catchment area km^2	352	743
Baseflow index	0.68	0.87
Av. annual recharge	232.1 Ml/d	489.9 Ml/d
Abstraction in 2017-19	110.8 Ml/d	323.1 Ml/d
Abstraction as %recharge	47.8%	66.0%
Reduction to achieve A10%R	**87.6 Ml/d**	**274.1 Ml/d**

Figure 12 - Abstraction and A%R for Main River Colne (locations shown in Figure 13)

Note: each yearly A%R is abstraction ÷ average annual recharge 1920-2019, not recharge for that year

Most of the main River Colne abstractions are in the valley bottom between Watford and Denham. For the whole catchment down to Denham, including the tributaries, abstraction has been around 60-70% of recharge throughout the last 20 years. The total abstraction above Watford (Berrygrove GS), including the tributaries, has been about 45-50% of recharge. The approximate locations of the public water supply abstractions in the main River Colne valley are shown in Figure 13:

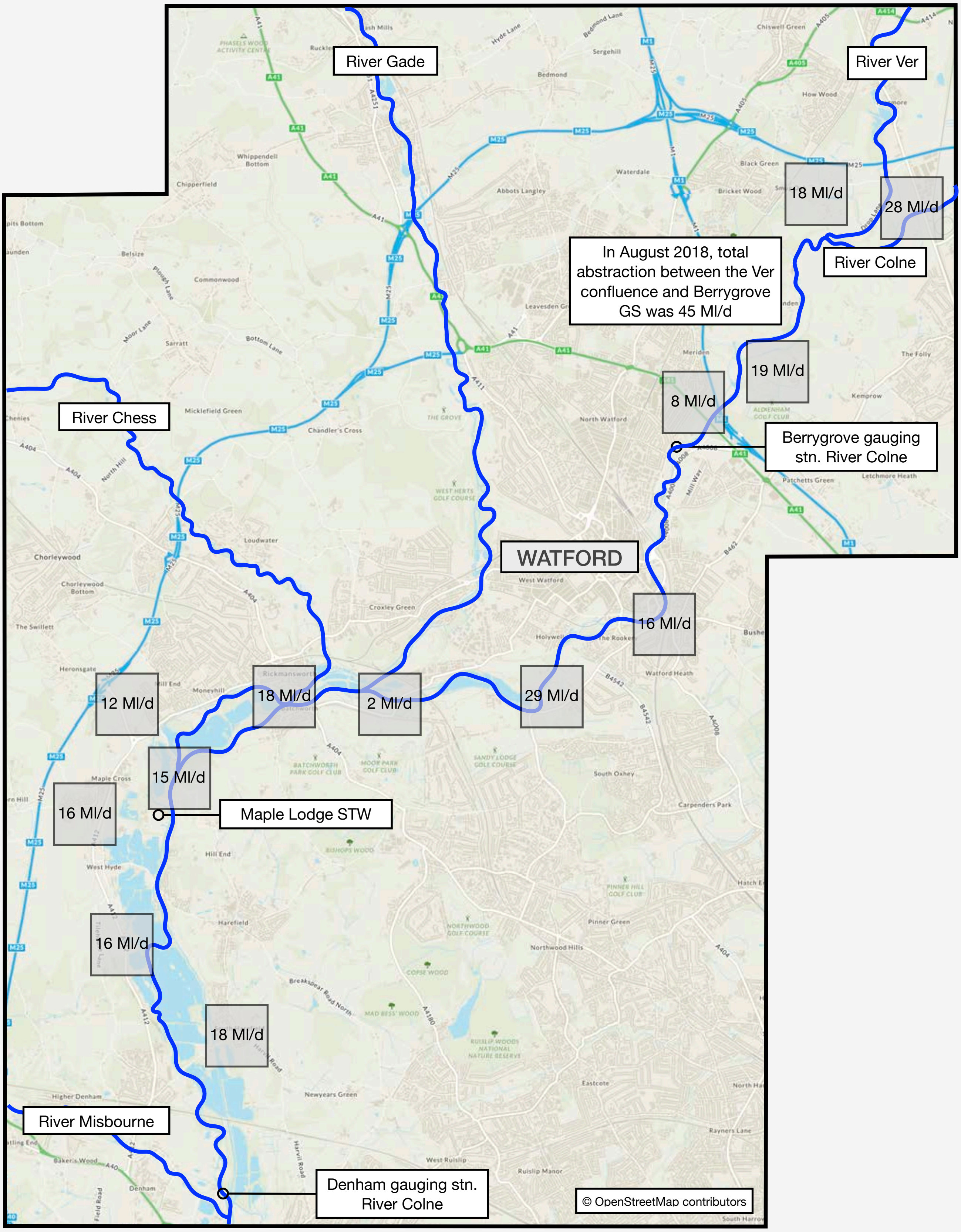


Figure 13 – Approximate locations of abstractions in main River Colne valley

Although the total groundwater abstraction in the Colne catchment above Denham is over 60% of total catchment recharge, about half comes from the valley bottom abstractions between Watford and Denham (shown on Figure 13) where the River Colne weaves between the gravel pits and must be hydraulically connected to them. The river also forms part of the Grand Union Canal for a lot of this reach and is classified as Heavily Modified from downstream of the Gade confluence. Flows at Denham are supported by effluent from Maple Lodge STW which returns much of the water abstracted further up the Colne catchment.

In December 2020, the EA provided detailed data on their assessment of the acceptability of flows in the Colne and Lea catchments in file *'Chilterns Flow Deficits 2020.xlsx'.* The EFI deficit data were mostly the same as the more recent data provided for comparison with the A%R assessment (a few small differences), but full detail was provided for the deficit calculation. The calculation took account of groundwater and surface water abstractions, and made allowance for STW effluent returns.

Table 5 compares the EA's detailed assessment for the Colne with the A10%R assessment based on limiting abstraction to 10% of average recharge:

	Environment Agency assessment							A%R Assessment			
River Assessment Point	Calculated Natural Low Flow (Q95)	Estimated sustainable low flow (EFI)	Recent Actual Q95 Flow	Surface water Abstraction	Cumulative Discharges	Flow Deficit to EFI at low flow (Q95)	Groundwater Abstraction impact on Flow	Catchment area	Average Recharge	Upstream abstraction in 2017-19	Over-abstraction in 2017-19 based on A10%R
Upper Colne to Ver	EA assessment not available.							183 km2	118.5 Ml/d	41.5 Ml/d	29.6 Ml/d
Ver to Redbourn	5.6 Ml/d	5.1	0.0 Ml/d	0.0	0.7 Ml/d	5.1 Ml/d	7.4 Ml/d	63 km2	40.8 Ml/d	8.8 Ml/d	4.7 Ml/d
Lower Ver	39.7 Ml/d	33.8	9.1 Ml/d	0.0	0.7 Ml/d	24.7 Ml/d	31.3 Ml/d	132 km2	85.5 Ml/d	28.1 Ml/d	19.5 Ml/d
Upper Colne (to Watford)	96.2 Ml/d	81.8 Ml/d	3.9 Ml/d	0.0 Ml/d	21.2 Ml/d	77.9 Ml/d	113.5 Ml/d	352 km2	232.1 Ml/d	110.8 Ml/d	87.6 Ml/d
Upper Gade	17.6 Ml/d	15.0 Ml/d	4.3 Ml/d	0.0 Ml/d	0.0 Ml/d	10.7 Ml/d	13.3 Ml/d	48 km2	25.2 Ml/d	12.2 Ml/d	9.7 Ml/d
Bulbourne to Gade	16.4 Ml/d	14.8 Ml/d	13.8 Ml/d	2.2 Ml/d	7.0 Ml/d	1.0 Ml/d	7.4 Ml/d	66 km2	34.8 Ml/d	9.8 Ml/d	6.3 Ml/d
Lower Gade incl Bulbourne	98.0 Ml/d	83.3 Ml/d	37.8 Ml/d	10.4 Ml/d	9.2 Ml/d	45.5 Ml/d	59.0 Ml/d	184 km2	96.5 Ml/d	53.4 Ml/d	43.8 Ml/d
Chess	19.6 Ml/d	16.7 Ml/d	11.5 Ml/d	0.0 Ml/d	6.9 Ml/d	5.2 Ml/d	15.0 Ml/d	105 km2	67.3 Ml/d	16.5 Ml/d	9.8 Ml/d
Misbourne	12.6 Ml/d	10.7 Ml/d	0.0 Ml/d	0.0 Ml/d	0.0 Ml/d	10.7 Ml/d	14.7 Ml/d	95 km2	78.3 Ml/d	17.5 Ml/d	9.6 Ml/d
Middle Colne	312.6 Ml/d	265.7 Ml/d	136.9 Ml/d	15.8 Ml/d	143.1 Ml/d	128.8 Ml/d	303.0 Ml/d	743 km2	489.9 Ml/d	323.1 Ml/d	274.1 Ml/d
Lower Colne	371.9 Ml/d	334.7 Ml/d	130.0 Ml/d	48.7 Ml/d	152.0 Ml/d	204.7 Ml/d	326.6 Ml/d	Minimal GW abstraction downstream of Denham			

Table 5 - Comparison of EA and A%R assessment of acceptable abstraction for the Colne

Notes:

1. EA figures (in green) are as per file *'Chilterns Flow Deficits 2020.xlsx'*
2. A%R figures (in blue) are as per table in Appendix B
3. Upper Colne upstream of the Ver is chalk influenced but not a classic chalk stream

Table 5 shows that the EA's deficit analysis allows for surface water abstractions and STW effluents.

Extracting the figures for EFI deficits and A%R reductions from Table 5, and taking account of the A%R view of the lesser significance on chalk stream flows of the impacts of the abstractions in the middle/ lower Colne, it can be seen that there are substantial differences in the required amounts of abstraction reduction which are shown below:

River	2017-19 A%R	Reduction to meet A10%R	Reduction to meet EA's EFI
Ver	28%	20 Ml/d	25 Ml/d
Bulbourne	28%	6.3 Ml/d	0 Ml/d
Upper Gade	48%	9.7 Ml/d	11 Ml/d
Chess	21%	10 Ml/d	5 Ml/d
Misbourne	25%	10 Ml/d	11 Ml/d
Total for tributary chalk streams		**56 Ml/d**	52 Ml/d
Lower Gade	87%	28 Ml/d (or 0?)[1]	33 Ml/d
Upper Colne to Ver	30%	30 Ml/d (or 0?)[2]	not available[3]
Upper Colne to Watford	42%	38 Ml/d (or 0?)[4]	53 Ml/d[5]
Middle Colne to Denham	58%	0[6]	0[7]
Lower Colne to Thames	n/a	0[8]	65 Ml/d[7]
		152 Ml/d **(or 56 Ml/d?)**	203 Ml/d

Table 6 - Summary of comparison for Colne catchment

Notes on Table 6:

1. The Gade downstream of the Gade/Bulbourne confluence is a heavily modified channel, effectively a canal.
2. The Upper Colne is a chalk influenced stream, but the large abstractions at the Ver confluence may well impact flows in the Ver.
3. The EA's assessments of flow deficits are not available, but the hydrological regimes of the water bodies are classified as 'does not support good'.
4. If the Ver is reduced by 20 Ml/d and Upper Colne by 30 Ml/d, 38 Ml/d reductions are needed to get A10%R at Watford (88 – 20 – 30 = 38).
5. From Table 5, the EFI deficit due to abstraction in the main Colne valley to Watford is 78 – 25 = 53 Ml/d.
6. Colne below Watford is heavily modified and would benefit from 56 Ml/d tributary cuts upstream, so arguably no more needed.
7. If abstraction in the tributaries is reduced by 56 Ml/d and Upper Colne by 53 Ml/d, arguably no more reductions are needed for EFI at Denham.
8. There are minimal groundwater abstractions downstream of Denham.
9. Additional 65 Ml/d needed for EFI at Thames confluence (203 – 52 – 53 - 33 = 65)

The main difference between the outcomes of the EA and A%R assessment of reductions – total 203 Ml/d vs 152 Ml/d – is in the need to reduce the groundwater abstractions in the valley bottom of the heavily modified lower Colne downstream of Watford and in the lower Gade/Grand Union Canal.

Resolving the much publicised over-abstraction in the Ver, upper Gade/Bulbourne, Chess and Misbourne is arguably the main ecological priority in the Colne catchment. The cuts needed to achieve A10%R in the

Ver, upper Gade/Bulbourne, Chess and Misbourne are similar in total to the EA's deficits to EFI in these tributaries.

Arguably, the over-abstraction in the main River Colne is of a lower priority than the tributaries. In the Upper Colne above the Ver confluence, most of the abstraction is only just above the confluence, so the upper river above London Colney is little affected. Downstream of Watford, where the valley is highly developed and the river course is shared with the Grand Union Canal and winds between gravel pits, resolving over-abstraction might arguably offer limited benefit relative to the cost.

Therefore, it is suggested that there is no need to reduce abstraction from any of the main River Colne boreholes downstream of Watford shown in Figure 13, particularly as flows in the main river will benefit from the abstraction reductions in the tributary chalk streams. Arguably, if the abstractions in the tributary chalk streams are reduced, some of the replacement water could even come from increased abstraction from the main River Colne boreholes – ie shifting the abstraction downstream. This could be a less costly alternative to the Chalk Stream First proposal to bring all the replacement water from the River Thames via the lower Thames reservoirs. However, it would mean no benefit to river flows in the heavily modified reaches downstream of Watford.

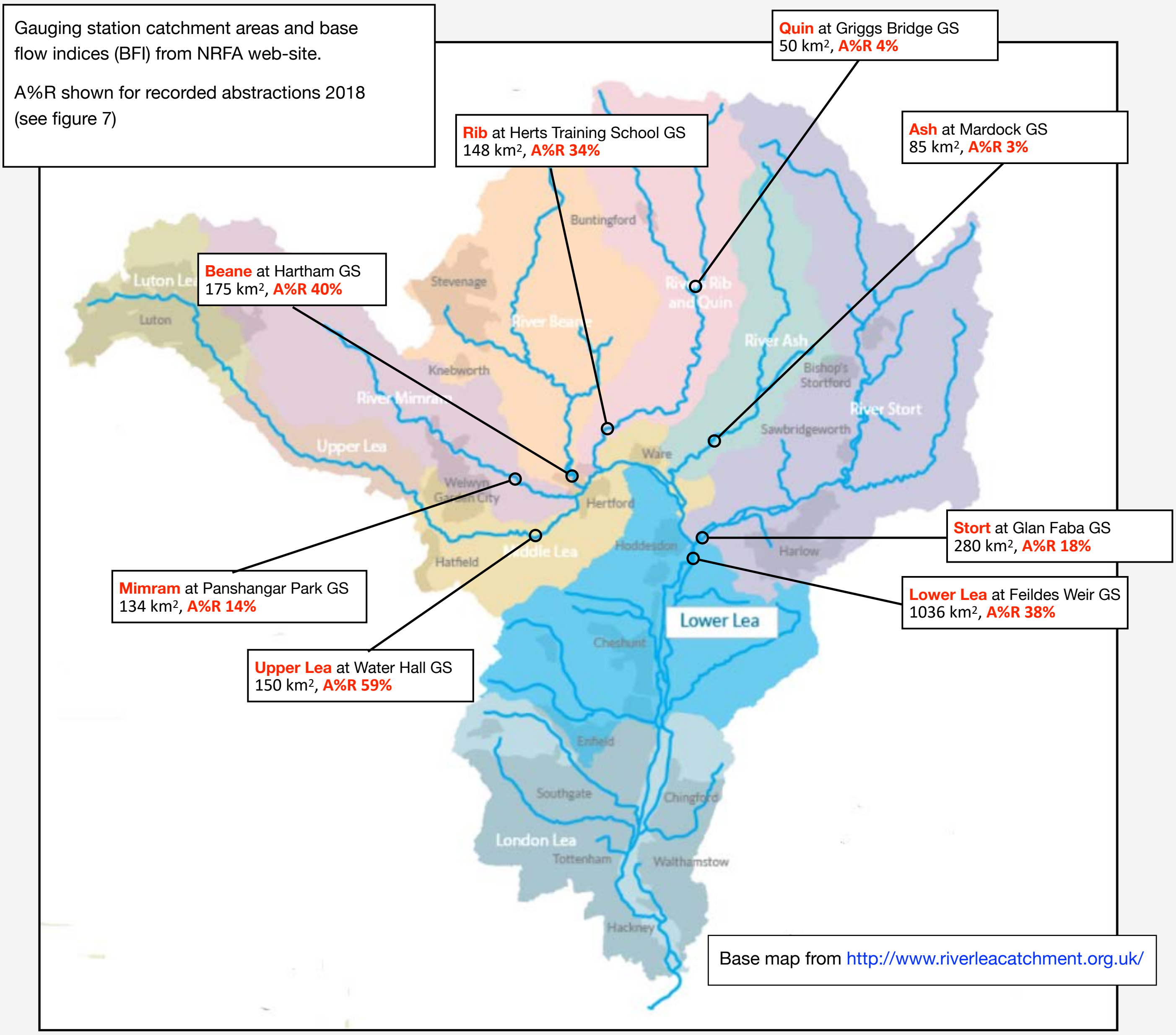
Assuming 18 Ml/d of reduced abstraction from the Ver catchment, achievement of A10%R at Watford (Berrygrove gauging station) would require an additional 66 Ml/d reduction in the four boreholes in the 5 km reach between the Ver confluence and Watford (see Figure 13). However, it is questionable whether this is worthwhile or even necessary for such a short reach, bearing in mind the improvement the Colne would get from reducing abstraction in the River Ver upstream.

In summary for the Colne catchment, although there is currently about 320 Ml/d of total groundwater abstraction in the Colne valley above Denham, with 58% of recharge abstracted, the great majority comes from boreholes in the valley bottom between the Ver confluence and Denham. Achievement of A10%R in the Misbourne, Chess, upper Gade/Bulbourne and Ver would only require about 56 Ml/d of abstraction reduction – far less than the 274 Ml/d reduction need to get A10%R at Denham (see table 5). The equivalent total EFI deficit for the Misbourne, Chess, upper Gade/Bulbourne and Ver is 52 Ml/d.

The main River Colne from the Ver confluence to Denham would benefit from abstraction reduction in the tributaries, so can be considered a lower priority for additional abstraction reduction.

3.3 The River Lea catchment

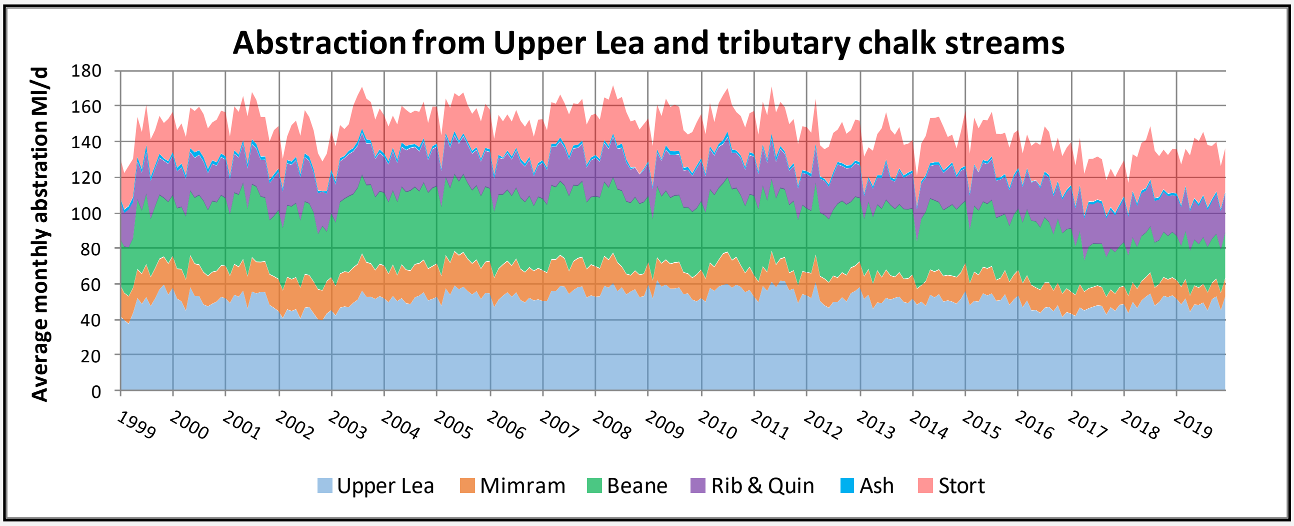
Figure 14 shows the location of the A%R assessments for the River Lea and its main tributaries.



	Upper Lea (to Water Hall GS)	Upper Lea to Luton Hoo	Mimram	Beane	Rib & Quin	Quin	Ash	Stort	Upper Stort to Bishops Stortford	Lea tribs and Upper Lea	All Lea to Feildes Weir
Catchment area	150 km2	65 km2	136 km2	175 km2	152 km2	50 km2	89 km2	280 km2	60 km2	982 km2	1036 km2
Baseflow index	0.82	0.64	0.93	0.76	0.60	0.45	0.55	0.48			0.6
Av. annual recharge	82.0 Ml/d	35.5 Ml/d	74.4 Ml/d	61.9 Ml/d	68.1 Ml/d	22.4 Ml/d	39.9 Ml/d	135.5 Ml/d	29.0 Ml/d	461.8 Ml/d	452.4 Ml/d
Abstraction in 2017-19	48.4 Ml/d	32.9 Ml/d	10.4 Ml/d	24.9 Ml/d	22.9 Ml/d	0.9 Ml/d	1.2 Ml/d	25.0 Ml/d	12.2 Ml/d	132.8 Ml/d	173.5 Ml/d
A%R in 2017-19	59.0%	92.5%	13.9%	40.3%	33.6%	4.2%	3.1%	18.5%	41.9%	28.8%	38.4%
Reduction to achieve A10%R	40.2 Ml/d	29.3 Ml/d	2.9 Ml/d	18.7 Ml/d	16.1 Ml/d	0.0 Ml/d	0.0 Ml/d	11.5 Ml/d	9.3 Ml/d	86.6 Ml/d	128.3 Ml/d
GW consumptive licence total	82.9 Ml/d	55.0 Ml/d	19.2 Ml/d	28.7 Ml/d	28.7 Ml/d	1.4 Ml/d	4.8 Ml/d	35.6 Ml/d	19.1 Ml/d	200.0 Ml/d	242.2 Ml/d
Licence A%R	101.1%	154.7%	25.9%	46.4%	42.2%	6.1%	11.9%	26.3%	65.7%	43.3%	53.5%
Licence reduction for A10%R	74.7 Ml/d	51.4 Ml/d	11.8 Ml/d	22.5 Ml/d	21.9 Ml/d	0.0 Ml/d	0.8 Ml/d	22.1 Ml/d	16.2 Ml/d	153.8 Ml/d	196.9 Ml/d

Figure 14 - A%R in the River Lea and its chalk stream tributaries

Abstraction in the Lea chalk stream tributaries and its percentage of recharge are shown in Figure 15:



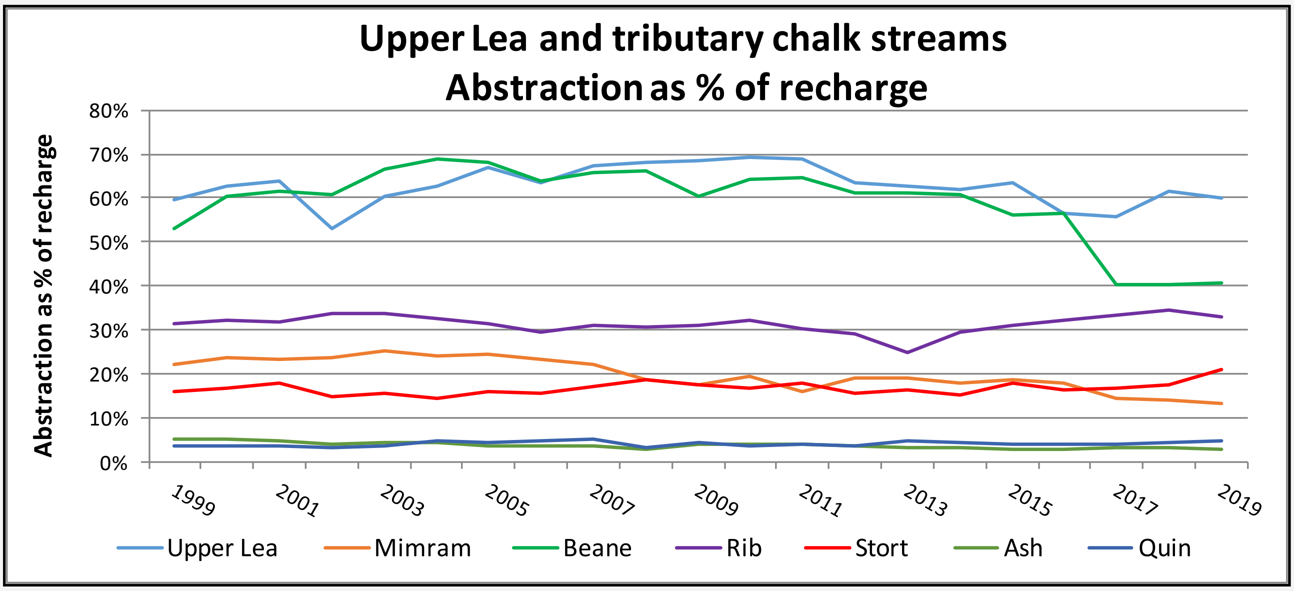


Figure 15 - Abstraction and A%R in the Lea chalk streams

Note: each yearly A%R is abstraction ÷ average annual recharge 1920-2019, not recharge for that year.

There is a wide variation in the intensity of groundwater abstraction in the various catchments. It is less than 5% in the Ash and Quin, now only just over 10% in the Mimram, about 20% in the lower Stort, but much higher in the Upper Stort, Rib, Beane and, especially, the Upper Lea above the Mimram confluence. Abstraction in the Beane has reduced substantially in the past 5 years, but A%R is still about 40%.

For the Lea catchment as a whole, down to below the Stort confluence at Feildes Weir, the total groundwater abstraction of 201 Ml/d in 2018 was 38% of the total catchment average recharge.

Abstraction in the Upper Lea (and possibly the Mimram and Ver) is dominated by a large abstraction (28 Ml/d in 2018) in Luton close to the top of the catchment. The location of the main abstractions in the Upper Lea, Mimram and Ver are shown on Figure 16:

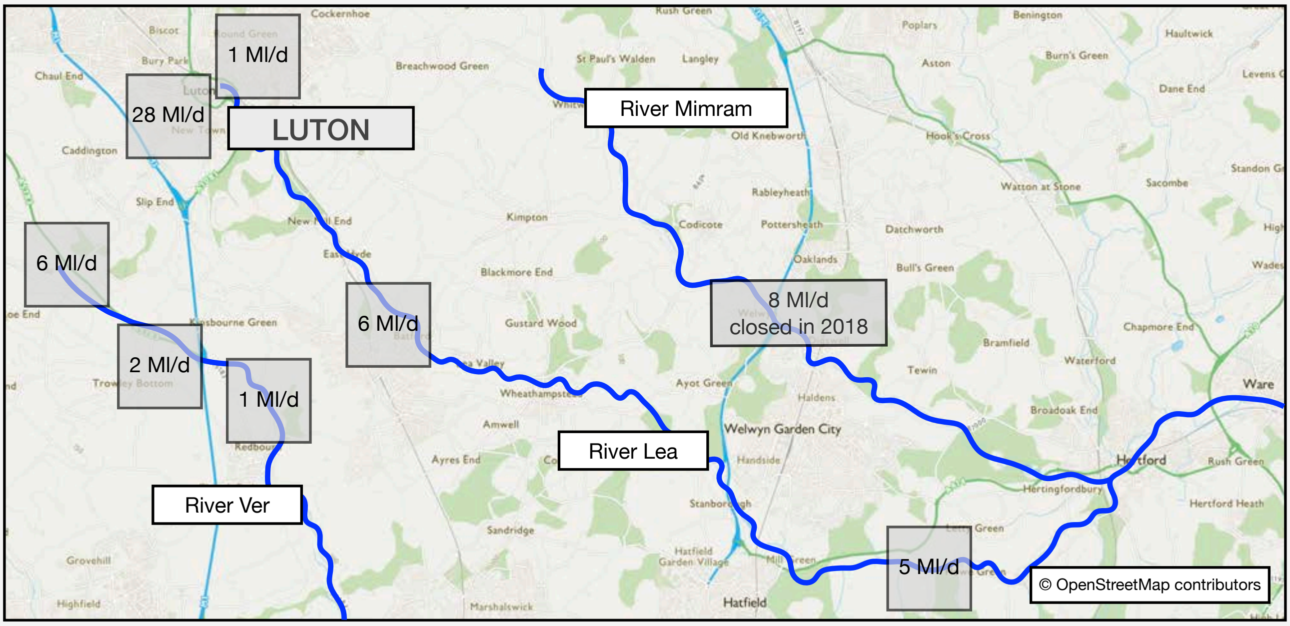


Figure 16 - Location of main abstractions in the Upper Lea, Upper Mimram and Upper Ver

Showing abstractions in 2018

The proximity of the Upper Mimram and Upper Ver suggests both streams could be affected by lowering of the water table due to the large abstraction at Luton. Flows in the Upper Lea, Upper Mimram and Upper Ver are compared in Figure 17:

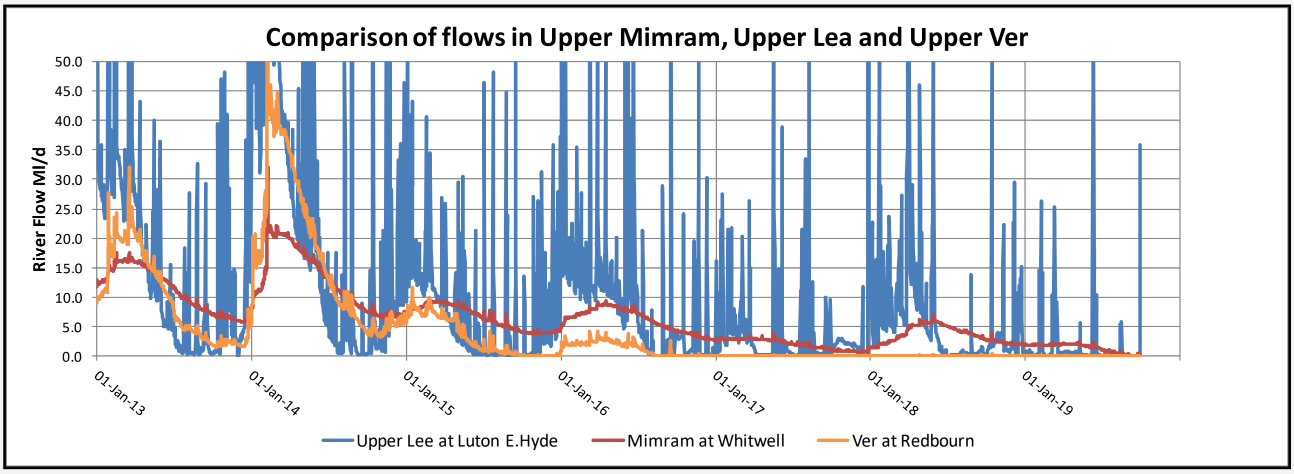


Figure 17 - Comparison of flows and drying in the Upper Lea, Mimram and Ver

Catchment areas: Lea at E.Hyde 71 km², Mimram at Whitwell 39 km², Ver at Redbourn 49 km²

Some observations from Figure 17 are:

1. The Upper Lea is flashier than the Ver and Mimram (the base-flow index at East Hyde is only 0.48).
2. The Upper Lea dries at roughly similar periods to the Ver drying.
3. The Mimram dries much less than the Lea and Ver, although it is the smallest catchment.
4. The Mimram kept flowing through 2017-2019, when the Ver was mostly dry at Redbourn.

On the basis of the gauged flows, the Mimram appears to have been less affected by abstraction than the Upper Lea and Upper Ver. This suggests that flows in the Mimram may not be as affected by the 28 Ml/d abstraction at Luton, which is only about 8km away.

Some observed and modelled GWLs in the Upper Lea, Mimram and Ver catchments under average conditions are shown on Figure 18:

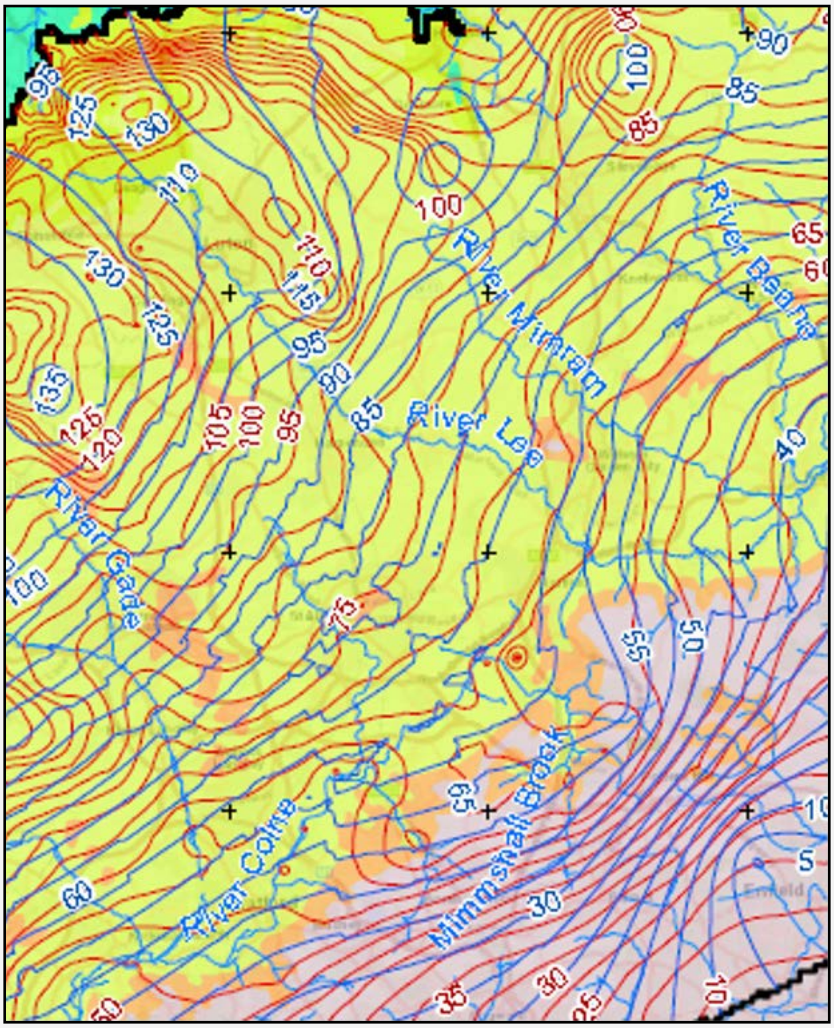


Figure 18 - Modelled and observed GWLs in Upper Lee, Mimram and Ver catchments

Map and GWLs copied from Map 41 in Mott MacDonald 2019 report on Hertfordshire groundwater model

Interpolated observed contours (mAOD)

Hertfordshire model contours (mAOD)

The observed and modelled GWLs show the continuity of the water table across the Gade, Ver, Lea, Mimram and Beane catchments. The modelled GWL contours around the Crescent Road pumping station provide evidence of the local cone of depression around the borehole, but give no indication of the changes in level of the regional water table.

Overall, the observed records of river flows and groundwater levels do not provide conclusive evidence of whether or not the large abstraction at Luton affects the adjoining Ver and Mimram catchments. If it does, the values of A%R for the individual catchments could be unreliable measures of the need for abstraction reduction in each catchment. This emphasises the need to consider abstraction reduction for the regional aquifer as a whole, as well as for each catchment.

The table on Figure 14 shows that a total reduction in abstraction of 87 Ml/d would be needed to achieve A10%R in the chalk tributaries, mostly in the Upper Lea, Beane, Rib and upper Stort. There is no reduction required for the Ash and Quin.

This analysis shows that only a 2 Ml/d reduction is needed for the Mimram in which the recent abstractions have been a total of about 10 Ml/d (approximate locations on Figure 16). The Lea partnership web-site describes plans to reduce abstraction in the Mimram as follows:*

> *“Affinity Water's latest business case includes closing Fulling Mill PS in 2018 and reducing Digswell PS to 2.5 Ml/d. This was approved by Ofwat in April 2014 and the abstraction licences have now been revoked. This will make a significant difference to the flow of the river.”*

Reduction of the Digswell abstraction from 8 Ml/d to 2.5 Ml/d would appear to take the A%R well below 10%. However, the EA’s considered need for more reduction in abstraction from the Mimram could be because flows are being affected by large abstractions in the adjacent Upper Lea and Beane catchments. This again suggests that abstraction reductions in the Lea valley should be considered for the catchment as a whole rather than piecemeal for each tributary (the same applies to the Colne tributaries).

There are some large groundwater abstractions in the valley of the River Lea between Hertford and the River Stort confluence, as shown on Figure 19:

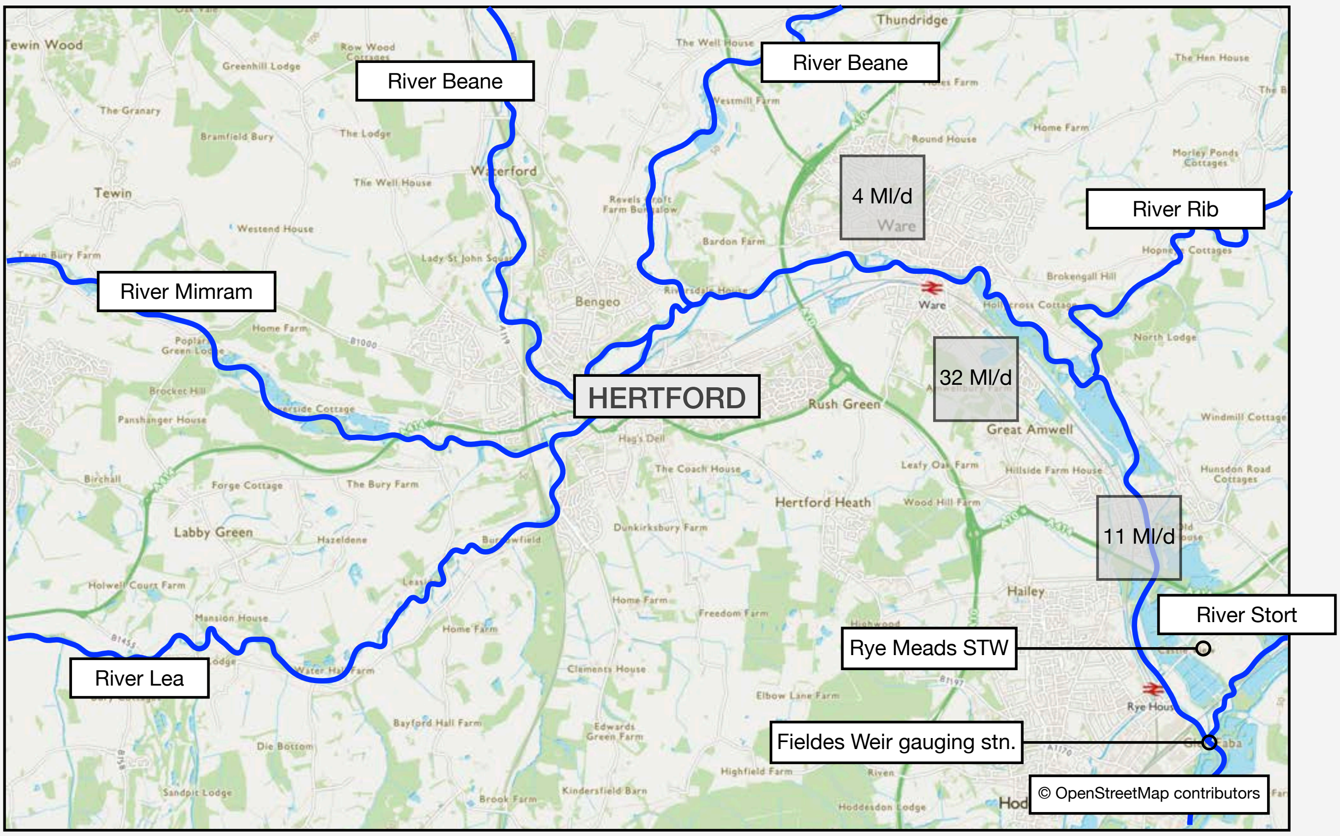


Figure 19 – Approximate location of abstractions in the lower Lea valley

Achievement of A10%R for the whole Lea valley down to Feildes weir would require these abstractions to be reduced entirely in addition to the 87 Ml/d reduction in the chalk tributaries. However, the River Lea downstream of the chalk tributaries is classed as heavily modified, is intertwined with the canal and increasingly urbanised. The WFD water body is described as the ‘Lee Navigation’. Reductions in abstractions in the lower river are arguably of a lower priority, especially bearing in mind the considerable river flow increases that would arise from the reductions in abstraction in the chalk tributaries upstream.

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* http://www.riverleacatchment.org.uk/index.php/river-mimram-cmp/river-mimram-projects/52-stop-the-abstraction

Arguably, the water supplies lost from reduced abstractions in the Lea chalk tributaries could be replaced by increased abstraction from the lower reaches, either boreholes or surface flows as per the Chalk Streams First proposal.

The make-up of the EA's assessed Lea catchment EFI flow deficits is shown in their file *'Chilterns Flow Deficits 2020.xlsx', provided in December 2020.* Table 7 compares the EA's assessment with the assessment based on limiting abstraction to 10% of average recharge:

	Environment Agency assessment							A%R Assessment			
River Assessment Point	Calculated Natural Low Flow (Q95)	Estimated sustainable low flow (EFI)	Recent Actual Q95 Flow	Surface water Abstraction	Cumulative Discharges	Flow Deficit to EFI at low flow (Q95)	Groundwater Abstraction impact on Flow	Catchment area	Average Recharge	Upstream abstraction in 2017-19	Over-abstraction in 2017-19 based on A10%R
Lee to Luton Hoo	24.4 Ml/d	21.9 Ml/d	0.0 Ml/d	0.0 Ml/d	0.0 Ml/d	21.9 Ml/d	28.4 Ml/d	65 km2	35.5 Ml/d	32.9 Ml/d	29.3 Ml/d
Lee to Water Hall	43.1 Ml/d	36.6 Ml/d	36.0 Ml/d	0.0 Ml/d	40.0 Ml/d	0.6 Ml/d	47.1 Ml/d	150 km2	82.0 Ml/d	48.4 Ml/d	40.2 Ml/d
Upper Mimram	4.0 Ml/d	3.6 Ml/d	0.2 Ml/d	0.0 Ml/d	0.5 Ml/d	3.4 Ml/d	4.3 Ml/d	49 km2	26.8 Ml/d	2.5 Ml/d	0.0 Ml/d
Lower Mimram	46.8 Ml/d	42.1 Ml/d	29.2 Ml/d	0.0 Ml/d	0.5 Ml/d	12.9 Ml/d	18.1 Ml/d	136 km2	74.4 Ml/d	10.4 Ml/d	2.9 Ml/d
Stevenage Brook	1.4 Ml/d	1.2 Ml/d	1.2 Ml/d	0.0 Ml/d	0.0 Ml/d	0.0 Ml/d	0.2 Ml/d	39 km2	21.3 Ml/d	5.0 Ml/d	2.8 Ml/d
Beane	42.7 Ml/d	36.3 Ml/d	25.3 Ml/d	0.0 Ml/d	0.7 Ml/d	11.0 Ml/d	18.1 Ml/d	175 km2	61.9 Ml/d	24.9 Ml/d	18.7 Ml/d
Upper Rib	15.7 Ml/d	14.1 Ml/d	11.0 Ml/d	0.0 Ml/d	2.2 Ml/d	3.1 Ml/d	6.9 Ml/d	51 km2	17.9 Ml/d	3.0 Ml/d	1.2 Ml/d
Lower Rib	14.2 Ml/d	12.7 Ml/d	3.4 Ml/d	0.0 Ml/d	2.2 Ml/d	9.3 Ml/d	13.0 Ml/d	152 km2	68.1 Ml/d	22.9 Ml/d	16.1 Ml/d
Ash	10.4 Ml/d	8.9 Ml/d	3.9 Ml/d	0.0 Ml/d	0.7 Ml/d	5.0 Ml/d	7.2 Ml/d	89 km2	39.9 Ml/d	1.2 Ml/d	0.0 Ml/d
Upper Stort to Bishop Stortford	1.7 Ml/d	1.4 Ml/d	0.6 Ml/d	0.0 Ml/d	0.5 Ml/d	0.8 Ml/d	1.6 Ml/d	60 km2	29.0 Ml/d	12.2 Ml/d	9.3 Ml/d
Lower Stort	17.9 Ml/d	14.3 Ml/d	14.4 Ml/d	0.7 Ml/d	17.5 Ml/d	0.0 Ml/d	20.3 Ml/d	280 km2	135.5 Ml/d	25.0 Ml/d	11.5 Ml/d
Rye Bridge	230.6	196.0 Ml/d	37.0 Ml/d	83.0 Ml/d	44.0 Ml/d	159.0 Ml/d	154.6 Ml/d	756 km2	461.8 Ml/d	132.8 Ml/d	86.6 Ml/d
Feildes Weir	279.9	223.9 Ml/d	98.4 Ml/d	136.8 Ml/d	135.7 Ml/d	125.5 Ml/d	180.4 Ml/d	1036 km2	452.4 Ml/d	173.5 Ml/d	173.5 Ml/d
Lower Lee	419.1	335.3 Ml/d	145.5 Ml/d	414.4 Ml/d	323.1 Ml/d	189.8 Ml/d	182.3 Ml/d				

Table 7 - Comparison of EA and A%R assessment of acceptable abstraction for the Lea

Notes:
1. EA figures (in green) are as per file *'Chilterns Flow Deficits 2020.xlsx'*
2. A%R figures (in blue) are as per table in Appendix B, but adjusted to match EA assessment points

Extracting the figures for EFI deficits and A%R reductions from Table 8, and taking account of the A%R view of the insignificance of the impacts of the abstractions in the middle/lower Colne, it can be seen that there are some substantial differences in the required amounts of abstraction reduction which are shown below:

River	2017-19 A%R	Reduction to meet A10%R	Reduction to meet EA's EFI
Upper Lea to Water Hall	59%	40 Ml/d	1 Ml/d
Mimram	14%	3 Ml/d	13 Ml/d
Beane	40%	19 Ml/d	11 Ml/d
Rib/Quin	34%	16 Ml/d	9 Ml/d
Ash	3%	0 Ml/d	5 Ml/d
Stort	18%	11 Ml/d	0 Ml/d
Total for tributary chalk streams		87 Ml/d	39 Ml/d
Main Lea (excl. tribs) Hertford to Feildes Weir	38%	0[1]	87 Ml/d[2]
Total incl Main Lea		87 Ml/d	126 Ml/d[7]

Table 8 - Summary of comparison for Lea catchment

Notes on above table:

1. The Lea below Hertford, a waterbody termed ‘Lea navigation’, is heavily modified and would benefit from 87 Ml/d reductions in the tributaries upstream.

2. From Table 7 the EFI deficit due to abstraction in the main Lea to Feildes Weir, including some surface water abstractions is 126 – 39 = 87 Ml/d.

As for the Colne catchment, there are some big difference in the reductions for individual streams and apparently anomalous aspects of the EFI assessments:

• the EA’s assessment of the deficit in the Upper Lea to Howe Green allows for 40 Ml/d of effluent returns. The A%R methodology does not allow for effluent returns on the grounds that the ecological objective for flows is to re-naturalise groundwater-fed river flows

• the EA’s assessed deficit of 13 Ml/d for the lower Mimram exceeds the recent abstraction of only 10 Mld. This apparent anomaly could be due to the EA assuming a higher recent actual abstraction (perhaps not taking account of the closure of the Fulling Mill abstraction in 2017)

• the EA’s assessment of zero deficit for the Stort allows for 17 Ml/d of effluent returns

Overall, there is a 39 Ml/d difference in the EA and A%R assessments of the required reduction in abstraction in the Lea valley. Most of this difference is due to the EA’s adjudged need to reduce groundwater abstraction in the heavily modified parts of the Lower Lea, while requiring less reduction in the upper Lea and tributaries because the EA methodology allows for STW effluents. It would appear much preferable to reduce the abstractions in the upper Lea and tributaries, which would also benefit flows below Hertford.

3.5 The River Darent catchment

Figure 20 shows the locations of the A%R assessments for the Rivers Darent and Cray (upstream abstractions are average for 2017/19):

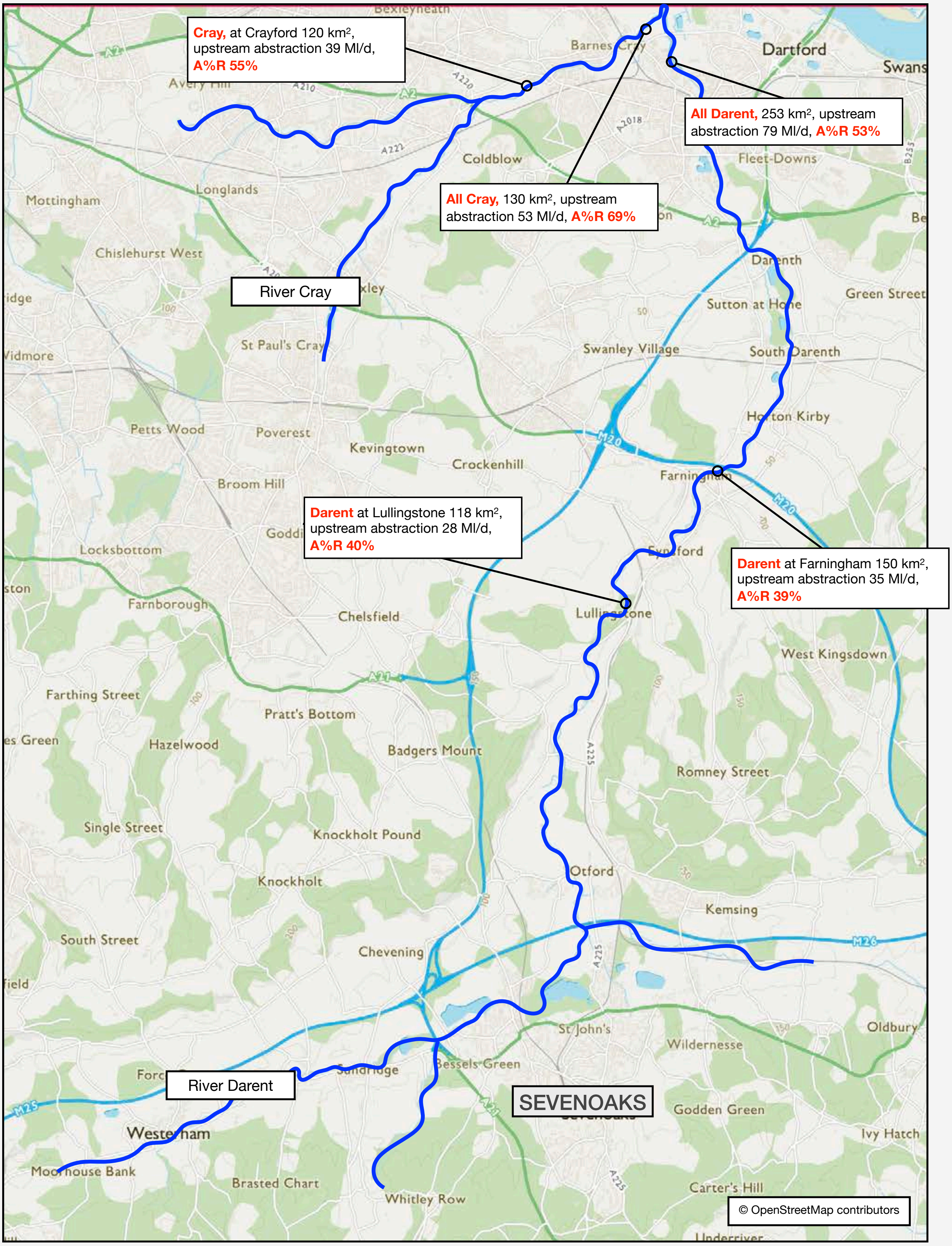


Figure 20 - Location of A%R assessments for the Rivers Darent and Cray

Annual abstractions and A%R values at these locations are shown in Figure 21:

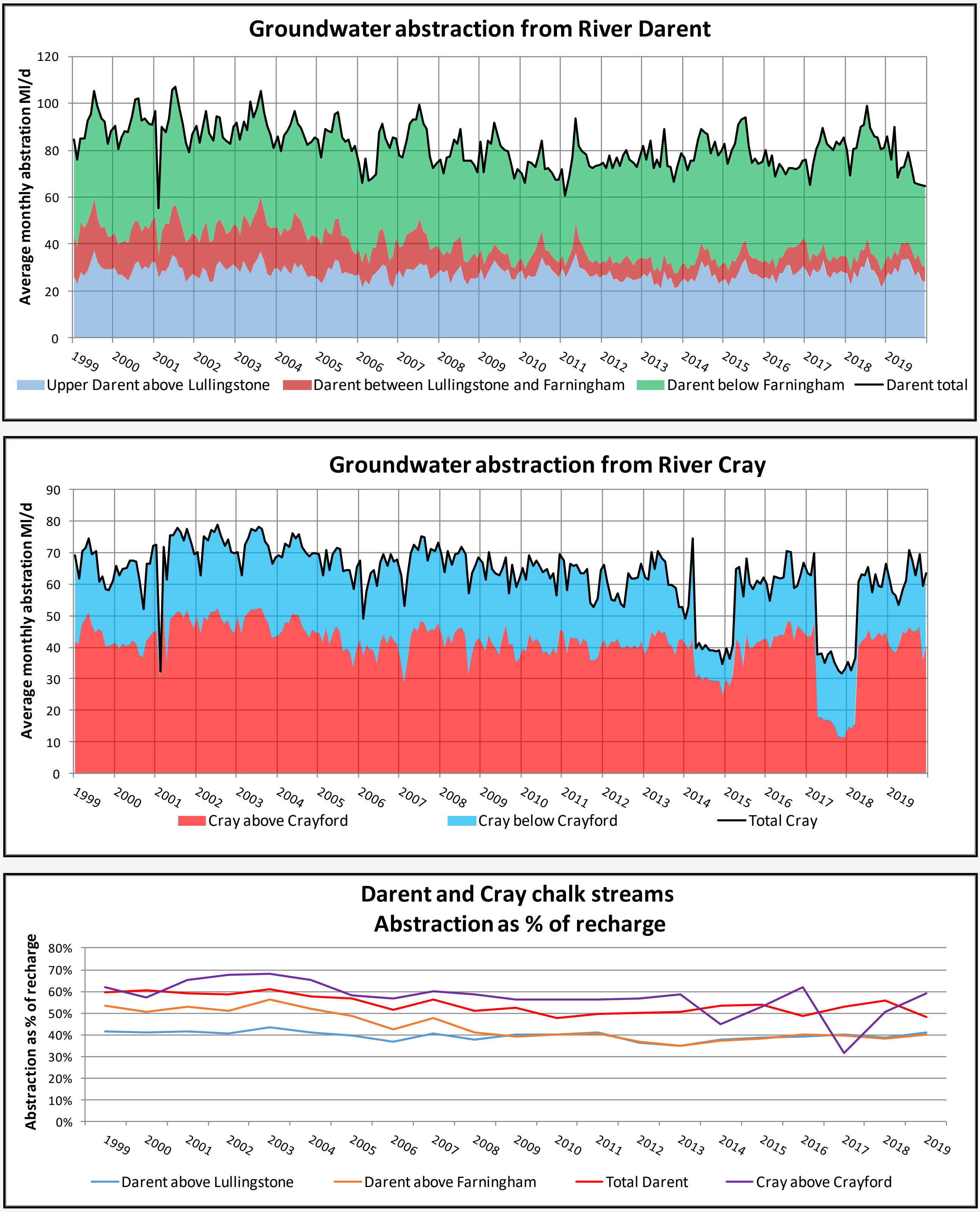
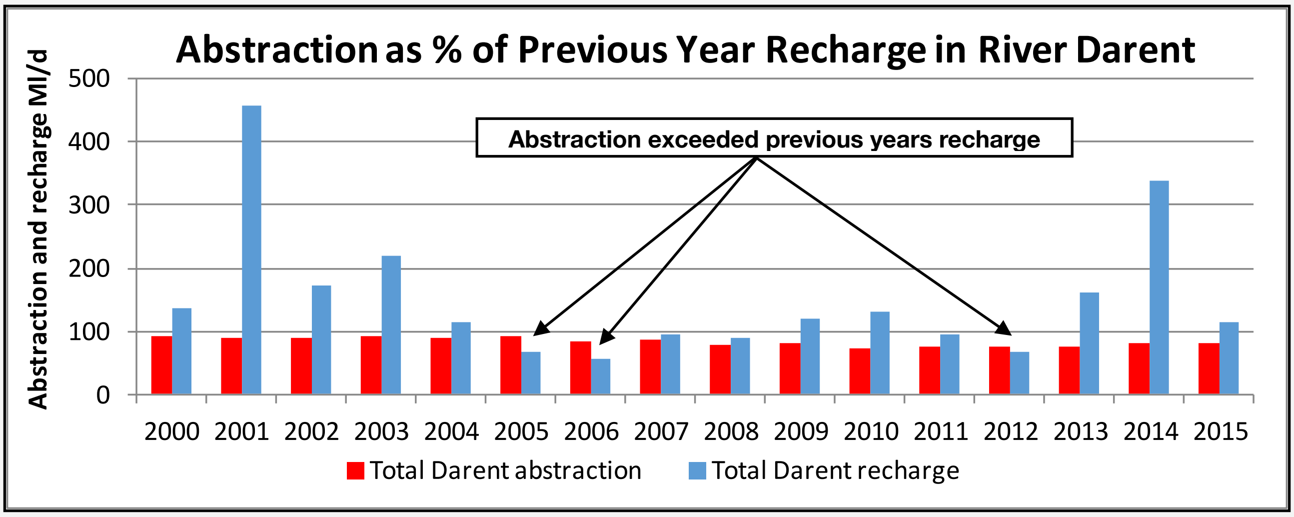


Figure 21 - Annual abstraction and A%R for the Rivers Darent and Cray

Note: each yearly A%R is abstraction ÷ average annual recharge 1920-2019, not recharge for that year.

Although there have been slight reductions in abstraction from both the Darent and Cray over the past 20 years, the percentage of annual average recharge abstracted remains amongst the highest in the country (see Figure 5). The abstraction in the upper Darent above Lullingstone, the most environmentally sensitive part in the AONB, has remained more or less constant throughout the period.

The A%R values shown on Figure 21 are percentages of average annual recharge, not recharge in each particular year. This means that in drought years the abstraction has exceeded the aquifer recharge as shown in Figure 22:



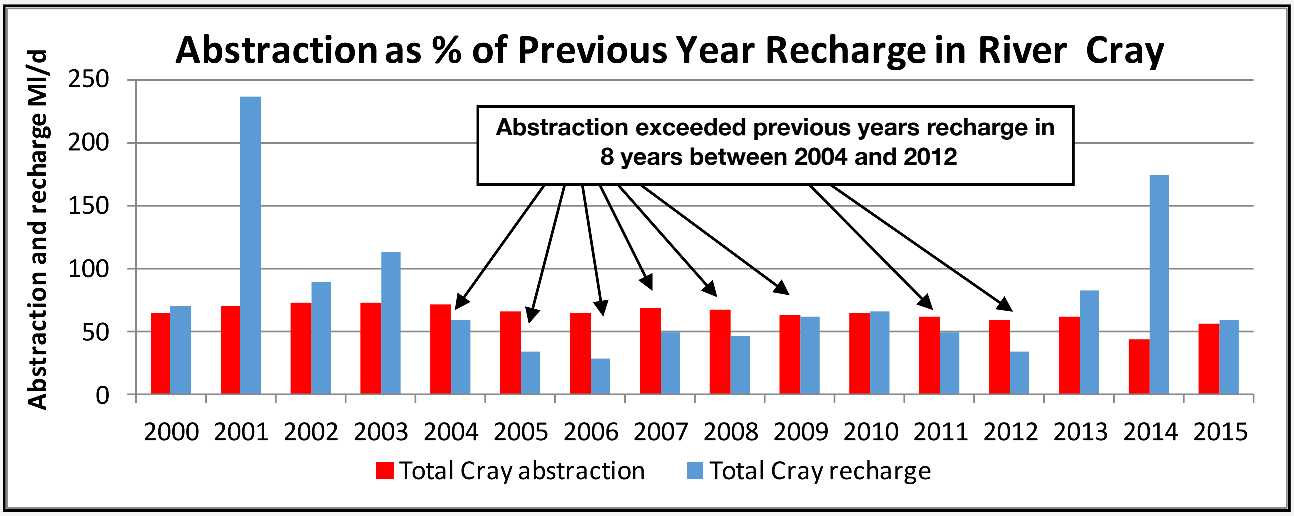


Figure 22 - Abstraction as % of previous year's recharge for Darent and Cray

Note: previous year recharge is previous year's October to current year's September

Over the past 30 years, there have been various measures to mitigate over-abstraction in the Darent and Cray catchments, including some abstraction licence reductions, actual abstraction reductions, seasonal variations in abstraction, pumping groundwater back into the river via artificial springs in dry periods and even cutting down bank-side trees to reduce take-up of water.

For example, the changes in Thames Water's licensed and actual annual abstractions are shown in Figure 23 on the following page.

Although the reductions in abstraction have been substantial, the overall amounts of abstraction and A%R remain so high that the river is still grossly over-abstracted. With abstraction exceeding recharge in dry years, it is inevitable that total drying of the river will still be far more widespread than the natural drying of winterbourne sections. It is not surprising that the efforts to mitigate over-abstraction in the Darent and Cray have been perceived as having disappointingly little effect.

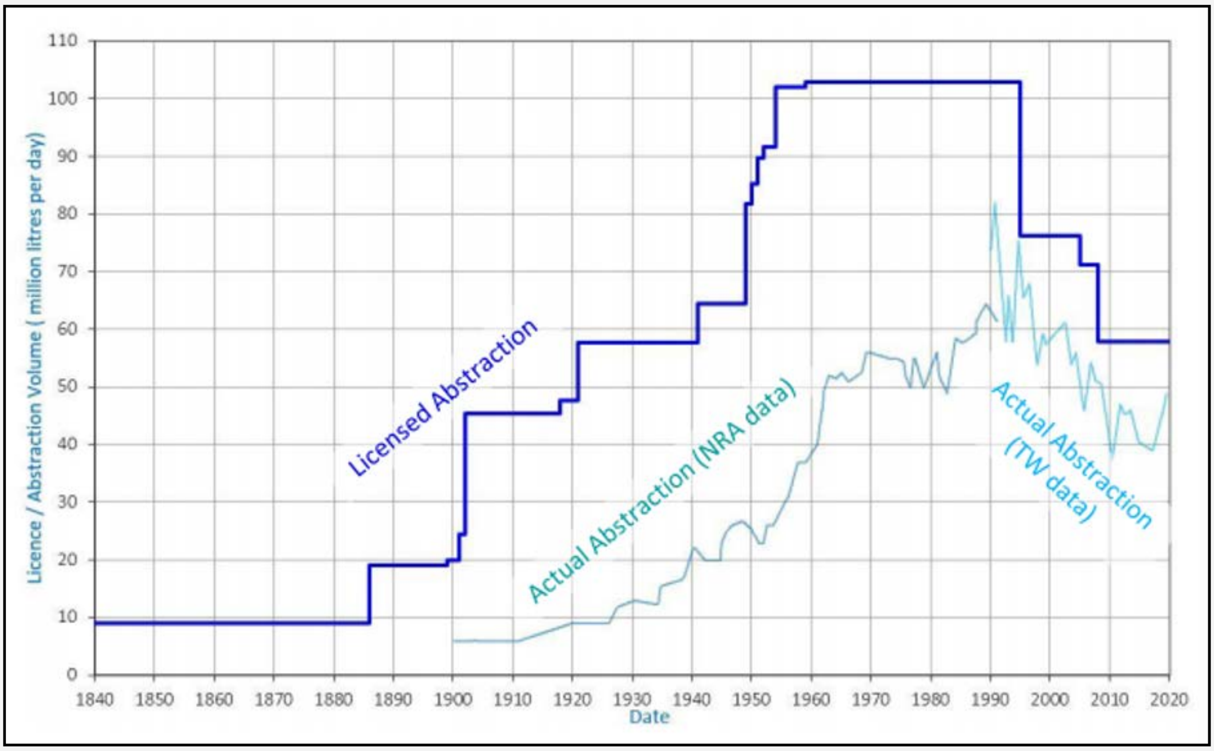


Figure 23 - Changes in Darent actual and licensed abstraction over past 180 years

Source: Thames Water presentation to DRPS AGM in 2019

The EA's EFI quoted flow deficits are only 4 Ml/d for the Upper Darent, 12 Ml/d for the Lower Darent (including the upstream figure) and 19 Ml/d for the River Cray.

River	2017-19 A%R	Reduction to meet A10%R	Reduction to meet EA's EFI
Total Darent	52.5%	64.2 Ml/d	12 Ml/d
Total Cray	69%	46 Ml/d	19 Ml/d
Total Darent/Cray	58%	110 Ml/d	31 Ml/d

Table 9 - Summary of comparison for Darent/Cray

The EA has explained that their deficits are capped if the abstraction exceeds the natural Q95 flow:

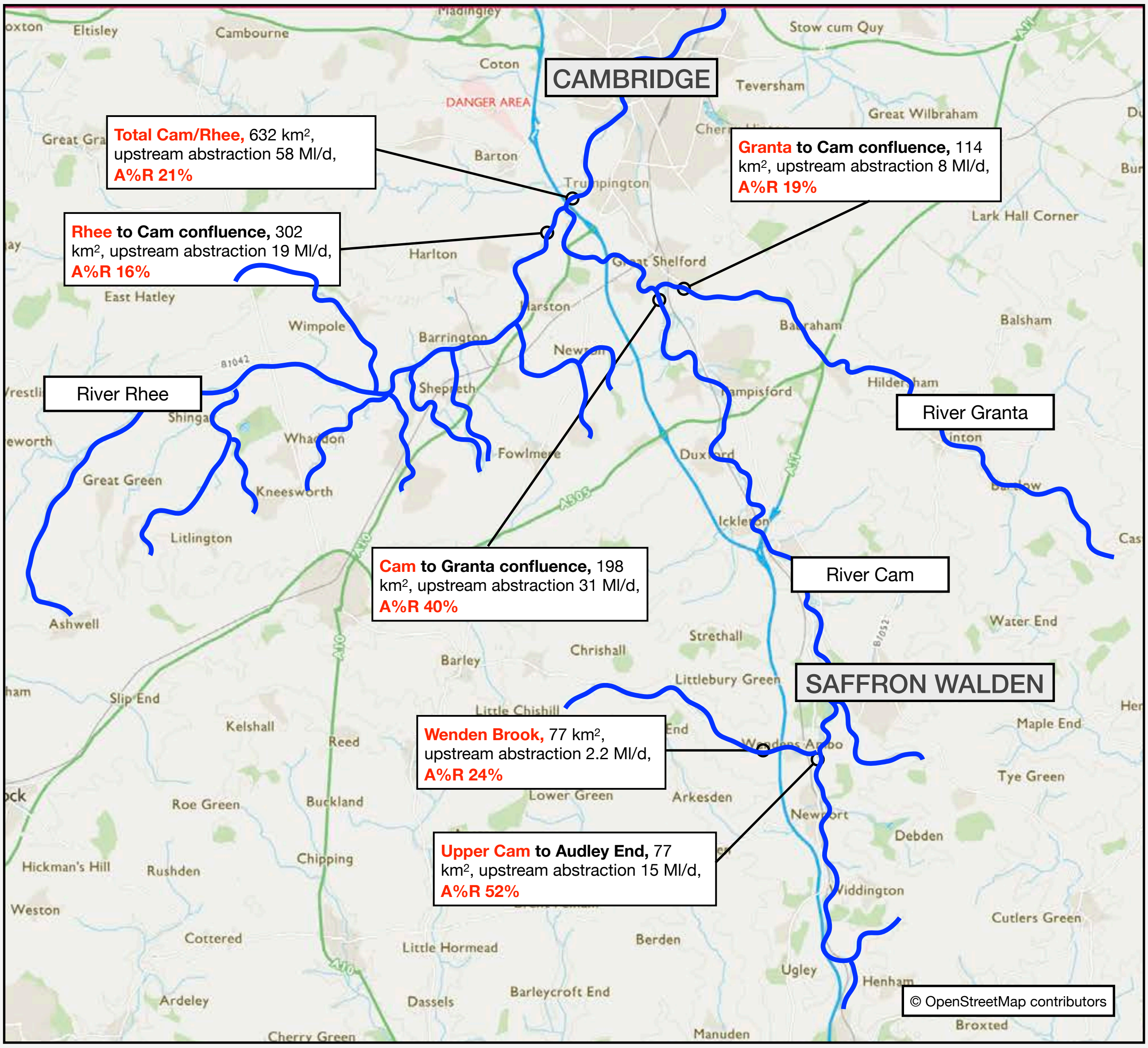
"Where the net abstraction for a water body exceeds the natural flow, the net abstraction/impact is capped to prevent the scenario flows falling below 0, resulting in what we call a modified net impact. If net abstraction doesn't exceed natural flows then the modified net impact will be equal to the sum of the upstream artificial influences."

Therefore, the EA flow deficits for the Darent and Cray are not comparable with the required reductions in abstraction to achieve A10%R. However, the EA says that it does further investigations in these situations and does not rely on one tool to understand the abstraction pressure.

Based on the A%R assessment the deficits to natural flow in the Darent and Cray are considerable and far greater than the EFI assessment and its 'modified net impact' would imply.

3.6 The River Cam catchment

Figure 24 shows the locations of the A%R assessments for the River Cam and its chalk stream tributaries (upstream abstractions are average for 2017/19):



	Cam above Audley End	Wenden Brook	All Cam/Wenden to Audley End	All Cam to Granta	Granta	Rhee	All Cam to below Rhee confl
Catchment area	77 km2	24 km2	101 km2	198 km2	114 km2	303 km2	632 km2
Baseflow index	0.66			0.76	0.58	0.74	
Av. annual recharge	29.7 Ml/d	9.0 Ml/d	38.7 Ml/d	75.9 Ml/d	43.7 Ml/d	116.2 Ml/d	242.3 Ml/d
Abstraction in 2017-19	15.3 Ml/d	2.2 Ml/d	17.5 Ml/d	30.7 Ml/d	8.3 Ml/d	19.0 Ml/d	58.1 Ml/d
A%R in 2017-19	51.6%	24.2%	45.2%	40.5%	19.0%	16.4%	24.0%
Reduction to achieve A10%R	**12.3 Ml/d**	**1.3 Ml/d**	**13.6 Ml/d**	**23.2 Ml/d**	**3.9 Ml/d**	**7.4 Ml/d**	**33.8 Ml/d**
GW consumptive licence total	23.7 Ml/d	4.5 Ml/d	28.2 Ml/d	48.1 Ml/d	16.5 Ml/d	30.5 Ml/d	95.2 Ml/d
Licence A%R	79.7%	50.5%	72.9%	63.4%	37.8%	26.3%	39.3%
Licence reduction for A10%R	**20.7 Ml/d**	**3.6 Ml/d**	**24.3 Ml/d**	**40.5 Ml/d**	**12.2 Ml/d**	**18.9 Ml/d**	**71.0 Ml/d**

Figure 24 - Location of A%R assessments for Rivers Cam and Rhee

Note: The "recent actual" abstraction for the Upper Cam above Audley End has been assumed to be as for the recorded 2016 amount, because Affinity Water's large Uttlesford source was out of operation for repair in 2017-18 – see the Upper Cam plot on Figure 25

The changes in abstraction and A%R since 1999 are shown on Figure 25:

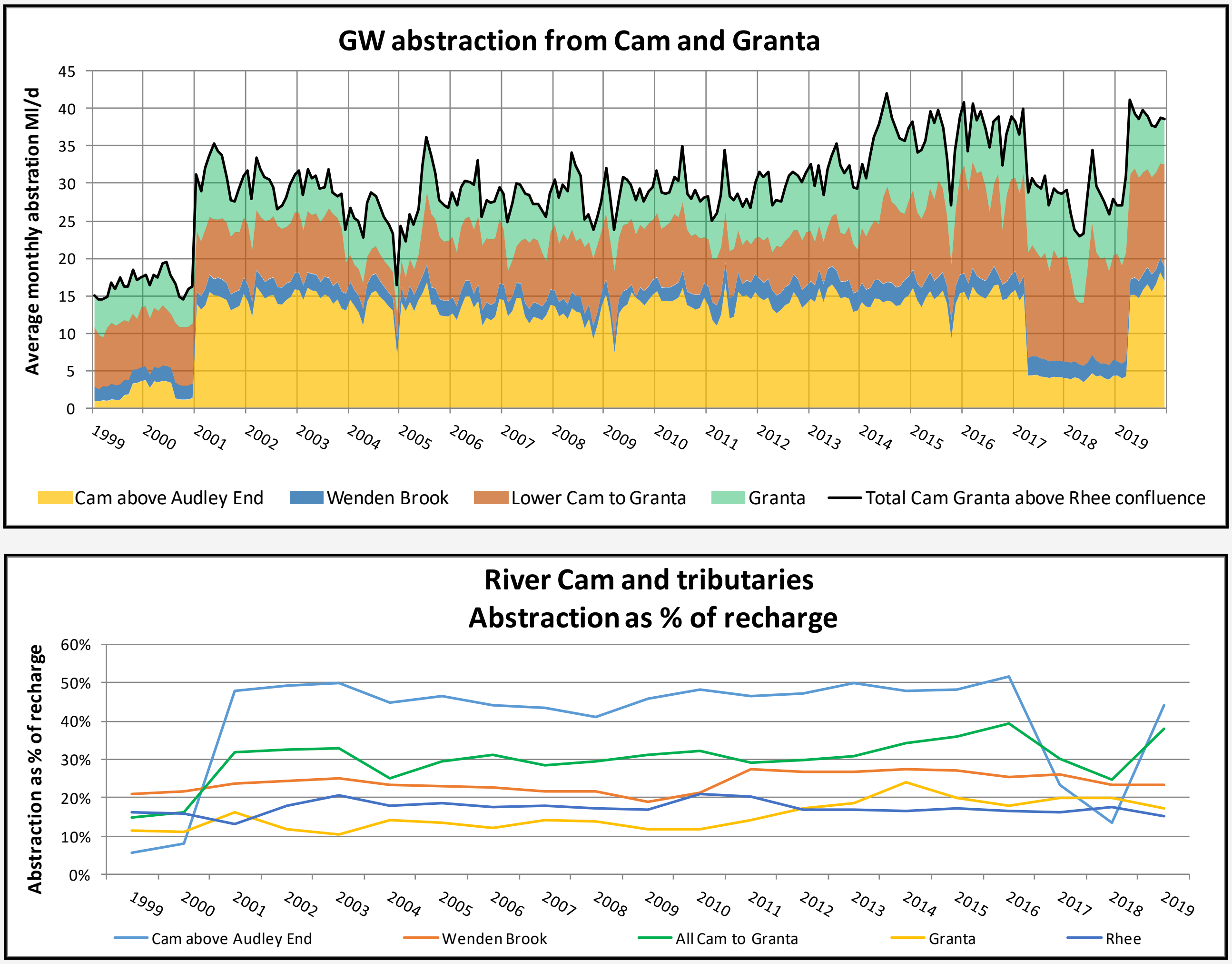


Figure 25 - Changes in abstraction and A%R in the River Cam catchment

The A%R values are around 30% for the Cam above the Granta confluence and around 50% for the Cam upstream of Audley End. In dry years, virtually all the recharge has been abstracted from the Cam upstream of Audley End as shown in Figure 26:

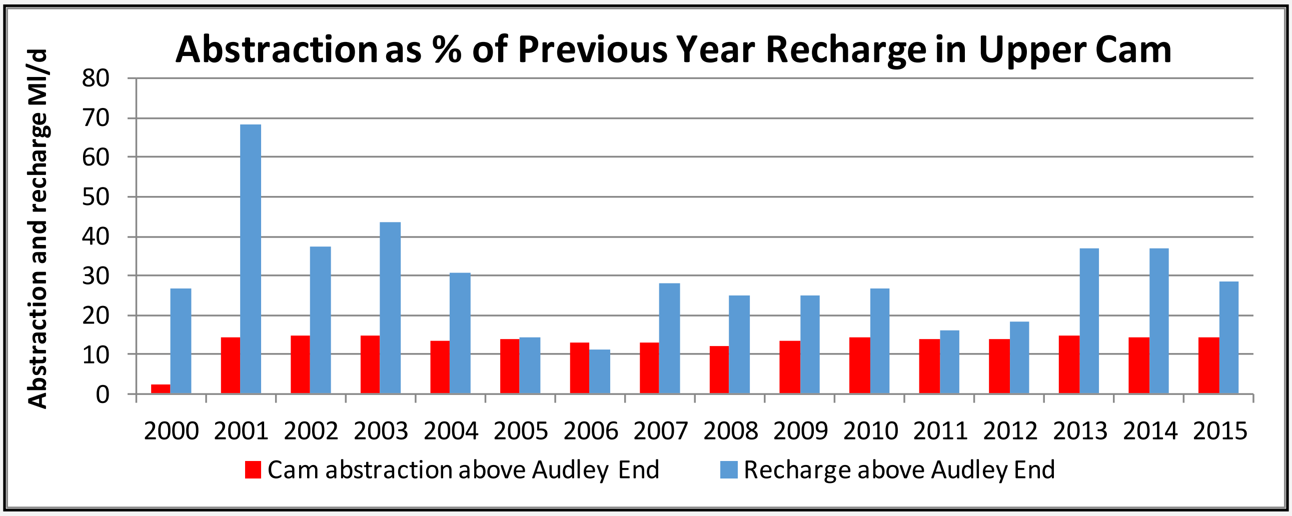
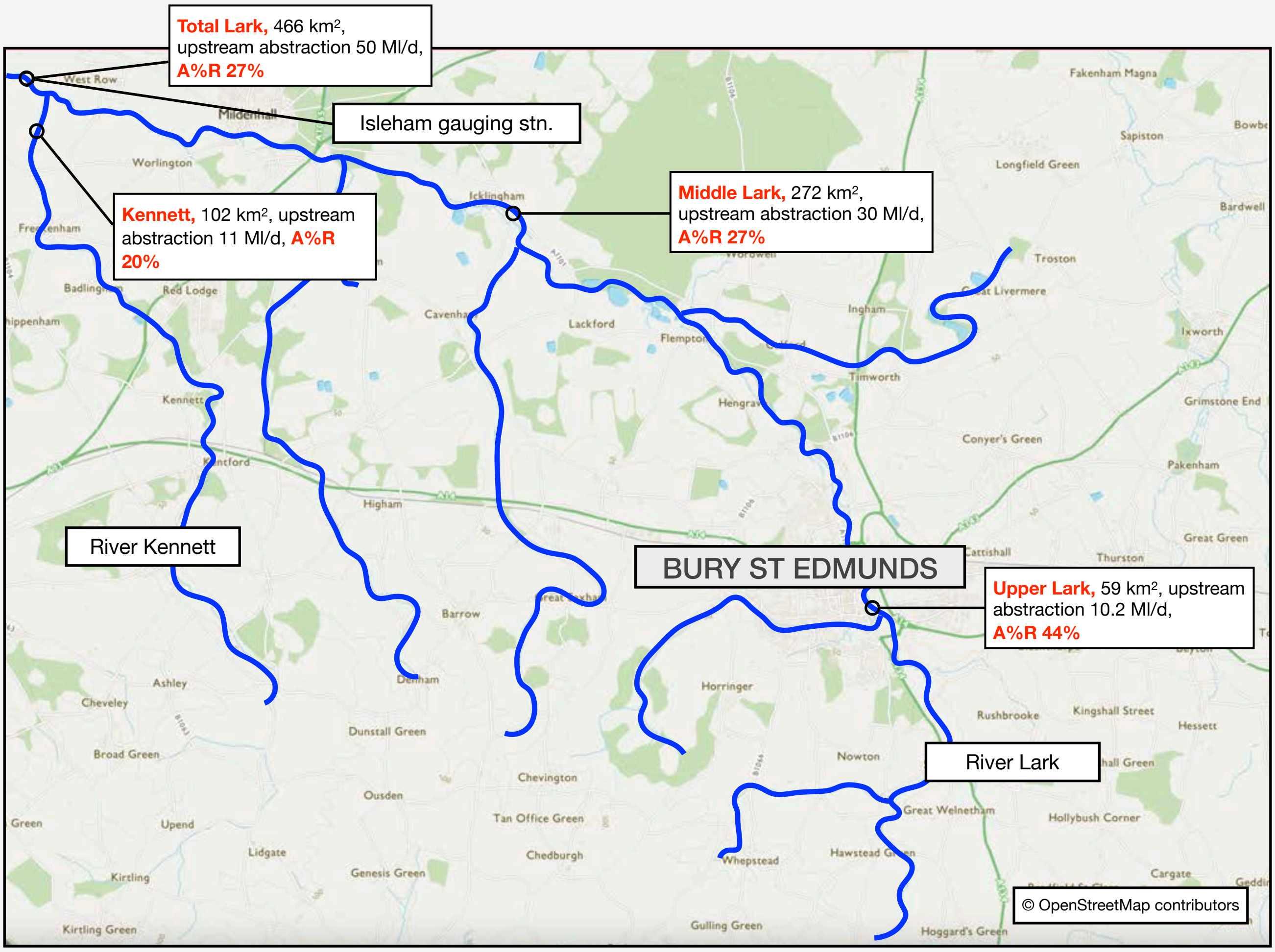


Figure 26 - Abstraction as % of previous year's recharge in the Upper Cam

The EA’s assessments of EFI flow deficits are only 3 Ml/d for the Upper Cam and 5 Ml/d for the Cam to the Granta confluence. However, there are six STWs between Newport and the Granta confluence (Newport, Saffron Walden, Audley End, Great Chesterfield, Duxford and Sawston). The NRFA gauged Q95 at Dernford, just above the Granta confluence, is only 22 Ml/d, which could be mostly STW effluent arising from the 31 Ml/d of abstraction upstream.

3.6 The River Lark catchment

Figure 27 shows the locations of the A%R assessments for the River Lark (upstream abstractions are average for 2017/19):



	Upper Lark to Bury St Edmunds	Middle Lark to Temple GS	Kennet/Lea Brook	Total Lark to Isleham GS
Catchment area	59 km2	272 km2	102 km2	466 km2
Baseflow index		0.77	0.69	0.64
Av. annual recharge	23.2 Ml/d	106.9 Ml/d	40.1 Ml/d	183.2 Ml/d
Abstraction in 2017-19	10.2 Ml/d	29.6 Ml/d	8.2 Ml/d	47.4 Ml/d
A%R in 2017-19	43.9%	27.7%	20.3%	25.9%
Reduction to achieve A10%R	**7.9 Ml/d**	**18.9 Ml/d**	**4.1 Ml/d**	**29.1 Ml/d**
GW consumptive licence total	28.4 Ml/d	58.1 Ml/d	24.6 Ml/d	117.3 Ml/d
Licence A%R	122.4%	54.3%	61.4%	64.0%
Licence reduction for A10%R	**26.1 Ml/d**	**47.4 Ml/d**	**20.6 Ml/d**	**99.0 Ml/d**

Figure 27 - Locations of A%R assessments in the Lark catchment

The abstraction of 44% of average recharge in the upper Lark above Bury St Edmunds is likely to have had a large impact on river flows. In dry years, most of the recharge above Bury St Edmunds has been abstracted, as shown on Figure 28:

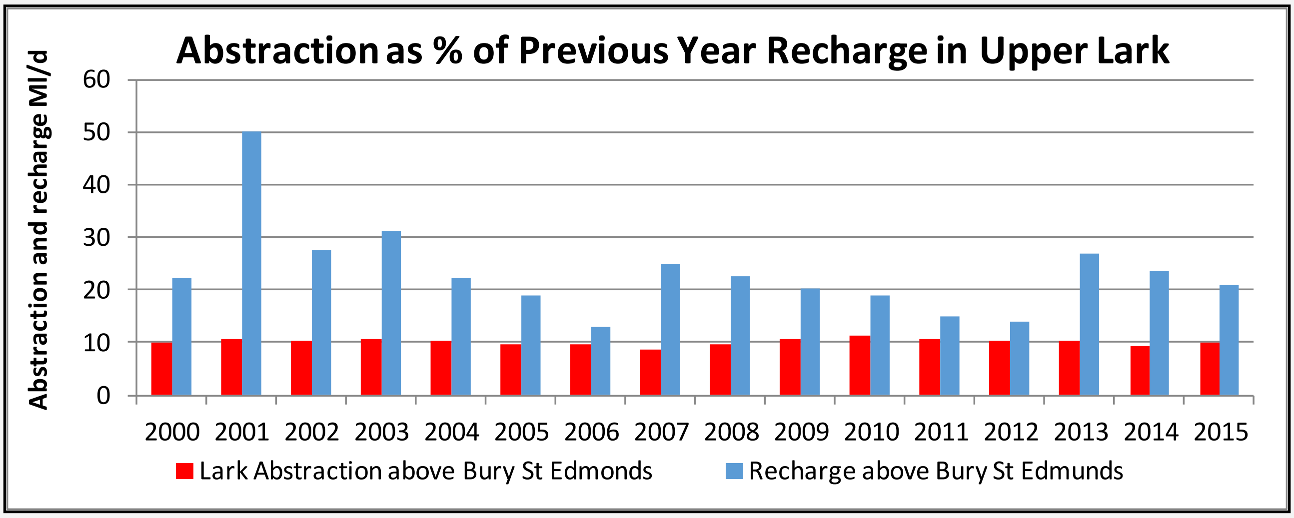


Figure 28 - Abstraction as % of previous year's recharge in the Upper Lark

Most of the recharge has been abstracted in dry years, so spring-fed river flow must have been close to zero in periods like 2011/12. However, the EA's assessed EFI flow deficit is only 1 Ml/d at Bury St Edmunds and they show a surplus flow of 2 Ml/d for the total Lark to Isleham. Presumably the EA's low deficit assessments also take account of substantial effluent returns from Bury St Edmunds and Mildenhall STWs and some small village STWs.

All of the public water supply abstraction from the River Kennett is in the upper river above Kentford, so the abstraction upstream of Kentford is about 30% of the recharge and is likely to have a substantial influence on flows.

3.8 Comments on some other catchments

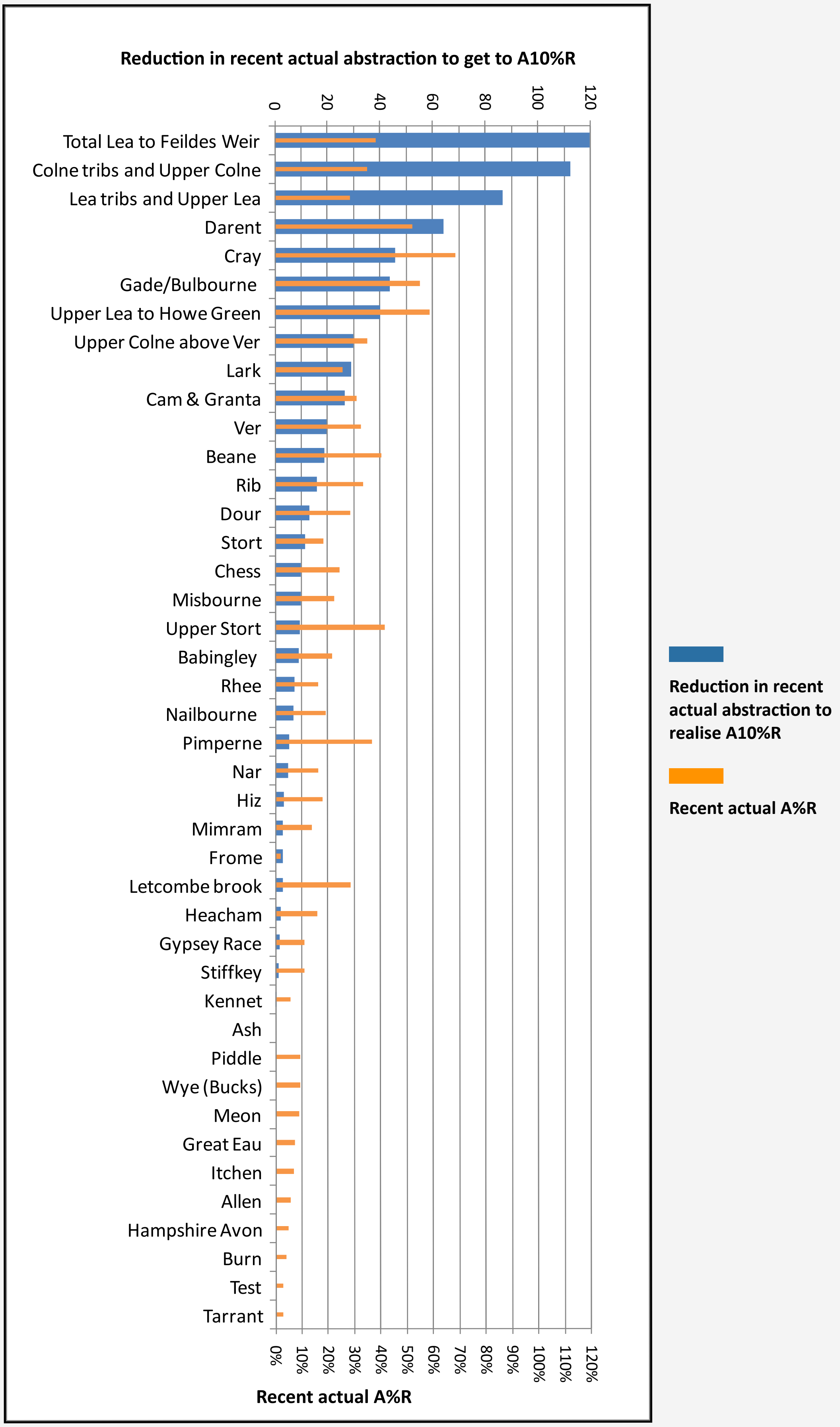


Figure 29 - Recent A%R and reductions needed to get A10%R

Figure 29 summarises recent actual A%R and the abstraction reductions needed to achieve A10%R. The Hampshire Avon, Test and Itchen A%Rs are each shown as single values for the whole catchment on Figure 29, because all their tributaries and reaches fall within the suggested A10%R target – values can be seen in the table in Appendix B. Similarly for the Kennet, all the tributaries and reaches fall within A10%R, except for a small deficit in the Shalbourne.

Figure 29 shows that the catchments of the Rivers Colne, Lea, Darent, Cam and Lark include most of the chalk streams with high values of A%R and the need for large reductions in abstraction to get to A10%R. These catchments have been reviewed in some detail in sections 3.3 to 3.7. However, some of the other rivers have high values of A%R which probably need to be addressed. For example some of the catchments have notably high abstraction in their sensitive upper reaches:

• in the upper **River Babingley** above Flitcham, recent abstraction in the 40 km^2 catchment has been about 11 Ml/d which is 55% of average recharge

• in the upper **River Hiz** above Hitchin, recent abstraction in the 18 km^2 catchment has been about 5 Ml/d which is 58% of average recharge

For the **Pimperne Brook**, a tributary of the Dorset Stour, recent abstraction is about 7 Ml/d in the 18km^2 catchment, equivalent to A37%R. The main Pimperne abstraction is close to the topographic divide from the **River Tarrant** and only 4 km from the river itself. Abstraction in the Tarrant catchment is only 3% of average recharge, but there have been long running local concerns about low river flows. It seems possible that the Pimperne abstraction may be affecting the Tarrant, although this is not shown by groundwater modelling.

3.9 Sensitivity of A%R analysis to choice of effective rain data

As referred to in Section 3.2, the A%R analysis has used the Qube effective rain data taken from the EA's file *'Copy of Effective Rainfall_ QUBE_1999_2015.xlsx'*. These data are in some cases substantially different to the daily effective rainfall data, 1920-2019, previously supplied by EA for the Berkshire Downs, Colne Chalk and Lea Chalk (see Figure 4). As a check on the sensitivity of the A%R analysis to the choice of effective rainfall data, the calculations for the Colne and Lea catchments have been re-run using the EA's previously supplied data for the Colne Chalk and Lea chalk as shown in Table 9:

Average effective rain (ER) 1999 - 2015 mm/ year	Chilterns Colne ER	Lea chalk ER
Qube data	241	159
Previous EA data	285	212
% difference Qube relative to previous EA	-15%	-25%

		Effective rain Er mm/yr		Recent actual A%R		Abstraction reduction to get A10%R	
		Qube Er	Previous EA Er	Qube Er data	Previous EA Er data	Qube Er data	Previous EA Er data
Colne	Upper Colne above Ver	236 mm/year	285 mm/year	35.0%	29.0%	29.6 Ml/d	27.2 Ml/d
	Ver above Redbourn	236 mm/year		21.6%	17.9%	4.7 Ml/d	3.9 Ml/d
	Total Ver	236 mm/year		32.8%	27.2%	19.5 Ml/d	17.7 Ml/d
	Bulbourne	191 mm/year		28.2%	18.9%	6.3 Ml/d	4.6 Ml/d
	Upper Gade	191 mm/year		48.4%	32.5%	9.7 Ml/d	8.4 Ml/d
	Total Gade Bulbourne	191 mm/year		55.4%	37.2%	43.8 Ml/d	39.1 Ml/d
	Chess	234 mm/year		24.6%	20.2%	9.8 Ml/d	8.4 Ml/d
	Misbourne	301 mm/year		22.3%	23.5%	9.6 Ml/d	10.0 Ml/d
	Total Colne to Watford	243 mm/year		47.8%	40.3%	87.6 Ml/d	83.4 Ml/d
	Total Colne to Denham	241 mm/year		66.0%	55.7%	274.1 Ml/d	265.1 Ml/d
Lea	Upper Lea to Luton Hoo	200 mm/year	212 mm/year	92.5%	87.0%	29.3 Ml/d	29.1 Ml/d
	Upper Lea to Water Hall	200 mm/year		59.0%	55.5%	40.2 Ml/d	39.7 Ml/d
	Upper Mimram to Codicote	200 mm/year		9.2%	8.7%	0.0 Ml/d	0.0 Ml/d
	Total Mimram	200 mm/year		13.9%	13.1%	2.9 Ml/d	2.5 Ml/d
	Stevenage Brook	129 mm/year		23.4%	22.0%	2.8 Ml/d	2.7 Ml/d
	Total Beane	129 mm/year		40.3%	24.5%	18.7 Ml/d	14.8 Ml/d
	Upper Rib	164 mm/year		16.7%	10.1%	1.2 Ml/d	0.0 Ml/d
	All Rib/Quin	164 mm/year		33.6%	25.9%	16.1 Ml/d	14.0 Ml/d
	Ash	128 mm/year		3.1%	2.4%	0.0 Ml/d	0.0 Ml/d
	Upper Stort to Clavering	177 mm/year		8.1%	6.8%	0.0 Ml/d	0.0 Ml/d
	Upper Stort to Bishops Stortford	177 mm/year		41.9%	34.9%	9.3 Ml/d	8.7 Ml/d
	All Stort	177 mm/year		18.5%	15.4%	11.5 Ml/d	8.7 Ml/d
	Total Lea to Feildes weir	159 mm/year		38.4%	28.8%	128.3 Ml/d	113.3 Ml/d

Table 10 - Sensitivity of Colne and Lea A%R assessments to choice of effective rain data

This table shows that the A%R analysis is relatively insensitive to the choice of effective rainfall data, particularly the calculation of the abstraction reduction needed to achieve A10%R. This is further shown in Figure 30:

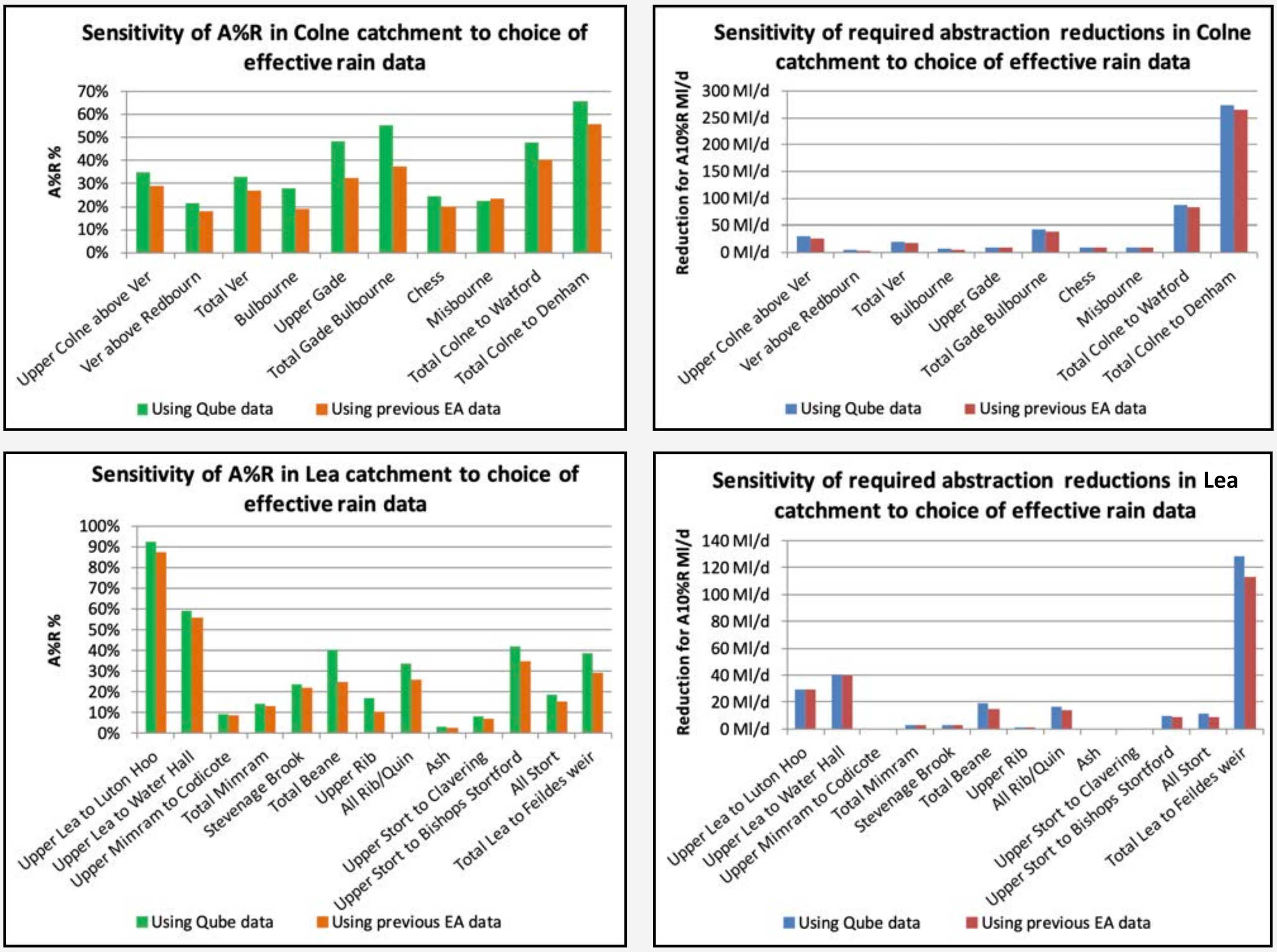


Figure 30 - Sensitivity of A%R and abstraction reductions to choice of effective rain data

Although the values of A10%R vary considerably with the choice of effective rain data, this has a relatively smaller impact on the abstraction reduction needed to achieve A10%R. The reason is illustrated in the calculation below for the Beane, which has a recent abstraction of 24.9 Ml/d and a large difference in effective rain data (129 mm/year from Qube data and 212mm/year from EA data):

Using Qube data:

Average recharge, 62 Ml/d, so allowed abstraction for A10%R is 6.2 Ml/d and required reduction is 24.9 Ml/d – 6.2 Ml/d = 18.7 Ml/d

Using EA data:

Average recharge, 102 Ml/d, so allowed abstraction for A10%R is 10.2 Ml/d and required reduction is 24.9 Ml/d – 10.2 Ml/d = 14.7 Ml/d

It can be seen that the large difference in effective rain (+64% Qube to EA) and recharge leads to a relatively small difference in required abstraction reduction to achieve A10%R (+27% Qube to EA).

It should be noted that the groundwater modelling used in assessing EFI deficits also uses effective rainfall data and so is subject to the same uncertainty.

4. The scale of chalk over-abstraction and priorities for improvements

4.1 Reductions needed in recent abstraction to get A10%R

The significant reductions in recent actual abstraction needed to achieve A10%R in assessed catchments are shown in Table 10 (some small reductions are excluded):

	Reduction in recent actual abstraction (2017-2019) to achieve A10%R				
River	**Recent abstraction 2017-2019**	**Reach or tributary Recent Actual A%R**	**Catchment Recent Actual A%R**	**Reach or tributary reduction in recent actual to get A10%R**	**Catchment recent actual reduction for A10%R**
Darent above Lullingstone	28.2 Ml/d	40.0%	52.5%	21.1 Ml/d	**110 Ml/d**
Darent above Farningham	35.2 Ml/d	39.3%		26.2 Ml/d	
Total Darent	79.3 Ml/d	52.5%		64.2 Ml/d	
Cray above Crayford	39.2 Ml/d	54.7%		32.0 Ml/d	
Total Cray	53.4 Ml/d	68.7%		45.6 Ml/d	
Upper Colne above Ver	41.5 Ml/d	35.0%	35.2%	29.6 Ml/d	**112 Ml/d**
Ver above Redbourn	8.8 Ml/d	21.6%		4.7 Ml/d	
Total Ver	28.1 Ml/d	32.8%		19.5 Ml/d	
Bulbourne	9.8 Ml/d	28.2%		6.3 Ml/d	
Upper Gade	12.2 Ml/d	48.4%		9.7 Ml/d	
Total Gade Bulbourne	53.4 Ml/d	55.4%		43.8 Ml/d	
Chess	16.5 Ml/d	24.6%		9.8 Ml/d	
Misbourne	17.5 Ml/d	22.3%		9.6 Ml/d	
Colne tribs incl Upper Colne to Ver	157.0 Ml/d	35.2%		112.4 Ml/d	
Total Colne to Watford	110.8 Ml/d	47.8%		87.6 Ml/d	**88 Ml/d**
Total Colne to Denham	323.1 Ml/d	66.0%		274.1 Ml/d	**274 Ml/d**
Upper Lea to Luton Hoo	32.9 Ml/d	92.5%	28.8%	29.3 Ml/d	**87 Ml/d**
Upper Lea to Water Hall	48.4 Ml/d	59.0%		40.2 Ml/d	
Total Mimram	10.4 Ml/d	13.9%		2.9 Ml/d	
Stevenage Brook	10.4 Ml/d	13.9%		2.9 Ml/d	
Total Beane	24.9 Ml/d	40.3%		18.7 Ml/d	
Upper Rib	3.0 Ml/d	16.7%		1.2 Ml/d	
All Rib/Quin	22.9 Ml/d	33.6%		16.1 Ml/d	
Upper Stort to Bishops Stortford	12.2 Ml/d	41.9%		9.3 Ml/d	
All Stort	25.0 Ml/d	18.5%		11.5 Ml/d	
Lea tributaries & Upper Lea	132.8 Ml/d	28.8%		86.6 Ml/d	
Total Lea to Feildes weir	173.5 Ml/d	38.4%		128.3 Ml/d	**128 Ml/d**
Cam above Audley End	15.3 Ml/d	51.6%	30.9%	12.3 Ml/d	**34 Ml/d**
All Cam to Granta	30.7 Ml/d	40.5%		23.2 Ml/d	
Granta	8.3 Ml/d	19.0%		3.9 Ml/d	
All Cam/Granta to Rhee confluence	39.0 Ml/d	30.9%		26.4 Ml/d	
Rhee to Cam confluence	19.0 Ml/d	16.4%	24.0%	7.4 Ml/d	
All Cam to below Rhee confluence	58.1 Ml/d	24.0%		33.8 Ml/d	
Upper Lark to Bury St Edmunds	10.2 Ml/d	43.9%	25.9%	7.9 Ml/d	**29 Ml/d**
Upper/middle Lark to Temple GS	29.6 Ml/d	27.7%		18.9 Ml/d	
Kennett/Lea Brook	8.2 Ml/d	20.3%		4.1 Ml/d	
All Lark to Isleham GS	47.4 Ml/d	25.9%		29.1 Ml/d	
Dour above Crabble Mill	8.8 Ml/d	17.4%	19.2%	3.8 Ml/d	**7 Ml/d**
Total Dour	14.7 Ml/d	19.2%		7.0 Ml/d	
Babingley above Flitcham	10.9 Ml/d	54.5%	22.2%	8.9 Ml/d	**9 Ml/d**
Total Babingley	3.1 Ml/d	22.2%		1.7 Ml/d	
Nailbourne above Barham	9.3 Ml/d	19.4%	19.2%	4.5 Ml/d	**7 Ml/d**
Total Nailbourne	14.7 Ml/d	19.2%		7.0 Ml/d	
Upper Hiz	5.0 Ml/d	58.0%		4.1 Ml/d	**4 Ml/d**
			Totals excluding lower Colne and lower Lea		**399 Ml/d**
			Totals with lower Colne and Lea		**602 Ml/d**

Table 11 - All assessed catchments: reductions in recent actual abstraction for A10%R

4.2 Prioritisation of reductions in recent abstraction

In the Chilterns chalk streams north of London, the deficits are considerable: for example 20 Ml/d on the River Ver and 40 Ml/d on the Upper Lea. Even so, these deficits are all relatively small compared to those for the entire River Colne. The deficit for the whole Colne down to the Thames is 274 Ml/d, but much of the abstraction is in the heavily modified lower river between Watford and the Thames, where the river winds between gravel pits and shares its course with the Grand Union Canal (see also Section 3.3). Excluding the lower main river, the deficit for all the Colne tributaries – Ver, Gade, Bulbourne, Chess and Misbourne and the upper Colne to the Ver confluence is 112 Ml/d.

However, the Gade downstream of the confluence with the Bulbourne is a much modified system, mostly a canal. While the upper Colne upstream of the Ver is a mixed-geology stream, mostly incised watercourses rising on Thames Group clays, silts, sands and gravels. It is not a 'classic' chalk stream in the sense that the Ver or upper Gade are and it is heavily urbanised. If we therefore ordered these deficits, aiming to prioritise the classic Colne / Chilterns chalk streams, they amount to Ver 20 + Upper Gade 10 + Bulbourne 6 + Chess 10 + Misbourne 10 Ml/d = 56 Ml/d. This is still a large amount of water, but it is a very different number from 274 Ml/d and ecologically it is by far the more significant water.

A similar analysis can be made for the Lea system (see also Section 3.4): the total Lea A%R deficit to Feildes Weir is 128 Ml/d. The 'classic' chalk stream deficits are Upper Lea 29 + Mimram 3 + Beane 19 + Rib/Quin 16 + Upper Stort 9 = 76 Ml/d. The lower Stort, like the lower Gade is mostly a modified and canalised stream while the River Lea migrates from the chalk downstream of Stantead Abbots and becomes heavily urbanised, with flows substantially boosted by discharge of treated effluent from Rye Meads sewage treatment works.

If the abstraction reductions in the Colne and Lea catchments are prioritised to the 'classic' upper reaches and tributaries, the total reduction for the Colne and Lea would be 131 Ml/d and the gain would be felt throughout the system, including the lower reaches. The chalk streams improved would form a continuous band in the Chilterns chalk from the Misbourne to the Quin, with no gaps and no possibility that reductions in one tributary could be replaced by additional abstraction in an adjacent tributary, nullifying the benefit. This would also eliminate concerns that topographic catchments assumed in calculating A%R may not align with groundwater catchments – abstraction would be reduced to 10% of recharge over the full width of the upper Colne and Lea catchments. There would be no concern about whether or not the 28 Ml/d abstraction at Luton affects the adjacent Rivers Ver and Mimram.

The total reduction in abstraction to achieve A10%R in the Darent/Cray catchment is 104 Ml/d. However, most of the existing abstraction is in the lower Darent and Cray catchment. In the most ecologically sensitive part of the Darent catchment, the AONB upstream of Farningham (see Figure 20), a reduction of 28 Ml/d would achieve A10%R. The Cray catchment is heavily developed and is arguably a lower priority than the upper Darent. However, there could be concerns that continuing high abstraction in the Cray, and in the Darent catchment downstream of Farningham, will still lower the regional water table and affect the upper Darent. If the Darent/Cray system is considered a high priority here could be a case for reduction to A10%R throughout, but this would entail the much larger abstraction reduction.

There could be similar prioritisation in the Cam and Lark catchments. The total abstraction reduction to achieve A10%R in the Cam/Rhee catchment is 34 Ml/d, but only 14 Ml/d reduction is needed in the ecologically sensitive upper Cam above Audley End. The required reduction in the Lark catchment is 29 Ml/d, of which 10 Ml/d is in the 'classic' chalk stream section upstream of Bury St Edmunds.

A prioritisation of abstraction deficits is needed according to their significance in terms of chalk stream ecology – ecologically essential, ecologically desirable, or of limited ecological benefit. Large deficits have been identified by the EA and are currently being considered in regional water resource plans. The regional planners, Water Resources South East and Water Resources East are required to identify the water resources options that give best value to customers, society and the environment, rather than simply

High priority abstraction reductions		
Chalk stream	**Recent A%R**	**Required reduction**
Misbourne	22%	10 Ml/d
Chess	25%	10 Ml/d
Upper Bulbourne	28%	6 Ml/d
Upper Gade	48%	10 Ml/d
Ver	33%	20 Ml/d
Total Colne catchment		**55 Ml/d**
Upper Lea to Luton Hoo	92%	29 Ml/d
Beane	40%	19 Ml/d
Rib/Quin	34%	16 Ml/d
Upper Stort	42%	9 Ml/d
Total Lea catchment		**73 Ml/d**
Upper Darent	39%	26 Ml/d
Upper Cam	52%	12 Ml/d
Upper Lark	44%	8 Ml/d
Kennett/Lea Brook	20%	4 Ml/d
Upper Babingley	54%	9 Ml/d
Upper Hiz	58%	4 Ml/d
Total reduction in recent abstraction		**188 Ml/d**

Table 12 - Suggested top priority reductions in recent abstraction to achieve A10%R

Note: the Mimram is not in this list because recent abstraction is only 14% of recharge

focusing on the lowest cost. However, cost will come into the equation, so EA require regional planners to ensure that the ecologically essential reaches of chalk streams benefit from the scale of abstraction reductions needed to properly facilitate their recovery (in conjunction with measures to address water quality and physical habitat).

Therefore, it is suggested that the top priority reductions in recent actual abstraction could be made on the ‘classic’ chalk streams where abstraction is over 20% of recharge:

These reductions would cover all the sensitive upper reaches of the chalk streams so would also benefit the river reaches downstream. The list covers all the rivers which have been the subject of long running local concerns about over-abstraction. There are a few relatively minor reductions in less well known rivers not covered in the list, for example the Nailbourne and the Dour. There may be reductions in abstraction needed in a few others chalk streams not covered by this report, for example the Rivers Loddon, Wey, Kentish Stour and Wensum.

The chalk streams improved north of London would form a continuous band from the Misbourne to the upper Cam, achieving A10%R throughout and eliminating the possibility that the benefit of reducing abstraction in one catchment would be negated by continuing high abstraction in adjacent catchments. Reducing abstraction to A10%R throughout the Chilterns would also would allay concerns that topographic catchments assumed in calculating A%R may not align with groundwater catchments.

Many of the most heavily abstracted chalk streams are in quite urbanised areas, so abstraction reduction to achieve A10%R and re-naturalise river flows could cause problems with high groundwater levels and local flooding. This issue will need to be addressed on a case-by-case basis.

As a suggested principle, abstraction reductions should be planned on a regional aquifer basis, rather than piecemeal for each catchment. This recognises that the water table is continuous across chalk catchment boundaries and it is the water table level that drives the springs that create the river flows.

4.3 Reductions needed in abstraction licences to comply with A10%R

Table 12 shows, for the chalk streams where recent actual abstraction exceeds A10%R, the reductions in annual licensed abstraction to stay within A10%R:

<table>
<tr><th></th><th colspan="5">Reduction in full licensed abstraction (2017-2019) to achieve A10%R</th></tr>
<tr><th>River</th><th>Reach or tributary annual licence</th><th>Reach or tributary licensed A%R</th><th>Catchment licensed A%R</th><th>Licence reduction to get A10%R</th><th>Catchment licence reduction for A10%R</th></tr>
<tr><td>Darent above Lullingstone</td><td>40.9 Ml/d</td><td>58.0%</td><td rowspan="5">80.9%</td><td>33.9 Ml/d</td><td rowspan="5">181 Ml/d</td></tr>
<tr><td>Darent above Farningham</td><td>53.5 Ml/d</td><td>59.7%</td><td>44.5 Ml/d</td></tr>
<tr><td>Total Darent</td><td>122.3 Ml/d</td><td>80.9%</td><td>107.2 Ml/d</td></tr>
<tr><td>Cray above Crayford</td><td>53.4 Ml/d</td><td>74.5%</td><td>46.3 Ml/d</td></tr>
<tr><td>Total Cray</td><td>81.7 Ml/d</td><td>105.2%</td><td>73.9 Ml/d</td></tr>
<tr><td>Upper Colne above Ver</td><td>48.7 Ml/d</td><td>41.1%</td><td rowspan="11">47.7%</td><td>36.9 Ml/d</td><td rowspan="9">168 Ml/d</td></tr>
<tr><td>Ver above Redbourn</td><td>22.8 Ml/d</td><td>55.9%</td><td>18.7 Ml/d</td></tr>
<tr><td>Total Ver</td><td>36.3 Ml/d</td><td>42.4%</td><td>27.7 Ml/d</td></tr>
<tr><td>Bulbourne</td><td>21.3 Ml/d</td><td>61.3%</td><td>17.9 Ml/d</td></tr>
<tr><td>Upper Gade</td><td>24.9 Ml/d</td><td>99.1%</td><td>22.4 Ml/d</td></tr>
<tr><td>Total Gade Bulbourne</td><td>78.0 Ml/d</td><td>80.8%</td><td>68.3 Ml/d</td></tr>
<tr><td>Chess</td><td>24.2 Ml/d</td><td>36.0%</td><td>17.5 Ml/d</td></tr>
<tr><td>Misbourne</td><td>25.6 Ml/d</td><td>32.7%</td><td>17.8 Ml/d</td></tr>
<tr><td>Colne tribs incl Upper Colne to Ver</td><td>212.8 Ml/d</td><td>47.7%</td><td>168.2 Ml/d</td></tr>
<tr><td>Total Colne to Watford</td><td>250.5 Ml/d</td><td>107.9%</td><td>227.3 Ml/d</td><td>227 Ml/d</td></tr>
<tr><td>Total Colne to Denham</td><td>531.1 Ml/d</td><td>108.4%</td><td>482.1 Ml/d</td><td>482 Ml/d</td></tr>
<tr><td>Upper Lea to Luton Hoo</td><td>55.0 Ml/d</td><td>154.7%</td><td rowspan="11">43.3%</td><td>51.4 Ml/d</td><td rowspan="10">154 Ml/d</td></tr>
<tr><td>Upper Lea to Water Hall</td><td>82.9 Ml/d</td><td>101.1%</td><td>74.7 Ml/d</td></tr>
<tr><td>Total Mimram</td><td>19.2 Ml/d</td><td>25.9%</td><td>11.8 Ml/d</td></tr>
<tr><td>Stevenage Brook</td><td>19.2 Ml/d</td><td>25.9%</td><td>11.8 Ml/d</td></tr>
<tr><td>Total Beane</td><td>28.7 Ml/d</td><td>46.4%</td><td>22.5 Ml/d</td></tr>
<tr><td>Upper Rib</td><td>4.5 Ml/d</td><td>25.4%</td><td>2.8 Ml/d</td></tr>
<tr><td>All Rib/Quin</td><td>28.7 Ml/d</td><td>42.2%</td><td>21.9 Ml/d</td></tr>
<tr><td>Upper Stort to Bishops Stortford</td><td>19.1 Ml/d</td><td>65.7%</td><td>16.2 Ml/d</td></tr>
<tr><td>All Stort</td><td>35.6 Ml/d</td><td>26.3%</td><td>22.1 Ml/d</td></tr>
<tr><td>Lea tributaries & Upper Lea</td><td>200.0 Ml/d</td><td>43.3%</td><td>153.8 Ml/d</td></tr>
<tr><td>Total Lea to Feildes weir</td><td>242.2 Ml/d</td><td>53.5%</td><td>196.9 Ml/d</td><td>197 Ml/d</td></tr>
<tr><td>Cam above Audley End</td><td>23.7 Ml/d</td><td>79.7%</td><td rowspan="6"></td><td>20.7 Ml/d</td><td rowspan="6">71 Ml/d</td></tr>
<tr><td>All Cam to Granta</td><td>48.1 Ml/d</td><td>63.4%</td><td>40.5 Ml/d</td></tr>
<tr><td>Granta</td><td>16.5 Ml/d</td><td>37.8%</td><td>12.2 Ml/d</td></tr>
<tr><td>All Cam/Granta to Rhee confluence</td><td>64.6 Ml/d</td><td>51.3%</td><td>52.0 Ml/d</td></tr>
<tr><td>Rhee to Cam confluence</td><td>30.5 Ml/d</td><td>26.3%</td><td>18.9 Ml/d</td></tr>
<tr><td>All Cam to below Rhee confluence</td><td>95.2 Ml/d</td><td>39.3%</td><td>71.0 Ml/d</td></tr>
<tr><td>Upper Lark to Bury St Edmunds</td><td>28.4 Ml/d</td><td>122.4%</td><td rowspan="4">64.0%</td><td>26.1 Ml/d</td><td rowspan="4">99 Ml/d</td></tr>
<tr><td>Upper/middle Lark to Temple GS</td><td>58.1 Ml/d</td><td>54.3%</td><td>47.4 Ml/d</td></tr>
<tr><td>Kennett/Lea Brook</td><td>24.6 Ml/d</td><td>61.4%</td><td>20.6 Ml/d</td></tr>
<tr><td>All Lark to Isleham GS</td><td>117.3 Ml/d</td><td>64.0%</td><td>99.0 Ml/d</td></tr>
<tr><td>Dour above Crabble Mill</td><td>15.0 Ml/d</td><td>29.8%</td><td rowspan="2">35.7%</td><td>10.0 Ml/d</td><td rowspan="2">20 Ml/d</td></tr>
<tr><td>Total Dour</td><td>27.3 Ml/d</td><td>35.7%</td><td>19.6 Ml/d</td></tr>
<tr><td>Babingley above Flitcham</td><td>13.7 Ml/d</td><td>68.5%</td><td rowspan="2">60.7%</td><td>11.7 Ml/d</td><td rowspan="2">12 Ml/d</td></tr>
<tr><td>Total Babingley</td><td>8.4 Ml/d</td><td>60.7%</td><td>7.0 Ml/d</td></tr>
<tr><td>Nailbourne above Barham</td><td>15.9 Ml/d</td><td>33.3%</td><td rowspan="2">35.7%</td><td>11.1 Ml/d</td><td rowspan="2">20 Ml/d</td></tr>
<tr><td>Total Nailbourne</td><td>27.3 Ml/d</td><td>35.7%</td><td>19.6 Ml/d</td></tr>
<tr><td>Upper Hiz</td><td>5.7 Ml/d</td><td>66.5%</td><td></td><td>4.8 Ml/d</td><td>5 Ml/d</td></tr>
<tr><td colspan="3" rowspan="2"></td><td colspan="2">Totals excluding lower Colne and lower Lea</td><td>729 Ml/d</td></tr>
<tr><td colspan="2">Totals with lower Colne and Lea</td><td>1086 Ml/d</td></tr>
</table>

Table 13 - Reductions in annual licensed abstraction for A10%R

The amounts by which annual licensed quantities would need to be reduced is generally a lot more than the reductions need in recent actual abstraction. For example, the total reductions of 729 Ml/d shown in Table 12 compare with the 410 Ml/d of reductions in recent actual abstractions shown in Table 10. There are also some rivers not shown in Table 12, where recent abstraction is less than A10%R, but licensed abstraction is more than A10%R, for example the Piddle (A16%R) and the Kennet (A14%R).

However, the water companies may not plan to use the excess headroom in their licences or may even be unable to abstract the annual licensed amounts. An example of this for Affinity Water's Lea supply zone is shown in the earlier Table 3. Nevertheless, the amount of unused headroom in abstraction licences is a threat to the future well-being of chalk streams and needs to be addressed.

Appendix A – Scope of work for review of scale of chalk catchment abstraction

Objectives

To understand the scale of over-abstraction of chalk aquifers and chalk streams in southern and eastern England.

To investigate "Abstraction as a % of aquifer recharge" as a simpler and more accessible method for determining acceptable levels of abstraction in chalk catchments and prioritising action, not as an alternative to EFI, but as a means of independent validation.

Scope of work

Assemble a list of chalk catchments, with a defined downstream extent for each. The aim would be for each catchment to be a recognised chalk stream in its own right, keeping the number of catchments manageable, perhaps 40, whilst maintaining separate identities for individually well-known streams. For example, the Colne could be subdivided into its main upper tributaries, but the Bulbourne and Gade could be one catchment; the five Hampshire Avon tributaries joining around Salisbury would be considered as separate catchments, but the Till could be part of the Wylye. The number of catchments needs to be limited initially, to make the data collection manageable for the EA.

The defined downstream boundary could be either a gauging station, an EA CAMS assessment point (AP) or a confluence of a tributary.

Data gathering by Environment Agency – abstraction data and effective rainfall. The abstraction data should be for significant consumptive sources, say licensed over 1 Ml/d, and include licensed annual maximum and annual average for each of the last, say, 10 years. This will be the most difficult part of the exercise. There will need to be discussion with EA to see what can be done reasonably easily. It will probably be easier for EA to provide all available data in its current format for me to sort out, as already done for the Colne catchment abstractions.

Effective rainfall daily for the past 50 years should be available for any catchment covered by an existing regional groundwater model (I already have Berkshire Downs and Chilterns, 1920 to present). If the Effective Rainfall data is not available, it can be estimated from the nearest records.

Analysis and Reporting – The recharge for each catchment is simply *effective rainfall x catchment area*. The main task will be sorting out the abstraction data by location and type (surface or groundwater, PWS or private, consumptive or non-consumptive). This would generate abstraction as % of recharge, and how it has varied over whatever the duration of the abstraction records supplied. An example for the 20 years of Colne records is shown in the attached Excel file 'Colne LIVE JDL 9.12.20'. This information would provide a lot of what is needed, but further analysis could include:

1. Discussion of the impact on GWLs and flows from varying levels of "Abstraction as a % of aquifer recharge". This could be done for some sample catchments for which we have groundwater model output. The EA has already provided the GW model output we have requested for all the Colne tributaries and they would provide a good set of case studies.

2. Comparison of "Abstraction as a % of aquifer recharge" with WFD classification data, including the "Flows would support Good" classification.

3. Comparison of "Abstraction as a % of aquifer recharge" with the EA's past and planned "sustainability reductions" in chalk catchments.

4. Comparison of “Abstraction as a % of aquifer recharge” with the catchment categorisation in EA CAMS report, ie “Over-abstracted”, “Over licensed” or “Water available”.

5. Requesting comments from individual rivers trusts on their perception of abstraction impacts.

The output would be a report (or two), plus an Excel file of the assembled data. The first report could simply be on the initial data analysis, possibly followed by a second report covering any agreed further analysis.

Timing and inputs

It will probably take the EA at least a month to assemble the data, perhaps providing it in batches, maybe with all available after 2 months. My time in analysing and reporting would depend on the number of catchments and the extent of the “further analysis” suggested above. I think that the analysis of data for 40 catchments could be, say, 15 days work. It took several days to do the analysis for the Colne catchments shown in the attached Excel file, but it was a steep learning curve. Having done it once, I would do it faster, if EA produce all the data in the same format. However, it’s likely to come in different formats and there could be quite a lot of querying and requests for more information.

A second phase of further analysis could cover more than the initial 40 catchments and whatever additional work was thought appropriate after reviewing the first phase outputs, depending on budget availability.

John Lawson, FREng, FICE, FCIWEM

23rd February 2021

Appendix B – Summary of A%R assessments and EA ‘recent actual’ deficits: page 1 of 3

					A%R analysis for recent actual abstraction (2017-2019)					EA EFI analysis of recent actual flow deficits			A%R analysis for licensed abstraction				
Catchment	River	Catchment Area	Average catchment Effective rain	Average recharge	Recent abstraction 2017-2019	Reach or tributary Recent Actual A%R	Catchment Recent Actual A%R	Reach or trib reduction in recent actual to get A10%R	Catchment recent actual reduction for A10%R	EA recent surplus/deficit using EFIs	EA recent deficit for whole catchment	EA ASB band	Reach or tributary licence	Reach or tributary licensed A%R	Catchment licensed A%R	Licence reduction to get A10%R	Catchment licence reduction for A10%R
	Hooke	40 km2	538 mm/year	59 Ml/d	0.0 Ml/d	0.0%		0.0 Ml/d		-1.0 Ml/d		3	0.1 Ml/d	0.2%		0.0 Ml/d	
	Frome to Dorchester	206 km2		304 Ml/d	1.6 Ml/d	0.5%		0.0 Ml/d		0.0 Ml/d		3	2.5 Ml/d	0.8%		0.0 Ml/d	
Frome	Cerne	35 km2		50 Ml/d	7.9 Ml/d	15.7%	2.1%	2.8 Ml/d	2.8 Ml/d	2.0 Ml/d	0.0 Ml/d	2	10.6 Ml/d	21.0%	4.7%	5.5 Ml/d	5.5 Ml/d
	South Winterborne	55 km2	524 mm/year	79 Ml/d	0.0 Ml/d	0.0%		0.0 Ml/d		1.0 Ml/d		3	4.0 Ml/d	5.1%		0.0 Ml/d	
	Frome to East Stoke	414 km2		594 Ml/d	12.6 Ml/d	2.1%		0.0 Ml/d		42.0 Ml/d		2	27.8 Ml/d	4.7%		0.0 Ml/d	
	Upper Piddle to Tolpuddle	65 km2		90 Ml/d	1.2 Ml/d	1.4%		0.0 Ml/d		1.0 Ml/d		3	0.6 Ml/d	0.6%		0.0 Ml/d	
	Devils Brook	34 km2		47 Ml/d	4.0 Ml/d	8.5%		0.0 Ml/d		-1.0 Ml/d		3	5.1 Ml/d	10.9%		0.4 Ml/d	
Piddle	Piddle to Briantspuddle	112 km2	503 mm/year	154 Ml/d	14.6 Ml/d	9.5%	9.5%	0.0 Ml/d	0.0 Ml/d	-3.0 Ml/d	0.0 Ml/d	3	23.9 Ml/d	15.5%	15.5%	8.4 Ml/d	8.4 Ml/d
	Bere	48 km2		66 Ml/d	3.0 Ml/d	4.5%		0.0 Ml/d		1.0 Ml/d		3	6.4 Ml/d	9.7%		0.0 Ml/d	
	Piddle to Wareham	183 km2		252 Ml/d	17.6 Ml/d	7.0%		0.0 Ml/d		4.0 Ml/d		2	30.3 Ml/d	12.0%		5.1 Ml/d	
Pimperne		18 km2	415 mm/year	20 Ml/d	7.3 Ml/d	36.7%	36.7%	5.3 Ml/d	5.3 Ml/d	-	-		8.5 Ml/d	42.8%	42.8%	6.5 Ml/d	6.5 Ml/d
Tarrant		53 km2	415 mm/year	60 Ml/d	1.7 Ml/d	2.9%	2.9%	0.0 Ml/d	0.0 Ml/d	-	-		2.4 Ml/d	3.9%	3.9%	0.0 Ml/d	0.0 Ml/d
Allen (lower)		0 km2	415 mm/year	200 Ml/d	11.7 Ml/d	5.8%	5.8%	0.0 Ml/d	0.0 Ml/d	3.0 Ml/d	3.0 Ml/d	3	19.5 Ml/d	9.8%	9.8%	0.0 Ml/d	0.0 Ml/d
	Upper Avon	355 km2		291 Ml/d	18.5 Ml/d	6.3%		0.0 Ml/d		12.0 Ml/d		3	27.3 Ml/d	9.4%		0.0 Ml/d	
	Wylye	361 km2	300 mm/year	296 Ml/d	17.3 Ml/d	5.8%		0.0 Ml/d		10.0 Ml/d		3	29.2 Ml/d	9.9%		0.0 Ml/d	
Hampshire Avon	Nadder	231 km2		190 Ml/d	5.8 Ml/d	3.1%	4.7%	0.0 Ml/d	0.0 Ml/d	4.0 Ml/d	0.0 Ml/d	3	13.4 Ml/d	7.1%	9.8%	0.0 Ml/d	0.0 Ml/d
	Bourne	173 km2		142 Ml/d	7.6 Ml/d	5.4%		0.0 Ml/d		4.0 Ml/d		3	19.9 Ml/d	14.0%		5.7 Ml/d	
	Ebble	109 km2	454 mm/year	136 Ml/d	0.1 Ml/d	0.1%		0.0 Ml/d		3.0 Ml/d		2	13.3 Ml/d	9.8%		0.0 Ml/d	
	Total to Ebble confluence	1229 km2	313 mm/year	1054 Ml/d	49.3 Ml/d	4.7%		0.0 Ml/d		21.0 Ml/d		2	103.1 Ml/d	9.8%		0.0 Ml/d	
	Anton	185 km2		190 Ml/d	12.9 Ml/d	6.8%		0.0 Ml/d		0.0 Ml/d		3	0.0 Ml/d	0.0%		0.0 Ml/d	
	Bourne Rivulet	131 km2		135 Ml/d	0.9 Ml/d	0.7%		0.0 Ml/d		10.0 Ml/d		3	5.7 Ml/d	4.2%		0.0 Ml/d	
Test	Upper Test to Chilbolton	453 km2	375 mm/year	465 Ml/d	5.9 Ml/d	1.3%	2.9%	0.0 Ml/d	0.0 Ml/d	37.0 Ml/d	0.0 Ml/d	3	27.9 Ml/d	6.0%	6.1%	0.0 Ml/d	0.0 Ml/d
	Total Test to Anton confluence	638 km2		655 Ml/d	18.8 Ml/d	2.9%		0.0 Ml/d		56.0 Ml/d		3	33.6 Ml/d	5.1%		0.0 Ml/d	
	Total Test to Timsbury	978 km2		1004 Ml/d	24.8 Ml/d	2.5%		0.0 Ml/d		77.0 Ml/d		2	61.5 Ml/d	6.1%		0.0 Ml/d	
	Candover Brook	72 km2		74 Ml/d	2.8 Ml/d	3.8%		0.0 Ml/d		0.0 Ml/d		3	4.5 Ml/d	6.2%		0.0 Ml/d	
Itchen	Upper Itchen to Winchester	280 km2	612 mm/year	470 Ml/d	13.8 Ml/d	2.9%	6.9%	0.0 Ml/d	0.0 Ml/d	17.0 Ml/d	29.0 Ml/d	3	18.2 Ml/d	3.9%	9.2%	0.0 Ml/d	0.0 Ml/d
	Itchen to Chandlers Ford	360 km2		604 Ml/d	41.6 Ml/d	6.9%		0.0 Ml/d		-29.0 Ml/d		2	55.7 Ml/d	9.2%		0.0 Ml/d	
Meon	Meon above Mislingford	73 km2	455 mm/year	91 Ml/d	8.1 Ml/d	8.9%	8.9%	0.0 Ml/d	0.0 Ml/d	-4.0 Ml/d	4.0 Ml/d	2	11.5 Ml/d	12.6%	12.6%	0.0 Ml/d	0.0 Ml/d
	Total Meon	108 km2		134 Ml/d	8.1 Ml/d	6.0%		0.0 Ml/d		-3.0 Ml/d		2	11.5 Ml/d	8.6%		0.0 Ml/d	
	Upper Kennet to Marlborough	142 km2		79 Ml/d	3.5 Ml/d	4.4%		0.0 Ml/d		0.0 Ml/d		3	8.3 Ml/d	10.5%		0.4 Ml/d	
	Og	59 km2		33 Ml/d	0.6 Ml/d	1.7%		0.0 Ml/d		-1.0 Ml/d		3	0.6 Ml/d	1.9%		0.0 Ml/d	
	Kennet to Knighton	295 km2		165 Ml/d	13.5 Ml/d	8.2%		0.0 Ml/d		3.0 Ml/d		3	19.5 Ml/d	11.8%		3.0 Ml/d	
Kennet	Dunn	101 km2	315 mm/year	56 Ml/d	1.2 Ml/d	2.1%	8.1%	0.0 Ml/d	0.2 Ml/d	1.0 Ml/d	0.0 Ml/d	3	1.6 Ml/d	2.8%	11.2%	0.0 Ml/d	6.0 Ml/d
	Shalbourne	20 km2		11 Ml/d	1.3 Ml/d	11.7%		0.2 Ml/d		1.0 Ml/d		3	1.7 Ml/d	15.7%		0.6 Ml/d	
	Lambourn	234 km2		131 Ml/d	4.9 Ml/d	3.8%		0.0 Ml/d		5.0 Ml/d		3	7.5 Ml/d	5.7%		0.0 Ml/d	
	Kennet to Theale (excl Enborne)	1033 km2		577 Ml/d	46.8 Ml/d	8.1%		0.0 Ml/d		99.0 Ml/d		2	55.5 Ml/d	11.2%		6.0 Ml/d	
Pang		171 km2	188 mm/year	96 Ml/d	1.0 Ml/d	1.1%	1.1%	0.0 Ml/d	0.0 Ml/d	-4.0 Ml/d	4.0 Ml/d	3	2.6 Ml/d	2.8%	2.8%	0.0 Ml/d	0.0 Ml/d
Letcombe brook		26 km2	188 mm/year	15 Ml/d	4.1 Ml/d	28.5%	28.5%	2.7 Ml/d	2.7 Ml/d	-	-		7.7 Ml/d	52.8%	52.8%	6.2 Ml/d	6.2 Ml/d

Notes:

1. The EA’s EFI flow deficits and ASB allocations are taken from Excel file ‘SurplusDeficit_JohnLawson’ supplied by EA on 19.7.21
2. Effective rain based upon Qube methodology and data, Wallingford HydroSolutions Ltd, [2021]

Appendix B – Summary of A%R assessments and EA 'recent actual' deficits: page 2 of 3

					A%R analysis for recent actual abstraction (2017-2019)					EA EFI analysis of recent actual flow deficits			A%R analysis for licensed abstraction				
Catchment	River	Catchment Area	Effective rain	Average recharge	Recent abstraction 2017-2019	Reach or tributary Recent Actual A%R	Catchment Recent Actual A%R	Reach or trib reduction in recent actual to get A10%R	Catchment recent actual reduction for A10%R	EA recent surplus/deficit using EFIs	EA recent deficit for whole catchment	EA ASB band	Reach or tributary licence	Reach or tributary licensed A%R	Catchment licensed A%R	Licence reduction to get A10%R	Catchment licence reduction for A10%R
Darent & Cray	Darent above Lullingstone	118 km2	218 mm/year	70 Ml/d	28.2 Ml/d	40.0%	58%	21.1 Ml/d	64.2 Ml/d	-4.0 Ml/d	31.0 Ml/d	2	40.9 Ml/d	58.0%	80.9%	33.9 Ml/d	181.2 Ml/d
	Darent above Farningham	150 km2		90 Ml/d	35.2 Ml/d	39.3%		26.2 Ml/d		-12.0 Ml/d		2	53.5 Ml/d	59.7%		44.5 Ml/d	
	Total Darent	253 km2		151 Ml/d	79.3 Ml/d	52.5%		64.2 Ml/d		-12.0 Ml/d		2	122.3 Ml/d	80.9%		107.2 Ml/d	
	Cray above Crayford	120 km2		72 Ml/d	39.2 Ml/d	54.7%		32.0 Ml/d	45.6 Ml/d	-19.0 Ml/d		2	53.4 Ml/d	74.5%		46.3 Ml/d	
	Total Cray	130 km2		78 Ml/d	53.4 Ml/d	68.7%		45.6 Ml/d		-19.0 Ml/d		2	81.7 Ml/d	105.2%		73.9 Ml/d	
Nailbourne (Stour tributary)	Nailbourne above Barham	80 km2	218 mm/year	48 Ml/d	9.3 Ml/d	19.4%	19.2%	4.5 Ml/d	7.0 Ml/d	-	11.0 Ml/d		15.9 Ml/d	33.3%	35.7%	11.1 Ml/d	19.6 Ml/d
	Total Nailbourne	128 km2		76 Ml/d	14.7 Ml/d	19.2%		7.0 Ml/d		-11.0 Ml/d		1	27.3 Ml/d	35.7%		19.6 Ml/d	
Dour	Dour above Crabble Mill	50 km2	372 mm/year	50 Ml/d	8.8 Ml/d	17.4%	28.5%	3.8 Ml/d	13.0 Ml/d	-2.0 Ml/d	10.0 Ml/d	2	15.0 Ml/d	29.8%	42.8%	10.0 Ml/d	23.0 Ml/d
	Total Dour	69 km2		70 Ml/d	20.0 Ml/d	28.5%		13.0 Ml/d		-10.0 Ml/d		2	30.1 Ml/d	42.8%		23.0 Ml/d	
Wye (Bucks)	Above High Wycombe	69 km2	367 mm/year	69 Ml/d	1.2 Ml/d	1.7%	9.4%	0.0 Ml/d	0.0 Ml/d	-	1.0 Ml/d		3.3 Ml/d	4.8%	10.1%	0.0 Ml/d	0.2 Ml/d
	Total Wye	134 km2		134 Ml/d	12.6 Ml/d	9.4%		0.0 Ml/d		-1.0 Ml/d		3	13.6 Ml/d	10.1%		0.2 Ml/d	
Colne	Upper Colne above Ver	183 km2	193 mm/year	119 Ml/d	41.5 Ml/d	35.0%	35.2%	29.6 Ml/d	112.4 Ml/d	-	68.0 Ml/d		48.7 Ml/d	41.1%	47.7%	36.9 Ml/d	168.2 Ml/d
	Ver above Redbourn	63 km2		41 Ml/d	8.8 Ml/d	21.6%		4.7 Ml/d		-5.0 Ml/d		3	22.8 Ml/d	55.9%		18.7 Ml/d	
	Total Ver	132 km2		85 Ml/d	28.1 Ml/d	32.8%		19.5 Ml/d		-24.0 Ml/d		2	36.3 Ml/d	42.4%		27.7 Ml/d	
	Bulbourne	66 km2		35 Ml/d	9.8 Ml/d	28.2%		6.3 Ml/d		0.0 Ml/d		3	21.3 Ml/d	61.3%		17.9 Ml/d	
	Upper Gade	48 km2		25 Ml/d	12.2 Ml/d	48.4%		9.7 Ml/d		-11.0 Ml/d		2	24.9 Ml/d	99.1%		22.4 Ml/d	
	Total Gade Bulbourne	184 km2		96 Ml/d	53.4 Ml/d	55.4%		43.8 Ml/d		-44.0 Ml/d		2	78.0 Ml/d	80.8%		68.3 Ml/d	
	Chess	105 km2		67 Ml/d	16.5 Ml/d	24.6%		9.8 Ml/d		-5.0 Ml/d		2	24.2 Ml/d	36.0%		17.5 Ml/d	
	Misbourne	95 km2		78 Ml/d	17.5 Ml/d	22.3%		9.6 Ml/d		-8.0 Ml/d		2	25.6 Ml/d	32.7%		17.8 Ml/d	
	Colne tribs incl Upper Colne to Ver	699 km2		446 Ml/d	157.0 Ml/d	35.2%		112.4 Ml/d		-81.0 Ml/d			212.8 Ml/d	47.7%		168.2 Ml/d	
	Total Colne to Watford	352 km2		232 Ml/d	110.8 Ml/d	47.8%		87.6 Ml/d	87.6 Ml/d	-68.0 Ml/d	68.0 Ml/d	2	250.5 Ml/d	107.9%		227.3 Ml/d	227.3 Ml/d
	Total Colne to Denham	743 km2		490 Ml/d	323.1 Ml/d	66.0%		274.1 Ml/d	274.1 Ml/d	-176.0 Ml/d	176.0 Ml/d	2	531.1 Ml/d	108.4%		482.1 Ml/d	482.1 Ml/d
Lea	Upper Lea to Luton Hoo	65 km2	159 mm/year	36 Ml/d	32.9 Ml/d	92.5%	28.8%	29.3 Ml/d	86.6 Ml/d	-22.0 Ml/d	61.0 Ml/d	3	55.0 Ml/d	154.7%	43.3%	51.4 Ml/d	153.8 Ml/d
	Upper Lea to Water Hall	150 km2		82 Ml/d	48.4 Ml/d	59.0%		40.2 Ml/d		3.0 Ml/d		2	82.9 Ml/d	101.1%		74.7 Ml/d	
	Upper Mimram to Codicote	49 km2		27 Ml/d	2.5 Ml/d	9.2%		0.0 Ml/d		-3.0 Ml/d		3	2.3 Ml/d	8.5%		0.0 Ml/d	
	Total Mimram	136 km2		74 Ml/d	10.4 Ml/d	13.9%		2.9 Ml/d		-13.0 Ml/d		3	19.2 Ml/d	25.9%		11.8 Ml/d	
	Stevenage Brook	39 km2		21 Ml/d	5.0 Ml/d	23.4%		2.8 Ml/d		0.0 Ml/d		2	6.8 Ml/d	32.0%		4.7 Ml/d	
	Total Beane	175 km2		62 Ml/d	24.9 Ml/d	40.3%		18.7 Ml/d		-12.0 Ml/d		2	28.7 Ml/d	46.4%		22.5 Ml/d	
	Upper Rib	51 km2		18 Ml/d	3.0 Ml/d	16.7%		1.2 Ml/d		1.0 Ml/d		2	4.5 Ml/d	25.4%		2.8 Ml/d	
	All Rib/Quin	152 km2		68 Ml/d	22.9 Ml/d	33.6%		16.1 Ml/d		-9.0 Ml/d		3	28.7 Ml/d	42.2%		21.9 Ml/d	
	Ash	89 km2		40 Ml/d	1.2 Ml/d	3.1%		0.0 Ml/d		-5.0 Ml/d		2	4.8 Ml/d	11.9%		0.8 Ml/d	
	Upper Stort to Clavering	45 km2		22 Ml/d	1.8 Ml/d	8.1%		0.0 Ml/d		-1.0 Ml/d		2	5.5 Ml/d	25.0%		3.3 Ml/d	
	Upper Stort to Bishops Stortford	60 km2		29 Ml/d	12.2 Ml/d	41.9%		9.3 Ml/d		-		-	19.1 Ml/d	65.7%		16.2 Ml/d	
	All Stort	280 km2		136 Ml/d	25.0 Ml/d	18.5%		11.5 Ml/d		18.0 Ml/d		2	35.6 Ml/d	26.3%		22.1 Ml/d	
	Lea tributaries & Upper Lea	982 km2		462 Ml/d	132.8 Ml/d	28.8%		86.6 Ml/d		-61.0 Ml/d			200.0 Ml/d	43.3%		153.8 Ml/d	
	Total Lea to Feildes weir	1036 km2		452 Ml/d	173.5 Ml/d	38.4%		128.3 Ml/d	128.3 Ml/d	-160.0 Ml/d	160.0 Ml/d		242.2 Ml/d	53.5%		196.9 Ml/d	196.9 Ml/d
Hiz	Oughton	10 km2	173 mm/year	5 Ml/d	0.9 Ml/d	18.4%	18.1%	0.4 Ml/d	4.1 Ml/d	-	3.0 Ml/d		6.8 Ml/d	143.9%	36.3%	6.4 Ml/d	9.9 Ml/d
	Upper Hiz	18 km2		9 Ml/d	5.0 Ml/d	58.0%		4.1 Ml/d		-3.0 Ml/d		3	5.7 Ml/d	66.5%		4.8 Ml/d	
	Purwell	52 km2		25 Ml/d	1.0 Ml/d	4.1%		0.0 Ml/d		0.0 Ml/d		2	1.2 Ml/d	4.9%		0.0 Ml/d	
	Total Hiz above Ickleford	80 km2		38 Ml/d	6.8 Ml/d	18.1%		3.1 Ml/d		-			13.7 Ml/d	36.3%		9.9 Ml/d	
	Total Hiz above Arlesey	108 km2		51 Ml/d	6.8 Ml/d	13.3%		1.7 Ml/d		7.0 Ml/d		2	13.8 Ml/d	26.8%		8.6 Ml/d	

Appendix B – Summary of A%R assessments and EA ‘recent actual’ deficits: page 3 of 3

					A%R analysis for recent actual abstraction (2017-2019)					EA EFI analysis of recent actual flow deficits			A%R analysis for licensed abstraction				
Catchment	River	Catchment Area	Effective rain	Average recharge	Recent abstraction 2017-2019	tributary Recent Actual A%R	Catchment Recent Actual A%R	reduction in recent actual to get A10%R	recent actual reduction for A10%R	EA recent surplus/deficit using EFIs	deficit for whole catchment	EA ASB band	Reach or tributary licence	Reach or tributary licensed A%R	Catchment licensed A%R	Licence reduction to get A10%R	licence reduction for A10%R
Cam, including Granta and Rhee	Wenden Brook	24 km2	140 mm/year	9 Ml/d	2.2 Ml/d	24.2%	30.9%	1.3 Ml/d	33.8 Ml/d	-1.0 Ml/d	5.0 Ml/d	2	4.5 Ml/d	50.5%	39.3%	3.6 Ml/d	71.0 Ml/d
	Cam above Audley End	77 km2		30 Ml/d	15.3 Ml/d	51.6%		12.3 Ml/d		-3.0 Ml/d		2	23.7 Ml/d	79.7%		20.7 Ml/d	
	All Cam to Granta	198 km2		76 Ml/d	30.7 Ml/d	40.5%		23.2 Ml/d		-3.0 Ml/d		1	48.1 Ml/d	63.4%		40.5 Ml/d	
	Granta	114 km2		44 Ml/d	8.3 Ml/d	19.0%		3.9 Ml/d		-1.0 Ml/d		2	16.5 Ml/d	37.8%		12.2 Ml/d	
	All Cam/Granta to Rhee confluence	329 km2		126 Ml/d	39.0 Ml/d	30.9%		26.4 Ml/d		-5.0 Ml/d		2	64.6 Ml/d	51.3%		52.0 Ml/d	
	Rhee to Cam confluence	303 km2		116 Ml/d	19.0 Ml/d	16.4%	24.0%	7.4 Ml/d		-		-	30.5 Ml/d	26.3%		18.9 Ml/d	
	All Cam to below Rhee confluence	632 km2		242 Ml/d	58.1 Ml/d	24.0%		33.8 Ml/d		-		-	95.2 Ml/d	39.3%		71.0 Ml/d	
Lark	Upper Lark to Bury St Edmunds	59 km2	144 mmyear	23 Ml/d	10.2 Ml/d	43.9%	25.9%	7.9 Ml/d	29.1 Ml/d	-1.0 Ml/d	1.0 Ml/d	2	28.4 Ml/d	122.4%	64.0%	26.1 Ml/d	99.0 Ml/d
	Upper/middle Lark to Temple GS	272 km2		107 Ml/d	29.6 Ml/d	27.7%		18.9 Ml/d		-			58.1 Ml/d	54.3%		47.4 Ml/d	
	Kennett/Lea Brook	102 km2		40 Ml/d	8.2 Ml/d	20.3%		4.1 Ml/d					24.6 Ml/d	61.4%		20.6 Ml/d	
	All Lark to Isleham GS	466 km2		183 Ml/d	47.4 Ml/d	25.9%		29.1 Ml/d		2.0 Ml/d		3	117.3 Ml/d	64.0%		99.0 Ml/d	
Nar	Nar above West Lexham	60 km2	189 mm/year	31 Ml/d	0.3 Ml/d	1.1%	4.5%	0.0 Ml/d	0.0 Ml/d	-	12.0 Ml/d		1.2 Ml/d	3.7%	6.7%	0.0 Ml/d	17.9 Ml/d
	Nar above Narborough	140 km2		72 Ml/d	3.2 Ml/d	4.5%		0.0 Ml/d		-			4.9 Ml/d	6.7%		0.0 Ml/d	
	Total Nar to Marham (Abbey Farm)	154 km2		80 Ml/d	12.8 Ml/d	16.1%	16.1%	4.9 Ml/d	4.9 Ml/d	-12.0 Ml/d		1	25.9 Ml/d	32.5%	32.5%	17.9 Ml/d	
Babingley	Babingley above Flitcham	40 km2	182 mm/year	20 Ml/d	10.9 Ml/d	54.5%	21.6%	8.9 Ml/d	8.9 Ml/d	-5.0 Ml/d	5.0 Ml/d	3	13.7 Ml/d	68.5%	26.9%	11.7 Ml/d	11.7 Ml/d
	Total Babingley	102 km2		51 Ml/d	11.0 Ml/d	21.6%		5.9 Ml/d		-2.0 Ml/d		2	13.7 Ml/d	26.9%		8.6 Ml/d	
Heacham	Heacham above Fring	40 km2	126 mm/year	14 Ml/d	3.1 Ml/d	22.2%	15.9%	1.7 Ml/d	2.1 Ml/d	-	0.0 Ml/d		8.4 Ml/d	60.7%	60.7%	7.0 Ml/d	7.5 Ml/d
	Total Heacham	100 km2		35 Ml/d	5.5 Ml/d	15.9%		2.1 Ml/d		0.0 Ml/d		1	11.0 Ml/d	31.8%		7.5 Ml/d	
Burn	Burn to Burnham Market	80 km2	120 mm/year	26 Ml/d	0.2 Ml/d	0.8%	4.1%	0.0 Ml/d	0.0 Ml/d	1.0 Ml/d	0.0 Ml/d	2	0.4 Ml/d	1.4%	9.0%	0.0 Ml/d	0.0 Ml/d
	Total Burn	101 km2		33 Ml/d	1.3 Ml/d	4.1%		0.0 Ml/d		1.0 Ml/d		1	3.0 Ml/d	9.0%		0.0 Ml/d	
Stiffkey	Main Stiffkey to Warham	88 km2	120 mm/year	29 Ml/d	4.0 Ml/d	13.9%	11.0%	1.1 Ml/d	1.1 Ml/d	-	0.0 Ml/d		8.5 Ml/d	29.3%	25.5%	5.6 Ml/d	7.1 Ml/d
	Binham tributary	37 km2		12 Ml/d	0.7 Ml/d	6.2%		0.0 Ml/d		-			2.7 Ml/d	22.5%		1.5 Ml/d	
	Total Stiffkey	137 km2		45 Ml/d	4.9 Ml/d	11.0%		0.4 Ml/d		-			11.5 Ml/d	25.5%		7.0 Ml/d	
Great Eau	Great Eau above South Thoresby	38 km2	207 mm/year	22 Ml/d	2.3 Ml/d	10.5%	7.5%	0.1 Ml/d	0.0 Ml/d	1.0 Ml/d	15.0 Ml/d	2	5.0 Ml/d	23.4%	19.4%	2.9 Ml/d	4.9 Ml/d
	Total Great Eau	93 km2		53 Ml/d	3.9 Ml/d	7.5%		0.0 Ml/d		-15.0 Ml/d		1	10.2 Ml/d	19.4%		4.9 Ml/d	
Driffield Beck	Driffield Trout Stream	54 km2	257 mm/year	38 Ml/d	1.4 Ml/d	3.7%	2.8%	0.0 Ml/d	0.0 Ml/d	-1.0 Ml/d	1.0 Ml/d	3	2.6 Ml/d	6.8%	9.5%	0.0 Ml/d	0.0 Ml/d
	Foston Beck	57 km2		40 Ml/d	0.0 Ml/d	0.1%		0.0 Ml/d		-1.0 Ml/d		3	0.2 Ml/d	0.5%		0.0 Ml/d	
	Total Driffield West Beck to Wansford	192 km2		135 Ml/d	3.8 Ml/d	2.8%		0.0 Ml/d		12.0 Ml/d		2	12.9 Ml/d	9.5%		0.0 Ml/d	
Gypsey Race	Upper to Boynton	240 km2	257 mm/year	169 Ml/d	14.6 Ml/d	8.6%	10.9%	0.0 Ml/d	1.6 Ml/d	-	0.0 Ml/d		17.7 Ml/d	10.5%	15.7%	0.8 Ml/d	10.6 Ml/d
	Total to Bridlington	265 km2		187 Ml/d	20.3 Ml/d	10.9%		1.6 Ml/d		14.0 Ml/d		2	29.2 Ml/d	15.7%		10.6 Ml/d	

Appendix C – Lists of data files and A%R data analysis files

The abstraction data were provided by the EA in the files shown in below:

Name	Date modified	Type	Size
CAM AND ELY OUSE INCLUDING SOUTH LEVEL CAMS act	20/04/2021 11:34	Microsoft Office Excel ...	63,437 KB
CAM AND ELY OUSE INCLUDING SOUTH LEVEL CAMS_done	24/03/2021 11:10	Microsoft Office Excel ...	3,155 KB
CHERWELL TAME AND WYE act	23/03/2021 09:10	Microsoft Office Excel ...	1,810 KB
CHERWELL TAME AND WYE_done	24/03/2021 10:12	Microsoft Office Excel ...	109 KB
COLNE act	23/03/2021 09:11	Microsoft Office Excel ...	4,810 KB
COLNE_done	24/03/2021 11:13	Microsoft Office Excel ...	137 KB
DARENT act	23/03/2021 09:13	Microsoft Office Excel ...	2,193 KB
DARENT_done	24/03/2021 10:42	Microsoft Office Excel ...	54 KB
DORSET STOUR act	23/03/2021 09:15	Microsoft Office Excel ...	3,657 KB
DORSETSTOUR_done	25/05/2021 10:32	Microsoft Office Excel ...	146 KB
EAST HAMPSHIRE act	23/03/2021 09:17	Microsoft Office Excel ...	1,778 KB
EAST HAMPSHIRE_done	24/03/2021 10:45	Microsoft Office Excel ...	51 KB
FROME PIDDLE AND PURBECK_done	24/03/2021 10:43	Microsoft Office Excel ...	138 KB
FROME PIDDLE PURBECK act	23/03/2021 09:18	Microsoft Office Excel ...	3,901 KB
HAMPSHIRE AVON act	23/03/2021 09:22	Microsoft Office Excel ...	4,777 KB
HAMPSHIRE AVON_done	24/03/2021 10:57	Microsoft Office Excel ...	211 KB
HULL AND EAST RIDINGS act	23/03/2021 08:37	Microsoft Office Excel ...	6,002 KB
HULL AND EAST RIDINGS_done	24/03/2021 10:41	Microsoft Office Excel ...	286 KB
KENNET AND VALE OF WHITE HORSE act	23/03/2021 08:40	Microsoft Office Excel ...	4,743 KB
KENNET AND VALE OF WHITE HORSE_done	24/03/2021 10:39	Microsoft Office Excel ...	178 KB
NORTH NORFOLK act	23/03/2021 08:43	Microsoft Office Excel ...	2,147 KB
NORTH NORFOLK_done	24/03/2021 10:39	Microsoft Office Excel ...	118 KB
NORTH WEST NORFOLK act	23/03/2021 08:45	Microsoft Office Excel ...	3,941 KB
NORTH WEST NORFOLK_done	24/03/2021 11:00	Microsoft Office Excel ...	303 KB
STEEPING GREAT EAU AND LONG EAU act	23/03/2021 08:48	Microsoft Office Excel ...	2,142 KB
STEEPING GREAT EAU AND LONG EAU_done	24/03/2021 10:50	Microsoft Office Excel ...	148 KB
STOUR act	23/03/2021 08:51	Microsoft Office Excel ...	8,598 KB
STOUR_done	24/03/2021 10:47	Microsoft Office Excel ...	189 KB
TEST AND ITCHEN act	23/03/2021 08:58	Microsoft Office Excel ...	10,337 KB
TEST AND ITCHEN_done	24/03/2021 10:51	Microsoft Office Excel ...	226 KB
UPPER LEE act	23/03/2021 09:03	Microsoft Office Excel ...	4,334 KB
UPPER LEE_done	24/03/2021 11:07	Microsoft Office Excel ...	136 KB
UPPER OUSE AND BEDFORD OUSE act	23/03/2021 09:06	Microsoft Office Excel ...	10,747 KB
UPPER OUSE AND BEDFORD OUSE_done	24/03/2021 11:08	Microsoft Office Excel ...	884 KB

Table C1 - Abstraction data files provided by Environment Agency

The files labelled ‘act’ in Table C1 contain monthly abstraction data since 1999, each comprising tens of thousands of rows of data in 23 columns, which include licence number and name, grid references, owner’s name and use descriptions. The files labelled ‘done’ contain licence details including licence number and name, owner, grid references, surface or ground water, dates of issue and expiry, and annual and daily licensed quantities.

The ‘done’ files also include the EA’s assessment of the river catchment affected by some of the abstractions. These were a useful guide to the river catchments affected, but mostly did not sub-divide into river reaches or tributaries. Therefore, the river reach or tributary affected was reassessed for all public water supply and other major abstractions by plotting the locations on OS mapping and application of personal judgement based on topography. This also provided a check on the EA’s assessments of rivers affected, with no major differences found.

The Excel files listed below are linked to the summary file “Summary of A%R analysis 23.9.21” which created the summary table in Appendix B. These files also generated most of the figures and tables shown in the main report.

Name	Size
All effective rain new data 20.6.21	2,168 KB
Burn & Stiffkey all data 15.7.21	4,745 KB
Cam all data 27.8.21	9,275 KB
Colne all data 20.9.21	26,723 KB
Darent all data 19.9.21	4,147 KB
Dorset Stour & Tarrant all data 22.8.21	4,826 KB
EA Chilterns Flow Deficits with JDL additions 20.9.21	34 KB
EA surplus-deficit 25.7.21	100 KB
Frome & Piddle all data 27.6.21	6,659 KB
Great Eau all data 20.6.21	3,797 KB
Hampshire Avon all data 28.6.21	8,883 KB
Hiz all data 7.6.21	19,070 KB
Hull & East Ridings all data 18.6.21	12,886 KB
Kennet all data 1.9.21	6,304 KB
Kent Stour all data 6.6.21	14,592 KB
Lark only all data 16.9.21	7,611 KB
Lee all data 19.9.21	12,744 KB
Meon all data 20.6.21	3,200 KB
North West Norfolk all data 14.7.21	7,119 KB
Summary of A%R analysis 23.9.21	151 KB
Test & Itchen all data 20.6.21	14,654 KB
Wye (Chilterns) all data 25.5.21	2,500 KB

Table C2 - List of A%R analysis files