Darent River Preservation Society
South East Rivers Trust
Darent Valley Trout Fishers

Re-naturalising flows in the Rivers Darent and Cray

12th May 2026

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Frontispiece – Map of Darent-Cray valleys showing locations of river flow gauging stations and observation boreholes referred to in this report

Key points of this report

Despite some modest abstraction reductions in the past 30 years, the Rivers Darent and Cray are still amongst the most over-abstracted chalk streams in the country. There is good measured and modelled evidence to show that the relatively small abstraction reductions to date have converted into increased river flows, but there is still a long way to go in re-naturalising river flows and ecology. There should be a rejection of any suggestion that the abstraction reductions to date have not led to river flow increases.

Present water company plans propose almost complete cessation of Darent-Cray abstractions, but not until after 2050 and with several billion pounds cost of replacement sources. Although river flows would be restored to close to natural, the important aquifer storage would be lost for public water supply resilience – throwing the baby out with the bathwater. No decision will be taken on actual reductions until after more investigations, not due until 2035. In view of the huge cost of replacement sources, the reductions eventually agreed seem likely to be much less than currently planned.

This report proposes a fast and low cost re-naturalisation of flows in the Rivers Darent and Cray by using existing Darent-Cray supplies in conjunction with supplies from London. At most times, areas currently supplied from the Darent-Cray sources would be supplied from London. During droughts, the supplies would instead come from the Darent-Cray sources. The scheme concept would be similar to a smaller Darent-London conjunctive use scheme proposed in the 1990s but not significantly used.

Modelling shows that, with the proposed conjunctive use scheme, river flows would be almost completely restored to natural levels at most times. During droughts, river flows would be lower than natural, but still far above the flows that currently occur in droughts. There would be minimal effect on London's supplies, because the Darent supply from London would not be used in droughts. There would be no need for water from any major new resource schemes like the planned £6.6 billion White Horse Reservoir near Abingdon.

The Darent-London conjunctive use scheme would require a new connection between existing London supplies and the Darent-Cray valleys (a connection that would also be needed in the water companies' current plans). Developed in phases, the scheme could be operational within about 10 years, possibly starting earlier with a pilot scheme.

If feasible, the development of the Darent-London conjunctive use scheme would be a triumph for the water industry, enabling quick repair of long-standing and notorious environmental damage to the rivers, combined with several billion pounds of cost saving through avoidance of need for major new infrastructure elsewhere. The conjunctive use scheme would be strategically significant in plans for future water resources in London and the South East. In this context, it is recommended that DRiPS, South East Rivers Trust and DVTF should now engage with the water companies and regulators confidentially, with a limited circulation of this report.

Summary

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Scope of this report

This report reviews the impact of public water supplies on flows in the Rivers Darent and Cray and the effectiveness of past supply reductions in improving river flows. It considers current water company plans for improving the rivers and proposes some alternative measures. The over-riding objective has been to find a cost effective solution to over-abstraction that can restore the rivers reasonably soon, avoiding the long delays and uncertainty in current water company plans to deal with the over-abstraction after 2050.

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Models used in the report

Changes in groundwater levels and flows in the Darent and Cray valleys have been assessed using a new version of the Chalk Streams First (CSF) lumped parameter model which simulates the seasonal rise and fall of groundwater levels and the consequent variation in river flows. The model simulates daily river flows and groundwater levels over a 50 year period. To account for the differences in geology in the Darent-Cray catchment, the model has separate but inter-linked components for the Greensand aquifer in the upper Darent catchment and the Chalk aquifer elsewhere in the Darent-Cray valleys.

13-24

The CSF model gives a reasonably good fit between modelled and observed groundwater levels and river baseflows in all parts of the Darent-Cray catchment. The fit of modelled and observed data is as good or better than those from the Environment Agency's London Basin Model (LBM) coverage of the Darent-Cray valleys.

24-28

If some Darent-Cray supplies are replaced by supplies from London, it will affect the deployable output and resilience of London's supplies. Modelling of the effect on London's supplies has been done using a replica of Thames Water's Aquator model, which simulates daily operation of London's supplies over the past 100 years.

55-59

Impact of existing abstractions in the upper and middle rivers

The CSF modelling shows that water supply abstractions have reduced groundwater levels (GWLs) by about 1 to 1.5 m, somewhat more than the reductions shown by the Environment Agency's LBM model. The CSF and LBM models both show similarly large amounts of reduced flows in all parts of both the Rivers Darent and Cray, including the total drying of the River Darent at Hawley. Both models show that at times of low flows, the abstractions reduce flows to typically around 1/10th of the natural flow.

30-34

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Impact of existing lower river abstractions

Analysis of the water balances in the Darent and Cray Chalk aquifers – the balance between inflows from rainfall recharge and the outflows from river baseflows, abstraction and aquifer underflow – showed that the lower Darent and lower Cray abstractions are probably not affecting GWLs and river flows in the upper and middle parts of the rivers**.** However, some of the lower river sources are located close to the rivers, so their cones of influence will affect 34 GWLs in the valley bottom and they are likely to be drawing some water directly from river flows. They could also be causing cause loss of river flow through river-bed leakage. In addition, the lower river sources could be reducing groundwater levels close to the Thames estuary and steepening the gradient of the water table falling towards the estuary, thereby lowering groundwater levels, spring outflows and river flows in the middle and upper rivers.

The effect of the lower river sources on river flows is therefore somewhat uncertain and warrants further investigation, possibly through pump shut-off tests and spot flow gauging 77 to measure leakage losses in the lower river.

Effectiveness of past abstraction reductions

In the mid-1990s, the upper Darent Greensand abstractions were reduced by about 11 Ml/d, from 34 Ml/d to 23 Ml/d, mainly from closure of Thames Water's Brasted abstraction and a 35-38 large reduction in their Sundridge abstraction. There has been no significant reduction in South East Water's abstractions around Sevenoaks.

The average abstraction from the Chalk in the middle Darent reduced from 36 Ml/d to 20 Ml/d between about 1998 and 2007, mainly from Thames Water's abstractions at Eynsford, Horton Kirby and Lullingstone. However, the upper Cray abstraction increased by 3 Ml/d, so 38 the overall chalk abstraction upstream of the lower rivers has only reduced by about 13 Ml/d, from 76 Ml/d to 63 Ml/d.

Analysis of gauged river baseflows has shown that the Chalk and Greensand abstraction reductions have both led to an equivalent measured increase in river flows. This is also 38-39 shown by both the CSF model and the LBM model.

The conclusions from this analysis of past abstraction reductions in the Darent-Cray catchment are:

1. The scale of the abstraction reductions has been very modest – only a 26 Ml/d reduction in a total abstraction of 110 Ml/d in the upper and middle rivers. 40 Abstraction as % of average recharge (A%R) still remains very high at 61%.
2. There is good measured and modelled evidence to show that most of the abstraction reductions have converted into river baseflows.

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3. Despite the high conversion of the abstraction reductions into river flows, the flow gains have been small in percentage terms, so any improvements in river ecology will have been small and difficult to detect.
4. Despite the abstraction reductions to date, the Rivers Darent and Cray are still amongst the most over-abstracted chalks streams in the country.

Overall, there should be a rejection of any suggestion that abstraction reductions to date have led to minimal river flow improvements. Flows have improved by an amount almost equivalent to the modest reductions in abstraction to date, but there is still a long way to go in re-naturalising river flows and ecology. 40

Water company planned abstraction reductions

The water companies' latest, Government-approved water resource management plans have assumed large reductions in abstraction in line with a 'High' scenario in Water Resource South East's regional plan. 41-42 There are 158 Ml/d of Darent-Cray reductions in the plans, with much of the replacement water coming from Thames Water's planned new reservoir near Abingdon. 49 If it actually takes place, this amount of abstraction reduction would largely re-naturalise flows in the Rivers Darent and Cray, but the important aquifer storage would be lost for public water supply resilience – throwing the baby out with the bathwater.

However, there is only 14 Ml/d of abstraction reduction planned by 2035 (mainly at Thames Water's Lullingstone, Eynsford and Horton Kirby sources) and 55 Ml/d by 2040 (mainly Thames Water's Bexley source). All of the remaining 103 Ml/d of reductions are planned to be left until after 2050. Thames Water have justified this delay as follows:

> *"In view of this need for a strategic solution [the £6.6 billion new reservoir near Abingdon and connection of the Darent valley to London], our consideration is that we should (by 2035, following investigations) confirm the licence reductions which are required and then (by 2040) design strategic network solutions to enable those licence reductions. Given that the construction of infrastructure would then take a significant amount of time, we do not think it would be possible to accelerate most of these licence reductions ahead of the "backstop" date of 2050."* 43

Thames Water plan to investigate the Lullingstone, Eynsford and Horton Kirby reductions by 2030 but all the other big reductions will only be investigated by 2035. The need for these investigations was emphasised in a joint water company letter to the Environment Agency in December 2025, expressing concerning over the huge scale of planned abstraction reductions nationally. 44

Understandably, the water companies plan thorough investigation of the need for the all the planned Darent-Cray reductions, before any decision on what reductions should proceed. 44 With replacement source costs of about £4 billion, the full amount of the

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planned cuts seems unlikely to be justified by benefit/cost analysis. Most of the investigations are not planned to be completed until 2035. However, the costs of the investigations will be a tiny proportion of the several billion pounds of capital cost of replacement sources, if the investigations show they are all needed. Therefore, it makes economic sense to complete all the investigations by 2030 and before any commitment to building the replacement sources.

The scope of Thames Water's planned initial investigations of the Lullingstone, Eynsford and Horton Kirby reductions, due in 2026, appears aimed at showing that past abstraction reductions have provided little benefit, so targets for future reductions can be much less ambitious. 45 It seems that the huge reductions in current water company plans are likely to be greatly scaled back. This is disappointing, but understandable given the enormous cost of replacement sources like the Abingdon reservoir.

South East Water plan about 16 Ml/d of abstraction reductions from their upper Darent sources around Sevenoaks, introduced gradually up to 2055. The replacement water is said to come from leakage reductions and demand management, so there would be no need to 45 import replacement water from Thames Water's London supplies.

Potential for conjunctive use of existing London and Darent supplies

At most times in most years, there is enough water in the Rivers Thames and Lee to maintain London's supplies, without using reservoir storage. The surplus Thames-Lee water could be used to replace supplies from the Darent aquifers at most times, with the existing 49-52 Darent-Cray sources used only in droughts. The overall amount of water taken from the aquifers would be greatly reduced, groundwater levels would rise and river flows would increase to close to natural levels. This is the principle behind the Darent-London conjunctive use scheme proposed in this report.

Proposed Darent-London conjunctive use scheme

The new infrastructure needed to implement the conjunctive use scheme would comprise the pipe network connecting the London ring main to areas currently supplied by the 52 existing Darent -Cray sources and some enhancement of the existing London distribution and water treatment works to provide the additional supply to the Darent. The layout of a Darent-London conjunctive use scheme is shown schematically below:

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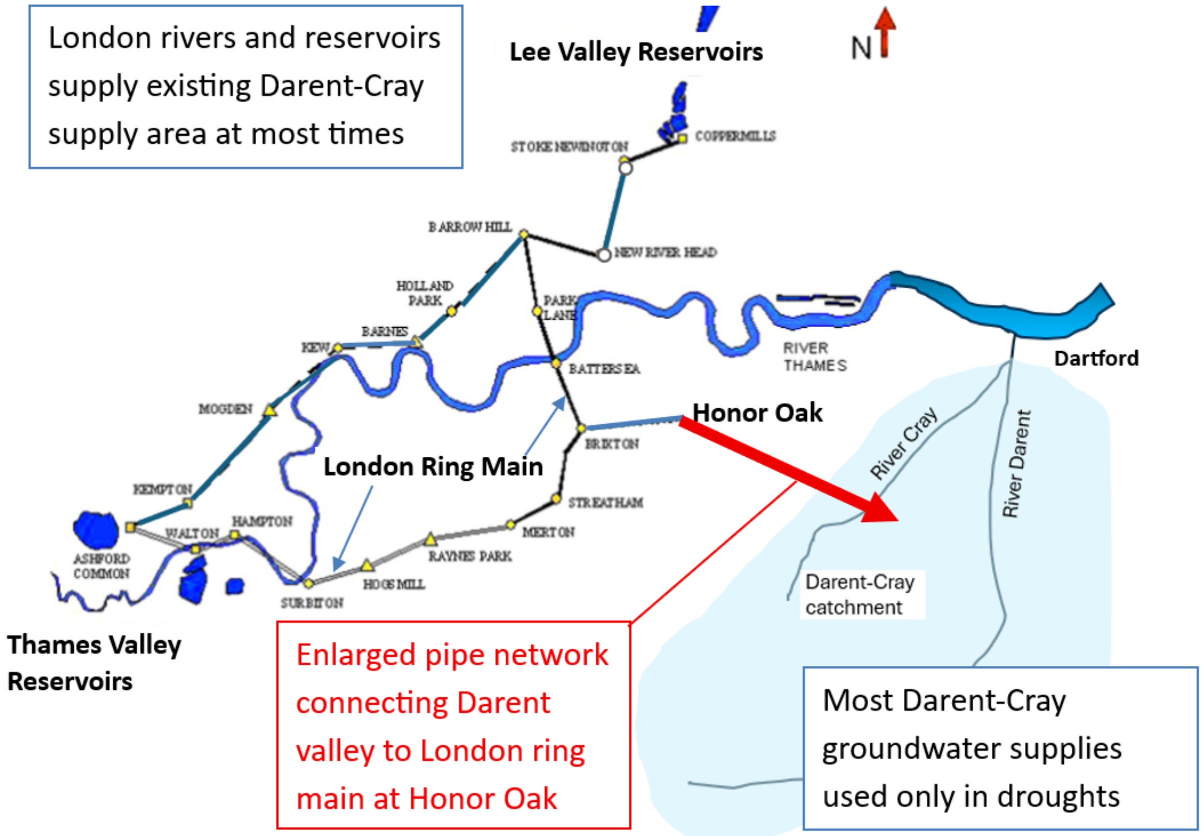

Schematic layout of the Darent-London conjunctive use scheme

In Thames Water's current plans, these works will all be needed by 2050 to enable the 150 Ml/d of Darent-Cray abstraction reductions planned after 2050 – therefore it is a matter of bringing these works forward by about 15 years; they are not a new requirement. 52

The pipe network enhancement will be very costly – probably of the order of several hundred million pounds. However, it would eliminate the need for about 150 Ml/d of new resource planned by Thames Water, i.e. about half of the output of the new 271 Ml/d reservoir near Abingdon with a capital cost recently estimated as £6.6 billion. 52

An initial assessment of the conjunctive use scheme has assumed all of the existing upper and middle Darent-Cray sources, totalling 84 Ml/d, would be used only in droughts, with an 84 Ml/d replacement supply from London. The switching from London supplies to the Darent drought-only sources would be controlled by the same operating rules as currently used for switching on and off the London Gateway desalination plant and some of Thames Water's other drought sources. 53-55

Effectiveness of Darent-London conjunctive use scheme

Modelling shows that the use of most Darent-Cray sources only in droughts would allow 61-62 groundwater levels in the Chalk and Greensand to rise by about 1 m, becoming close to natural levels at most times. During droughts, use of the Darent-Cray sources would cause

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the GWLs to fall by about 0.5 m. After droughts, it would take about 18 months for groundwater levels to rise back to natural levels.

Modelling shows that in normal and moderate drought years, the river flows with the proposed Darent-London conjunctive use scheme would be a huge improvement on the present flows with continuous use of the 84 Ml/d of the planned drought sources. At most times in most years flows would be fully re-naturalised or just slightly below. In the drought years, summer flows would still be substantial and well above the 50% reduction target that has been previously suggested as an acceptable minimum. The improvements in river flow would seem likely to allow a dramatic improvement in river ecology, back to the natural ecology of a “classic” chalk stream. 62-66

The initial proposal for a Darent-Cray conjunctive use scheme would be to allow continued use of the sources in the lower Rivers Darent and Cray, with a total output of total about 76 Ml/d. Water balance analysis shows that these large lower river sources probably have little effect on the seasonal fluctuations of regional groundwater levels in the chalk aquifer that are the main driver of flows in the middle and upper Rivers Darent and Cray. 66-67

Effect of Darent-London conjunctive use scheme on London’s supplies

The existing London supply system, without the Darent supply, can maintain an output of 2283 Ml/d in the 1933-34 drought, equivalent to a 1:100 year drought. If the London supplies are also required to supply 84 Ml/d to the Darent, except in droughts, the supply that can be maintained falls to 2276 Ml/d – only a 7 Ml/d loss of deployable output. There would be no effect on Thames Water’s service levels for the frequency of use of demand reduction measures. If the lower river abstractions are also only used as drought sources, increasing the amount supplied from London to 158 Ml/d, the loss of London deployable output would still be only 14 Ml/d. 67-71

Effectiveness of the conjunctive use scheme in droughts of over 1:100 year severity

Although the effectiveness of the conjunctive use scheme has not yet been modelled in droughts of severity up to the London supplies resilience standard of 1:500 years, some general comments can be made. Firstly, the output of London’s supplies will be little affected because the trigger rule for use of the Darent drought sources will stop the supply to the Darent during the drought. Secondly, even though the Darent-Cray drought sources will be used for longer during a 1:500 year drought, the groundwater levels will be a lot higher at the start of the drought than they would be if the sources are used continuously, as they are at present. Therefore, the rivers flows will still be much improved compared with what they would be if the sources were being used continuously in a 1:500 year drought. 73-74

Conclusions on effectiveness of the conjunctive use scheme 74-75

The conclusions from the initial assessment of the potential for a Darent-London conjunctive use scheme are:

1. Use of all the existing upper and middle Darent-Cray sources only in droughts, totalling 84 Ml/d, with replacement supplies from London, would restore river flows to close to the fully natural flow regime, with minimal impact on London's supplies.
2. The lower Darent supplies totalling 76 Ml/d, including the Bean wellfield, can probably still be used on a continuous basis, but this needs further investigation.
3. The loss of London deployable output would be less than 10 Ml/d, because output would be protected by the early triggering of use of the Darent sources in droughts. There would be no effect on Thames Water's service level compliance.
4. The use of the Darent sources in droughts would cause groundwater levels and river flows to fall below natural for several months. However, river flows in droughts would still be greatly increased from current levels and well above the 50% of natural flow target that has previously been proposed as acceptable by the Environment Agency and water companies.
5. After droughts, it would take about 18 months for groundwater levels and river flows to recover to natural levels.

In view of these conclusions, the conjunctive use scheme should now be fully investigated as part of the planned Darent WINEP investigations in AMP8 (2025 to 2030), with an aim for early implementation of the scheme in the 2030s, about 15 years ahead of the abstraction reductions in current water company plans. 75

The pipe network enhancements that would be needed to connect London's supplies to the Darent valley would be same network enhancements that would be needed for the large scale reductions in abstraction that are in the water companies' latest Water Resource Management Plans, mostly for implementation after 2050. With the conjunctive use scheme, these network enhancements would need to be brought forward by about 15 years. 75

Investigations of the conjunctive use scheme

The current Darent WINEP investigations in 2026 are focused on Thames Water's abstractions and the state of the River Darent downstream of Lullingstone. There is no mention of the impacts of other water companies' abstractions, especially in the upper Darent, or of alleviation of low flows in the River Cray. The overall tone of the planned WINEP investigation appears to be scepticism over whether past abstraction reductions have provided any benefits and whether any more abstraction reduction is needed. 75-76

It is proposed that the scope of the currently planned WINEP investigation, due for completion by December 2026, should include a detailed review of this report's evidence of 76

abstraction impacts and the river flow benefits of past abstraction reductions.

It is proposed that investigation of the Darent-Cray conjunctive use scheme should include:

1. Modelling of the effectiveness of the scheme on river flows and its impact on London's supplies, including consideration of how the scheme would perform in droughts of more than 1:100 year severity.
2. Modelling of the impact of the lower Darent and Cray groundwater sources on river flows, with due consideration also of data from spot gauging of lower river flows and the results of pump-shut-off tests for the lower river sources. This will enable a decision on whether or not the lower river groundwater sources should be used as drought-only sources.
3. Investigation of the pipe network needed to transfer water from London to the Darent supply area and enhancements needed for the London water treatment and distribution system. 76-78
4. Consideration of water quality, operational and flooding issues arising from the intermittent switch between London supplies and Darent-Cray sources.
5. Consideration of options for phasing the implementation of the conjunctive use scheme, possibly with an initial pilot scheme using existing network capacity connecting Darent-Cray supply areas to London.
6. Consideration of the inter-company operating agreements that would be needed.

It is proposed that the investigation of the conjunctive use scheme should be completed in time for implementation to be included in water company AMP9 business plans (2030-35).

Implementation of the conjunctive use scheme

The Darent-Cray conjunctive use scheme is a Strategic Resource Option in its own right, because it would obviate the need for about 150 Ml/d of strategic resource options elsewhere, with a potential capital cost saving of several billion pounds. The up to 150 Ml/d of network enhancements needed to connect existing Darent-Cray supply areas to the London supplies would be a major infrastructure project at a comparable scale to some of the projects in Ofwat's strategic resource option programme, for example the Thames to Southern transfer (120 Ml/d) and the Grand Union Canal transfer (130 Ml/d). 78

Therefore, consideration should be given to a rapid implementation programme for the Darent-Cray conjunctive use scheme, bringing it in line with programmes for other major water resource developments. At its simplest, the programme could be: 78-79

1. An initial review of the findings of this report by December 2026.

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2. Detailed investigation of the scheme to be completed by 2029, to an equivalent level of development to ‘Gate 3’ in the current Ofwat strategic resource option programme under RAPID’s supervision.

3. Inclusion of the conjunctive use scheme in water company ‘preferred plans’ in their 2029 WRMPs and as part of the investment programmes in AMP9 business plans.

4. If feasible, around 2030, implement a pilot scheme making use of existing network connections between the London supply system and Darent-Cray supply areas.

5. Phased implementation of at least half the potential capacity by 2035 and the full scheme by 2040.

If feasible, the development of the Darent-London conjunctive use scheme would be a triumph for the water industry, with repair of long-standing and notorious environmental 79
damage, combined with several billion pounds of capital cost saving through avoidance of need for major infrastructure elsewhere.

Recommended next steps

The scale of the Darent over-abstraction problem and the solution proposed in Government-approved water company plans has wide implications for plans for new water supplies in the South East and, possibly, other parts of the country. In particular, the plans for Thames Water’s proposed new £6.6 billion ‘White Horse Reservoir’ near Abingdon has been justified 80
by a water deficit forecast that would be made good by using about half of its planned supply output to replace about 130 Ml/d of present Darent-Cray supplies. Plans for the White Horse reservoir are at an advanced stage, with an application for a Development Consent Order to be submitted later in 2026.

Therefore, it is recommended that DRiPS, the South East Rivers Trust and Darent Valley Trout Fishers should engage with the water companies and regulators confidentially, with a limited circulation of this report. The next steps could be:

1. Issue of this report to the local Environment Agency, Thames Water and the other interested water companies, with a request for an in-person meeting, allowing sufficient time for a full presentation and proper discussion of the report’s findings. 80

2. Copying the report and covering letters to Ofwat, the Environment Agency’s national water resource management team and RAPID (the regulator organisation responsible for the national programme of Strategic Resource Option development), initially for their information, but inviting feedback.

It is recommended that, until there has been discussion with the water companies and regulators, there should be limited external communication about this report.

1. Introduction

1.1 Background

The River Darent and its tributary the River Cray are amongst the most heavily over-abstracted chalk streams in the country[1]. Flows in the rivers mainly come from groundwater outflows from the Greensand and Chalk aquifers that underlie the valleys. The total abstraction of groundwaters from these aquifers amounts to over half their average recharge from rainfall. In dry years, the abstractions can exceed the aquifer recharge over the year. Inevitably, river flows have been reduced to far below their natural amounts.

The Environment Agency's predecessors, the National Rivers Authority, started a River Darent Action Plan in 1995 to address the very poor condition of the rivers, particularly due to the over-abstraction of water for public water supplies[2]. Although some improvements have been achieved, the rivers are still amongst the most heavily over-abstracted chalk streams in the country, and their condition is far removed from the iconic state of similar large chalk streams like the Rivers Test and Itchen.

Current water company plans recognise the need for major abstraction reductions in the Darent and Cray catchments but mostly delay them until after 2050. New concerns over the costs and benefits of abstraction reductions throw doubt on whether the far-off planned reductions will ever materialise after the detailed investigations of needs, costs and benefits planned under the Water Industry National Environment Programme (WINEP) in the next 5 years. A joint water company letter to the Environment Agency in December 2025 expressed big concerns about the scale of planned abstraction reductions nationally, with fears about the extremely high costs of replacement water sources, the disproportionality of these costs relative to benefits and the impact of the replacement sources themselves[3].

These concerns are reflected in the scope of work planned for the WINEP investigations of River Darent being undertaken by consultants, Atkins[4]. The first phase of this investigation, planned for completion by December 2026, will focus on:

- the appropriateness of flow targets which currently drive the almost total abandonment Darent-Cray existing supplies by 2050, as allowed for in current water company plans

- what benefits, if any, have come from previous reductions in abstractions

[1] A%R – Review of abstraction as a % of recharge in chalk streams, pages 7 and 43-46 https://chalkstreams.org/2022/01/23/ar-abstraction-as-a-of-recharge-in-chalk-streams/
[2] River Darent Action Plan, Summary paper, October 2000 https://darent-drips.org.uk/wp-content/uploads/2023/07/22-River-Darent-Action-Plan-Oct-2000.pdf
[3] Joint water company letter to Environment Agency, December 2025,
[4] Details of scope of Atkins work as attached to email from Steve Tuck to John Lawson dated 12th March 2026

- whether any further abstraction reduction is needed to meet ecological objectives for the River Darent

The tone of the scope of work indicates scepticism over the need and justification for currently planned Darent-Cray reductions in abstraction, which total about 150 Ml/d by 2050. The replacement water would mainly come from Thames Water's planned new reservoir near Abingdon, which has an output of 271 Ml/d and a capital cost of £6.6 billion. The replacement water for the Darent would therefore use about 60% of the output from Abingdon reservoir at an equivalent capital cost of about £3.6 billion, not including the substantial cost of new connections between the Darent valley and London's supply system. It is, therefore, not surprising that the water companies appear sceptical of the need and justification for the planned Darent reductions.

1.2 Scope of this report

In this context, the Darent River Preservation Society, South East Rivers Trust and Darent Valley Trout Fishers have commissioned their own investigation to review the impacts of water abstraction on the Rivers Darent and Cray and consider faster and less costly means of reinstatement of river flows to much closer to their natural condition. The scope of the investigation is shown in Appendix A and comprises:

1. Development of a lumped parameter groundwater model for the Darent/Cray.

1. New estimates of how groundwater levels and river flows in the Rivers Darent and Cray have been affected by abstraction of groundwater for public water supplies.

2. Comparison of estimated abstraction impacts with previous impact assessments by the water companies and Environment Agency (EA), providing a basis for challenging water company estimates, if needed.

3. Assessing the effectiveness of past abstraction reductions in the catchment, providing a basis for challenging water company and EA assessments of the effectiveness of the reductions, if needed.

4. Modelling the effectiveness of the water companies' planned abstraction reductions, as described in their latest Water Resource Management Plans.

5. Modelling the effectiveness of alternative abstraction reduction plans that could bring improvements faster and at less cost than the improvements foreseen in water company plans.

The over-riding objective of the work is to find cost effective solutions to over-abstraction, that can restore the rivers in the reasonably near future, avoiding the long delays and uncertainty in current water company plans.

2. CSF lumped parameter model of the Darent-Cray catchment

2.1 Principles behind the CSF modelling approach

The CSF (Chalk Streams First) lumped parameter modelling approach was originally developed to investigate abstraction impacts in the upper River Kennet valley and has subsequently been used on chalk stream investigations for the rivers Ver, Chess, Mimram, Bean[5], Ivel[6] and Tarrant[7].

The main driver of baseflows in chalk streams is the groundwater level (GWL) relative to the springs and river bed levels at any given point, as illustrated by the diagram of a typical chalk valley in Figure 1[8]:

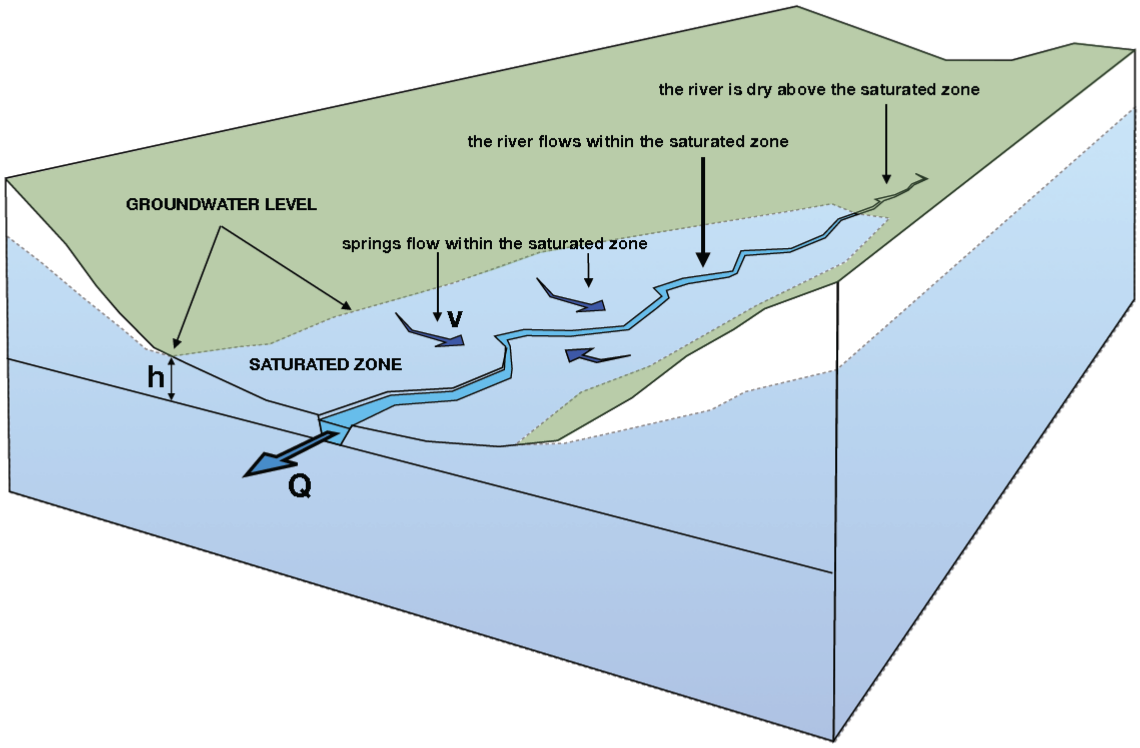

Figure 1 - Schematic representation of a typical chalk valley

As groundwater levels rise, so does the force of gravity (hydraulic head) driving water to the springs and seepages in the valley and stream below. In addition, as groundwater levels rise, more springs rise further up the valley and spill water from the aquifer to the stream.

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[5] Dealing with impacts of groundwater abstraction on the chalk streams of the Colne and Lea valleys, John Lawson for the Chalk Streams First consortium, February 2023 https://chalkstreams.org/flow-recovery-following-abstraction-reduction/

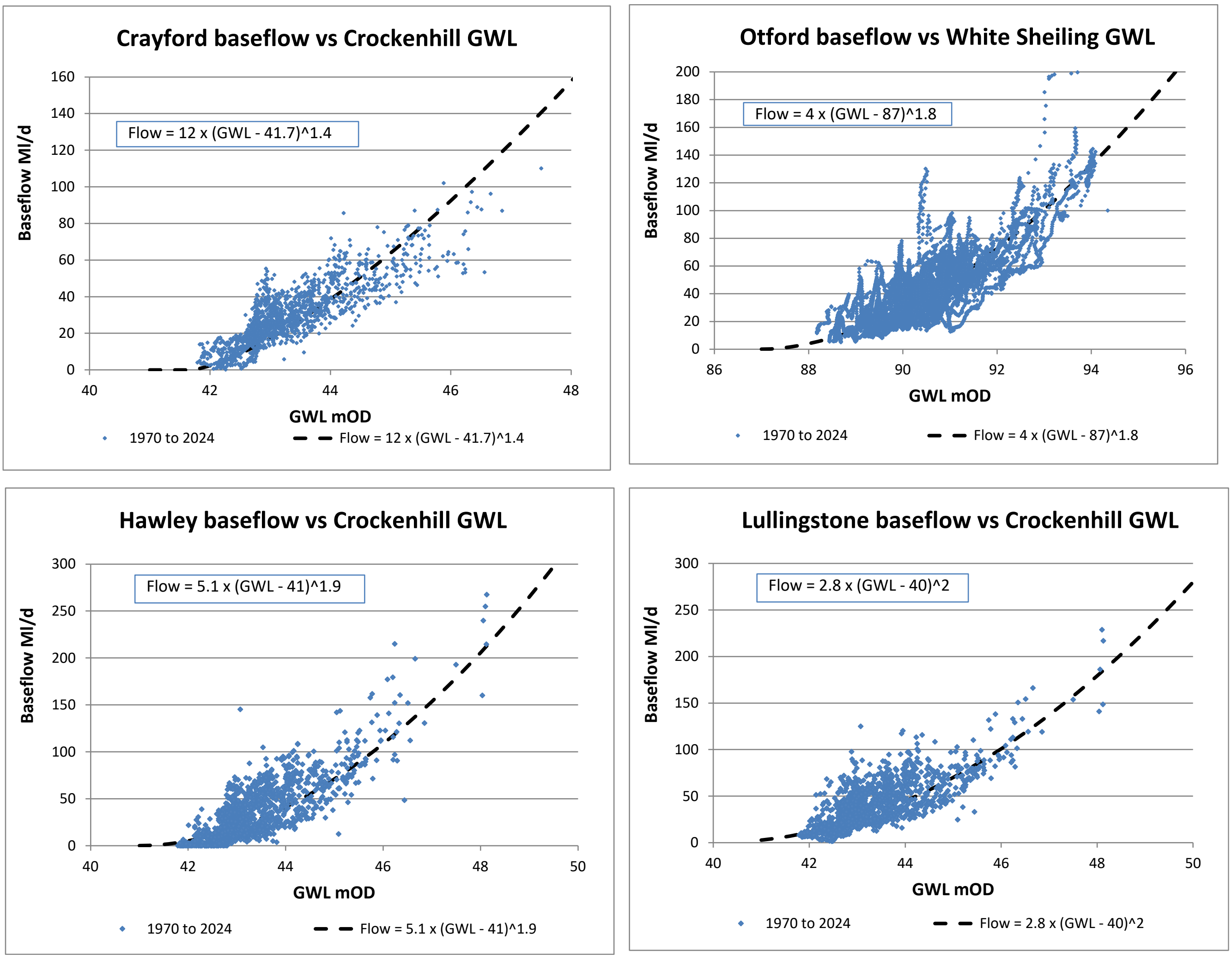
[6] Alleviation of abstraction impacts on the River Ivel, John Lawson for RevIvel, June 2022 https://www.revivel.org/app/uploads/2022/07/Ivel-report-21.6.21-BHs-redacted.pdf

[7] Alleviation of abstraction impacts on the River Tarrant, John Lawson for River Tarrant Protection Society, September 2025 https://static1.squarespace.com/static/68af200e9c79482d4d623ee2/t/695a2e012980754a1203df4a/1767517697189/River+Tarrant+Abstraction+Report+Sept+25.pdf

[8] Diagram from page 36 of the CaBA Chalk Stream Strategy https://catchmentbasedapproach.org/learn/chalk-stream-strategy/

Recorded data in chalk valleys always show a close relationship between the rise and fall of chalk stream flows and aquifer groundwater levels. The relationship is non-linear – i.e. for a given unit of rise in GWL, river flows increase more at high GWLs than at low GWLs. This is because the higher GWLs cause more springs to start flowing further up the valley, and the spring outflows to be faster.

This type of relationship can be seen in the flows and groundwater levels in the Darent-Cray valley shown in Figure 2 below, although the river flows come from two different aquifers, the Chalk and Greensand.



Locations of gauging stations and observation boreholes (OBHs) are shown on the Frontispiece.

Figure 2 - Relationships between river baseflows and GWLs in the Darent-Cray valley

The CSF lumped parameter model simulates the process of seasonally rising and falling GWLs and the consequent variation in river flows, as illustrated on Figure 1. The principles behind the CSF model are:

a) that chalk stream baseflows are driven by the hydraulic head of the regional water table, as shown schematically in Figure 1, and by relationships between river flows and groundwater levels like those shown in Figure 2.

b) that the hydraulic head of the water table is determined by the aquifer water storage within the catchment, which rises due to recharge from rainfall and falls due to river outflows, throughflows (within the aquifer) and abstraction.

c) that the water balance within a catchment is maintained, i.e. the net sum of inflows, outflows and changes of storage in the aquifer are zero on every modelled day

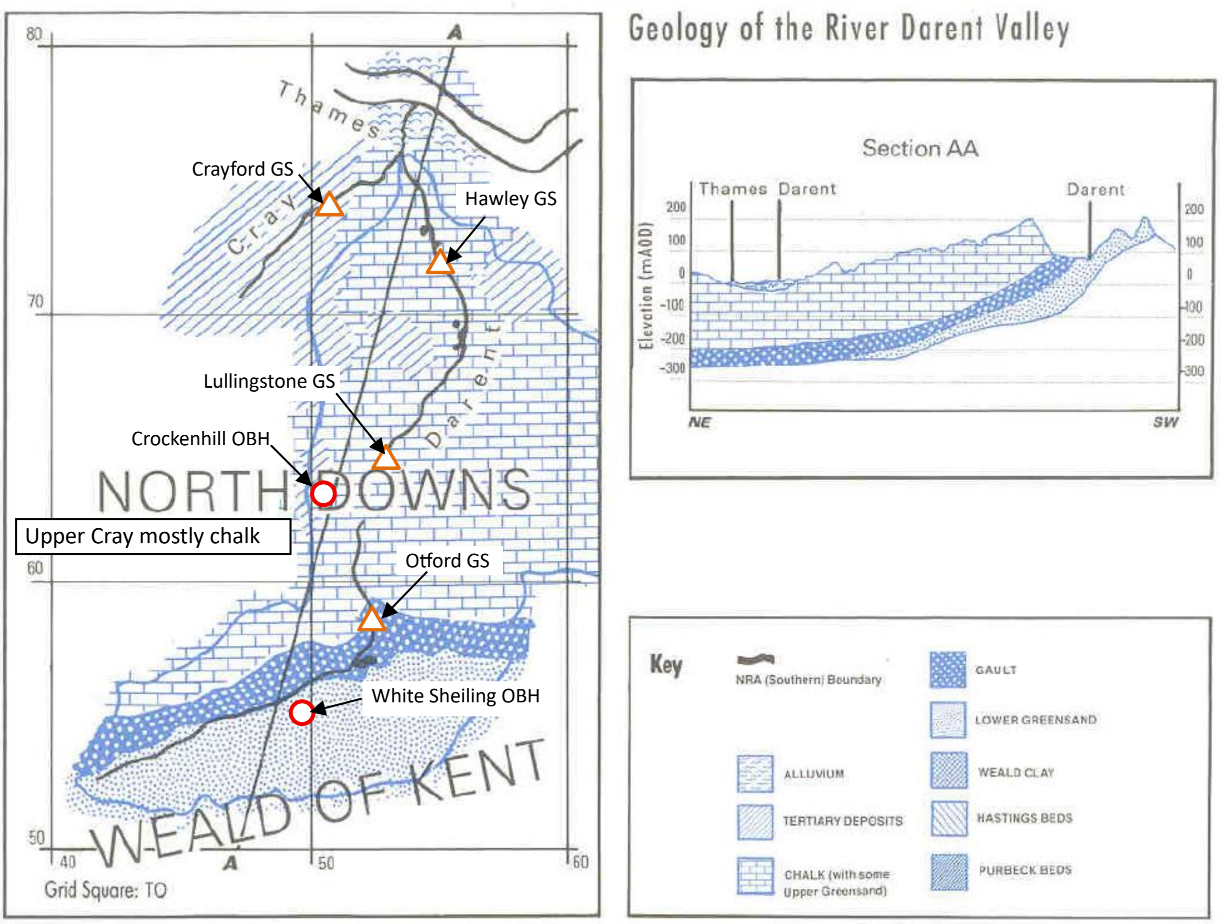
The CSF model is an Excel spreadsheet typically of about 100 Mb, including all the graph plotting and analysis routines. The model uses daily data for effective rain to simulate daily groundwater levels and river flows at the locations of selected observation boreholes and flow gauging sites. The model simulates daily river flows and groundwater levels over a long historic period – typically about 50 years. The primary location for modelling GWLs is chosen to be at the site of an observation borehole (OBH) somewhere near the centre of the catchment, with good availability of recorded GWLs and at a good distance from the river and well away from the cone of influence of a major abstraction borehole. The model simulates the GWLs at the sites of other observation boreholes from the modelled GWLs, using best-fit equations between recorded GWLs, which usually correlate strongly with the GWL at the main OBH site.

In addition to the effect of borehole abstractions on the seasonal rise and fall of groundwater levels and river flows, the abstractions create cones of depressed GWLs around the boreholes, which can also affect river flows locally. This effect is superimposed on the effect that abstractions have on the rise and fall of regional groundwater levels. The effect of cones of depression is not simulated by the CSF model but is relatively small in relation to the impact of the abstractions on the regional groundwater levels.

2.2 Applicability of the CSF model concept for the Darent-Cray valley

The CSF modelling approach was developed for use on chalk streams and it has previously only been used on chalk streams with close to 100% chalk catchments and high baseflow indices (BFIs) – the proportion of river flows that come from groundwater rather than rainfall driven surface run-off. Pure chalk streams like the Rivers Itchen and Test have BFIs of over 90%.

About 30% of the Darent-Cray catchment is not chalk and includes a fair amount of impermeable clay and tertiary deposits. This can be seen on the sketch geological map in Figure3, which focuses on the Darent and shows part of the Cray catchment:



Original diagram copied from rom NRA Darent Conservation Project Report in 1993

Figure 3 - Sketch geological map of Darent catchment

The mixed geology of the Darent-Cray catchment is reflected in the baseflow indices for flows at the various gauging stations (GS), as below[9]:

- Hawley 74%
- Lullingstone 74%
- Otford 56%
- Crayford 74%

The baseflow indices at these gauging stations are lower than for "pure" chalk streams, but the relationships between river baseflows and groundwater levels on Figure 2 show similar characteristics to those of pure chalk streams. Although the Chalk and Greensand aquifers are hydraulically separated by a thick layer of gault clay (see section A-A on Figure 3), the groundwater levels in the Chalk and Greensand fluctuate similarly, as can be seen by plots of the GWLs at Crockenhill (chalk) and White Sheiling (greensand) shown on Figure 4:

[9] BFIs taken from NRFA web pages for these gauging stations, eg for Hawley https://nrfa.ceh.ac.uk/data/station/meanflow/40012

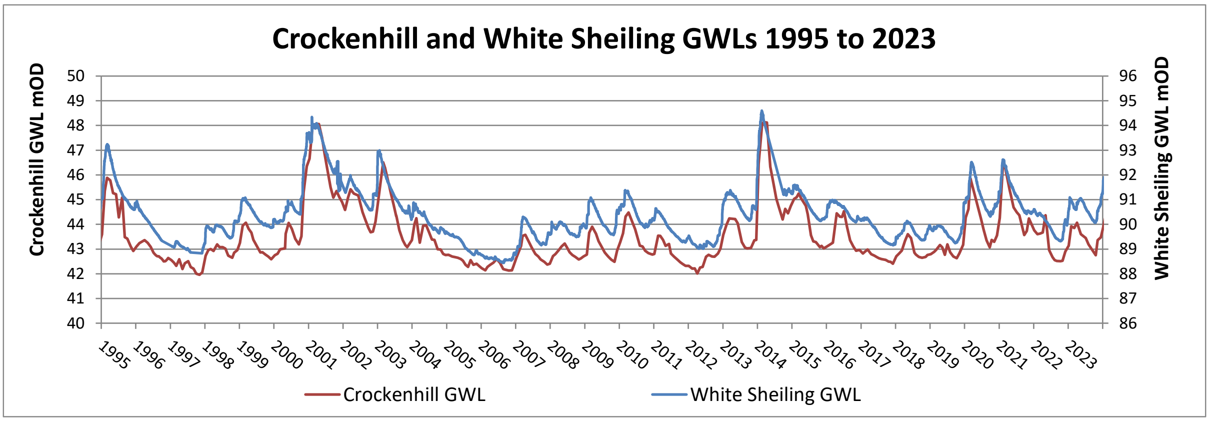


Figure 4 - Comparison of Crockenhill and White Sheiling GWL fluctuations 1995 to 2003

This shows that the GWLs in the chalk aquifer at Crockenhill and the greensand aquifer at White Sheiling respond in a similar way to recharge from effective rain. On that basis, the CSF modelling approach can still be used in the mixed geology of the Darent-Cray catchment, albeit with a likelihood that the fit between modelled and observed flows and GWLs will not be as good as those found with the application of the CSF model in pure chalk catchments.

Baseflows in the middle and lower Darent are heavily dominated by baseflows coming from the upper catchment above Otford. This can be seen in the hydrographs below showing baseflows at Otford, Lullingstone and Hawley:

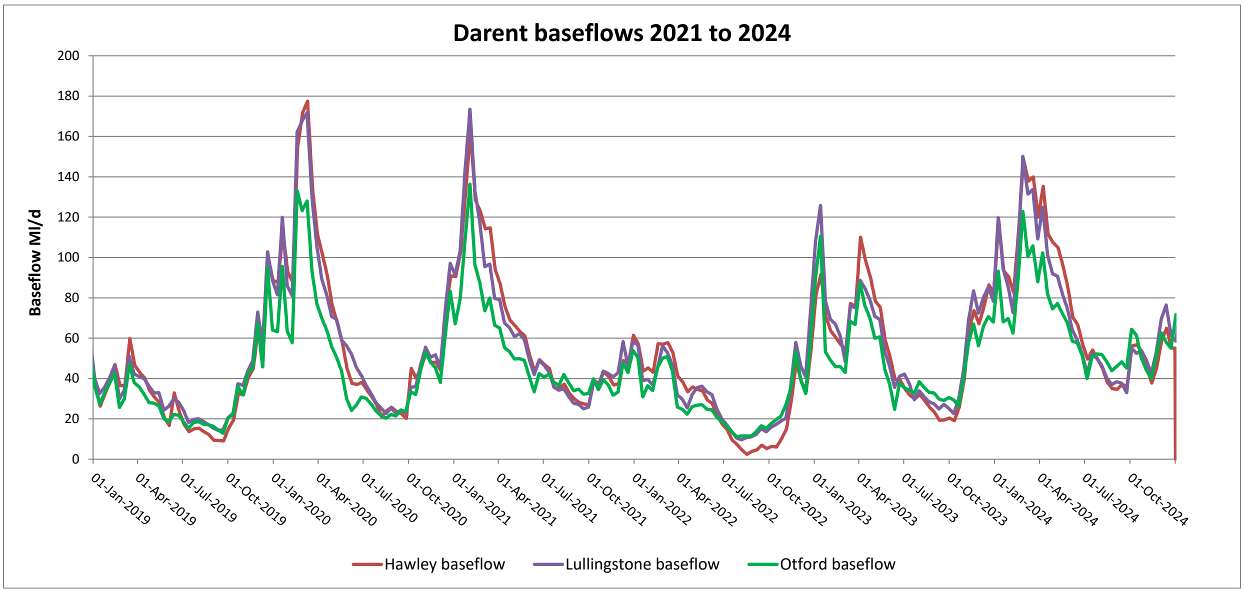
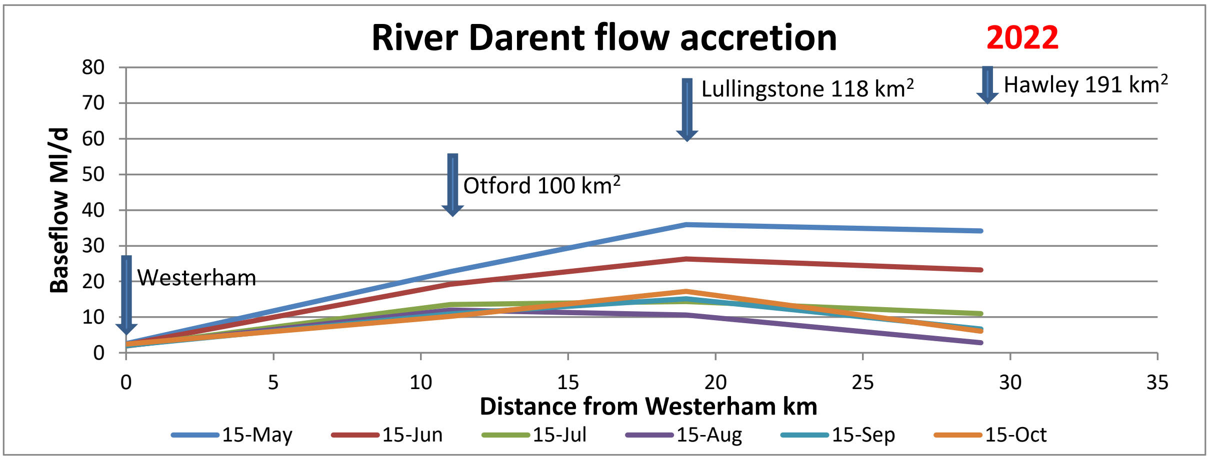
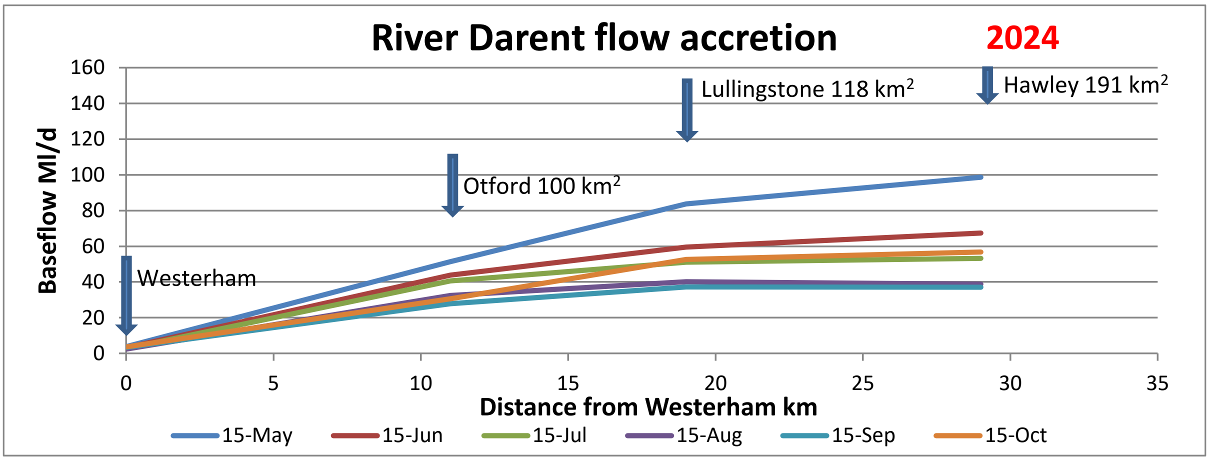


Figure 5 - Comparison of gauged baseflows in the Darent

The plots above show that, historically, there is little gain in Darent flow emanating from the chalk catchment downstream of Otford. The river baseflows between Otford and Hawley, mostly comprise flows coming from the mainly greensand catchment above Otford. Since 1970, there is hardly any contribution to middle and lower Darent flows from the Chalk, particularly in summer when there is significant loss of flow between Lullingstone and Hawley. A similar picture can be seen in the Darent flow accretion plots shown below:





Note the different vertical axes in the above two plots

Figure 6 - Flow accretion in the Darent valley (typical dry and wet years)

On the basis of the differences in geology and patterns of baseflows in the various parts of the Darent-Cray catchment, it makes sense for the CSF model to have two separate, but linked components:

- Firstly, for the mixed greensand/chalk catchment of the upper Darent above Otford.
- Secondly, for the combined Darent and Cray chalk catchment, which is underlain by a single aquifer, draining through the combined flow of the Rivers Darent and Cray.

Separation into these two components allows different values of specific yield to be used for each catchment, taking account of the predominance of greensand in the upper Darent. It also allows for a larger amount of effective rain in the upper Darent catchment, allowing for the higher rainfall in the more upland terrain and the lower urbanisation.

Inflows, outflows and inter-linking for the two components of the CSF model of the Darent-Cray catchment are shown schematically below:

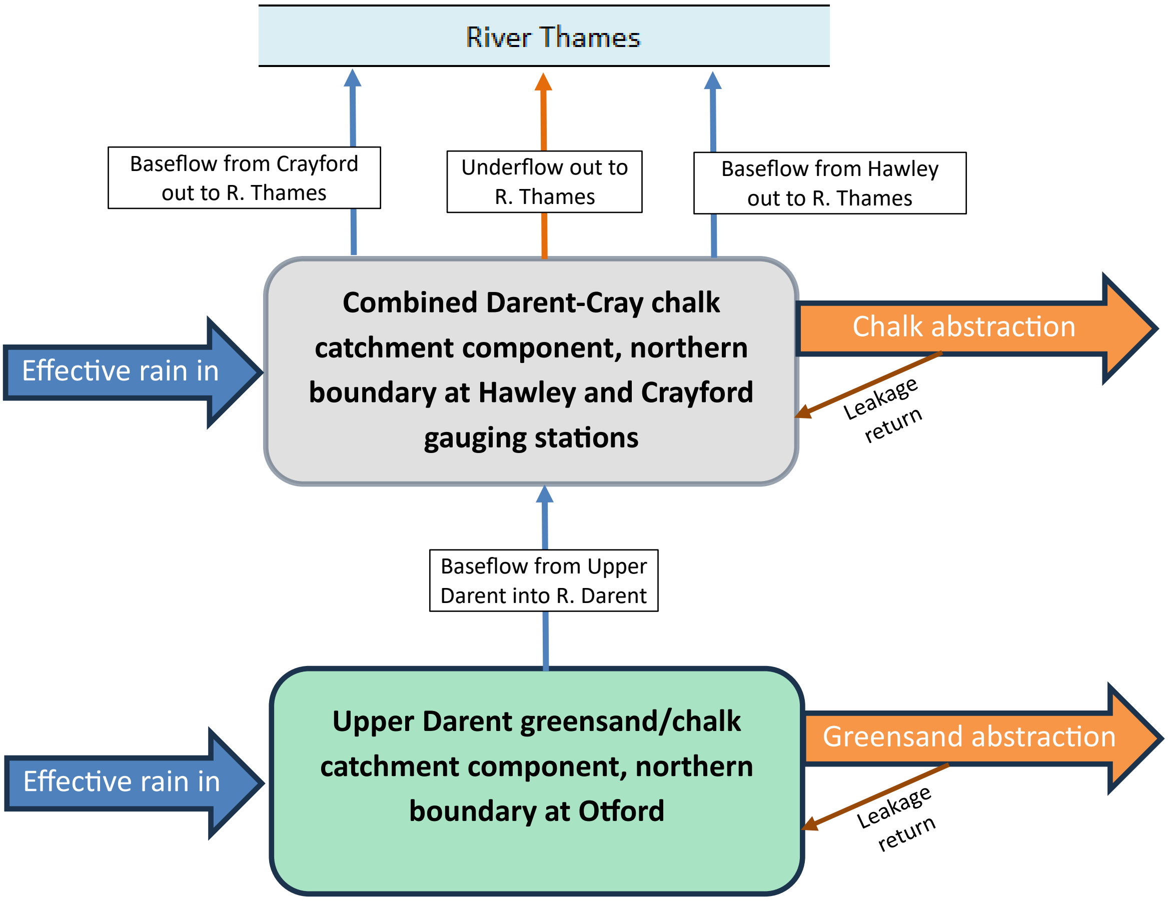


Figure 7 - Schematic of components and water balance for the CSF Darent-Cray model

2.3 Abstractions and water balance in the CSF model

Average daily abstraction in the Darent Cray catchment since 1970 is shown below:

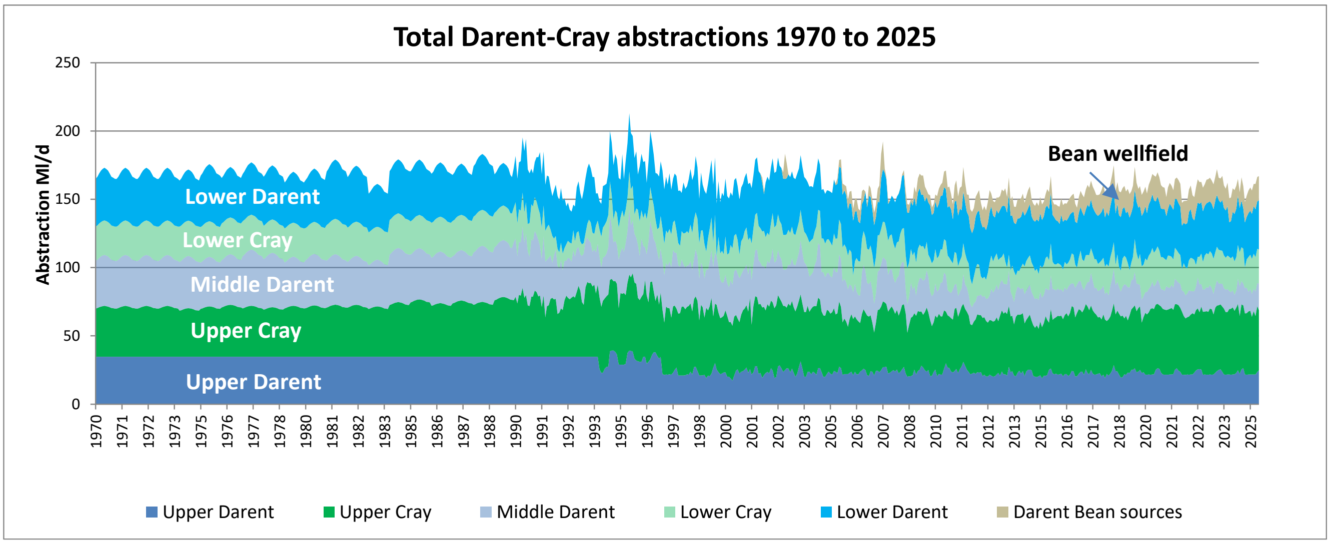


Figure 8 - Abstractions in the Darent-Cray valleys 1970 to 2024

The model takes into account the public water supply borehole abstractions shown on the map on the next page. The abstraction amounts shown for each source on the map are the recent average amounts over the period 2022 to 2024.

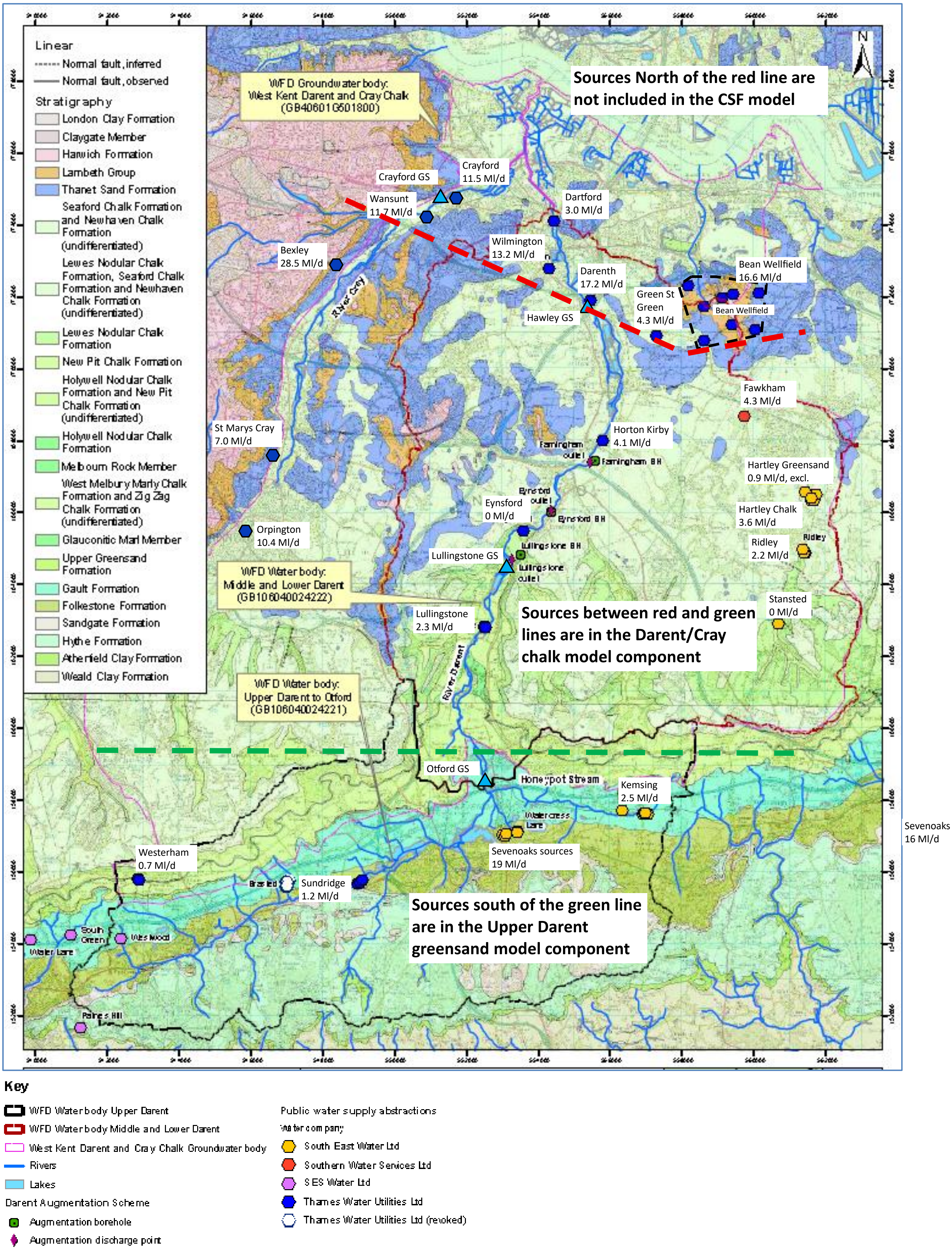


Figure 9 - Map of public water supply sources accounted for in the CSF model

The CSF model simulates the daily water balance for each of the two model components, so that each day the modelled change in storage equates with the difference between aquifer inflow from effective rain and aquifer outflows from abstractions, river baseflows and underflows. The daily effective rain is based on the time series of effective rain in the Darent and Cray catchments used in the Atkins London Basin Model (LBM) model (1970 to 2019), as supplied by the Environment Agency. The validity of these rainfall data can be checked by consideration of the observed long term water balances for each model component.

Table 1 below shows the observed aquifer water balance for the Upper Darent catchment down to Otford, with two different assumptions for effective rain data. The inflows and outflows shown in the table are the average daily values in Ml/d for the 50-year period from January 1970 to December 2019, with no change in aquifer storage over the period (starting and ending GWLs are about the same).

	Based on measured data, 1970 to 2019 (Ml/d)	
Upper Darent	1. Assuming effective rain used in Atkins LBM model for Cray (av. 156 mm/yr)	2. With Atkins effective rain increased by 30% as per CSF model (av. 203 mm/yr)
Inflows	**Inflows**	**Inflows**
Upper Darent recharge	42.8	55.7
Upper Darent leakage return	5.0	5.0
Total inflow	47.8	60.7
Outflows	**Outflows**	**Outflows**
Otford gauged baseflow	32.1	32.1
Upper Darent abstraction	29.3	29.3
Total outflow	61.4	61.4
Upper Darent Balance	**-13.6**	**-0.7**

Table 1 - Upper Darent aquifer water balance based on observed values

If the effective rain for the Upper Darent catchment is assumed to be as used in the Atkins LBM model (first column in Table 1), the average aquifer inflow is well short of the aquifer outflows from baseflows and abstraction, even after allowing for infiltration from water supply leakage. Aquifer inflows and outflows can be balanced by assuming a 30% uplift in the Atkins LBM effective rain, as shown by the second column in Table 1. The 30% uplift can be justified by the higher winter rainfall recorded at Sundridge compared to Orpington, with a further increase to allow for the lower urbanisation of the upper Darent catchment, compared to the Cray catchment. The annual effective rain of 203 mm, compares with the average annual effective rain of 218 mm for the Darent catchment, provided by the Environment Agency for use in a report on Abstraction as a % of Recharge[10].

[10] EA Excel file ‘Copy of EffectiveRainfall_QUBE_1999_2015.xlsx’

Table 2 below shows the observed aquifer water balances for the total Darent-Cray catchment, combining the Greensand and Chalk aquifers, with different assumptions for effective rain and aquifer abstractions.

	Based on measured data		
Total Darent-Cray catchment	1. Assuming Atkins effective rain and all Darent-Cray abstractions (no Bean wellfield)	2. Excluding lower Darent-Cray abstractions with Atkins effective rain	3. Excluding lower Darent-Cray abstractions with effective rain adjusted as per CSF model
Inflows	**Inflows**	**Inflows**	**Inflows**
Upper Darent recharge	42.8	42.8	55.7
Chalk recharge	89.6	89.6	103.0
Upper Darent leakage return	5.0	5.0	5
Chalk leakage return	10.0	10.0	10
Total inflow	147.4	147.4	173.7
Outflows	**Outflows**	**Outflows**	**Outflows**
Hawley baseflow	38.5	38.5	38.5
Crayford baseflow	30.3	30.3	30.3
Chalk underflow	3.0	3.0	3.0
Upper Darent abstraction	29.3	29.3	29.3
Chalk abstraction	131.0	71.4	71.4
Total outflow	229.1	172.6	173.2
Total Darent-Cray Balance	**-81.7**	**-25.1**	**0.5**

Table 2 - Total Darent-Cray aquifer water balances based on observed values

If effective rain is as for Atkins LBM model and all lower Darent and Cray abstractions (except the Bean wellfield) are included in the combined aquifer water balance, aquifer outflows greatly exceed inflows, as shown in the first column of Table 2. Even without any river outflow, the abstraction exceeds the inflow from effective rain by about 30 Ml/d, so the water would be "mined" from the aquifers, there would be progressive lowering of the water table and the rivers would be dry at most times. However, the rivers dry only very rarely and the groundwater levels records show no progressive lowering of the water table, so **it can be concluded that that the lower Darent and lower Cray abstractions are not affecting GWLs and river flows in the upper and middle parts of the rivers.** Therefore, the lower river abstractions should be excluded from the aquifer water balances.

Even without the lower river abstractions, if the aquifer recharge is based on the Atkins LBM effective rain, outflows would exceed inflows by about 25 Ml/d, as shown by the second column in Table 2. However, if the Akins LBM effective rain is increased by 30% for the Upper Darent and 15% for the middle Darent and Cray, as assumed in the CSF model, the aquifer outflows and inflows just balance, as shown by the third column in Table 2.

2.4 Features of the CSF model components

The main assumptions and parameters underlying the Upper Darent model component are:

1. The modelled catchment area above Otford is 100.4 km^2, as for the Upper Darent water body on the EA's Catchment Explorer website.

2. The daily effective rain is the time series of effective rain in the Cray catchment used in the Atkins groundwater model (1970 to 2019), increased by 30%.

3. The specific yield is 6%, giving best fit between modelled and recorded GWLs.

4. The primary location for modelling groundwater levels is the observation borehole at White Sheiling. The modelled baseflow at Otford is determined from the equation relating Otford baseflows to White Sheiling GWLs shown on Figure 2.

5. The abstraction from the Upper Darent catchment is the total abstraction from the Greensand public supply boreholes shown south of the green dashed line on the map on Figure 9.

6. The leakage from the water abstracted for the public supply back into the aquifer is assumed to be 5 Ml/d (roughly 20% of the total Upper Darent abstraction).

The assumptions and parameters underlying the combined Darent-Cray chalk model component are:

1. The modelled combined Darent-Cray catchment area is 245 km^2, as for the total of the Middle/Lower Darent and Upper Cray water bodies.

2. The daily effective rain is the weighted average (by catchment area) of the Darent and Cray effective rain time series, 1970 to 2019, as used in the Atkins groundwater model, increased by 15%.

3. The chalk aquifer specific yield is 4%, giving best fit between modelled and recorded GWLs.

4. The primary location for modelling groundwater levels is the observation borehole at Crockenhill.

5. The baseflow at Hawley emanating only from the chalk downstream of Otford is derived from an equation for the relationship between observed flow gains downstream of Otford and the GWL at Crockenhill.

6. Total baseflow at Hawley is the modelled baseflow from the chalk, plus the modelled baseflow at Otford less modelled losses between Otford and Hawley.

7. The modelled baseflow at Crayford is derived from the modelled Crockenhill GWL, using the equation shown on Figure 2.

8. Underflow from the chalk out of the Darent-Cray catchment is calculated from an equation linked to Crockenhill GWLs, adjusted through model calibration

9. The abstraction from the combined Darent-Cray chalk catchment is the total abstraction from the Chalk public supply boreholes which are shown between the

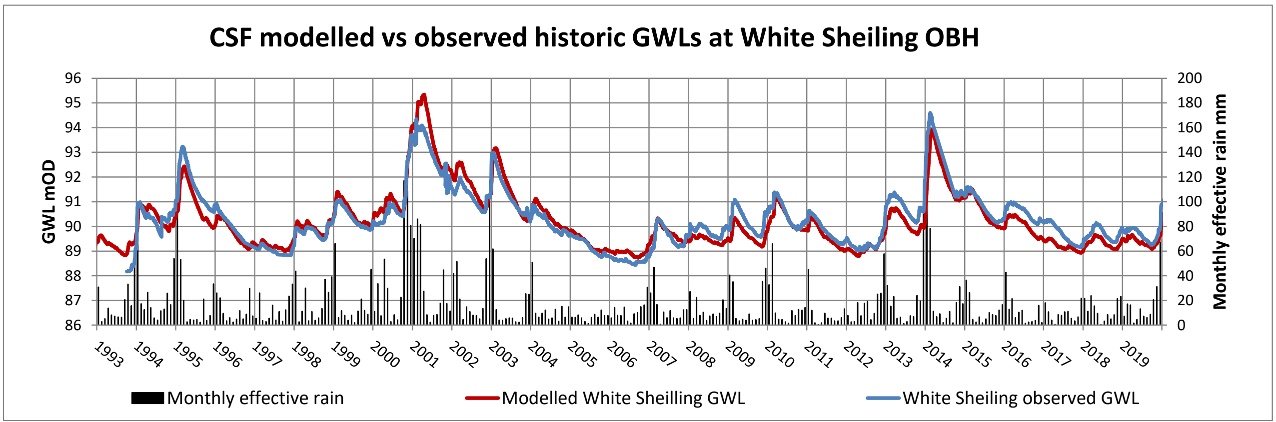
red and the green dashed line on the map on Figure 9, i.e. excluding the lower Darent and lower Cray abstractions.

10. The leakage from the water abstracted from the public supply back into the aquifer is assumed to be 10 Ml/d (roughly 15% of the abstraction from the combined Darent-Cray chalk catchment).

11. The modelled baseflows included the recorded amounts of support flows from the augmentation boreholes at Eynsford, Farningham and Lullingstone (none since 2012). These are assumed to flow without losses to Lullingstone and to reduce by 50% at Hawley.

2.5 Validation of the CSF model

The CSF model gives a good fit between daily modelled and recorded groundwater levels in the Greensand at White Sheiling and the Chalk at Crockenhill as below:



Note: White Sheiling GWL records start in 1993

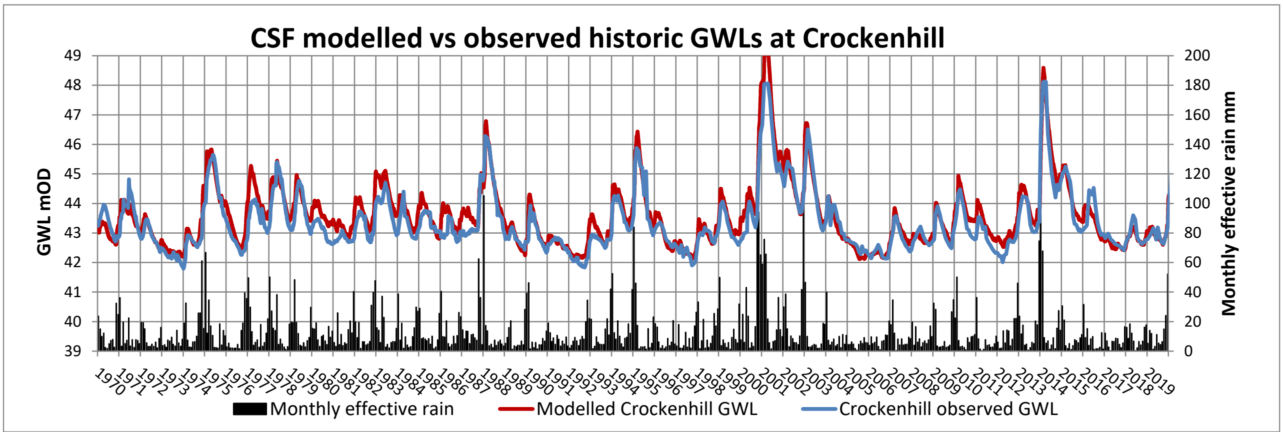
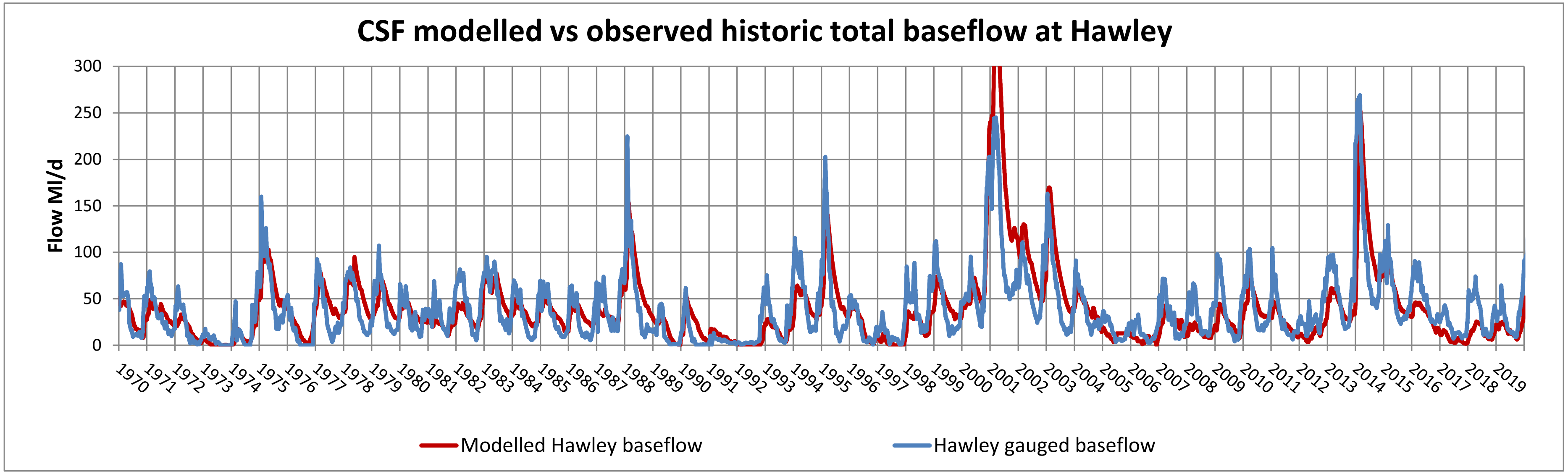


Figure 10 - CSF modelled vs recorded GWLs at White Sheiling and Crockenhill OBHs

It is evident from these plots that the CSF modelling provides a good representation of the behaviour of groundwater levels in the chalk and greensand aquifers and how they are affected by variations in rainfall and abstraction.

Modelled and observed baseflows at Hawley and Crayford are compared below:



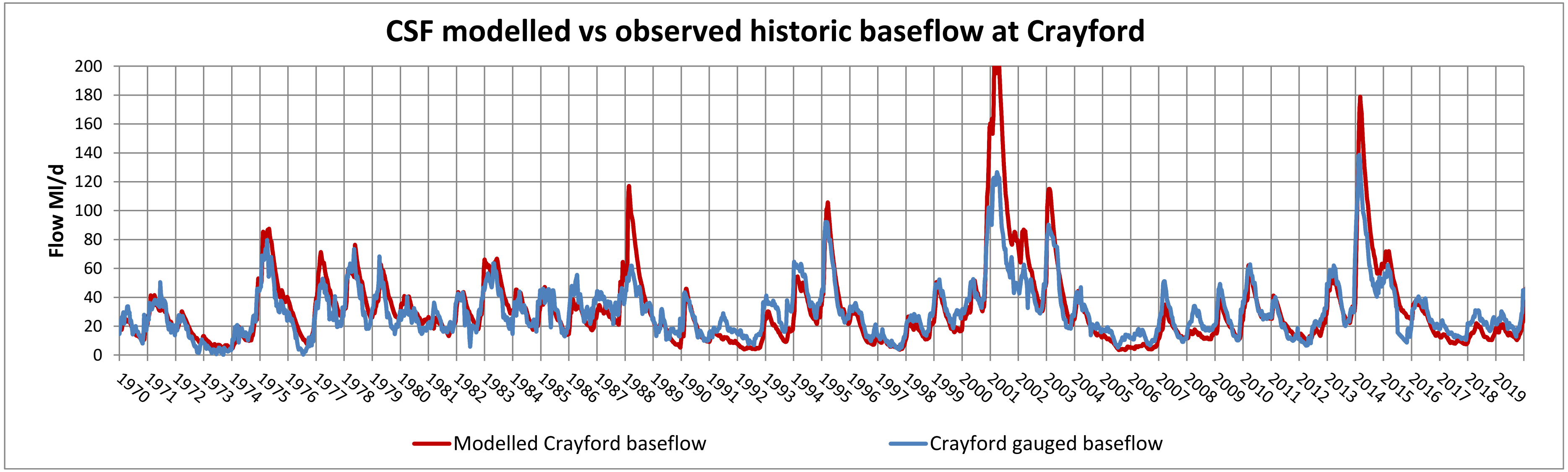


Figure 11 - CSF modelled vs gauged baseflows in Rivers Darent and Cray

The fits between modelled and gauged flows shown in Figure 11 are moderately good, but not as good as the modelled groundwater fits, or for the fits for modelled baseflows usually obtained when using the CSF model in pure chalk catchments. This reflects the difficulty of modelling the complex geology of the Darent-Cray catchment and the amount of losses in the Darent downstream of Lullingstone.

2.6 Comparison of validations of the CSF and Atkins LBM model

The CSF model output is not directly comparable with the Atkins model output because:

1. The Atkins LBM model only simulates flows and groundwater levels in the chalk part of the Darent-Cray catchment, excluding the upper Darent catchment above Otford. The LBM uses gauged flows at Otford as an input to the model. Although Atkins has also developed a model of the Kent Lower Greensand aquifer, which covers the Darent catchment above Otford, the model is not considered in Atkins' report to be reliable for simulating the Darent groundwater levels and flows.

2. The Atkins model simulates total river flows, i.e. baseflows from the chalk aquifer and surface run-off, whereas the CSF model only simulates the baseflows from the aquifers.

CSF and Atkins LBM modelling of the historic groundwater levels at the Crockenhill observation borehole are compared below:

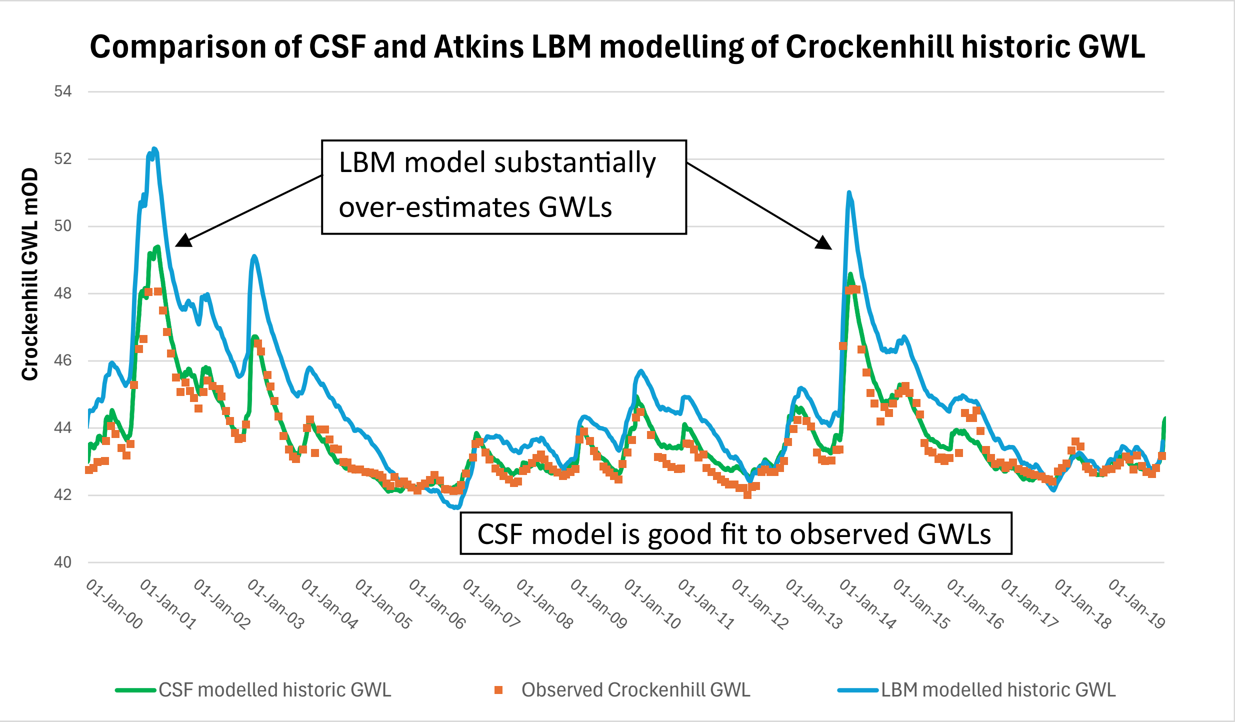
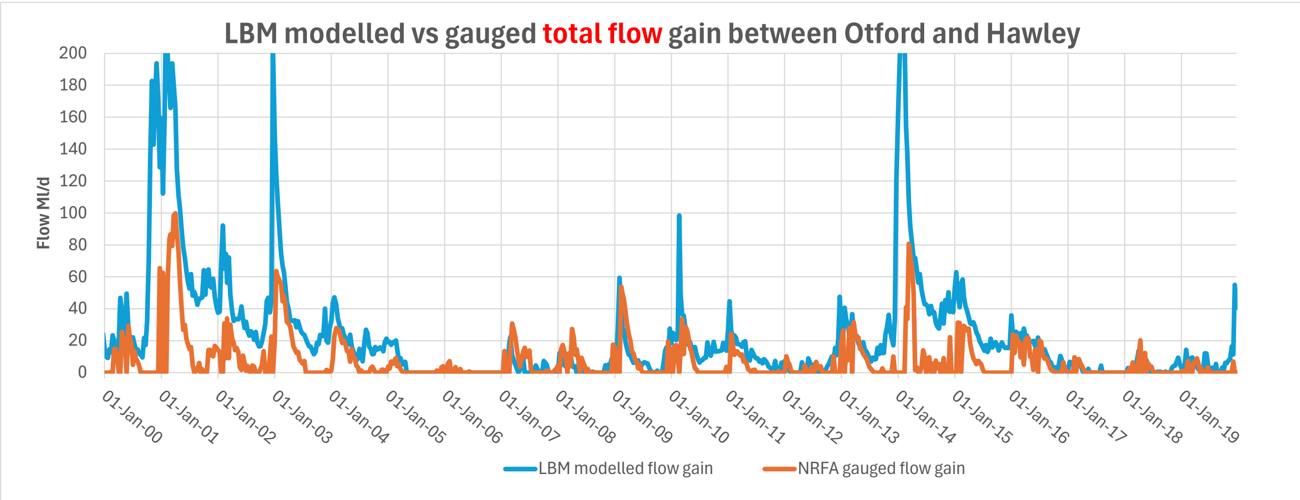


Figure B1 - Comparison of CSF and LBM modelling of Crockenhill GWLs

The Atkins LBM model provides a poor fit to observed historic GWLs at Crockenhill, mainly because it over-estimates the magnitude of GWL fluctuations. The highest LBM modelled GWLs exceed the recorded values by about 4 m. The CSF model provides a reasonably good fi to observed GWLs at Crockenhill and a much better fit that the Atkins LBM model.

Comparison of Atkins LBM modelled historic flows in the River Darent with the gauged flows does not provide any validation of the LBM modelling because the LBM model uses the gauged flows at Otford as an input to the model. As the flows in the River Darent below Otford are dominated by flows coming from the Upper Darent catchment, the modelled flows in the Darent downstream of Otford are inevitably very similar to the gauged flows at Otford.

However, comparison of modelled and gauged flow gains downstream of Otford does provide a realistic validation of the Atkins LBM modelling and allows comparison with the validation of the CSF modelled flows. It should be noted that the two plots below are not directly comparable, because the LBM plot shows total flow gains whilst the CSF model plot shows baseflow gains:



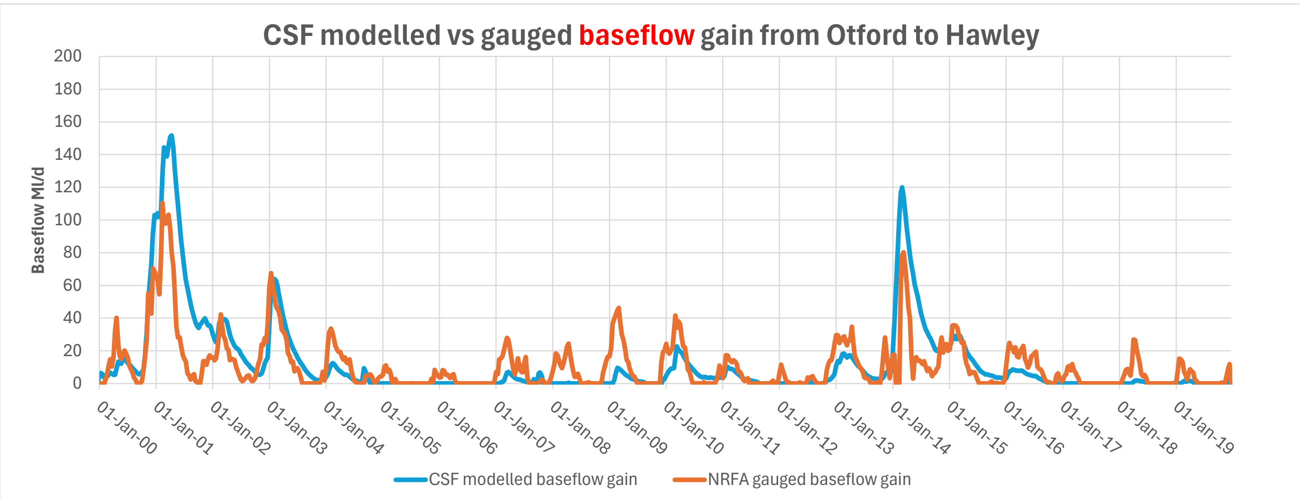


Figure 12 - Validation plots for LBM and CSF flow gains from Otford to Hawley

Both models struggle to match the gauged flow gains between Otford and Hawley, partly because:

- The flow gains from the chalk downstream of Otford are quite small
- The gauged flow gains could be subject to substantial errors due to them being the differences between two potentially inaccurate flow gaugings, with the Otford gauge being described on the NRFA website as "*highly erroneous due to downstream weeds causing a back-up of water*"[11].

Overall, the CSF modelling provides a slightly better fit than the LBM model for the gauged flow gain between Otford and Hawley, particularly for the frequency of flow gains falling to zero.

The validation plots for LBM and CSF flows in the River Cray at Crayford are shown below. As for the Darent flow validation plots, the LBM plot shows total flows and the CSF model plot shows baseflows. The plots show the 10-year period from 2000 to 2014, because the Crayford gauged flows have a lot of missing data in 2015-16:

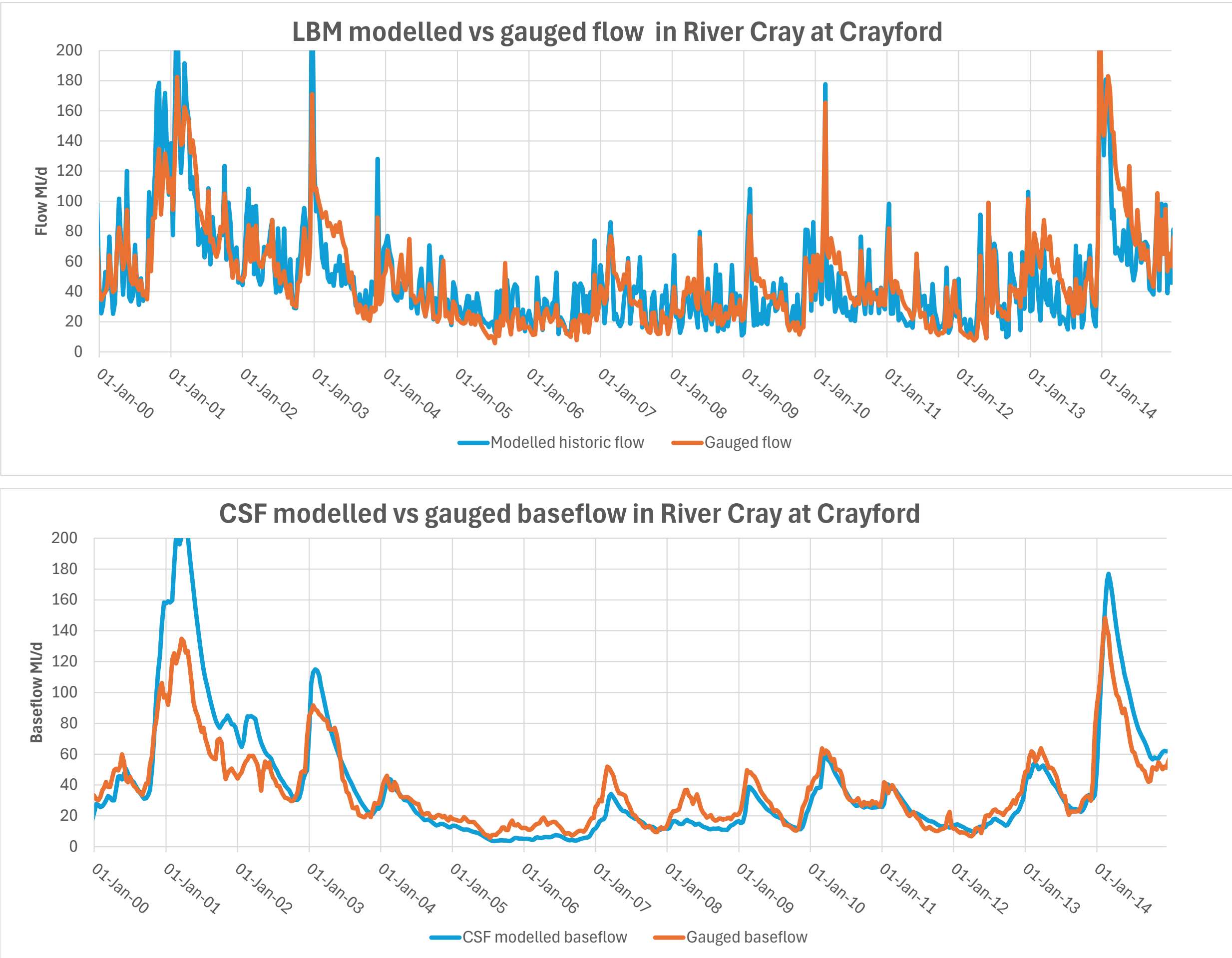


Figure 13 - Validation plots for LBM and CSF modelled flow in River Cray at Crayford

Both models gives a reasonably good fit to gauged baseflows at Crayford.

[11] NRFA website for Otford gauge https://nrfa.ceh.ac.uk/data/station/info/40013

2.7 Conclusions on the validity of CSF modelling

The CSF model gives a reasonably good fit between modelled and observed groundwater levels and river baseflows in all parts of the Darent-Cray catchment. Although the fits between modelled and gauged data are not as good as those obtained using the CSF model in some “pure” chalk catchments, the use of linked separate model components for the Chalk and Greensand parts of the catchment has worked well.

The overall conclusion is that the CSF model can be used as a tool for testing the effectiveness of measures to reduce abstraction impacts in the Darent-Cray catchment, including the impacts arising from the Greensand abstractions in the Upper Darent.

3. Impact of historic abstraction on flows

3.1 Modelled impacts of abstraction

The CSF modelled impacts of historic abstraction on groundwater levels at White Sheiling and Crockenhill are shown below, with the lower plot showing the LBM modelled impacts at Crockenhill:

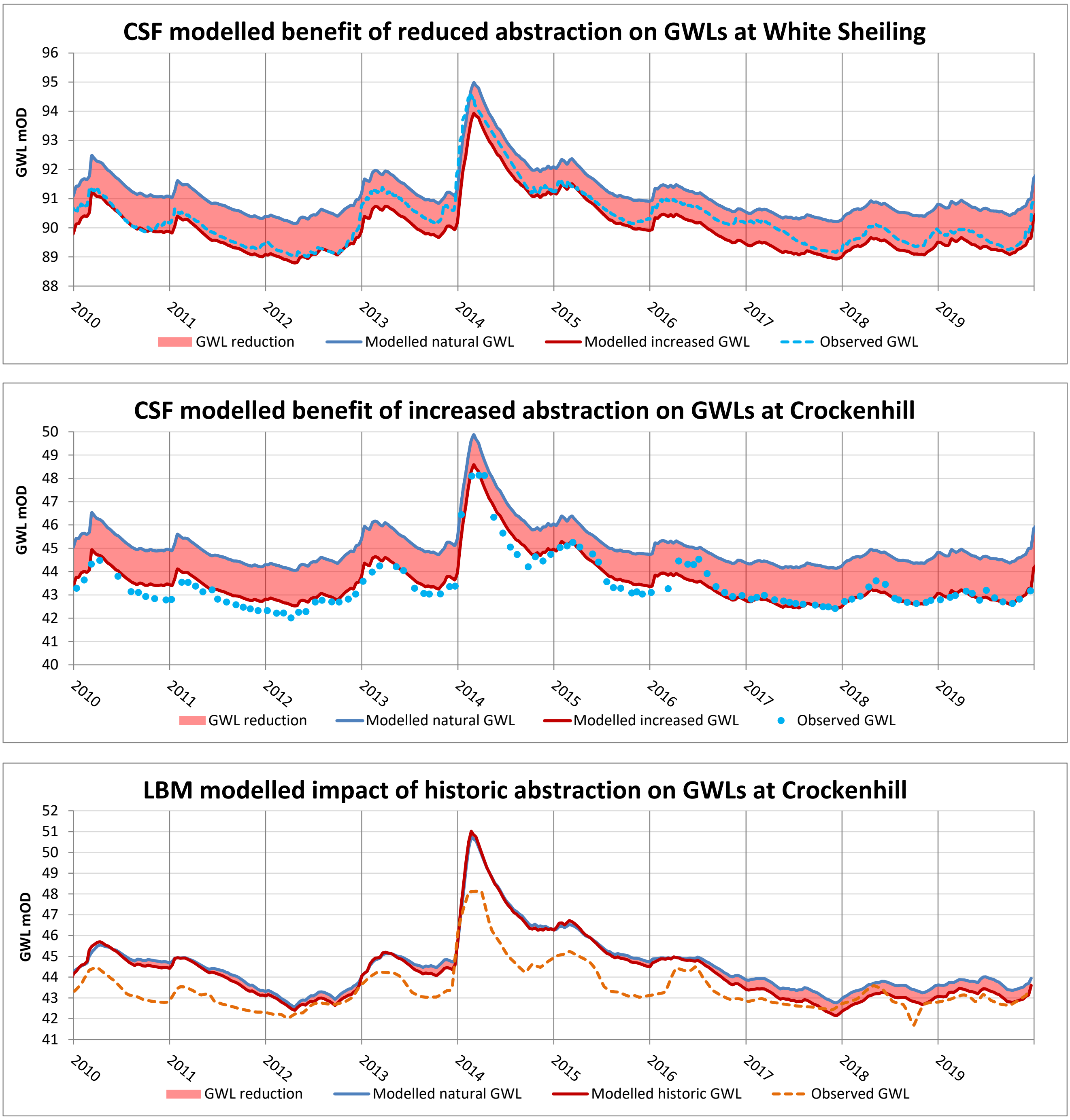


Figure 14 - Modelled impacts of historic abstraction on groundwater levels

The CSF modelling shows that groundwater levels have been reduced by about 1.0 to 1.5 m at both White Sheiling and Crockenhill. The LBM modelling shows much lower reductions in GWLs – at most, 0.7 m at times of low GWLs and no effect at high GWLs. However, in view of the poor match between observed and LBM modelled GWLs, the reliability of LBM modelling of GWLs is questionable. Bearing in mind that both models show similar magnitude of fluctuations in GWLs aligned with variations in aquifer recharge from effective rain, it is difficult to see why GWLs would not be substantially affected by the large abstractions, which are more than 50% of average annual recharge and close to 100% of recharge in dry years. On that basis the LBM simulation of groundwater levels does not look credible.

The plots on Figure 15 on the next page show the CSF modelled impacts of historic abstraction on river baseflows at Otford, Lullingstone, Hawley and Crayford in the period 2010 to 2019. These plots show very large reductions below natural flows – well in excess of the 50% reduction that was suggested in the original Darent Action Plan in the 1990s as an appropriate target for reinstatement of Darent-Cray flows. However, more recent Environment Agency Environmental Flow Indicator (EFI) targets for acceptable reductions in natural river flows are much more stringent, as below[12]:

RIVER TYPE	Q30	Q50	Q70	Q95
ASB3 HIGH SENSITIVITY	24%	20%	15%	10%
ASB2 MODERATE SENSITIVITY	26%	24%	20%	15%
ASB1 LOW SENSITIVITY	30%	26%	24%	20%

2008 EFI STANDARDS FOR ACHIEVING GOOD ECOLOGICAL STATUS FOR CHALK STREAMS GIVEN AS % OF ALLOWABLE REDUCTION OF NATURAL FLOW

Note: Q30 is the natural flow exceeded for 30% of the time, Q95 is flow exceeded 95% of the time, i.e. a moderate drought

Table 3 - EFI standards for 'Good' Ecological Status

The relatively natural and rural River Darent between Otford and Hawley should be classified as high sensitivity ASB3, although modified and urbanised reaches of rivers like the lower Darent and Cray could be deemed only moderate sensitivity ASB2. The following Figure 15 shows CSF modelled impacts on river flows and consequent EFI failures, with all the EFIs assumed to be for high sensitivity ASB3. This shows extensive EFI failures in all locations at most times except when GWLs and river flows are exceptionally high, like during and following the wet winter of 2013-14.

[12] CaBA chalk stream restoration strategy Appendix B2 https://catchmentbasedapproach.org/wp-content/uploads/2021/10/CaBA-CSRG-Strategy-APPENDICES-FINAL-12.10.21-Low-Res.pdf

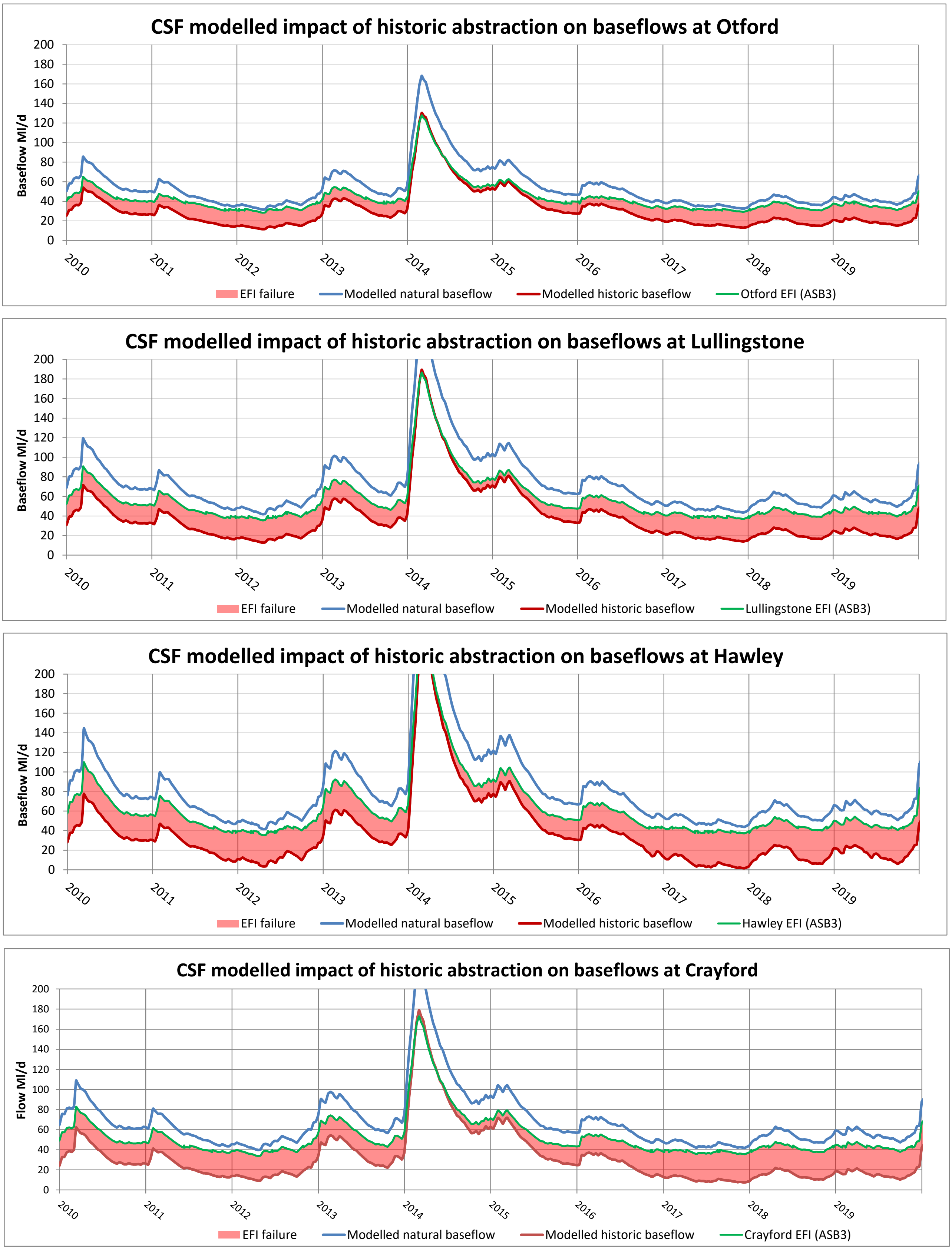


Figure 15 - CSF modelling of impacts of historic abstraction on natural river flows

The CSF and LBM modelled impacts of historic abstraction from 2010 to 2019 are plotted on a flow duration basis on Figure 16:

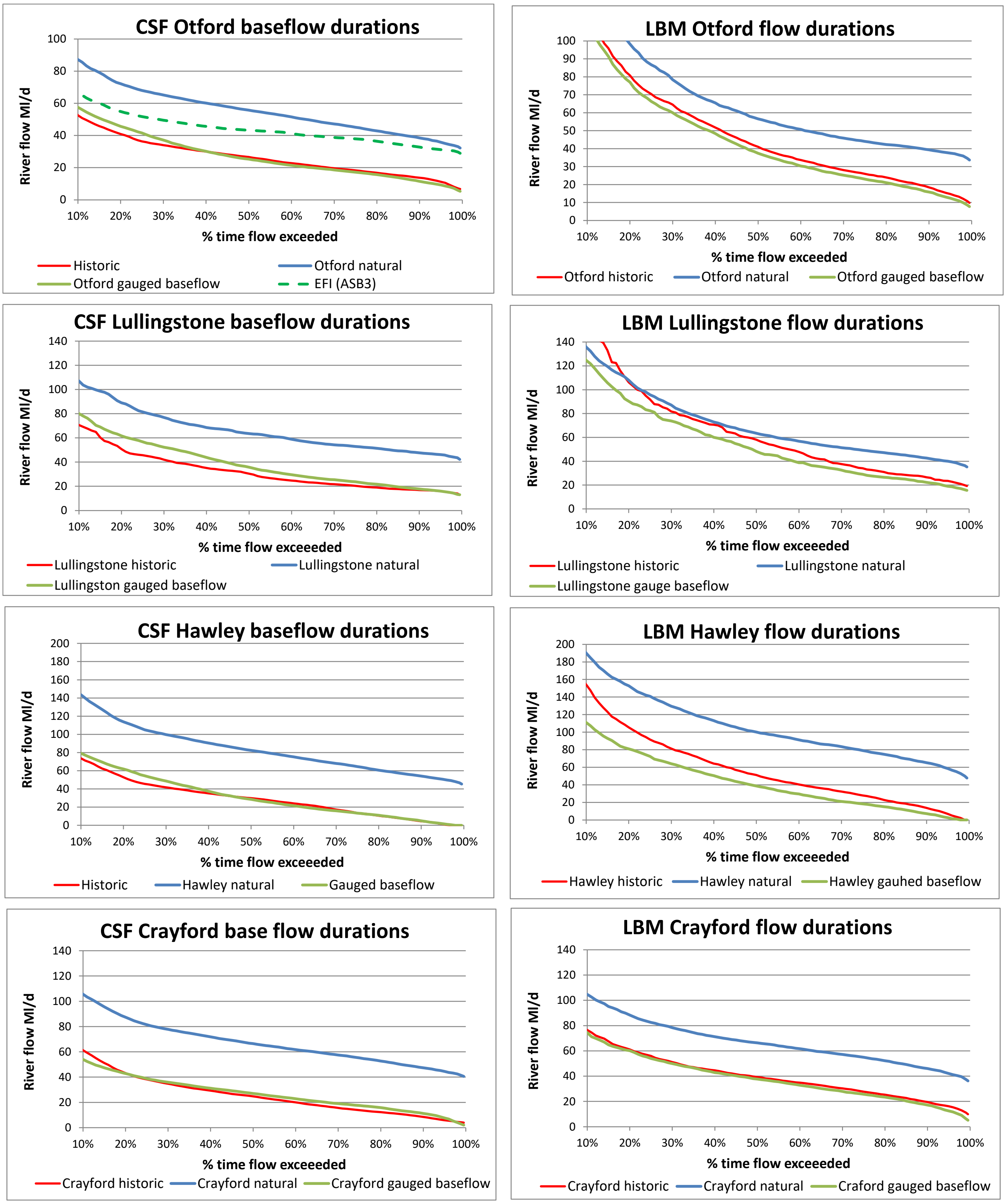


Figure 16 – CSF and LBM modelled impacts of abstraction on flow duration

The CSF and LBM models both show similarly large amounts of reduced flows in all parts of both the Rivers Darent and Cray, including the total drying of the River Darent at Hawley. Both models show that at times of low flows, the abstractions reduce flows to typically around 1/10th of the natural flow. Common sense suggests that reductions in flow of these magnitudes would have had a large impact on river ecology, contrary to what has been suggested in some quarters.

3.2 Impacts of abstractions in the lower Rivers Darent and Cray

The water balance analysis described in Section 2.3 of this report and shown in Table 2 showed that the lower Darent and lower Cray abstractions are not affecting GWLs and river flows in the upper and middle parts of the rivers**.** Therefore, the lower river abstractions have been excluded from the CSF modelling of the impacts of abstractions in the upper and middle rivers. The recent actual abstractions (2022-24) from these sources total about 77 Ml/d, including the Bean wellfield sources, at the locations shown below:

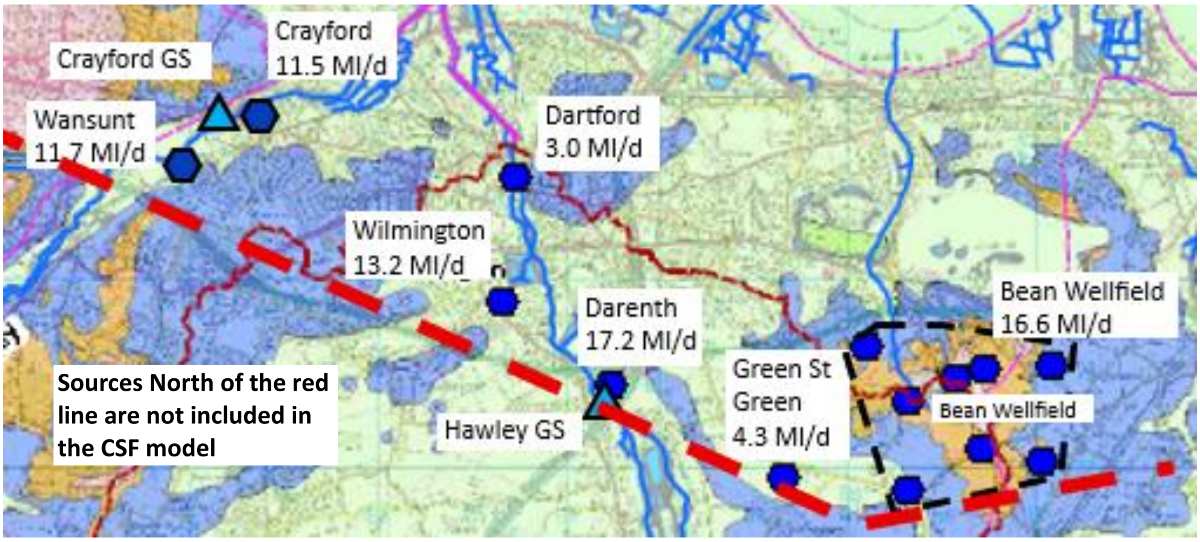


Figure 17 - Locations and recent abstraction amounts from lower Darent and Cray sources

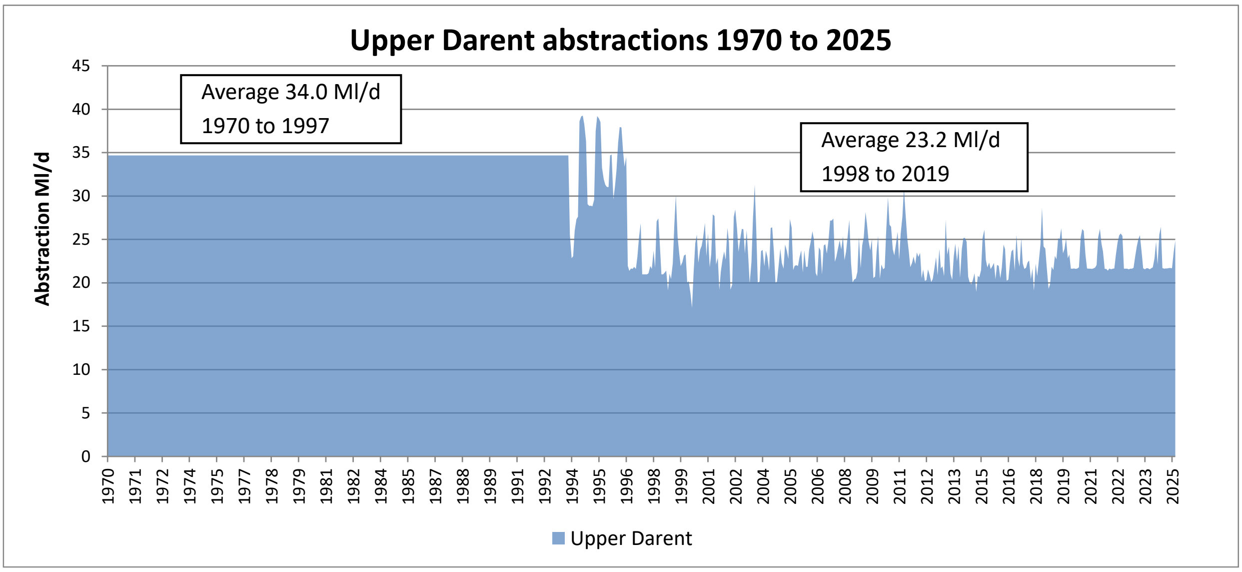
It can be seen that some of these sources are located close to the rivers, so their cones of influence will affect GWLs in the valley bottom and they are likely to be drawing some water directly from river flows and they could cause loss of flow through river bed leakage. Other sources, like the Bean wellfield, are located well away from the rivers and would seem unlikely to affect lower river flows, as has been found by water company investigations of the Bean wellfield.

However, the lower river sources are likely to be causing a general reduction in groundwater levels close to the Thames estuary, which could steepen the gradient of the water table falling towards the estuary, thereby lowering groundwater levels, spring outflows and river flows in the middle and upper rivers. This possible effect is not simulated in the CSF model. It is not known whether the influence of the lower river abstractions have been separately simulated by the LBM model or what effect they are found to have on GWLs and river flows further up the valleys.

3.3 Effectiveness of past reductions in abstraction

3.3.1 Effectiveness of reductions in the Upper Darent catchment

The changes in abstraction from groundwater sources in the Upper Darent above Otford since 1970 are shown below:



Note: abstraction data from 1970 to 1993 are averages from various NRA and consultant reports. Data from 1998 onwards are from water companies and EA.

Figure 18 - Changes in Upper Darent abstractions since 1970

The reductions of about 11 Ml/d are mainly from closure of Thames Water's Brasted abstraction and a large reduction in their Sundridge abstraction. There has been no significant reduction in South East Water's abstractions around Sevenoaks.

The substantial reductions in Upper Darent abstraction in the mid-1990s has resulted in a corresponding increase in average measured baseflow at Otford as shown below:

Upper Darent above Otford	1970 to 1997	1998 to 2019	Change	Comment
Average effective rain (mm/year)	203.1	202.8	0.4	Negligible difference
Average abstraction (Ml/d)	34.0	23.2	10.8	Flow increase matches
Average Otford baseflow (Ml/d)	26.4	38.0	-11.6	abstraction reduction
Average recharge (Ml/d)	55.9	55.8	0.10	Residual A%R still very
Abstraction as % of recharge (A%R)	**61%**	**42%**	**19%**	high

Table 4 - Measured flow increase at Otford following abstraction reductions

The average reduction in Upper Darent abstraction by about 11 Ml/d has resulted in a corresponding measured increase of about 11 Ml/d in average in baseflow at Otford. The average baseflows are the gauged flows converted to baseflows using the Institute of Hydrology "turning point" method. The average effective rainfall is almost exactly the same before and after the abstraction reduction, so the increase in baseflow must be due to the abstraction reduction. There can be doubts over the accuracy of the gauged flow records, but the Otford gauging station is a proper compound Crump gauging weir and the measured increases in baseflow are averages over many years, so this determination of the increased baseflow should be reliable.

The c.10 Ml/d increase in baseflows is also shown by CSF modelling of Otford flows as below:

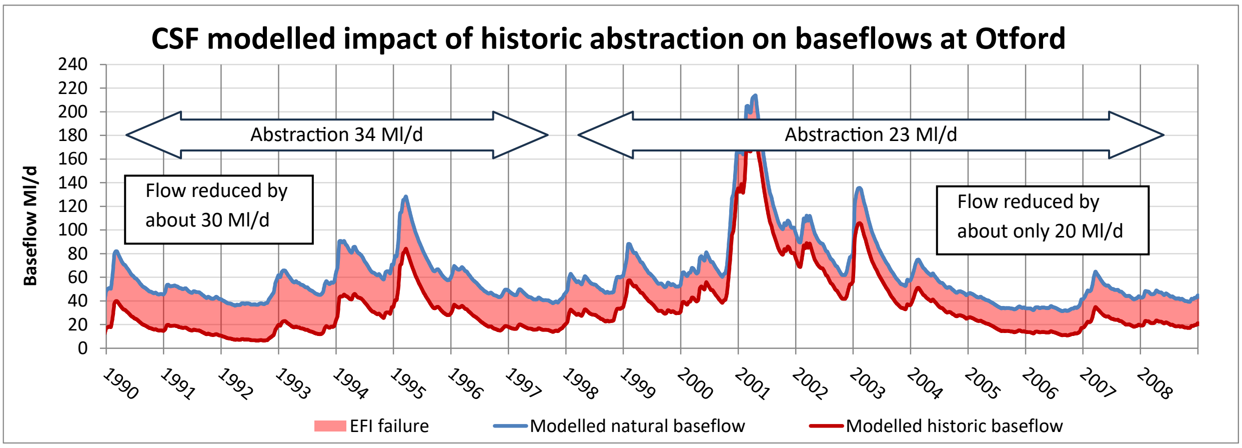


Figure 19 - Measured flow increase after Upper Darent abstraction reduction

The analysis of measured and modelled flows has provided good evidence that the reduction of about 11 Ml/d in abstraction in the 1990s led to a corresponding increase in river flows at Otford. This strong conclusion contrasts with the findings of the Atkins low flow investigation in 2018, which found no convincing evidence of flow recovery following the abstraction reductions. The Atkins report summary concludes somewhat tentatively:

> *"There is evidence that abstraction at Sundridge impacts groundwater levels near the River Darent and the reduction in heads may have an associated impact on summer flows in the Darent in the short reaches around Sundridge where the river and aquifers are in hydraulic continuity.*
>
> *Both Sundridge and Crampton's Road reduce heads in the Hythe Formation in this area and may reduce outflows from the springs. This has a potential impact on flows to the River Darent in the reach between Sundridge and Otford.*
>
> *Abstraction from the confined Hythe and confined Folkestone aquifers at Westwood may impact flows in the upper section of the river but there is no direct evidence for this.*
>
> *Abstraction in the upper Darent catchment is of a scale to be significant in the catchment water balance. Conceptually, it would be expected that abstraction from both the Hythe and Folkestone beds in the upper Darent catchment would be partially or substantially at the expense of flow in the river at the bottom of the catchment as there are few other outflows from the aquifers."*

The Atkins report may have been reluctant to draw firm conclusions about the Upper Darent abstraction impacts because:

1. The Environment Agency's Kent and Lower Greensand model (KLGS) provides a poor fit to observed data in the upper Darent valley, so there is no reliable modelling of abstraction impacts.

2. When considering the observed long term water balance of the upper Darent (equivalent to the data shown in Table 4 in this report), the Atkins analysis used full gauged flows, rather than the derived gauge <u>baseflows</u> used in Table 4. The inclusion of surface run-off in the water balance analysis is likely to have distorted the determination of flow differences before and after the abstraction reductions.

3. The various pump shut-off tests (so-called signal tests) referred to in Atkins' report were of only a few weeks duration. This meant that a) groundwater levels and river flows did not have enough time to recover – CSF modelling shows full recovery takes about 18 months, and b) the shut-off tests were likely to be overly influenced by wet weather.

However, Atkins rightly point out that "*the abstraction is of a scale to be significant in the catchment water balance ... so conceptually, it would be expected that abstraction … would be partially or substantially at the expense of flow in the river".* The increased flow following reduction in abstraction and raised GWLs would seem inevitable when considering the geology of the Darent valley upstream of Otford:

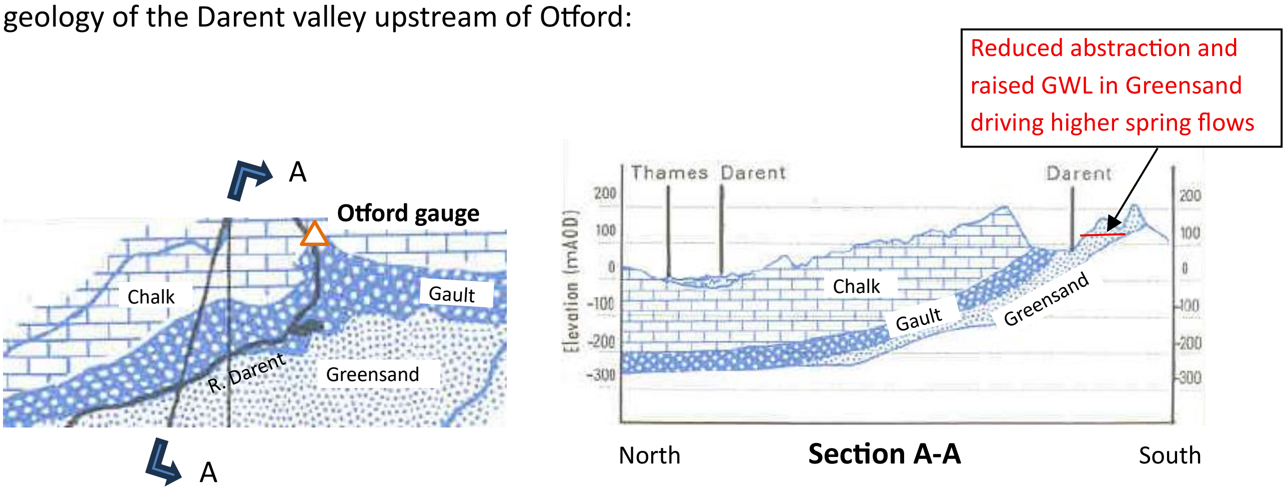


Figure 20 - Geology of Upper Darent valley showing outflow confinement to valley

The location of the thick layer of Gault clay separating the Greensand from the Chalk must force all the increased spring flows from the reduced Greensand abstraction to flow out of the valley via the river channel, crossing the Gault clay. The clay prevents any of the increased water retained in the Greensand aquifer from leaving the valley through the ground. The overall conclusion must surely be that all the Upper Darent abstraction is at the direct expense of flow in the Upper Darent and any reduction in the abstraction would lead to an equivalent increase in river flow at Otford.

Even after the 11 Ml/d of reduction of in Upper Darent abstraction in the 1990s, the remaining 23 Ml/d of abstraction is still about 40% of annual average recharge in the Upper Darent catchment. Any ecological benefits of the relatively small abstraction reduction to date can be expected to be insignificant and difficult to detect.

3.3.2 Effectiveness of reductions in the Darent-Cray catchment overall

Average daily abstraction in the middle and upper Darent Cray catchment since 1970 is shown below:

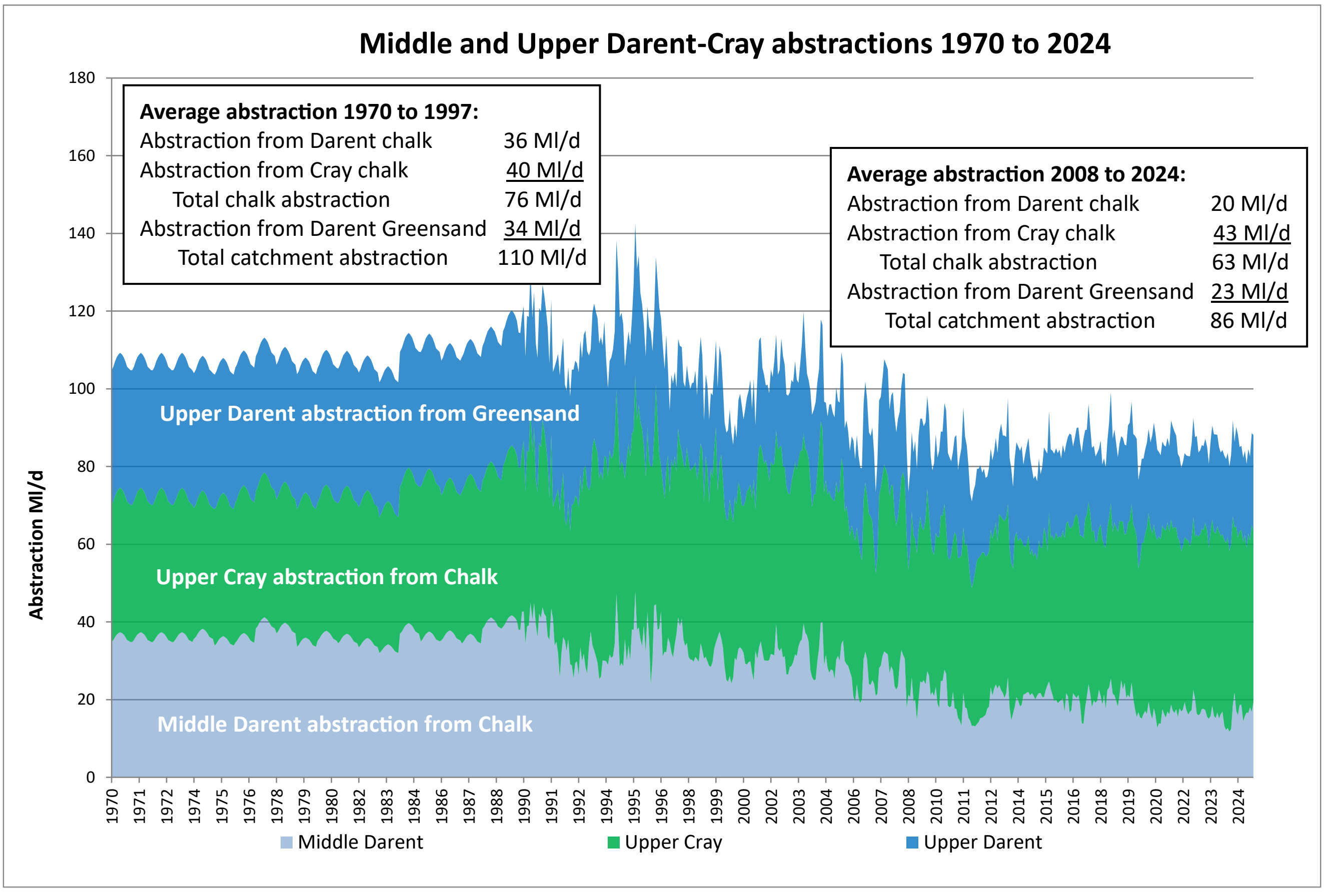


Figure 21 - Abstractions in the Middle and Upper Darent-Cray valleys 1970 to 2024

Figure 21 shows that average abstraction from the Chalk in the middle Darent has reduced from 36 Ml/d to 20 Ml/d. The 16 Ml/d reduction has mainly been from Thames Water's abstractions at Eynsford, Horton Kirby and Lullingstone. However, the Upper Cray abstraction has increased by 3 Ml/d, so the overall chalk abstraction upstream of the lower rivers has only reduced by 13 Ml/d, from 76 Ml/d to 63 Ml/d. Some measured river flow benefits from the 17% reduction in chalk abstraction can be detected from analysis of gauged lower river baseflows at Crayford and Hawley as below:

Whole Darent Cray catchment upstream of Hawley and Crayford	**1970 to 1997**	**2007 to 2019**	**Change**	**Comments**
Average effective rain (mm/year)	166.1	148.9	-17.2	Effective rain 10% lower in 2007 to 2019
Upper Cray abstraction	39.9	42.1	2.2	Nearly half the total
Middle Darent abstraction	36.1	21.0	-15.0	abstraction reduction
Total Chalk abstraction	76.0	63.1	-12.9	comes from reduced
Upper Darent Greensand abstraction	34.0	23.1	-10.9	Greensand reduction in
Total abstraction	**110.0**	**86.2**	**-23.8**	Upper Darent
Average Hawley baseflow (Ml/d)	31.4	44.0	12.6	Flow gain is mostly from
Average Crayford baseflow (Ml/d)	28.2	30.7	2.5	increased flows in the
Average total lower river baseflow (Ml/d)	**59.6**	**74.7**	**15.1**	Upper Darent
Average recharge (Ml/d)	157.3	141.0	-16.3	Only small reduction in
Abstraction as % of recharge (A%R)	**70%**	**61%**	**-9%**	the very high A%R

Table 5 - Measured flow increase at Hawley and Crayford following abstraction reduction

The combined average reduction in abstraction of 24 Ml/d from the Chalk has resulted in a total 15 Ml/d increase in the combined outflow of baseflows at Hawley and Crayford. This is only a 4 Ml/d increase over the 11 Ml/d flow increase in baseflow at Otford arising from the reduction in Greensand abstraction. On the face of it, this suggests that the 15 Ml/d reduction in Thames Water's chalk abstractions in the Middle Darent have only led to a 4 Ml/d increase in flows. However, account also needs to be taken of:

1. The effective rain in the period 2007 to 2019 was 10% less than the in the period 1970 to 1997. Therefore, overall baseflows can be expected to have been reduced by 10% on average, i.e. a reduction of about 7 Ml/d in the combined baseflows at Hawley and Crayford.

2. Some of the baseflow entering the Darent at Otford is lost due to leakage through the river bed before it reaches Hawley.

3. Some of the reduction in abstraction from the Chalk will leave the catchment as underflow in the Chalk, so is not detected at the Hawley and Crayford gauging stations.

Together, these factors show that the increase in baseflows at Hawley and Crayford has probably been close the full amount of the total abstraction reduction of 24 Ml/d. A similar amount of flow recovery is also shown by the CSF model and the LBM models, when comparing recent actual flows with historic flows in the period before the abstraction reductions in the 1990s. However, the overall scale of the abstraction reduction has been very modest – abstraction as % of recharge (A%R) still remains very high at 61%. Therefore, any improvement in river ecology will have been small and difficult to detect.

In addition to the modest long term reductions in abstraction from the chalk, there has been an attempt to boost river flows in droughts by augmentation from boreholes at Eynsford, Farningham and Lullingstone. The facility was made available in 1999 and used significantly in the dry years of 2004 to 2006, when augmentation releases of up to 13 Ml/d were made throughout most of the summers and autumns. However, much of the augmentation flow was lost through leakage through the river bed. The augmentations stopped being used significantly after 2009, when the introduction of up to about 15 Ml/d of new abstraction from the Bean wellfield allowed corresponding reduction in the water supply abstractions at Eynsford, Horton Kirby and Lullingstone. There have been no flow augmentations since 2012.

3.3.3 Conclusion on the effectiveness of past abstraction reductions

The conclusions from this analysis of past abstraction reductions in the Darent-Cray catchment are:

1. The scale of the abstraction reductions has been very modest – only a 24 Ml/d reduction in a total abstraction of 110 Ml/d in the upper and middle rivers.
2. There is good evidence to show that most of the abstraction reductions have converted into river baseflows.
3. Despite the high conversion of the abstraction reductions into river flows, the flow gains have been small in percentage terms, so any improvements in river ecology will have been small and difficult to detect.
4. Despite the abstraction reductions to date, the Rivers Darent and Cray are still amongst the most over-abstracted chalks streams in the country.

Overall, there should be a rejection of any suggestion that abstraction reductions to date have led to minimal river flow improvements. Flows have improved by an amount almost equivalent to the modest reductions in abstraction to date, but there is still a long way to go in re-naturalising river flows and ecology.

4. Current water company plans for reducing abstraction

4.1 WRSE abstraction reduction scenarios

WRSE is an alliance of the six water companies that cover the South East region of England, four of which have abstractions in the Darent-Cray catchments – Thames Water, South-East Water, Sutton & East Surrey Water and Southern Water. WRSE's aim is to secure the water supply for future generations through a collaborative, regional approach to managing water resources.

As part of the process of individual water companies producing their 5-yearly statutory Water Resource Management Plans in 2024 (WRMP24), WRSE developed a non-statutory Regional Water Resource Plan for the South East. The final Regional Plan contained High, Medium and Low scenarios for reductions in existing water supplies needed to restore sustainable river flows and ecology. These scenarios were developed in collaboration by the Environment Agency, the individual water companies and various stakeholder bodies.

WRSE have produced forecasts of reductions in abstraction require for individual Darent-Cray sources under each of the High, Medium and Low scenarios, as shown in Table 6 on the next page[13].

There are big differences between the three scenarios – total 158 Ml/d of Darent-Cray reductions by 2055 for the High scenario, but only 51 Ml/d reduction in the Medium Scenario and just 33 Ml/d in the low scenario. The main differences in these scenarios are:

- Abstraction reductions in the lower Rivers Cray and Darent are only included in the High scenario (total reductions of 75 Ml/d).
- High scenario reductions totalling 40 Ml/d in the Cray catchment at Orpington and Bexley are reduced to 15 Ml/d in the Medium scenario and 9 Ml/d in the Low scenario.

The final, government-approved versions of the WRMPs are largely based on WRSE's High scenario reductions – a total of 158 Ml/d of reductions, with much of the replacement water coming from Thames Water's planned new reservoir near Abingdon (the previously termed SESRO reservoir, recently re-named White Horse Reservoir).

However, WRSE recognise that there is still much uncertainty on "*what the final environmental ambition will be for each individual source and this is unlikely to be resolved until the proposed WINEP [water industry national environment programme] and other investigations are completed over the next five years*" [14].

[13] Source level abstraction reduction data as supplied by WRSE to Group Against Reservoir Development (GARD) in January 2023 in Excel file *'GARD-03 Source Level Environmental Ambition Data.xlsx'.*
[14] WRSE Final Regional Plan, July 2025, page 62 https://www.wrse.org.uk/media/m33fdxe3/wrse-final-regional-plan-june-2025.pdf

				High Scenario					Medium Scenario					Low Scenario				
Company	**Source**	**River**	**Reach**	**2034-35**	**2039-40**	**2044-45**	**2049-50**	**2054-55**	**2034-35**	**2039-40**	**2044-45**	**2049-50**	**2054-55**	**2034-35**	**2039-40**	**2044-45**	**2049-50**	**2054-55**
SES Water	Limpsfield A	Darent	Upper	-0.16	-0.32	-0.48	-0.64	-0.80	-0.16	-0.32	-0.48	-0.64	-0.80	-0.16	-0.32	-0.48	-0.64	-0.80
SES Water	Limpsfield B	Darent	Upper	-0.02	-0.04	-0.07	-0.09	-0.11	-0.02	-0.04	-0.07	-0.09	-0.11	-0.02	-0.04	-0.07	-0.09	-0.11
SES Water	Westwood	Darent	Upper	-0.34	-0.67	-1.01	-1.35	-1.68	-0.34	-0.67	-1.01	-1.35	-1.68	-0.34	-0.67	-1.01	-1.35	-1.68
South East	Cramptons Road	Darent	Upper	-2.55	-5.46	-8.20	-10.93	-13.66	-2.55	-5.28	-7.93	-9.30	-10.68	-2.55	-5.10	-7.66	-7.66	-7.66
South East	Kemsing	Darent	Upper	-1.00	-0.96	-1.44	-1.93	-2.41	-1.00	-2.07	-3.10	-3.64	-4.18	-1.00	-2.00	-3.00	-3.00	-3.00
South East	Oak Lane	Darent	Upper		-0.13	-0.20	-0.26	-0.33										
Thames	Sundridge	Darent	Upper				-1.36	-1.36										
Thames	Westerham	Darent	Upper				-0.88	-0.88				-0.97	-0.97					
Thames	Orpington	Cray	Upper				-8.55	-8.55										
Thames	Bexley	Cray	Upper		-31.70	-31.70	-31.70	-31.70				-15.00	-15.00				-9.00	-9.00
South East	Hartley Chalk	Darent	Middle	-0.46	-1.33	-1.99	-2.65	-3.32	-0.46	-1.10	-1.55	-1.92	-2.30	-0.46	-0.70	-0.84	-0.84	-0.84
South East	Hartley Greensand	Darent	Middle		-0.33	-0.50	-0.66	-0.83										
South East	Ridley	Darent	Middle	-0.46	-0.45	-0.67	-0.90	-1.12	-0.46	-1.10	-1.55	-1.92	-2.30	-0.46	-0.70	-0.84	-0.84	-0.84
Southern	Fawkham	Darent	Middle	-1.00	-2.60	-3.90	-5.20	-5.20	-1.00	-2.60	-3.90	-5.20	-5.20	-1.00	-1.00	-1.00	-1.00	-1.00
Thames	Horton Kirby and Eynsford	Darent	Middle	-3.40	-6.80	-6.80	-6.80	-6.80	-3.40	-3.40	-3.40	-3.40	-3.40	-3.40	-3.40	-3.40	-3.40	-3.40
Thames	Lullingstone	Darent	Middle	-4.50	-4.49	-4.49	-4.49	-4.49	-4.50	-4.50	-4.50	-4.50	-4.50	-4.50	-4.50	-4.50	-4.50	-4.50
Thames	Dartford	Darent	Lower				-3.63	-3.63										
Thames	Green St Green	Darent	Lower				-4.46	-4.46										
Thames	Wilmington	Darent	Lower				-19.00	-19.00										
Thames	Darenth	Darent	Lower				-20.70	-20.70										
Thames	Crayford	Cray	Lower				-13.60	-13.60										
Thames	Wansunt	Cray	Lower				-13.60	-13.60										
		Totals (Ml/d)		**-13.90**	**-55.29**	**-61.44**	**-153.37**	**-158.23**	**-13.90**	**-21.09**	**-27.48**	**-47.94**	**-51.12**	**-13.90**	**-18.43**	**-22.80**	**-32.31**	**-32.83**

Table 6 - WRSE abstraction reduction scenarios for the Darent-Cray catchment

4.2 Proposals in water company WRMPs

4.2.1 Abstraction reductions planned by Thames Water

Thames Water's Final WRMP24, approved by Government, has used the WRSE High scenario abstraction reductions in its forecasts of future supply deficits, including a loss of deployable output of 129 Ml/d due to the planned Darent-Cray source shut-downs[15]. Its forecast deficit has been used to justify its planned major new source developments:

- the 67 Ml/d Teddington Direct River Abstraction (DRA) scheme, using recycled effluent from Mogden sewage works, due for completion by 2033
- the 271 Ml/d White Horse Reservoir near Abingdon (previously known as SESRO), due for completion by 2040

The magnitude and timing of the reductions are almost exactly as the WRSE High scenario shown on Table 6, the only slight difference being to bring forward from 2040 to 2035 the planned 11.3 Ml/d of reductions at Horton Kirby, Eynsford and Lullingstone. The planned 31.7 Ml/d reduction at Bexley will be done by 2040. All the other planned reductions totalling 85 Ml/d will have to wait until 2050. Thames Water's WRMP explains this long delay as follows[16]:

"The total current Deployable Output of the groundwater sources in South East London is approximately 230 Ml/d. As such, a Deployable Output reduction of 65 Ml/d [should be 85 Ml/d according to TW/WRSE figures] would be very significant, recognising that this would be in addition to other licence reductions which are included before 2050 in the High scenario. While the Honor Oak transfer into South East London is significant, the existing transfer could not simply be increased to enable all of these licence reductions. Major strategic network solutions would be required across this part of the WRZ to ensure that customer supplies would be maintained if these licences were to be reduced. The most efficient network solution would be different according to the licence reductions which are identified as being part of the final solution.

In view of this need for a strategic solution, our consideration is that we should (by 2035, following investigations) confirm the licence reductions which are required and then (by 2040) design strategic network solutions to enable those licence reductions. Given that the construction of infrastructure would then take a significant amount of time, we do not think it would be possible to accelerate most of these licence reductions ahead of the "backstop" date of 2050."

[15] Thames Water Final WRMP24, Data Tables, Excel File worksheet 'TWSLND' rows 35 and 128 https://www.thameswater.co.uk/about-us/regulation/water-resources
[16] Thames Water Final WRMP24, Section 5, paragraphs 5.84-5.85, October 2024 https://www.thameswater.co.uk/media-library/h0pismyt/environmental-forecast.pdf

The timing of investigations of the required Darent-Cray reductions referred to by Thames Water are shown in their Final WRMP 24 as follows:

High Priority	Medium Priority	Low Priority
AMP8 (by 2030)	**AMP 8/9 (by 2035)**	**AMP9 (by 2035)**
Eynsford Horton Kirby Lullingstone	Sundridge Westerham	Orpington Darenth Wilmington Green St Green Crayford Wansunt Dartford

Table 7 - Timing of Thames Water's planned investigation of abstraction reductions[17]

These investigations are all part of the Water Industry National Environment Programme investigations (WINEP) which are used to justify infrastructure investments as part of the regulatory 5-year asset management planning cycles – AMP8 by 2030 and AMP9 by 2035. The need for these investigations is emphasised in the joint water company letter to the Environment Agency in December 2025, concerning the scale of planned abstraction reductions nationally, including these extracts[18]:

> *"These investigations [WINEP] will provide the robust evidence base needed to support licence changes, particularly demonstrating links between flow and ecology as well as understanding wider catchment pressures."*
>
> *"these investigations will … ensure we are not investing in expensive, carbon intensive solutions that may not be necessary or provide only marginal or insignificant benefits."*
>
> *"The impacts of the required solution(s) must also be taken into account, including environmental impacts and carbon emissions."*
>
> *"before any investment is made we need to have robust up to date evidence available to support proposed solutions anticipating benefit in flow, with this benefit anticipated to ecology. We consider that the proportionality of required changes and benefits to the environment and impact to water resource management should be considered and formally captured."*

The 129 Ml/d of abstraction reductions planned by Thames Water would use 48% of the 271 Ml/d output of the new White Horse Reservoir near Abingdon, whose estimated cost has recently escalated from £2.2 billion to £ 6.6 billion. The total cost of the River Darent

[17] From Table 5-7, Section 5 of Thames Water Final WRMP24

[18] Joint water company letter to Environment Agency, December 2025,

re-naturalisation would then be about £4 billion after including the cost of supply network improvements needed to connect the Darent valley to London's supplies.

It is, therefore, understandable that the water companies plan thorough investigation of the need for the all the planned Darent-Cray reductions, before any decision on what reductions should proceed. If the costs are to be about £4 billion, it is hard to imagine that the full amount of the planned cuts would survive any realistic assessment of benefits versus cost.

However, it seems unacceptable and unnecessary for some of the investigations to be delayed beyond 2030, i.e. extending into AMP9, bearing in mind the minimal progress that has been made in dealing with an over-abstraction problem that has been well known for at least 40 years. The costs of the investigations will be a tiny proportion of the several billion pounds of capital cost of replacement sources, if the investigations show they are all needed. Therefore, it makes economic sense to prioritise completion of all the investigations by 2030 and before any commitment to building the replacement sources.

4.2.2 Reductions planned by South East Water and other companies

South East Water's WRMP24 does not provide details of planned abstraction reductions for individual sources, but the total planned reductions for their Tonbridge Wells supply zone (Sevenoaks sources) and Maidstone supply zone (east Darent sources) appear based on the WRSE High scenario reductions as below:

Source	River	Reach	2034-35	2039-40	2044-45	2049-50	2054-55
Cramptons Road	Darent	Upper	-2.6	-5.5	-8.2	-10.9	-13.7
Kemsing	Darent	Upper	-1.0	-1.0	-1.4	-1.9	-2.4
Oak Lane	Darent	Upper		-0.1	-0.2	-0.3	-0.3
Hartley Chalk	Darent	Middle	-0.5	-1.3	-2.0	-2.7	-3.3
Hartley Greensand	Darent	Middle		-0.3	-0.5	-0.7	-0.8
Ridley	Darent	Middle	-0.5	-0.4	-0.7	-0.9	-1.1
	Totals (Ml/d)		**-4.5**	**-8.7**	**-13.0**	**-17.3**	**-21.7**

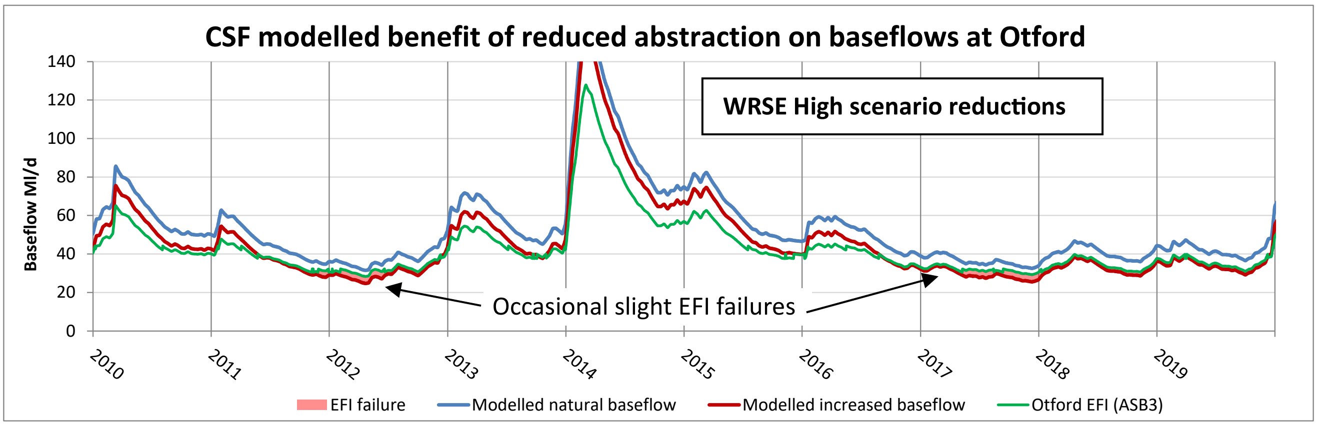
Table 8 - Abstraction reductions planned in South East Water's WRMP

These reductions are mostly in the upper Darent around Sevenoaks, introduced gradually up to 2055. The replacement water will come mainly from planned leakage reduction and demand management, with a small transfer from Sutton & East Surrey Water. There appears to be no need to receive water from Thames Water's London supplies and their planned White Horse Reservoir, although the size of the reductions suggests some will be needed.

Southern Water plan to reduce their Fawkham abstraction in the middle Darent by 5 Ml/d, with reduction introduced gradually up to 2055. Sutton & East Surrey Water plan to reduce their abstractions at Westerham and Limpsfield by 3 Ml/d, also introduced gradually up to 2055. The reductions are planned to be replaced mainly by leakage reduction and demand management. However, it seems likely that some supply from Thames Water will be needed for all the water companies' reductions, probably explaining why the full reductions are delayed until 2055 in line with Thames Water's reductions.

4.2.3 Modelled effectiveness of water company abstraction reduction scenarios

If the High scenario abstraction reductions were implemented by all the water companies, most of the Darent-Cray abstractions would be reduced to zero, leaving only about 8 Ml/d of abstraction from the Upper Darent Greensand and about 11 Ml/d from the Darent and Cray Chalk. Natural groundwater levels and river flows would be almost fully restored, and there would be just very occasional and slight EFI failures, as shown by CSF modelling in Figure 22:



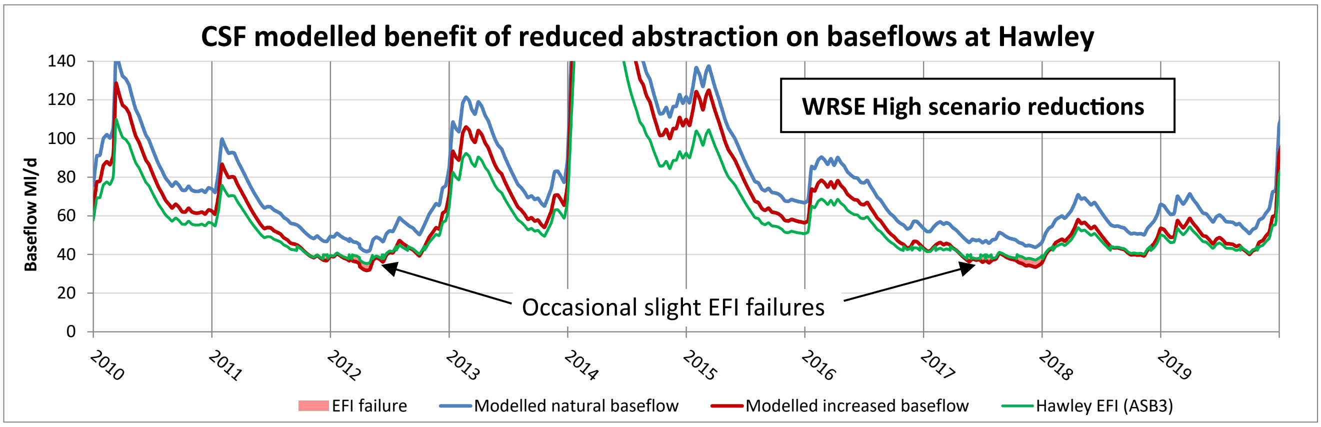


Figure 22 - EFI flow compliance arising from WRSE 'High' Scenario abstraction reductions

The CSF modelling shows that the High scenario abstraction reductions would give full compliance with EFIs at Lullingstone and Crayford. The High abstraction reduction scenario would deliver an almost complete re-naturalisation of Darent-Cray flows, but it seems unlikely that it will ever be implemented at a cost of about £4 billion.

Realistically, it seems more likely that the investigations planned for 2035 will conclude that only the Medium scenario reductions of 51 Ml/d can be justified, leaving residual abstractions of 8.4 Ml/d in the upper Darent, 34.5 Ml/d in the upper/middle Darent and Cray chalk and 60 .5 Ml/d in the lower Darent and Cray. CSF modelling of EFI compliance with the

Medium Scenario abstraction reductions is shown in Figure 23:

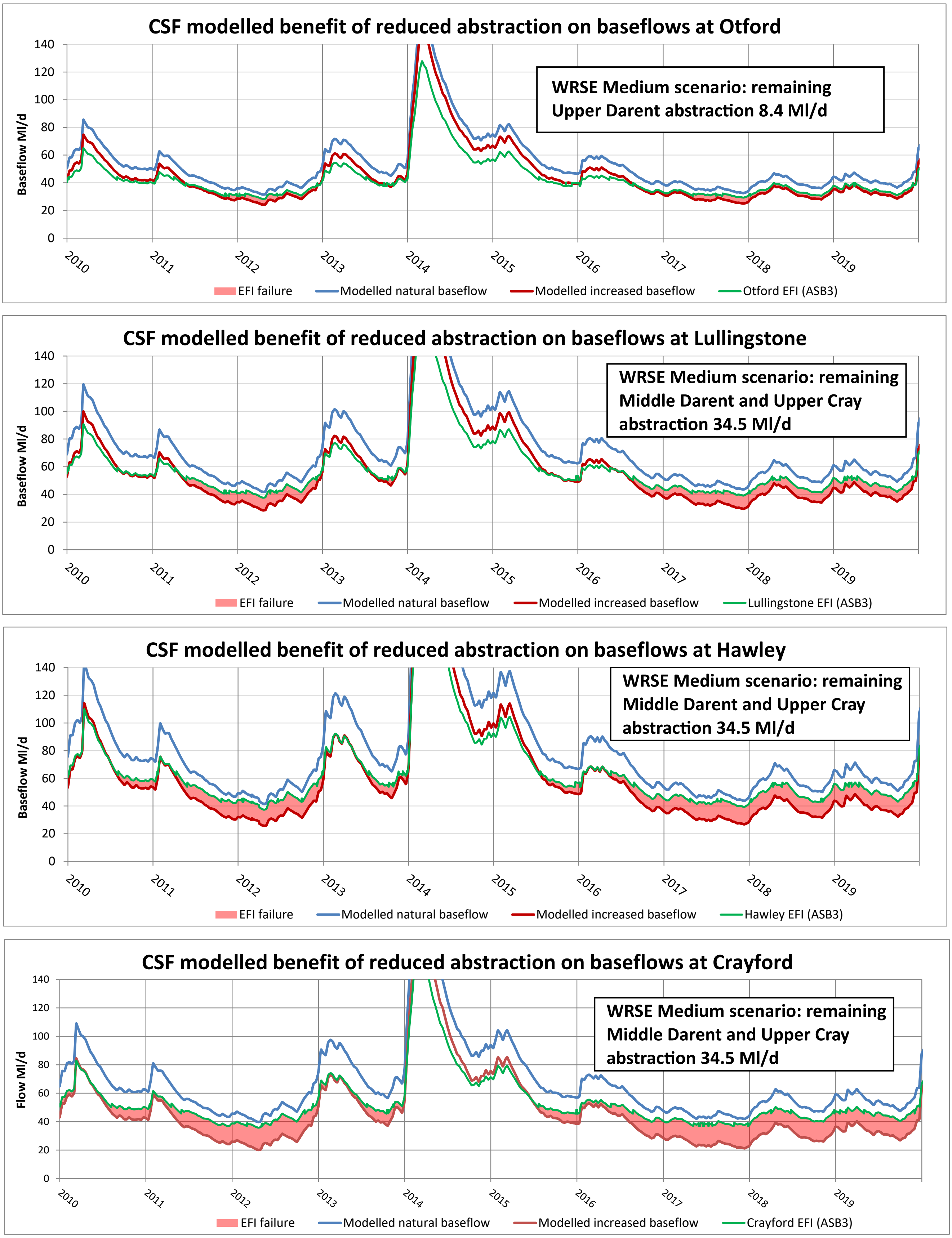


Figure 23 - EFI flow compliance arising from WRSE 'Medium' Scenario reductions

The CSF modelling shows that with the Medium scenario abstraction reductions there would still be widespread EFI failures in the Rivers Darent and Cray. Typical summer flows would still be reduced by about 30-50%. This would comply with the target of 50% reduction of flows that has previously been suggested, but it would be well short of a complete re-naturalisation of flows. The ecological benefits would be questionable.

Furthermore, as things are currently planned, there would be no decision on whether to proceed with even the Medium scenario reductions until 2035 and there would be no significant improvement in the river until 2050, some 70 years after the gross over-abstraction of the Rivers Darent and Cray became widely recognised.

5. Options for faster and less costly improvements

5.1 Potential for Darent-London conjunctive use

5.1.1 Principles behind conjunctive use of surface water and groundwater

At present, about 160 Ml/d of water are abstracted continuously from the Chalk and Greensand aquifers in the Darent-Cray valleys, 7 days per week and 365 days per year. The aquifers are used to provide a continuous 'baseload' of supply, rather than being used primarily as reservoirs in droughts.

Under the 'High' scenario reductions in abstraction, as proposed in the Government-approved WRMPs, the abstractions would be reduced by over 90% at all times, so river flows will recover to close to their natural levels. However, storage available in the Chalk and Greensand aquifers – the natural underground reservoirs – will no longer be available to support public water supplies in droughts. Although river flows will be greatly improved, the large and strategically important reservoirs in the aquifers will be no longer available for public water supplies – throwing the baby out with the bathwater.

Most of London's water supplies come from the Rivers Thames and Lee. When river flows are low, water is taken from storage in the reservoirs in the lower Thames valley to the west of London and the lower Lee valley in north-east London. At times of high river flows, water is pumped back to re-fill the reservoirs. At most times in most years, there is more than enough water in the rivers to maintain London's supplies, without using any reservoir storage. The surplus water in the Rivers Thames and Lee could be used to replace supplies from the Darent aquifers.

The principles behind conjunctive use of Darent and London supplies are:

1. Inter-connect the London and Darent supply systems, so that areas at present served by Darent sources can mostly be supplied from London, whilst still maintaining the aquifer storage to supply these areas from Darent sources in droughts.

2. The supplies from London to the Darent would be mostly at times when there is surplus water in the Rivers Thames and Lee, so making only minimal use of the water stored in London's reservoirs.

3. Water stored in the Darent aquifers would only be used for short periods during droughts, so groundwater levels would always be much higher than at present, driving larger spring flows and restoring river flows to close to natural levels. Although groundwater levels and river flows would be lower than natural during droughts, they would be a lot higher than under the present abstraction regime.

The Darent-London conjunctive use concept is not a new idea. The Environment Agency's 1999 report on the first phase of the Darent Action Plan described a similar scheme as follows:[19]

Thames Water has been obliged to modify its network of water mains in S E London/N W Kent in order to increase supply from metropolitan sources and from the London Ring Main. The following infrastructure changes have been reported by Thames Water, but not yet audited:

- Installation of new pumps at Farnborough reservoir
- Installation of new water main from Farnborough reservoir to Knockholt pressure zone
- Installation of repump at Southfleet for water transfer from the Eltham pressure zone to the Southfleet pressure zone
- Closure of Brasted

7.6 Conjunctive Use Agreement

The first of two Water Resource Management Schemes (WRMS) has been set up under the provisions of Section 20 of the Water Resources Act (1991). This serves to minimise actual use of Darent groundwater sources during winter by restricting actual abstraction to 32 Ml/d during averagely or above-averagely wet winters (October - March). In practice it offers a reduction in actual abstraction of about 8-13Ml/d thus allowing winter storage to be enhanced and to better withstand peak summer abstractions.

Operation of the scheme is controlled by reference to storage levels in the Thames Valley reservoirs, the time of year and baseflows in the River Thames at Teddington. Implementation of the Scheme by Thames Water has necessitated enhanced monitoring of reservoir storage, and real time control of abstraction rates from the Darent sources, in addition to the infrastructure changes already described in Section 7.4.

In response to a request for more information about this scheme in September 2025, Thames Water provided a copy of the Water Resources Act Section 20 operating agreement referred to above, dated August 1995, which describes the intended operation of the conjunctive use scheme as below, with 'Fig 1' reproduced as Figure 24:

> *"TWUL to maximise use of its London reservoirs (fed from the River Thames) in preference to the Darent groundwater sources (Lullingstone, Eynsford, Horton Kirby and Darenth) whenever available storage allows, using the X/Y/Z reservoir control curves agreed between the NRA and TWUL for the Lower Thames Abstraction Scheme. This is summarised diagrammatically in Fig 1."*

[19] Darent Action Plan Phase 1 Draft Final Report, PDF pages 39 and 40, Environment Agency, October 1999

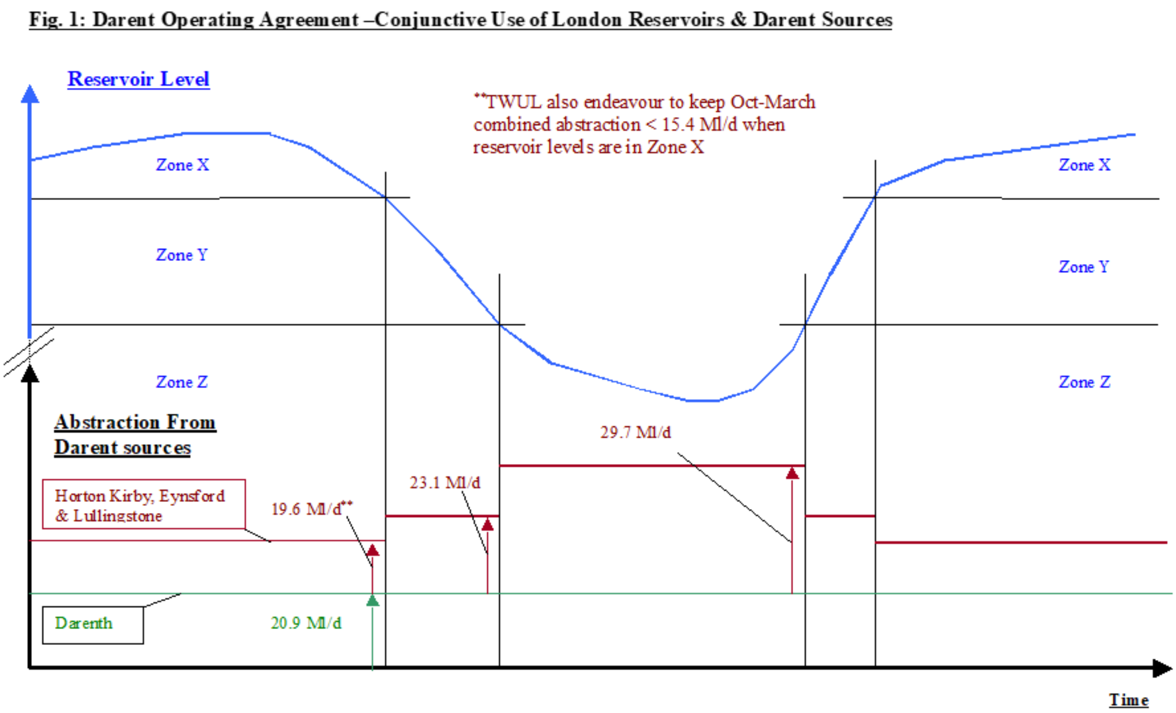


Figure 24 - Intended operation of previously considered conjunctive use scheme

Although, the diagram above suggests that winter abstraction at Lullingstone, Eynsford, Horton Kirby and Darenth could be reduced by as much as 35 Ml/d (total 50.4 Ml/d down to 15.4 Ml/d), the abstraction records post-1995 show no clear drop in winter abstraction beyond the small reduction expected in normal operation (less summer garden watering):

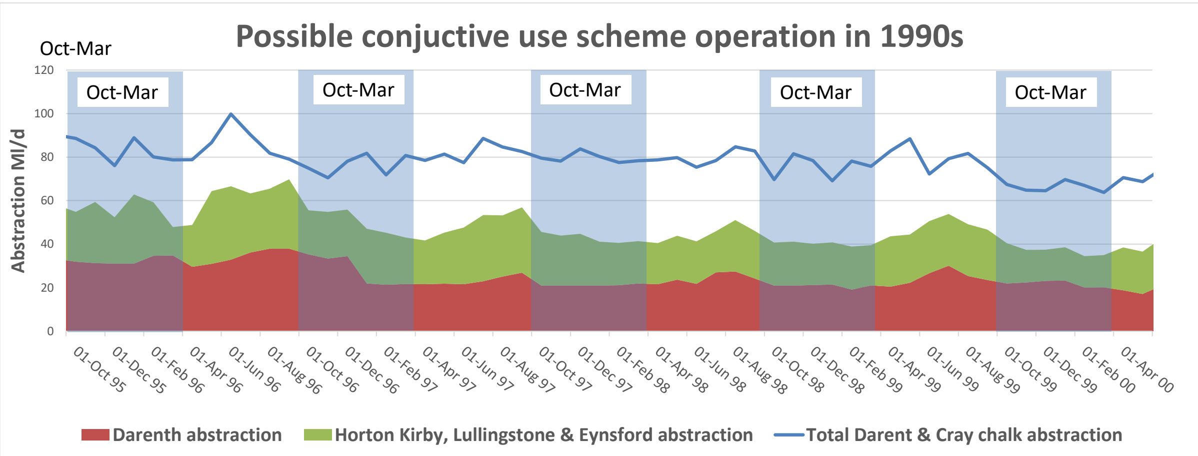


Figure 25 - Recorded summer-winter abstraction variation due to conjunctive use in 1990s

After start of the scheme in 1995, the total abstraction from the Middle and Upper Darent-Cray chalk remained fairly constant from summer to winter, suggesting that any reduced abstraction from Lullingstone, Eynsford, Horton Kirby and Darenth was mostly replaced from elsewhere in the Darent-Cray chalk rather than any connection to London.

This shows that the previously attempted conjunctive scheme, although potentially significant in size, was scarcely used in practice.

No more information about the current status of the conjunctive use scheme has been provided by Thames Water, so it appears that it is now defunct. This may be because a reduction in the Horton Kirby, Lullingstone and Eynsford abstractions was enabled by the introduction of the new Bean wellfield to the east of Dartford (see Figure 9) in the mid-2000s, meeting the relatively modest ambitions for reducing abstraction at that time.

Nevertheless, the principles behind the conjunctive use scheme remain valid, so now that much more ambitious reductions in abstraction are planned, accompanied by a much bigger appetite for expenditure on re-naturalising river flows, a much larger version of a conjunctive use scheme should be considered.

5.1.2 Layout of a Darent-London conjunctive use scheme

The layout of a Darent-London conjunctive use scheme is shown schematically below:

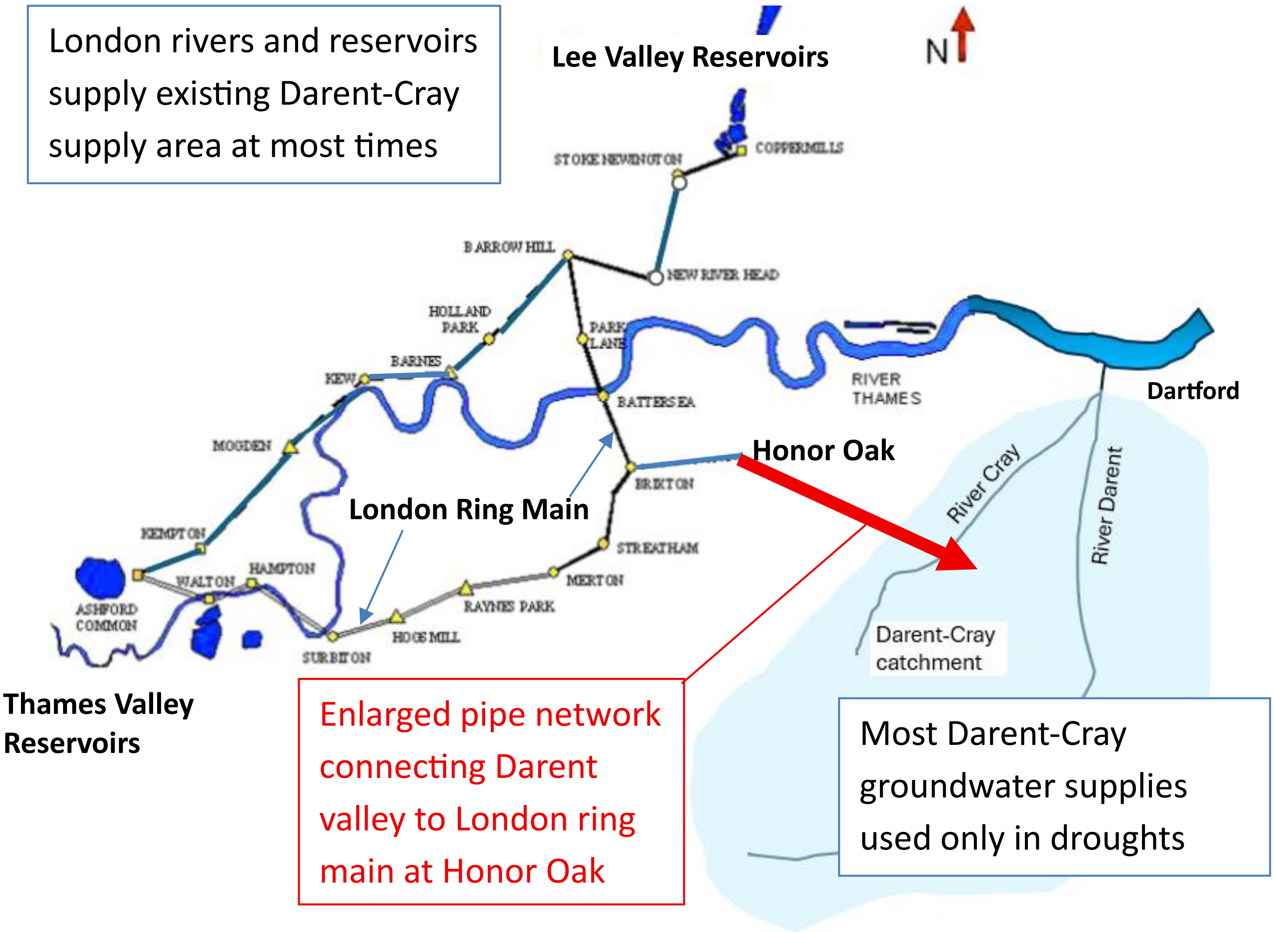


Figure 26 - Schematic layout of potential Darent-London conjunctive use scheme

The new infrastructure needed to implement the conjunctive use scheme would comprise:

- the pipe network connecting the London ring main to areas currently supplied by the existing Darent -Cray sources.

- Probably, some enhancement of the existing London distribution and water treatment works to provide the additional supply to the Darent.

In Thames Water's current plans, these works will all be needed by 2050 to enable the c.130 Ml/d of Darent-Cray abstraction reductions planned after 2050 – therefore it is a matter of bringing these works forward by about 15 years for the conjunctive use scheme; they are not a new requirement. There would be no new resource development. The new pipe network will be perhaps up to 100 Ml/d capacity and 15-20 km length, much of it through heavily urbanised terrain. It is likely to involve significant lengths of tunnelling. There could also need to be an increase in the capacity of the existing pipe spur connecting Honor Oak to the London ring main itself.

The pipe network enhancement will be very costly – possibly of the order of several hundred million pounds. However, it would eliminate the need for about 130 Ml/d of new resource planned by Thames Water, i.e. about half of the output of the 271 Ml/d White Horse Reservoir near Abingdon with a capital cost recently estimated as £6.6 billion.

5.1.3 Operating rules for conjunctive use with London supplies

The existing London supplies have a drought reliable deployable output of about 2280 Ml/d (assuming the London desalination scheme is functioning). At most times, London's supplies come mainly from the Rivers Thames and Lee supported by storage in the Thames Valley and Lee Valley reservoirs. In droughts, when river flows and storage in the reservoirs get low, additional supplies are obtained from various 'drought schemes' including the London Gateway desalination plant at Beckton, the North London artificial recharge scheme (NLARS) and the West Berkshire Groundwater Scheme (WBGWS).

The London ring main provides a high degree of inter-connectivity between all the sources and supply areas. The existing spur from the London ring main to Honor Oak provides the closest connection point between the main London supply system and the areas currently supplied from Darent-Cray sources.

The use of each existing drought scheme is triggered by operating rules based on the total storage in the reservoirs and the flow in the River Thames at Kingston, upstream of all the main abstractions. As the drought develops, the drought schemes are progressively triggered and water demand measures are introduced (e.g. hosepipe bans), while the Thames at Teddington target flows (TTF) are progressively reduced from 800 Ml/d to 300 Ml/d.

With the proposed London-Darent conjunctive use scheme, most of the existing Darent-Cray groundwater sources would change from being baseload supplies to another 'drought scheme', with similar operating rules to the existing drought schemes.

The operating rules controlling the introduction of demand control measures, the lowering of Teddington target flows and the use of the various existing drought schemes are based on the Lower Thames Control Diagram (LTCD) shown below[20]:

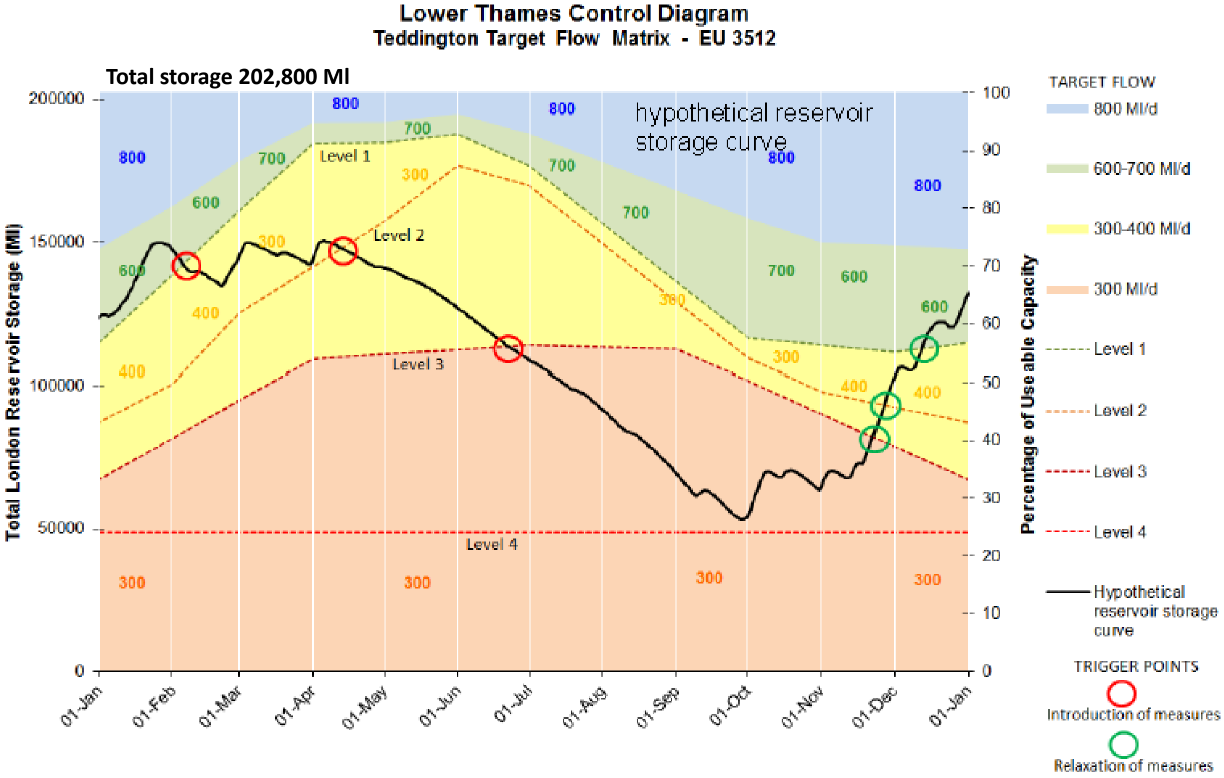


Figure 27 – Lower Thames Control Diagram

On Figure 27, the black line shows the storage in the London reservoirs during a typical severe drought, with the reservoirs not re-filling in spring after a previous dry year, followed by progressive lowering of storage during a second dry year, with recovery in the next autumn. The blue, green, yellow and pink shaded areas define the Teddington target flow (TTF) according to the reservoir storage and time of year – for example, when the storage was about 150,000 Ml in January, in the green zone, the TTF would be 600 Ml/d, but it would fall to 400 Ml/d when the storage went into the yellow zone in February.

The dotted lines on Figure 27 show Service Levels 1, 2, 3 and 4, as agreed by Ofwat to define how frequently Thames Water can apply demand restrictions:

Restriction	Frequency of occurrence	Water use restrictions
Level 1	1 year in 5 on average	Intensive media campaign
Level 2	1 year in 10 on average	Temporary Use Bans (e.g. hosepipe bans)
Level 3	1 year in 20 on average	Non-essential Use Bans requiring drought order and drought permits.
Level 4	Never (in reality 1 in 500 years)	Extreme measures such as standpipes and rotacuts

Table 9 - Thames Water service levels for frequency of demand restrictions

[20] Thames water Final Drought Plan, Figure 5, page 40, August 2022

The operating rules for triggering use of the existing drought schemes are based on combinations of storage zone on the LTCD and flow in the River Thames at Kingston. For example, the use of the London desalination plant is triggered when the flow in the River Thames at Kingston has been below 3000 Ml/d for 10 days and the reservoir storage is in the yellow zone on the LTCD. The 10-day delay is designed to prevent frequent switching on-and-off of the schemes.

The operating rules for use of existing Darent-Cray boreholes as drought sources in a Darent-Cray conjunctive use scheme could be based on a similar combination of storage on the LTCD and River Thames flow at Kingston. The detail of this operating rule would be part of the design of the conjunctive use scheme, as described in Section 5.1.5 of this report.

5.1.4 Modelling of the London supply system

Modelling of the effectiveness of the proposed conjunctive use scheme requires modelling of the London supply system, linked with the CSF model of the Darent-Cray groundwater supplies. This has been done using a model of the London supply system previously developed for GARD, the organisation that represents the interests of people and businesses who will be affected by the planned new reservoir near Abingdon. Examples of the previous use of the model can be seen in various reports on the GARD website[21].

The GARD model of Thames Water's supply system is an almost exact replica of the component of Thames Water's Aquator[22] model that simulates the daily operation of the London reservoirs, the various drought sources and the London ring main. Unlike Aquator, GARD's model does not use rainfall/run-off modelling to generate river flows. Instead, it uses the river flows supplied by Thames Water:

- Either, river flows generated by the rainfall/run-off component of the Aquator model, covering the historic period 1920 to 2013, with flows since 2013 adapted from daily data from the National River Flow Archive.
- Or flows generated stochastically by Atkins to provide 19,200 years of daily flow data that are used to generate extreme drought river flows for determining supply resilience in the new 1:500 year drought resilience standard.

GARD's model provides a daily simulation of the operation of the London and Thames valley supply systems for any period of available flow records. The model includes the detailed water supply operating rules simulated in the Aquator model:

1. The operation of the latest Lower Thames Control Diagram (LTCD) as reported in Thames Water's Final Drought Plan in August 2022.

[21] Group Against Reservoir Development (GARD) https://groupagainstreservoirdevelopment.org/archive/
[22] https://hydro-int.com/en/products/hydro-logic-aquator?language_content_entity=en

2. Levels of Service and Teddington Target Flows, triggered by the LTCD, including demand reductions at the various Levels of Service, as per the drought plan.
3. Inflows from the Thames, using the same pump ceilings as used in Aquator, the same rules for flows in the Mole and Hogsmill, and similar upper reservoir refill constraints.
4. Abstraction from the River Lee, storage in the Lee reservoirs, balancing flows in the Thames-Lee tunnel, are all simulated, as for Aquator.
5. Operation of the London desalination scheme, all ARS schemes, ELDRED, Hoddesdon, Stratford Box and the West Berkshire Ground Water Scheme, all as Aquator

Deployable output of London's supplies is determined as the demand that can be sustained throughout daily simulation of the period of river flow records, without storage dropping into the emergency zone defined by LTCD Level 4.

The model operates as a large, 150 Mb Excel spreadsheet. It takes about 2 minutes to run a 100-year simulation of the operation of the London supply system. This short run time compares with about 1 hour for running Thames Water's Aquator model.

GARD's model has been validated by comparing output with Aquator output that has been provided by Thames Water in 2024[23]. Figure 28 below shows the operation of the London reservoirs in the critical historic drought of 1933-34, with a deployable output of 2206 Ml/d – the output achievable in the most severe drought of the past 100 years without any supply from the desalination plant, as assumed in the Aquator modelling:

[23] Aquator output for the 2023 Annual Review of the WRMP, as provided to GARD by Thames Water in May 2024 in Excel file "AR23 2206, DO London, 1920-2013.xlsx". The Aquator and GARD modelling both assume no output from the London Gateway desalination plant, which was out of service at that time.

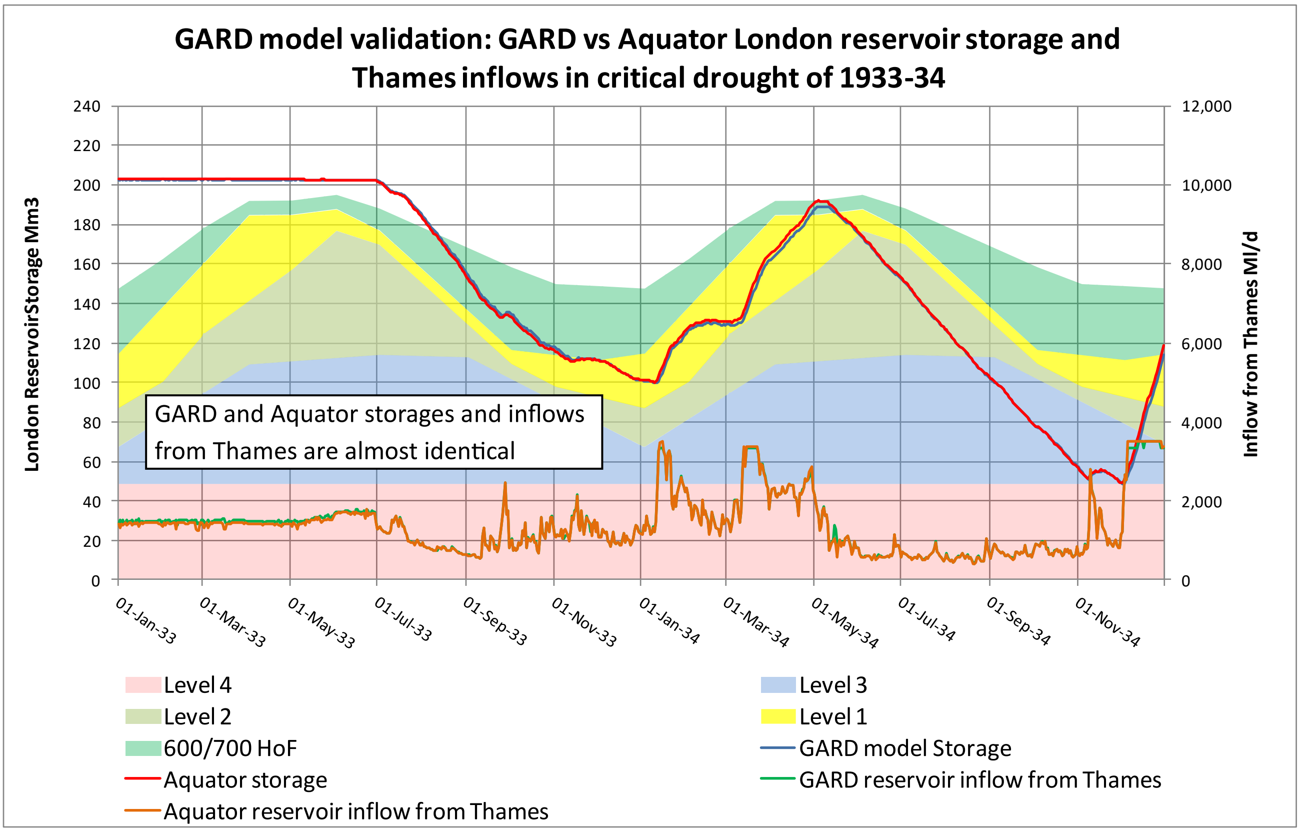


Figure 28 - Validation of GARD vs Aquator modelling of London reservoir operation

Figure 28 shows an almost exact match between GARD and Aquator modelling of London reservoir storage and inflows.

The GARD and Aquator models can both be validated by comparing the modelled London storages with the recorded London storages as shown in the published CEH monthly hydrological summaries for UK[24]:

[24] https://nrfa.ceh.ac.uk/nhmp/monthly-hydrological-summary-uk?gad_source=1&gad_campaignid=21257924601&gbraid=0AAAAA9T_B6uhg-eG5E1mCbJUGSxsHwuzC&gclid=CjwKCAjw-dfOBhAjEiwAq0RwI9huZM64EnBRhscgMQCF3-HcbJQHxlMS4_7ZEc_Il10hZOEfUrqnkRoCRawQAvD_BwE

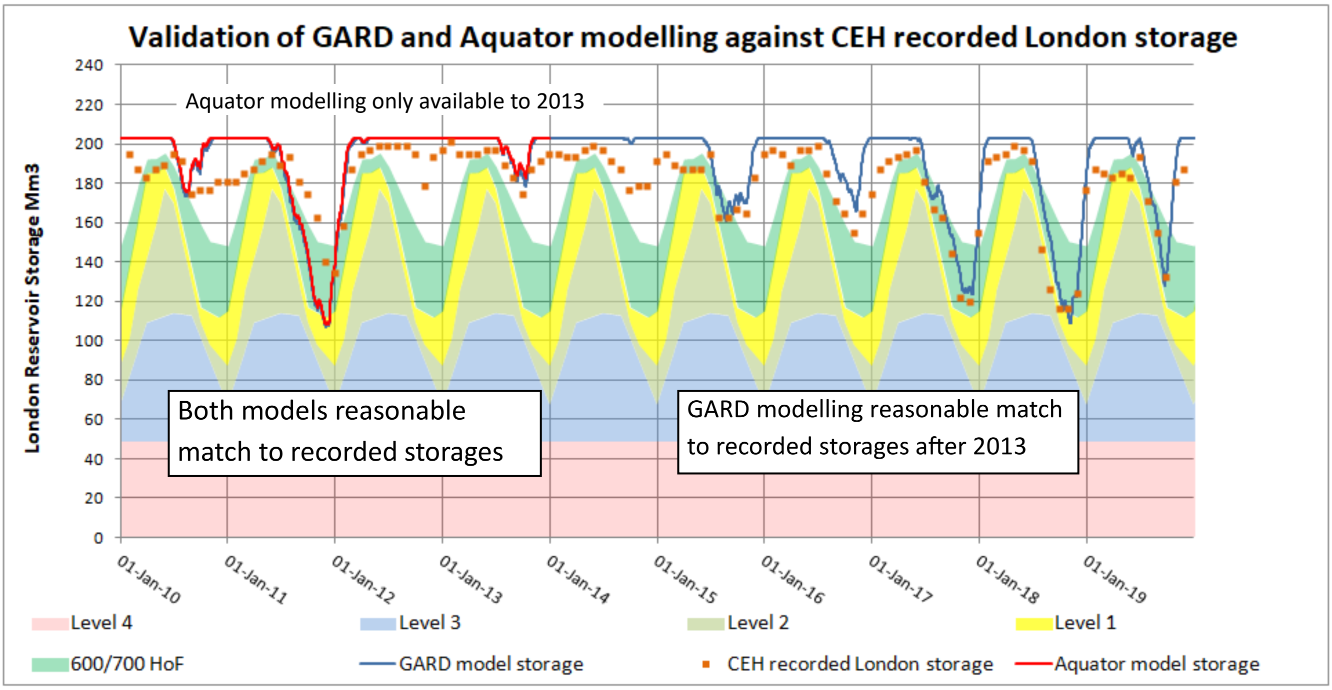


Figure 29- Validation of GARD and Aquator models against CEH recorded London storage

It can be seen that, up to 2013, both models provide a reasonably good to fit to the recorded storage. After 2013, when Aquator modelling is not available and the GARD model uses river flows based on NRFA gauge records, GARD's modelled storages are still a good match to the recorded storages, particularly the minimum storages in the dry years of 2017, 2018 and 2019. The modelled storages cannot be expected to be an exact match to recorded storages, because the models assume optimal operation of the supply system, which does not allow for:

- source outages, e.g. the non-availability of the desalination plant for long periods
- routine maintenance of the reservoirs, which may require extended periods of reservoir level drawdown
- not pumping to refill the reservoirs during floods to avoid poor water quality due to turbidity, sediment load and combined sewer overflows.

The GARD model also provides an almost exact match to Aquator modelling of the occasionally used drought schemes like the North London aquifer recharge scheme (NLARS) and the West Berkshire groundwater scheme (WBGWS) as shown below:

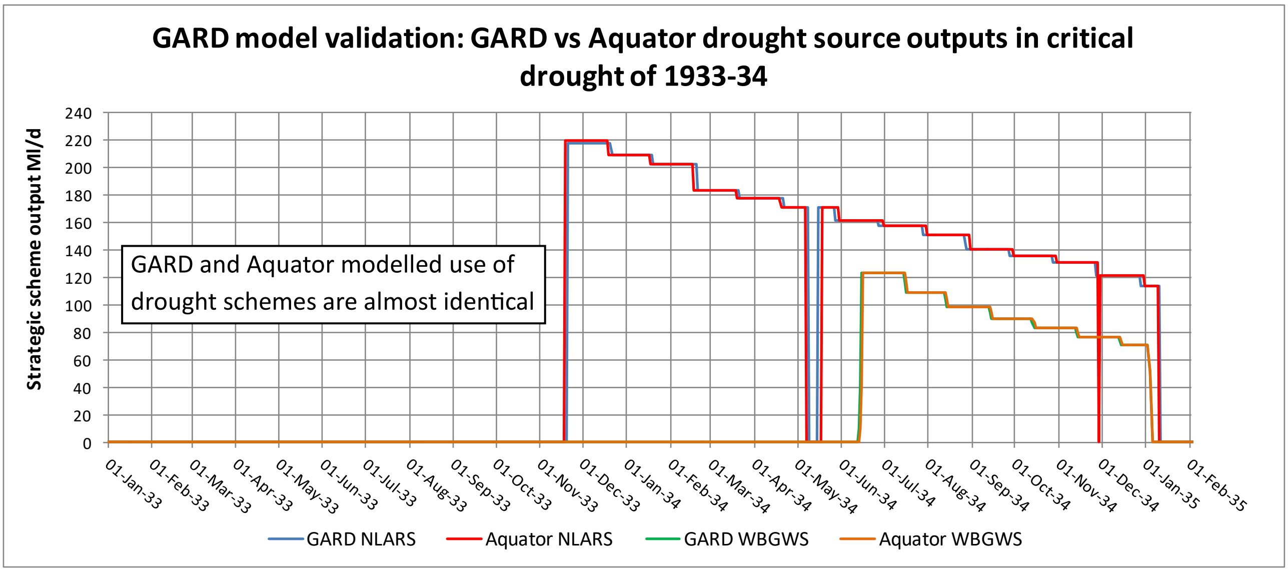


Figure 30 - Validation plots comparing GARD and Aquator modelling of drought schemes

The NLARS and the WBGWS are both major drought schemes that make large but time-limited use of Chalk aquifer storage. The amount of their permitted supply reduces monthly to limit the impact on the aquifers. There are also limits on how often they can be used, with set minimum times between usage to allow aquifer storage to recover. As can be seen in Figure 30, the GARD model can exactly mimic the Aquator simulation of the quite complex operating rules for these drought schemes.

It is concluded that the GARD model can be used as a reliable indicator of the effect that a Darent-London conjunctive use scheme would have on London's existing supplies.

5.1.5 Potential variants of the Darent-London conjunctive use scheme

The scope and effectiveness of a Darent-London conjunctive use scheme will depend on the choice of a number of design parameters:

1. The amount and location of the existing Darent-Cray sources that are only used in droughts.

2. The amount and location of existing sources that are permitted to continue as full-time base load supplies.

3. The timing of use of the Darent-Cray drought sources and the operating rules to control them – it is assumed that operating rules will be similar to those of Thames Water's existing drought schemes and dependent on reservoir control lines in the LTCD and possibly flows in the River Thames at Kingston.

4. The allowable impact on the deployable output of London's existing supplies – the less the Darent-Cray drought sources are used, the greater the need to provide replacement water from London and the larger the impact on London's supplies.

5. Possibly, a gradually reducing amount of usage of the Darent-Cray drought sources, similar to the gradually declining use of the NLARS and WBGWS schemes illustrated on Figure 30.

6. Possibly, limits on the frequency of use of the Darent-Cray drought sources, with a set minimum time between uses to allow aquifer storage to recover, similar to the existing frequency of use rules for the NLARS and WBGWS schemes.

Any or all of the existing Darent-Cray sources could be used only as drought schemes, but the big choice could be whether or not the c.60-75 Ml/d of lower Darent and Cray sources (the sources north of the red dashed line on Figure 17) are allowed to continue to provide baseload supplies, or whether they are only used in droughts. The choice of which of the middle and upper Darent-Cray sources are used for baseload, drought-only or not at all will depend on the level of river flow improvement sought, operational flexibility and, perhaps, the cost of network improvements needed to connect the Darent-Cray valley to London's supplies.

Thames Water's existing drought schemes have various different operating rules that govern when they are switched on and off. For example, the London Gateway desalination plant and several smaller drought sources are first switched on for full operation in a year when both the London reservoir storage has been below TTF Level 1 for more than 10 days and the River Thames flow at Kingston has been below 3000 Ml/d for 10 days. Use of these drought schemes ceases when both the TTF level storage and River Thames flows have been above their respective targets for 10 days. However, if the drought schemes are needed again in that year, they are switched on as soon as the storage and river flows fall below their targets rather than applying the 10-day rule.

Alternatively, a simpler rule operating rule for the Darent drought sources could be based only on a single reservoir control line – either one of the existing LTCD control lines or a new bespoke control line for the Darent drought sources. There could still be 'minimum time below target' rules to avoid the sources being frequently switched on and off, but not necessarily as long as 10 days delay.

There is a variety of possible design assumptions for scheme scope and operating rules, but as an initial assessment of the effectiveness of conjunctive use of Darent-Cray sources with London supplies, the following option has been considered as described in Section 5.2 of this report:

- All of the existing Greensand sources in the upper Darent and the Chalk sources in the upper/middle Darent and Cray to be used only in droughts at their recent actual amounts: 23 Ml/d in the upper Darent, 61 Ml/d in the upper/middle Darent and Cray total 84 Ml/d; zero from all these sources at all other times.

- Except in droughts, 84 Ml/d to be supplied from London to existing Darent-Cray supply areas.

- All lower Darent-Cray sources, recent abstraction 76 Ml/d including 16 Ml/d for Bean wellfield, continue to be used as baseload sources at all times.
- The switching on of 84 Ml/d of Darent sources and switch-off of 84 Ml/d from London to be controlled by the same operating rules as currently used for the London Gateway desalination plant – based on the TTF Level 1 control line and 3000 Ml/d Thames flow, with 10-day stop-start delay.

Other options for the amounts of Darent-Cray sources used as drought sources and operating rules are considered as sensitivity tests in Section 5.3.

5.2 Effectiveness of initially proposed conjunctive use option

5.2.1 Frequency of use of Darent-Cray drought sources

If most Darent-Cray sources are only used as drought sources, triggered by the London desalination plant operating rules, at most times in most years the areas currently supplied by these sources would instead be supplied from London, as shown below in modelling of how the conjunctive use scheme would have operated in the historic period 1970 to 2024:

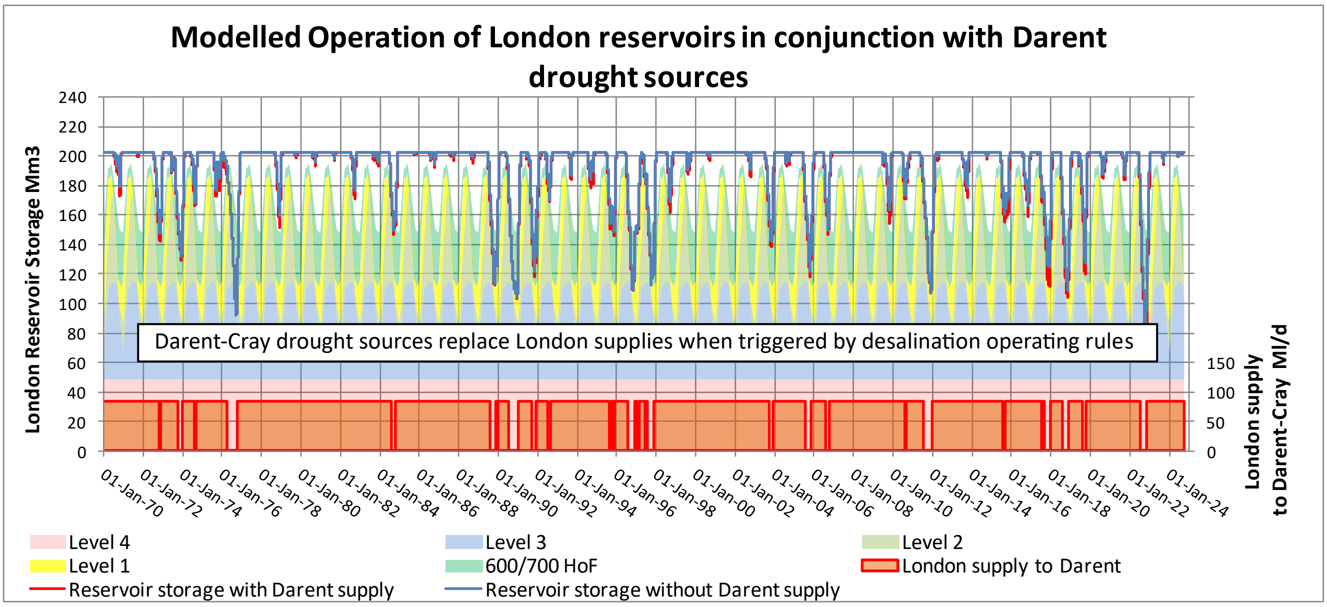


Figure 31 - Frequency of use of London supplies instead of Darent-Cray drought sources

The replacement supplies of 84 Ml/d from London would be used at most times. The Darent-Cray drought sources would only be used for a few weeks in dry summers, or for a few months in major droughts like 1976 or 2011.

As will be shown in Section 5.4, the use of London supplies to replace 84 Ml/d of Darent supplies at most times would only result in a 7 Ml/d loss of London deployable output.

5.2.2 GWL and flow increases arising from the conjunctive use scheme

The rises in groundwater levels from use of most Darent-Cray sources only in droughts are shown on Figure 32 for 2010 to 2019 – a decade including several droughts:

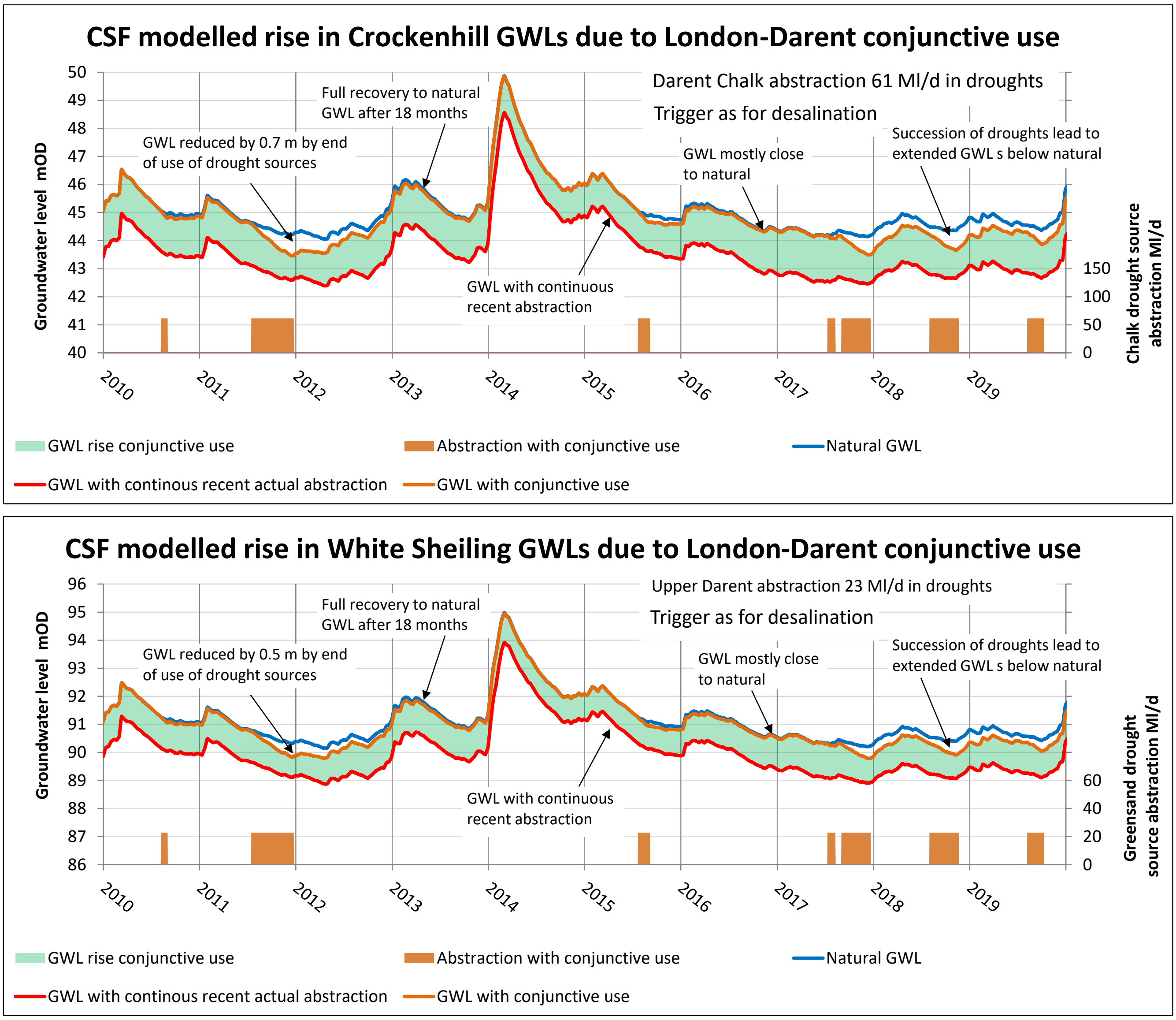


Figure 32 - Darent-Cray GWL rises from Darent-London conjunctive use 2010 to 2019

The use of most Darent-Cray sources only in droughts would allow Chalk groundwater levels at Crockenhill to rise by about 1.3 m, becoming close to natural GWLs at most times. The Greensand GWLs at White Sheiling would rise by about 1 m. During the droughts that occurred in this period, including quite severe droughts in 2011 and 2018, the use of the drought sources would cause the GWLs to fall by about 0.7 m at Crockenhill and 0.5 m at White Sheiling. It then takes about 18 months for GWLs to rise back to natural levels.

In the succession of droughts in 2017, 2018 and 2019, up to about 25% of the gain in GWLs would be lost for about 3-4 years, but the GWLs would still be a lot higher than with continuous use of the sources as at present.

Following the rises in GWLs, the corresponding Darent and Cray river flow improvements that would have occurred from 2010 to 2019 are shown on Figure 33:

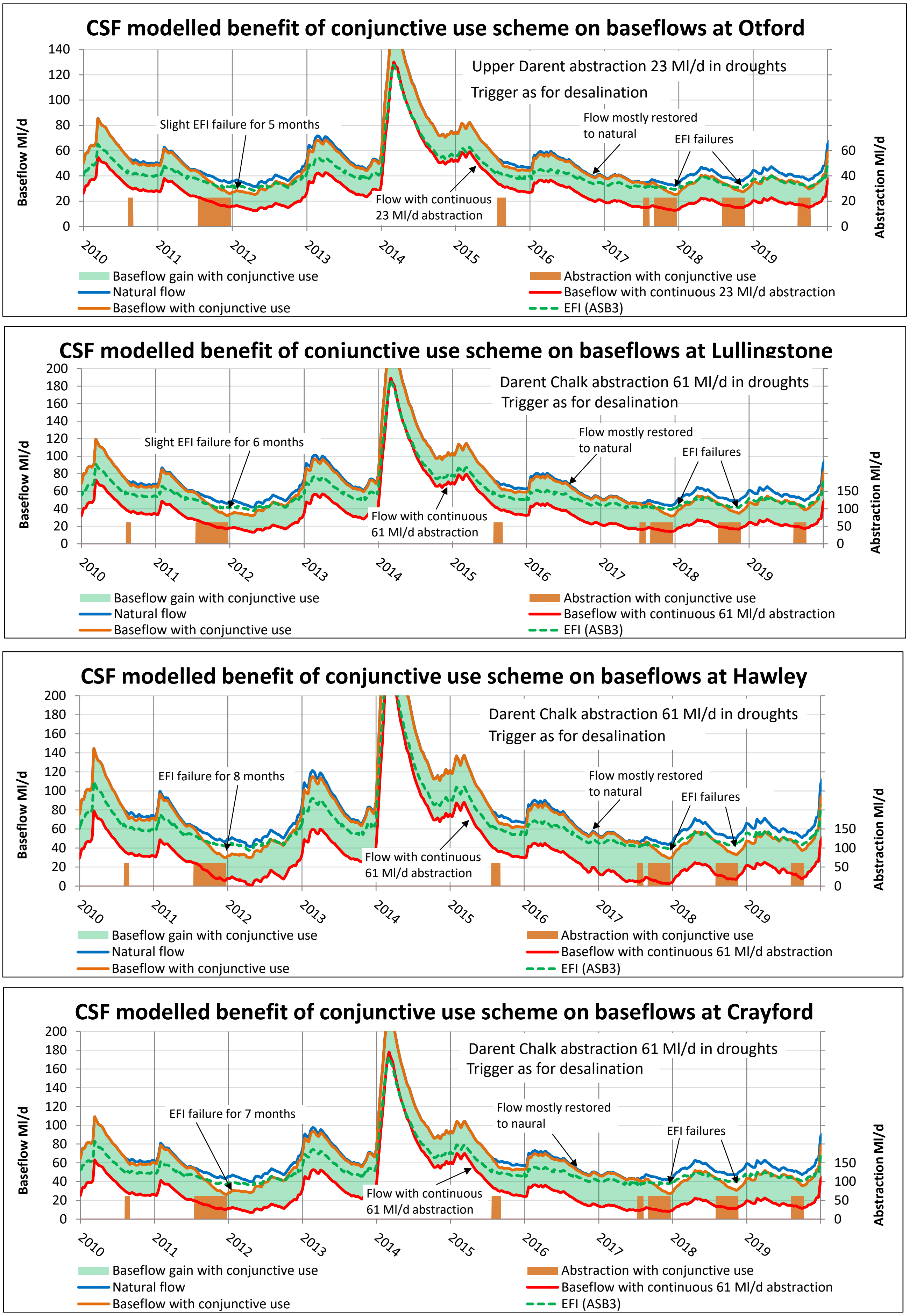


Figure 33 - Darent-Cray flow improvement from conjunctive use 2010 to 2019

The modelling shows that use of 84 Ml/d of Darent-Cray sources only during droughts would restore flows to close to natural at most times in most years at all locations in the upper and middle Rivers Darent and Cray.

During dry years, river flows would reduce steadily for the duration of use of the drought sources, mostly staying above the EFI flow, but falling a bit below EFIs for several months in severe droughts. However, even when flows are below the EFIs after severe droughts, they would still be only up to 30% below natural (compared with the EFI allowance of 10%) and much higher than they would have been in those years with the recent actual amount of continuous abstraction. Even at their lowest at the peaks of droughts in 2011, 2017 and 2018, the river flows would have been well above the 50% of natural that has previously been suggested as acceptable targets by water companies and the Environment Agency.

After the sources are switched off at the end of droughts, flows would climb slowly, typically getting back to natural flows after about 18 months.

In the event of a succession of dry years, river flows would remain below natural for several years, but still mostly staying above EFI flows. This can be seen in the succession of dry years 2017, 2018 and 2019. A similar pattern of small flow reductions can be seen in the modelling of comparable successions of dry years in 1989-91 and 1995-97.

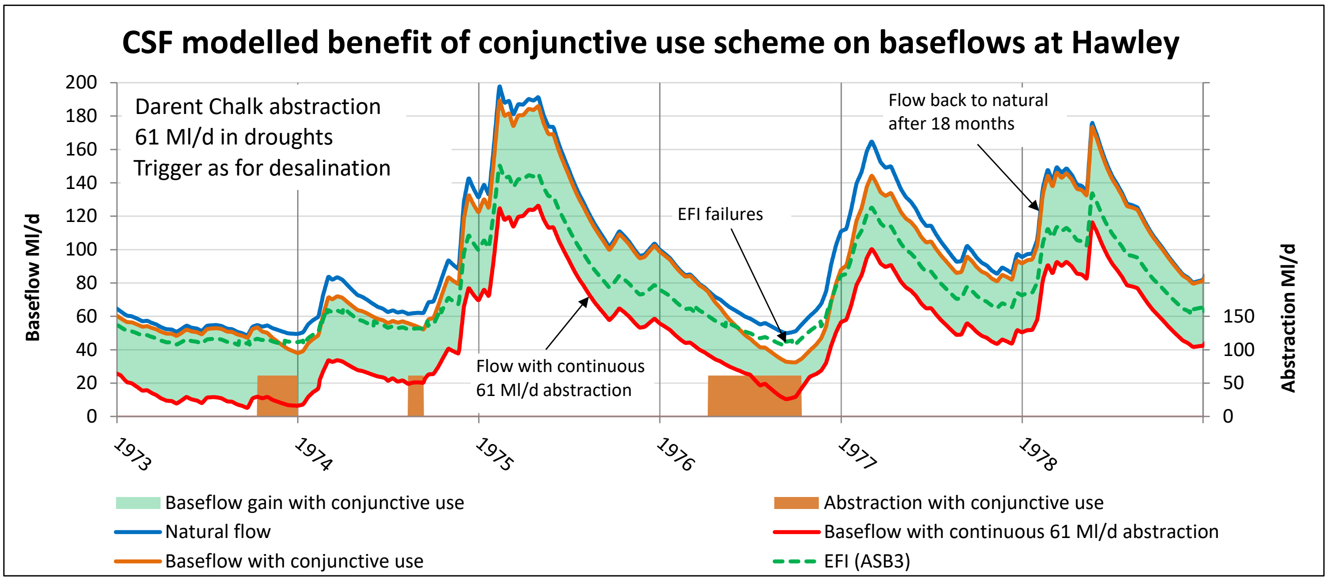
Figure 33 shows that in normal and moderate drought years, the modelled river flows with the proposed London-Darent conjunctive use scheme would be a huge improvement on the flows with continuous use of the 84 Ml/d of the planned drought sources. At most times in most years flows would be fully re-naturalised or just slightly below. In the drought years, summer flows would still be substantial and well above the 50% reduction target that has been previously suggested as an acceptable minimum. The improvements in river flow would seem likely to allow a dramatic improvement in river ecology, back to the natural ecology of a “classic” chalk stream.

The flow improvements in the severe drought year of 1976 are discussed in Section 5.2.3

5.2.3 Effectiveness of the proposed conjunctive use scheme in the 1976 drought

In the 50-year period for which CSF modelling is available, 1970 to 2019, the most severe drought was 1976, from the perspective of impact on London’s supplies and the duration of use of the Darent-Cray drought sources.

The effectiveness of the Darent-London conjunctive use scheme on river flows at Hawley in the 1976 drought is shown below:



Notes: 1. The 84 Ml/d of Darent-Cray drought sources include 23 Ml/d from Greensand sources in the upper Darent in addition to the 61 Ml/d of Chalk sources shown in this plot.

2. The river dried at Hawley in 1973 and 1976, because the actual abstraction was 106 Ml/d compared with the recent actual abstraction of 84 Ml/d modelled in this plot.

Figure 34 - Hawley flow improvements from conjunctive use during 1976 drought

The drought in spring/summer 1976 followed a very dry winter in which there was little aquifer recharge and continuing fall in river flows, both in the Rivers Darent-Cray and the River Thames. Therefore, the London reservoirs were quickly drawn down in spring 1976 and the modelling shows that use of the 84 Ml/d of Darent-Cray drought sources would have started on 7th April and ended on 12th October, a duration of over 8 months. This would have been the longest period of continuous use of the drought sources over the 55-year modelled period, 1970 to 2024.

The flows at Hawley would have been below the EFI from 8th June to 13th December 1976, just over 6 months. The lowest Hawley flow of 32 Ml/d on 30th September would have been 63% of the natural flow, which is considerably higher than the 50% reduction that has been previously suggested as acceptable by the water companies and Environment Agency.

The Hawley gauging records show that the river was dry from 27th June to 30th September 1976, although the actual abstraction from the proposed Darent-Cray drought sources was 106 Ml/d in 1976, compared with the 84 Ml/d recent actual abstraction assumed in the modelling.

After the use of the Darent-Cray drought sources ceased on 12th October 1976, groundwater levels and river baseflows would start to recover. The autumn-winter of 1976-77 was quite wet, so GWLs and flows would recover quickly, but it would still take about 18 months until summer 1978 before GWLs and baseflows would fully recover to natural levels.

5.2.4 Baseflow duration benefits from Darent-London conjunctive use

The baseflow gains on a flow duration basis from use of most Darent sources only in droughts are shown on Figure 35:

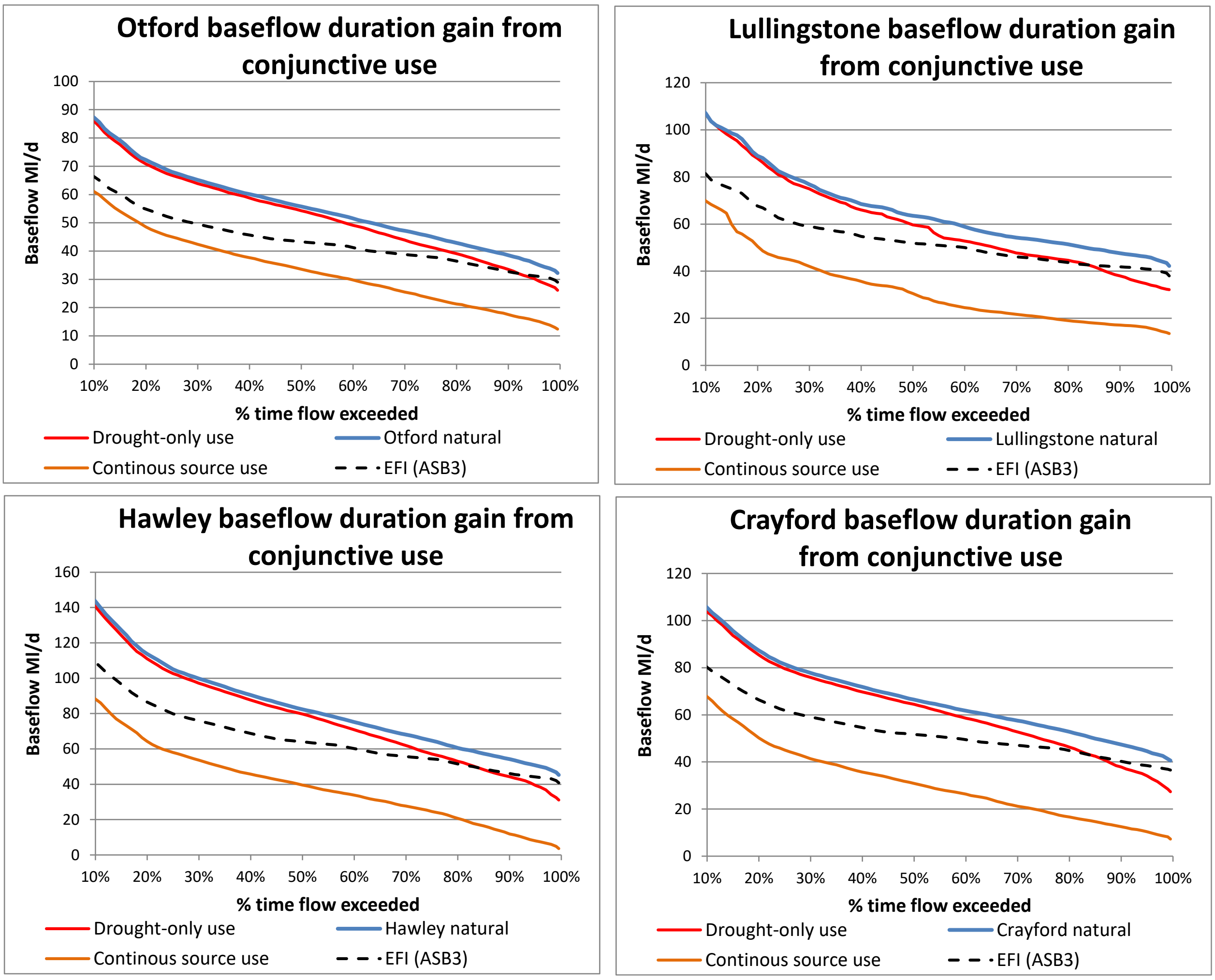


Figure 35 - Flow benefits from conjunctive use on a flow-duration basis

The pattern of flow gains at all sites is similar – flow recovery to above the EFI and close to natural for 90% of the time and falling below the EFI at flows below Q90. However, at flows below Q90, there is still a large flow increase over flows that occur at present with continuous use of the sources.

5.2.5 Improvements to flows in the lower Rivers Darent and Cray

The initial proposal for a Darent-Cray conjunctive use scheme would be to allow continued use of the lower Darent and Cray sources, including the Bean wellfield. The recent actual abstractions (2022-24) from these sources total about 77 Ml/d, including the Bean wellfield sources. Their locations are shown on Figure 17 in Section 3.2 of this report.

As explained in Section 3.2, water balance analysis shows that these large lower river sources probably have little effect on the seasonal fluctuations of regional groundwater levels in the chalk aquifer that are the main driver of flows in the middle and upper Rivers Darent and Cray. However, some of the lower river sources are close to the rivers – the Darenth, Wilmington and Dartford sources (recent total 33 Ml/d) near the River Darent, and the Wansunt and Crayford sources (total 23 Ml/d) near the River Cray. Therefore, they are likely to be drawing some water directly from river flows and could be causing flow losses through river bed leakage downstream of the Hawley and Crayford gauging stations.

The CSF modelling shows that the use of the middle and upper river sources only in droughts would lead to large increase in flows in the lower rivers at the gauging station sites at Hawley and Crayford – see the hydrographs on Figure 33 and the flow duration plots on Figure 35. Provided that these flows do not get abstracted directly by the lower river sources or leak through the river bed, the increased flows at Hawley and Crayford would seem likely to provide adequate flow regimes for the lower rivers, bearing in mind that much of the lower river valley is heavily urbanised and modified by weirs and river channel revetments.

For this report, no information has been available on spot flow gauging in the lower rivers or the results of pump shut-off tests that would show the influence the lower river sources on local groundwater levels and river flow losses. It is not known whether the influence of the lower river abstractions have been separately simulated by the LBM model or what effect they are found to have on GWLs and river flows further up the valleys. These are all matters that need more detailed consideration in further investigation of the Darent-London conjunctive use scheme.

If the lower river sources are found to be having unacceptable effects on river flows and GWLs, especially on flows further up the valleys, they could be included in the conjunctive use scheme and used only in droughts. This is considered in a sensitivity test in Section 5.4.

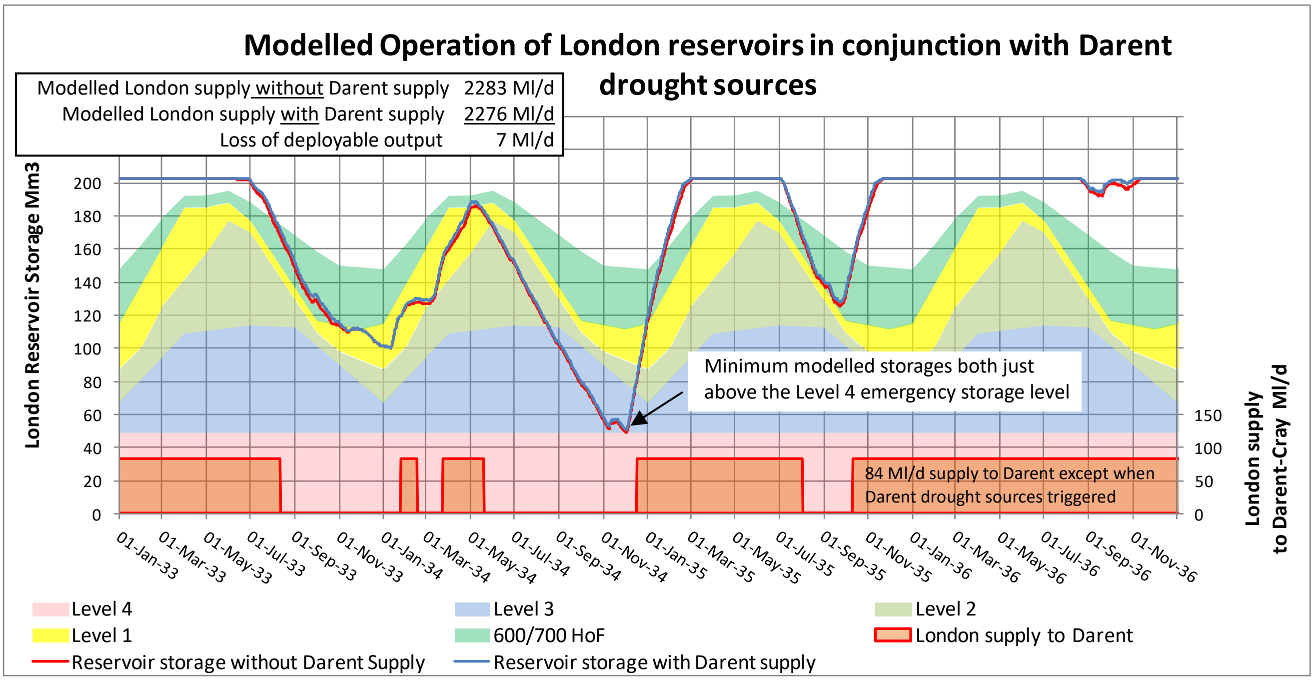
5.3 Impact of Darent-London conjunctive use on London supplies

The proposed Darent-London conjunctive use scheme would affect the London supply system in several ways:

- Firstly, by reducing the London system deployable output – the output that can be sustained in critical droughts.
- Secondly, by changing the frequency of invoking various demand management measures (non-essential use bans, etc) – the frequency of use of these measures must comply with Thames Water's levels of service as set by Ofwat and shown on Table 9.
- Thirdly, by increasing the amount of water pumped from the Rivers Thames and Lee to refill the London reservoirs and the frequency with which river flows are reduced to the hands-off flows in the River Thames at Teddington – see the Lower Thames Control Diagram on Figure 27.

The effect of the proposed conjunctive use scheme on the deployable output of London's supplies has been assessed by modelling the operation of the scheme in the historic drought of 1933-34. This is an 18-month drought that would be the most severe for London's supplies in the past 100 years. The 1933-34 drought is also probably the most severe for flows in the Rivers Darent and Cray because the drought of summer 1934 was preceded by a moderately severe drought in summer 1933 and a very dry winter in 1933-34.

The modelled Darent-Cray drought sources and replacement supplies from London are a total 84 Ml/d. The use of the drought sources is assumed to be triggered by the same operating rule that triggers use of Thames Water's London desalination scheme. The simulated use of London reservoir storage and replacement supply to the Darent in the 1933-34 drought are shown below:



Note: Modelling assumes that the London desalination plant can supply 75 Ml/d, as per Thames Water's WRMP.

Figure 36 - Conjunctive use of London supplies with Darent drought sources in 1933-34

The London supply system without the Darent supply can maintain an output of 2283 Ml/d in the 1933-34 drought, without storage falling into the Level 4 emergency storage. This is equivalent to a deployable output meeting a 1 in 100 year drought resilience standard. If the London supplies are also required to supply 84 Ml/d to the Darent, except in droughts, the supply that can be maintained falls to 2276 Ml/d – a 7 Ml/d loss of deployable output.

This shows that the large improvement in River Darent and Cray flows described in Section 5.2.5, with flows restored to close to natural levels at most times, can be achieved with a loss in London deployable output of only 7 Ml/d.

The effect of this initially proposed version of the conjunctive use scheme on Thames Water's service level compliance is shown below:

	Years in Level		
	1	2	3
With Darent supply	16	6	4
Base case 2283 Ml/d	**15**	**6**	**4**
Target LoS	**20**	**10**	**5**

Note: 1921/22 is counted a single drought

	Time between service level changes			
	With Darent supplies		2283 Ml/d Base case	
	Days between SLs		Days between SLs	
	SL1 to SL2	SL2 to SL3	SL1 to SL2	SL2 to SL3
1921	20	81	20	78
1934	18	79	18	79
1944	24	79	24	79
1949	51	#N/A	52	#N/A
1976	35	89	34	87

Table 10 - Effect of conjunctive use scheme on TW service levels and Teddington flows

The upper part of the table shows the modelled number of occurrences in the 104 year period 1920 to 2024 that the various demand restrictions are invoked. The target LoS numbers are the number of years allowed under Thames Water's Levels of Service agreed by Ofwat: 1 in 5 years for Level 1, 1 in 10 years for Level 2 and 1 in 20 years for Level 3.

The modelling shows that with the conjunctive use scheme the frequency of invoking Service Level 1, the use of intensive media campaign to reduce supplies, increases from 15 to 16 occurrences in the 104 years of modelling (the additional year is 2017). This is still well within the target of 20 occurrences set by the levels of service. There is no change to the frequency of use of the Levels 2 and 3 demand restrictions, so there would still be compliance with Thames Water's levels of service.

The lower part of Table 10 shows the modelled elapsed times between triggering of demand restrictions in various droughts. These times are important for Thames Water because they need time to warn consumers and get regulatory approval for each stage of demand restrictions. Thames Water's minimum requirements for these time intervals are not known, but there are only small reductions caused by the conjunctive use scheme.

The Darent-London conjunctive use scheme would, in effect, take water from the Rivers Thames and Lee instead of from the Rivers Darent and Cray. Therefore, flows in the River Thames at Teddington weir would be reduced. The modelled effect of the conjunctive use scheme on flows in the River Thames at Teddington is shown below on a flow-duration basis:

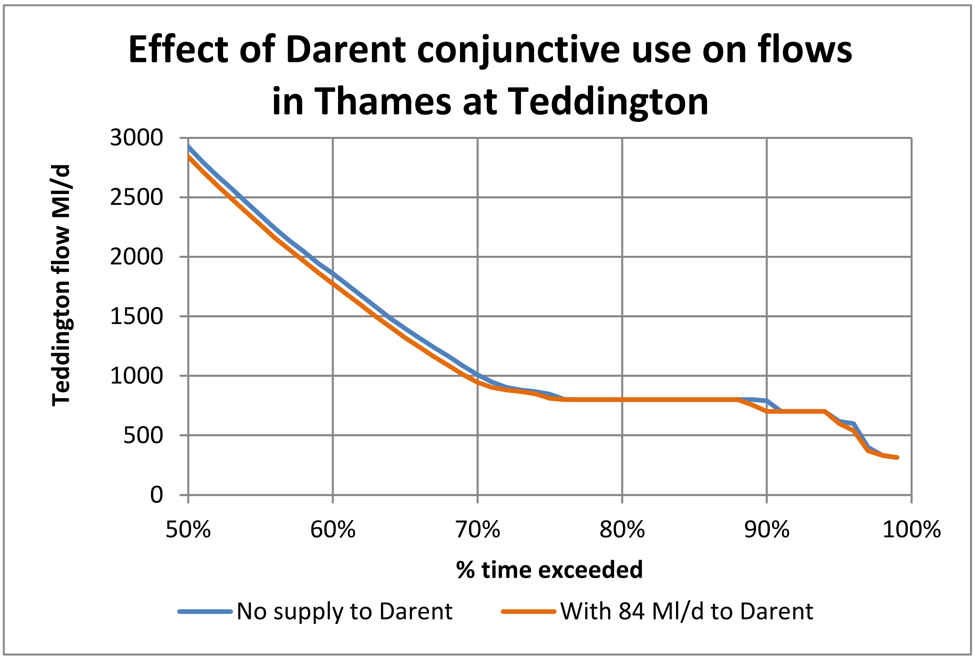


Figure 37 - Reduction in flows at Teddington weir due to conjunctive use scheme

This shows that when flows at Teddington weir are above about 1000 Ml/d, the conjunctive use scheme would reduce them by about 84 Ml/d, a reduction of about 8%. When flows are lower, they are protected by the various Teddington hands-off flows. Although, the reduction in the flows at Teddington weir should not be trivialised, bearing in mind they are already greatly reduced by London supplies, the amount of further reduction for supplying the Darent would not appear to be a significant concern.

5.4 Sensitivity tests on conjunctive use design assumptions

The conjunctive use scheme described in Section 5.3 assumes that all the existing upper and middle Darent and Cray sources are only used in droughts, with a total of 84 Ml/d of replacement supplies from London. The use of the Darent-Cray sources in droughts is assumed to be triggered by the same operating rules as currently used by Thames Water for switching on and off the London desalination plant.

The sensitivity of the effectiveness of the conjunctive use scheme to these assumptions has been tested for these alternative assumptions:

1. Assume all of the 158 Ml/d of sources in the WRSE High scenario reductions would be in the conjunctive use scheme, i.e. unused at most times but could still be used in droughts, triggered by the desalination operating rules. The WRSE High scenario reductions include 75 Ml/d of reductions in the lower Darent and Cray sources, as well as 83 Ml/d of upper and middle Darent and Cray included the initial conjunctive use proposal described in sections 5.2 and 5.3. The amount of replacement supply from London would increase from 84 Ml/d to 158 Ml/d.

2. Assume 20 Ml/d of existing upper and Middle Darent-Cray sources are still used continuously (10 Ml/d in the upper Darent Greensand and 10 Ml/d in the Darent-Cray chalk). Therefore, the amount of sources used only in droughts and the replacement supply from London would be reduced from 84 Ml/d to 64 Ml/d.

3. Assume that the initially proposed 84 Ml/d of drought-only sources would be triggered by only the TTF level 1 control line with a 5-day delay, i.e. not dependent on River Thames flows at Kingston and the delay time reduced from 10 days to 5 days.

5.4.1 Inclusion of all WRSE High scenario sources for conjunctive use

It might be necessary to include the lower Darent and Cray sources in the conjunctive use scheme (recent total 60 Ml/d and 75 Ml/d in the WRSE High scenario), if further investigations show that these sources are having a substantial impact on river flows. The CSF model is not able to simulate the river flow impacts of these sources which are assumed to arise from the effects of the cones of depression of boreholes close to the river, drawing water directly from the river and increasing river bed losses by lowering GWLs in the valley bottom.

Furthermore, the amount of abstraction could be more than the recent actual 60 Ml/d of abstractions, if demand increase due to population growth exceeds the planned demand reductions from planned leakage control and demand management measures like smart metering.

As a worst case, all of the WRSE planned 75 Ml/d of High scenario reductions for the lower rivers shown on Table 6 in Section 4.1 could be included in the conjunctive use scheme, giving a total of 158 Ml/d. The effect on London's supplies of increasing the Darent supply from London to 158 Ml/d has been simulated using the GARD model. This showed that the 158 Ml/d of supply to the Darent could be sustained (except in droughts) with a loss of only 14 Ml/d in London's deployable output. As for the 84 Ml/d conjunctive use scheme, the cessation of the supply to the Darent, triggered by the existing desalination control rule, would minimise the impact of the increased conjunctive use on the London deployable output.

However, the increase in Darent supply from 84 Ml/d to 158 Ml/d would increase the reduction of flows over Teddington weir in non-drought times. With a reduction of Teddington flows by up to 15%, this could become a significant impact.

5.4.2 Sensitivity to reducing amount of conjunctive use by 20 Ml/d

There could be reasons for retaining some of the upper/middle Darent-Cray and upper Darent sources as continuous supplies, perhaps to reduce the cost of connecting some more remote supply areas to the London supplies. A retention of a total of 20 Ml/d of sources for continuous supply has been modelled as a sensitivity test, with 10 Ml/d retained in the upper Darent Greensand and the other 10 Ml/d in the Darent Cray chalk. The amount of supply needed from London would be reduced from 84 Ml/d to 64 Ml/d.

Modelling of the London supply system shows that reduction in the amount supplied from London to the Darent from 84 Ml/d to 64 Ml/d reduces the loss of London deployable output from 7 Ml/d to 5 Ml/d.

The modelled effect on Darent-Cray river flows on a flow-duration basis is shown below:

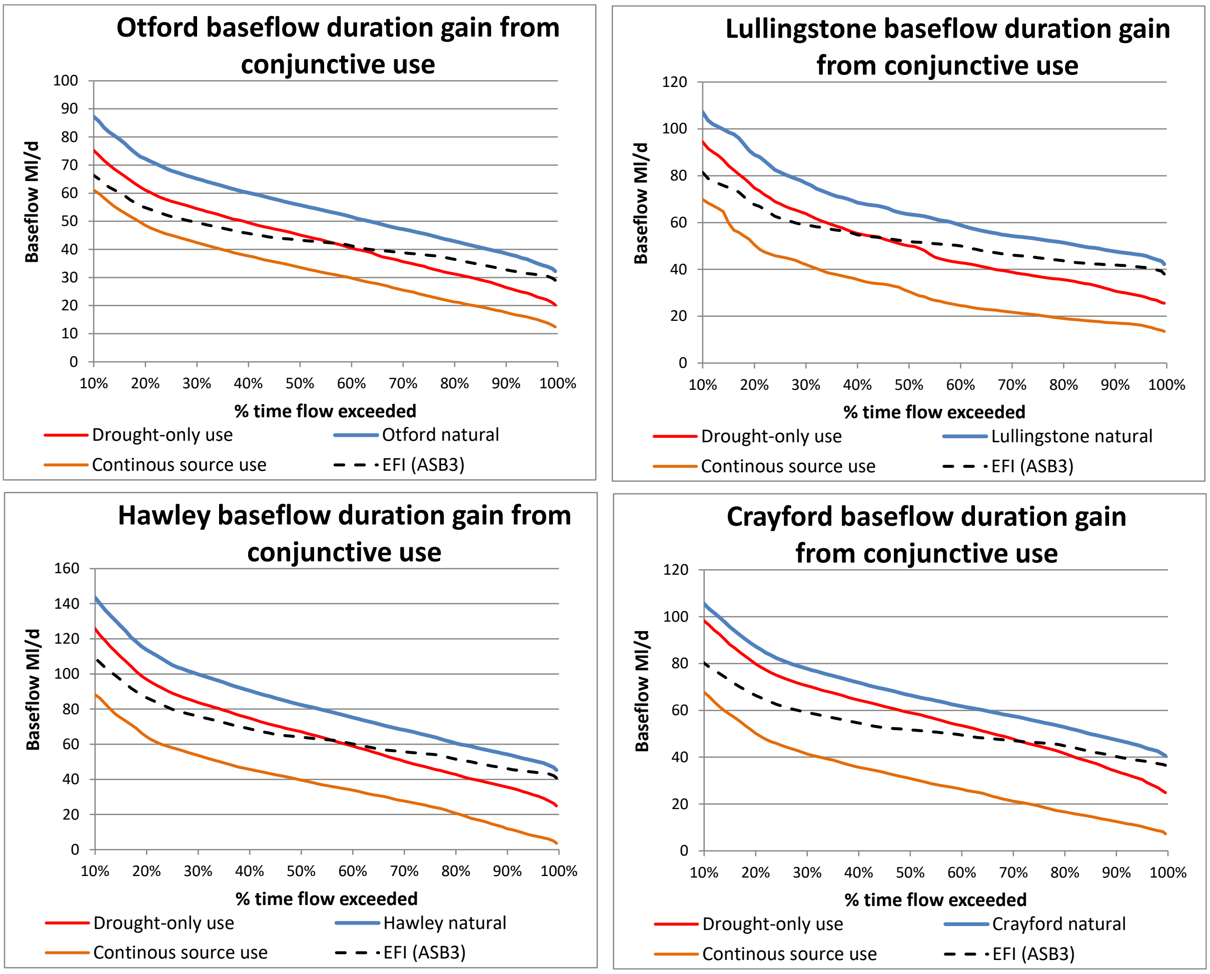


Figure 38 - Sensitivity to retaining 20 Ml/d of sources as continuous supply

If 20 Ml/d of sources are retained as continuous supply, the conversion of 64 Ml/d of sources to conjunctive use would still give a large improvement in flows. However, there would be a lot less compliance with EFIs. The lower EFI failures of the flows at Crayford is because Crayford flows are not affected by abstraction changes in the upper Darent catchment.

If compliance with EFIs is to be the main criterion for acceptability of Darent-Cray river flows, all the upper and middle Darent-Cray sources should be included in the conjunctive use scheme.

5.4.3 Sensitivity to changing the conjunctive use trigger rule

The conjunctive use scheme has been modelled assuming that the switch to using the Darent-Cray drought sources and cessation of the supply from London is triggered when London storage has been in the Level 1 zone for only 5 days and regardless of whether the flow in the Thames at Kingston is below 3000 Ml/d. This is a simpler operating rule than Thames Water's desalination trigger rule and has the effect of switching off the supply from London before the desalination scheme is turned on and before the start of the Level1 media campaign to save water. Typically, the switch off is about 6 days earlier than with the desalination rule and the loss of London deployable is reduced from 7 Ml/d to 2 Ml/d. The improvements to river flows are shown below on a flow-duration basis:

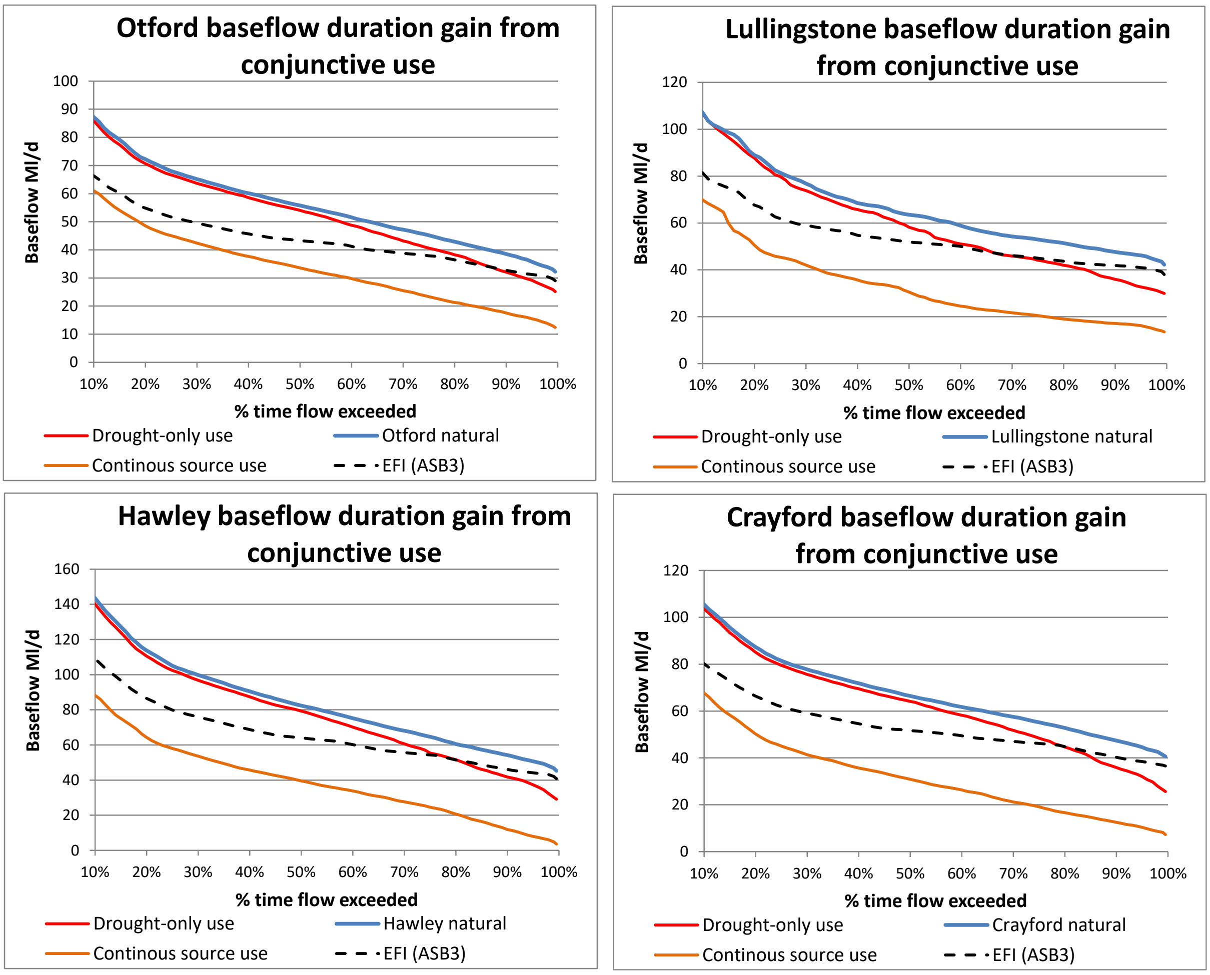


Figure 39 - Conjunctive use flow benefits with simplified trigger based on London storage

Comparing the plots above with Figure 35 (flow benefits with desalination trigger), the flow benefits are similar but with a slightly increased frequency of EFI failures at low flows. Overall, it seems that there is scope for simplifying the trigger rule.

5.5 Conjunctive use in droughts more severe than 1 in 100 years

The London supply system is required to be resilient to droughts up to a 1:500 year severity.

Thames Water assess the deployable output in droughts of 1:500 severity by modelling the operation of the London supply system in 19,200 years of river flows derived from stochastically generated weather data, including various scenarios of climate change. A version of the GARD model of the London supply system has been set up to use stochastically generated river flows, but Thames Water's latest version of these data is not available. Therefore, the effect of the Darent-London conjunctive use proposal on London's deployable output has not yet been modelled for a 1:500 year drought, or for the influence of climate change. In the absence of 1:500 year drought effective rain data, neither has the effect on Darent-Cray flows yet been modelled.

Although, no modelled data are currently available for assessing the performance of Darent-London conjunctive use in a 1:500 year drought, with or without climate change, some general comments can be made. Firstly, the London deployable output will be largely protected because the trigger rule for use of the Darent drought sources will obviate the need to supply the Darent from London during the summer drought. The conjunctive use scheme can be expected still to have a relatively small impact on London deployable output even during a 1:500 year drought and weather patterns affected by climate change.

Secondly, even though the Darent-Cray drought sources will be used for longer during a 1:500 year drought, the groundwater levels will be a lot higher at the start of the drought than they would be if the sources are used continuously, as they are at present. Therefore, the rivers flows will still be much improved compared with what they would be if the sources were being used continuously in a 1:500 year drought.

These general conclusions on the performance of the conjunctive use scheme in a 1:500 year drought need to be tested by modelling using river flow and effective rain data generated using the stochastic weather data, including some climate change scenarios.

5.6 Conclusions on effectiveness of the conjunctive use scheme

The conclusions from the initial assessment of the potential for a Darent-London conjunctive use scheme are:

1. Use of all the existing upper and middle Darent-Cray sources only in droughts, totalling 84 Ml/d, with replacement supplies from London, would restore river flows to close to the fully natural flow regime, with minimal impact on London's supplies.

2. The lower Darent supplies totalling 76 Ml/d, including the Bean wellfield, can probably still be used on a continuous basis, but this needs further investigation.

3. The loss of London deployable output would be only around 10 Ml/d or less, because deployable output would be protected by the early triggering of use of the Darent sources in droughts. There would be no effect on Thames Water's service level compliance.

4. The use of the Darent sources in droughts would cause a short term fall in groundwater levels and river flows to below natural, with some EFI failures. However, river flows in droughts would still be greatly increased from current levels and well above the 50% of natural flow target that has previously been proposed as acceptable by the Environment Agency and water companies.
5. After droughts, it would take about 18 months for groundwater levels and river flows to recover to natural levels.

In view of these conclusions, the conjunctive use scheme should be fully investigated as part of the planned WINEP investigations in AMP8 (2025 to 2030), with an aim for early implementation well ahead of the abstraction reductions in current water company plans.

It should be recognised that the extensive pipe network enhancements that would be needed to connect London's supplies to areas currently supplied by the proposed Darent-Cray drought sources would be same network enhancements that would be needed for the large scale reductions in abstraction that are in the water companies' latest Water Resource Management Plans, mostly for implementation after 2050. With the conjunctive use scheme, these network enhancements would need to be brought forward by about 15 years.

5.7 Further investigation and implementation of conjunctive use

5.7.1 Thames Water's currently planned AMP8 investigation

Thames Water are undertaking more investigation of alleviation of low flows in the River Darent as part of their AMP8 (2025-30) Water Industry National Environment Programme (WINEP). Some details of the planned investigation, as provided by Thames Water, are shown in Appendix B and can be summarised as:

1. Review of impacts of existing abstractions, especially at Eynsford, Horton Kirby and Lullingstone. Review ecological and hydrological monitoring data, and plan additional monitoring if needed.
2. Review evidence of benefits achieved by previous abstraction reductions.
3. In view of past lack of evidence of benefits of abstraction reductions, review need for further reductions and whether 2035 is the optimum timing for reducing abstractions at Eynsford, Horton Kirby and Lullingstone.
4. Assess bespoke flow objectives as an alternative to EFIs, based on the channel size and morphology downstream of Eynsford, Horton Kirby and Lullingstone.
5. Review whether the generic application of the EFI is the most appropriate basis for setting flow targets or whether alternative flow targets would be more appropriate.

6. Review existing groundwater models and determine whether any further model development or refinement is required.
7. The groundwater modelling would then be used to determine whether any abstraction change is needed to meet ecological objectives for the River Darent.
8. Following the investigation, if an adverse impact on flow and ecology is confirmed, identify options to mitigate and achieve good status under the WFD.
9. WINEP Report write-up by December 2026.

These investigations appear to be focused on Thames Water's own abstractions and the state of the River Darent downstream of Lullingstone. There is no mention of the impacts of other water companies' abstractions, especially in the upper Darent. There is no mention of alleviation of low flows in the River Cray.

The overall tone of the planned WINEP investigation appears to be scepticism over whether past abstraction reductions have provided any benefits and whether any more abstraction reduction is needed. This is disappointing, but understandable in view of the enormous cost of the replacement sources if the currently planned 150 Ml/d of abstraction reductions take place – of the order of several billion pounds. Also, the continuing poor state of the rivers no doubt contributes to the scepticism over benefits of past abstraction reductions.

This report presents modelling evidence of large impacts of abstraction, with similar findings shown by two different types of model (see Section 3.1). It also shows that the amount of past abstractions has been quite small (see Figure 21), so the correspondingly small increases in river flow will be hard to separate from flow changes due to climate variation. However, despite the relatively small reductions in abstraction, this report shows measured evidence of river flow improvement, both in the upper Darent (see Section 3.3.1) and in the chalk sections of the Rivers Darent and Cray (see Section 3.3.2).

Therefore, it is proposed that the scope of the currently planned WINEP investigation, due for completion by December 2026, should include a detailed review of this report's evidence of abstraction impacts and the river flow benefits of past abstraction reductions. It should also include and initial assessment of the feasibility of the proposed conjunctive use scheme.

If the initial investigation in 2026 concludes that the Darent-London conjunctive use scheme is worth pursuing, it is proposed that the subsequent WINEP investigation in AMP8 should include a full assessment of the conjunctive use scheme, as proposed in the following Section 5.7.2.

5.7.2 Proposed WINEP investigation of Darent-London conjunctive use

It is proposed that a full assessment of the Darent-Cray conjunctive use scheme should include:

1. Use of the existing, but improved, groundwater model(s) to simulate the timing and magnitude of groundwater level and flow recovery arising from the cessation of use of the proposed Darent-Cray drought sources and their intermittent short use in droughts. The pattern of use of the Darent-Cray drought sources will be set by running of Thames Water's Aquator model of the London supply system, simulating different options for the amount of Darent-Cray sources to be used as drought sources and the operating rules that trigger the use of the drought sources. This exercise would be a repeat of the Darent-Cray groundwater modelling and London supply system modelling described in Sections 5.2 and 5,3 of this report, but using the water companies' own models. It would require an effective groundwater model of the upper Darent Greensand sources and their effect on river flows.

2. Use of the models to simulate the effectiveness of the Darent-Cray conjunctive use scheme in a selection of droughts of between 1:100 and 1:500 year return period, with also some consideration of climate change scenarios. This would test the conclusions about the effectiveness of the conjunctive use scheme in extreme droughts that are tentatively put forward in Section 5.5 of this report. If the required stochastically generated river flow and effective rain data can be supplied to DRiPS, the extreme drought and climate change scenarios can also be modelled using the models described in this report.

3. Use of the groundwater model to examine the impact of the lower Darent and Cray groundwater sources on river flows, with due consideration also of data from spot gauging of lower river flows and the results of pump-shut-off tests for the lower river sources. This will provide information to decide whether or not the lower river groundwater sources should be used as drought-only sources.

4. Investigation of the pipe network enhancements needed to transfer water from the London supply system to the areas currently supplied by the proposed Darent-Cray drought sources. Noting the heavily urbanised terrain that the pipe network will need to cross, consideration should be given to alternative routes and the need for tunnelling of some sections.

5. Investigation of enhancements needed for the existing London water treatment and distribution system that to supply up to 150 Ml/d of water to the Darent-Cray supply areas that are currently served by Darent-Cray sources intended for drought-only supplies. This should include possible enhancements of the existing spur connecting Honor Oak to the London ring main.

6. Consideration of water quality and operational issues arising from the intermittent switch between London supplies and Darent-Cray supplies.

7. Consideration of potential flooding arising from the reductions in Darent-Cray abstractions and the consequent increases in river flows and groundwater levels. This should include identification of ways of mitigating any increased flood risk, for example by making more use of the groundwater sources in wet winters.

8. Consideration of options for phasing the implementation of the conjunctive use scheme. This could include:

    - An initial phase using existing network capacity connecting Darent-Cray supply areas to London supplies. If sufficient capacity exists for a significantly sized scheme, this could provide a relatively low cost pilot scheme to test the conjunctive use concept.

    - Conversion of the upper Darent Greensand sources to drought-only sources, thereby benefiting the whole River Darent (but not the River Cray).

    - Conversion of the large Cray sources at Orpington and Bexley to drought-only sources – these sources are closer to the London supply system so require less enhancement of the connecting pipe network.

    - Later conversion of the lower Darent and Cray sources to drought only sources, but only if conjunctive use of sources further up the valleys do not provide the required river flow improvements in the lower rivers.

9. Consideration of the inter-company operating and trading agreements that would be needed if all four of the water companies that use Darent-Cray sources are involved in the conjunctive use scheme.

It is proposed that the investigation of the conjunctive use scheme should be completed in time for phased implementation to be included in water company AMP9 business plans (2030-35).

5.7.3 Implementation of the Darent-Cray conjunctive use scheme

The Darent-Cray conjunctive use scheme has the potential for relatively rapid solution to the country's largest and most long-running case of over-abstraction, addressing a need that has been recognised since at least the 1976 drought when the River Darent dried for several months. The scheme could be implemented without needing to wait for completion of any of the major schemes under Ofwat's programme of Strategic Resource Options, including the planned White Horse Reservoir near Abingdon.

It could be argued the Darent-Cray conjunctive use scheme is a Strategic Resource Option in its own right, because it would obviate the need for about 150 Ml/d of strategic resource options elsewhere, with a potential capital cost saving of several billion pounds. The up to 150 Ml/d of network enhancements needed to connect existing Darent-Cray supply areas to the London supplies would be a major infrastructure project at a comparable scale to some of the projects in Ofwat's strategic resource option programme, for example the Thames to Southern transfer (120 Ml/d) and the Grand Union Canal transfer (130 Ml/d).

The need for a 150 Ml/d capacity Darent-London network connection is implicit in the plans for other Strategic Resource Options in the South East whose need has been settled by Government approval of Thames Water's 2024 WRMP. The approved WRMP includes 130 Ml/d of water supply deficit caused by the planned abandonment of 130 Ml/d of Thames Water's Darent-Cray supplies by 2050 (see Section 4.1 and Table 6 of this report).

Therefore, consideration should be given to a rapid implementation programme for the Darent-Cray conjunctive use scheme, bringing it in line with programmes for other major water resource developments. At its simplest, the programme could be:

1. An initial review of the findings of this report, including the independent modelling of the effectiveness of the conjunctive use scheme as described in paragraphs numbered 1 to 3 in Section 5.7.1 of this report. This review should be completed and reported upon by December 2026, in parallel with the completion of Thames Water's other Darent WINEP investigations in 2026.

2. Assuming this initial review confirms the conjunctive use scheme's potential, detailed investigation of the scheme to be completed by 2029, to an equivalent level of development to 'Gate 3' in the current Ofwat strategic resource option programme under RAPID's supervision.

3. Inclusion of the conjunctive use scheme in water company 'preferred plans' in their 2029 WRMPs and as part of the investment programmes in AMP9 business plans.

4. If feasible, around 2030, implement a pilot scheme making full use of existing network connections between the London supply system and Darent-Cray supply areas.

5. Phased implementation of at least half the potential capacity by 2035 and the full scheme by 2040.

If feasible, the development of the Darent-London conjunctive use scheme would be a triumph for the water industry, with repair of long-standing and notorious environmental damage, combined with several billion pounds of capital cost saving through avoidance of need for major infrastructure elsewhere.

5.8 The planned ASR scheme

The planned middle Darent aquifer storage and recovery (ASR) scheme is understood have a deployable output of in the region of 5-10 Ml/d. This could replace some of the existing Darent chalk abstraction with a corresponding benefit to the river. Although not at a scale to bring a major improvement to river flows, it would seem a worthwhile scheme. If the planned Darent-Cray conjunctive use scheme goes ahead, it would still be useful in reducing the amount of water to be supplied from London

5.9 Use of Sevenoaks STW effluent

It is understood that Thames Water are considering a new sewage works at Sevenoaks with a 7 Ml/d capacity. At present wastewater from Sevenoaks is transferred by a sewer to Long Reach sewage works near the Thames estuary, so the water is lost to the Darent catchment. The 7 Ml/d from the new sewage works could increase flows in the River Darent by that amount, provided it was not lost through river bed leakage.

Although 7 Ml/d would be useful flow enhancement, it would not make a major difference to flows, particularly if a lot of flow was lost to leakage in droughts, when flow enhancement is most needed. It would also bring a risk of pollution. The scheme would not provide any complementary benefit to the proposed conjunctive use scheme.

6. Next steps in the campaign for River Darent improvements

6.1 The wider context of the Darent-Cray low flow problem

This report reviews previous work on low flows in the rivers Darent and Cray, challenges previous findings and puts forward a radical new proposal for re-naturalising the river flows. The local water companies and Environment Agency have been very helpful in providing relevant data and reports, but so far there has been no engagement with them over the report findings or the proposed Darent-London conjunctive use scheme.

The scale of the Darent over-abstraction problem and the solution proposed in Government-approved water company plans has wide implications for plans for new water supplies in the South East and, possibly, other parts of the country. In particular, the plans for Thames Water's proposed new £6.6 billion reservoir near Abingdon, recently re-named 'the White Horse Reservoir', are at an advanced stage and an application for a Development Consent Order is to be submitted later in 2026.

The need for the White Horse Reservoir, with its planned deployable output of 271 Ml/d, has been justified in a large part by the planned supply of about 130 Ml/d from London to the existing Darent-Cray supply area, replacing the reduced abstraction of about 130 Ml/d from Thames Water's existing Darent-Cray sources. Therefore, this report will be of considerable interest to Ofwat, the Environment Agency nationally and Water Resources in the South East, the water company consortium with responsibility for the regional water resource planning that will feed into the next water company WRMPs due to be finalised by 2029.

6.2 Proposed next steps

In this context, it is recommended that DRiPS, South East Rivers Trust and Darent Valley Trout Fishers should engage with the water companies and regulators confidentially, with a limited circulation of this report. The next steps could be:

1. Issue of this report to the local Environment Agency, Thames Water and the other interested water companies (including WRSE), with a request for an in-person meeting, allowing sufficient time for a full presentation and proper discussion of the report's findings.

2. Copying the report and covering letters to Ofwat, the Environment Agency's national water resource management team and RAPID (the regulator organisation responsible for the national programme of Strategic Resource Option development), initially for their information, but inviting feedback.

It is recommended that, until there has been discussion with the water companies and regulators, there should be limited external communication about this report.

Appendix A – Scope of this investigation

The Darent Action Plan was started more than 30 years ago to address the very poor condition of the River Darent, particularly due to the over-abstraction of water for public water supplies https://darent-drips.org.uk/wp-content/uploads/2023/07/22-River-Darent-Action-Plan-Oct-2000.pdf

Although some improvements have been achieved, the rivers are still amongst the most heavily over-abstracted chalk streams in the country and their condition is far removed from the iconic state of similar large chalk streams like the Rivers Test and Itchen. Current water company plans recognise the need for major abstraction reductions in the Darent and Cray catchments but mostly delay them until after 2050. New concerns over the costs and benefits of abstraction reductions throw doubt on whether the far-off planned reductions will ever materialise.

In this context, the Darent River Preservation Society, South East Rivers Trust and Darent Valley Fly Fishers have appointed consulting engineer John Lawson, FREng, FICE to review the impacts of water abstraction on the Rivers Darent and Cray and consider plans for rapid reinstatement of river flows to much closer to their natural condition. John is on the Catchment Based Approach (CaBA) chalk stream restoration group's expert panel for water resources and has researched and published many influential reports on abstraction impacts in chalk streams, including these in recent years:

- A%R – abstraction as a % of recharge in chalk streams https://chalkstreams.org/2022/01/23/ar-abstraction-as-a-of-recharge-in-chalk-streams/ This report confirmed that the very high level of over-abstraction in the Darent/Cray catchments.
- Chalk Streams First (CSF) – a permanent and sustainable solution to the chalk streams crisis https://chalkstreams.org/2022/01/23/ar-abstraction-as-a-of-recharge-in-chalk-streams/ The solution is based on the principle of moving abstractions as far down the river as possible, making use of the flow recovered from the abstraction reductions upstream, whilst also making best use of storage in the chalk aquifer.
- Dealing with impacts of groundwater abstraction on the chalk streams of the Colne and Lea valleys https://chalkstreams.org/flow-recovery-following-abstraction-reduction/ The report includes a new modelling approach (the CSF model) to assess the extent of flow recovery from abstraction reductions.

John will be developing a CSF model of the Darent/Cray catchment and using it for:

1. New estimates of how groundwater levels and river flows in the Rivers Darent and Cray have been affected by abstraction of groundwater for public water supplies.

2. Comparison of estimated abstraction impacts with previous impact assessments by the water companies and EA, providing a basis for challenging water company estimates, if needed.

3. Assessing the effectiveness of past abstraction reductions in the catchment, providing a basis for challenging water company and EA assessments of the effectiveness of the reductions, if needed.

4. Modelling the effectiveness of the water companies' planned abstraction reductions, as described in their latest Water Resource Management Plans.

5. Modelling the effectiveness of alternative abstraction reduction plans that could bring improvements faster and at less cost than the improvements foreseen in water company plans.

The over-riding objective of John's work will be to find cost effective solutions to over-abstraction, that can restore the rivers in the reasonably near future, avoiding the long delays and uncertainty in current water company plans. This is an ambitious objective that may turn out to be unachievable. John will be working to a phased programme with regular assessment points that will allow DRiPS, SERT and DVTF to decide whether to continue with the assignment. The first report is due around the end of 2025, subject to the availability of data that has been requested from the various water companies and the Environment Agency.

Appendix B – Scope of Thames Water's AMP8 WINEP investigation

1. Excerpt from email from Hannah Poole (TW) to John Lawson on 14th October 2025

To answer some of your previous questions, the expected scope for the AMP8 WINEP investigations is as follows -

- A combined source-pathway-receptor impact investigation is required during AMP8 for all of the Darent sources. This is a follow-up to an "Upper Darent" investigation and "Middle & Lower Darent" abstraction reduction benefits assessment that were carried out in AMP6.
- The investigations recommended re-establishing a monitoring programme to build on the catchment understanding. Since July 2024, we have been conducting monthly spot flow gauging at over 40 sites from the headwaters to the bottom of the catchment just before the tidal reach. The ecological monitoring programme includes 18 macroinvertebrate sites monitored in spring and autumn since autumn 2023. In all of those sites, MoRPh surveys have been completed. The location of the sites and frequency of monitoring have been agreed with the EA to complement their own monitoring programme, maximise the benefits of the data and avoid redundancy. Please see attached map.
- We have also installed groundwater level loggers at five observation boreholes from Sundridge down to Wilmington.
- The London Basin Model (LBM) was reviewed and used in AMP6 to try and assess the benefits for flow improvement and groundwater recovery compared to observed data. This groundwater model will be used to enable us to assess the potential benefit of abstraction reduction and to determine whether any abstraction modification is needed to meet the ecological objectives for the River Darent.
- The project will include a review of the EFI to determine whether any further information or new approaches can build on the EFI to determine whether it is the best option on which to base decisions about future actions or whether an alternative approach would be more appropriate.
- A comprehensive review of the existing hydrometric and hydrogeological data will be undertaken to determine whether any modification to the ongoing programme of monitoring and data collection is needed to help with assessing abstraction impacts at all of the Darent sources.
- Following the investigation, if an adverse impact on flow and ecology is confirmed, we will identify options to mitigate or remove the impact of abstraction to contribute to the waterbody achieving good status under the WFD, following Options Development guidance.

2. Excerpt from document attached to email from Steve Tuck to john Lawson on 12th March 2026

Detailed scope of works from Actions Specification form

Further reductions at Eynsford, Horton Kirby and Lullingstone are planned for 2035 under our Environmental Destination programme set out in our WRMP, with each source reduced to zero under the high scenario. We have also included further reductions in licensed abstraction under the high scenario by 2050, closured planned at sources at Sundridge, Westerham, Darenth, Wilmington, Dartford, and Green St Green; Bean/Lane End will be reduced to 6.38Ml/d.

However, despite the requirement in the environmental destination scenario for further reduction to meet the catchment objectives based on the EFI there is little evidence that previous reductions have resulted in the anticipated benefits in terms of increased flows in the River Darent. Thames Water have established a monitoring programme in response to these recommendations.

In view of the above, further investigation and assessment is required to confirm whether these planned reductions are required and to determine whether 2035 is the optimum timing.

The previous and ongoing programme of Monitoring and data collection will be reviewed to determine whether the data available and monitoring locations are appropriate and to identify gaps that may require further data collection. This will be carried out with specific reference to Eynsford, Horton Kirby and Lullingstone.

The investigation will include assessment of alternative, bespoke flow objectives based on the channel dimensions and morphology of the River Darent downstream of Eynsford, Horton Kirby and Lullingstone. This will enable confirmation of whether the generic application of the EFI is the most appropriate basis for setting flow targets or alternative flow targets would be more appropriate,

- A combined source-pathway-receptor impact investigation is required during AMP8 for the Eynsford, Horton Kirby and Lullingstone abstraction sources. This is a follow-up to an investigation and catchment review from AMP6.
- The relevant groundwater model was used to try and assess the benefits for flow improvement and groundwater recovery compared to observed data in the AMP6 investigation. For this investigation we would review the model to assess its suitability for and to determine whether any further model development or refinement is required. The groundwater model would then be used to enable us to assess the potential benefit of abstraction reduction and to determine whether any abstraction modification is needed to meet the ecological objectives for the River Darent.
- The project will include a review of the EFI to determine whether any further information or new approaches can build on the EFI to determine whether it is the best option on which to base decisions about future actions or whether an alternative approach would be more appropriate.
- A comprehensive review of the existing hydrometric and hydrogeological data will be undertaken to determine whether any modification to the ongoing programme of monitoring and data collection is needed to help with assessing abstraction impacts at Eynsford, Horton Kirby and Lullingstone specifically.
- Ecological data will require review and the current baseline monitoring programme is required to be extended where sites are deemed appropriate (see ‘Overview of previous works’). See table and map at the end of the document for more detailed monitoring locations.

- Following the investigation, if an adverse impact on flow and ecology is confirmed, we will identify options to mitigate or remove the impact of abstraction to contribute to the waterbody achieving good status under the WFD, following Options Development guidance.

WINEP timelines & deliverables

- WINEP Report write-up by December 2026