Thames Water

Final Water Resources Management Plan 2019

Technical Appendices

Appendix XX: Programme of further studies 2019-2022

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Appendix XX.

Programme of further studies 2019-2022

XX.1 In the period to 2022 we have set out a continuing programme of ongoing studies to be undertaken with regulators, other water companies and third party organisations to continue to examine the feasibility of a number of water resource schemes in our WRMP19, namely further investigations of:

- Deephams reuse scheme
- Beckton reuse scheme
- Oxford canal transfer
- South East Strategic Reservoir Option (SESRO)
- Severn-Thames Transfer (STT)

XX.2 These studies are in addition to those associated with the delivery of groundwater schemes which are planned in the period 2020-2030, and the ongoing investigations into a number of other potential resource schemes which are either currently considered infeasible e.g. Teddington Direct River Abstraction scheme, or are secondary to the above list e.g. Mogden Re-Use.

Deephams reuse scheme

XX.3 For the Deephams reuse scheme, we will carry out further investigations of the potential effects of operation of this scheme, including:

- Agreeing with the Environment Agency the most appropriate hydrological datasets to update the assessment of the hydrological effects on the freshwater River Lee from the Pymmes Brook confluence at Tottenham Locks to the tidal limit at Three Mills Lock (and particularly the reach at Hackney Marshes). These agreed datasets will be used to support additional assessments set out below.
- Assessing the impact on fish habitat and other ecology in more detail (including effects on the Water Framework Directive (WFD) ecological potential), building on the recent ecological survey and modelling evidence gathered by Thames Water.
- Assessing the cumulative impact of pollution incidents arising from storm events.
- Assessing effects on the salinity and sediment conditions in Bow Creek (Lee estuary) to support the assessment of effects on the Bow Creek water environment.
- Reviewing, with the Port of London Authority, whether the scheme will lead to any adverse effects on navigation in Bow Creek.
- Assessing the effects of the scheme on the water environment of the Thames Tideway.

- Exploring any additional mitigation measures that may be required to protect the river or estuarine environment during operation of the scheme, as well as any opportunities for delivering net environmental gain.

Beckton reuse scheme

XX.4 For the Beckton reuse scheme we will carry out further investigations of the potential effects of operation of this scheme, including:

- Reviewing the effects of this scheme on the dilution and dispersion of chemicals in the Thames Tideway. This may require monitoring and/or modelling of the Tideway water quality to support the assessment.
- Updating the assessment of the effects of the scheme on the salinity regime of the Middle Thames Tideway and possible adverse effects on aquatic species that are sensitive to small changes in salinity. In particular, we will update the assessment in relation to the species designated within the Lower Thames Estuary recommended Marine Conservation Zone.
- Reviewing the environmental effects relating to the construction of the conveyance infrastructure from Beckton to the Lee Valley Reservoirs, including consideration of alternative conveyance routes and capacities.
- Agreeing any requirements for additional baseline water quality monitoring.
- Reviewing with the Port of London Authority whether there would be any navigation effects in the Middle Thames Tideway arising from operation of the scheme.
- Exploring any environmental or navigation mitigation measures that may be required during operation of the scheme, as well as any opportunities for delivering net environmental gain.

Oxford canal transfer scheme

XX.5 For the Oxford canal transfer scheme we will carry out further investigations of the potential effects of operation of this scheme, including:

- Additional water resource modelling to validate current findings in relation to yield - CRT is developing a new water resources model using current industry standard software. It has been agreed that the new model will be used to validate the predicted 15Ml/d yield available for transfer to the River Thames. The new model is unlikely to be available in 2019, but this work will be completed as soon as the model is available.
- Working with the Canal and River Trust (CRT) to assess the environmental effects of the CRT groundwater abstraction in the Birmingham area that will support the raw water transfer. Where necessary, this might include pumping tests to monitor the effects of the pumping on the water environment (groundwater and surface water).
- Optimisation of the transfer arrangement - Undertake additional option design development, particularly review of the discharge point to the River Cherwell. Discharging the transfer into the River Cherwell at Cropredy could have both positive and negative impacts on water quality and ecology in the river at this point (depending on conditions in the river at the time of transfer). Further work on the way the transfer is discharged would

reduce concerns and potentially provide some benefit to the river. This may lead to an option that discharges some transfer flow at Cropredy and the remaining flow downstream at Aynho / Nell Bridge where the Oxford Canal and River Cherwell currently interact. Any change to the discharge arrangement would have a cost impact that would also require assessment.

- Carrying out an agreed baseline water quality monitoring programme for the canal and the relevant reaches of the River Cherwell to support the assessment of possible changes to water quality in the canal or River Cherwell (including on algal growth).
- Assessing the effects of the existing CRT abstraction from the River Cherwell at Cropredy to inform the environmental baseline conditions.
- Carrying out an agreed monitoring programme of the baseline flow, habitat condition and ecology of agreed reaches of the River Cherwell.
- Development of provisional plan for transfer operation - The way the transfer is switched on and off will impact the canal system and the River Cherwell. Further work would provide provisional recommendations for operation to reduce impacts on water quality and ecology. This work would also inform permitting requirements and discussions to develop a commercial agreement between CRT and TW.
- Assessing any effects of the plan for transfer operation on the environment of the Oxford Canal and the River Cherwell (downstream to Cropredy), in particular on canal and river water quality, ecology, aquatic habitats and the potential risks of the transfer from any invasive non-native species (INNS).
- Exploring any environmental mitigation measures that may be required during operation of the scheme, as well as any opportunities for delivering net environmental gain.

South East Strategic Reservoir Option (SESRO)

XX.6 For the SESRO scheme, we will carry out some specific further investigations relating to water quality and invasive non-native species (INNS):

- Review previous work carried out on reservoir water quality and the proposed mitigation measures to maintain good water quality conditions in the reservoir (including algae). Review whether the mitigation measures remain appropriate or if changes are required.
- Review the information on reservoir mixing in relation to water quality under a range of drought conditions and consider whether further water quality monitoring and/or reservoir water quality modelling needs to be undertaken.
- Updating previous modelling and assessment work to examine the effects of the discharge of water from the reservoir on the River Thames, particularly on river water temperature, water quality and ecology, under a range of different drought conditions and climate change scenarios. Consider the need for any additional mitigation measures.
- Assessing the potential risk of transfer of INNS from the reservoir into the River Thames under a range of drought and climate change scenarios. This will include assessing the risks of INNS entering the reservoir from a range of possible entry pathways. Consider the need for any additional mitigation measures.

- Reviewing the assessment of the volume of water that is “lost” between the discharge of water to the River Thames and the downstream abstraction intakes in the Lower River Thames.
- Assessing the potential effects of the scheme operation on water levels and navigation in the River Thames, and consider whether any additional mitigation measures may be required.
- Review the potential effects on the River Thames arising from the construction of the abstraction and discharge facilities at Culham, including any mitigation measures that may be required during construction.
- Exploring any further opportunities for delivering net environmental gain beyond those associated with the diversion of various small watercourses and the reduction in abstraction from various chalk streams enabled by the reservoir scheme.
- Building on existing modelling of flood risk, complete Flood Risk Assessment taking account of latest requirements for climate change and including refinement of flood risk mitigation measures
- Extend rail access review to consider paths to potential quarry locations and to include engagement with Network Rail
- Review road access and diversions with Oxfordshire County Council.

Teddington direct river abstraction scheme

XX.7 The Teddington direct river abstraction scheme is not currently considered to be a feasible option in our Water Resources Management Plan because the scheme has been identified as having a high risk of compliance failure with WFD objectives. We will continue to undertake further studies of this potential option to identify whether mitigation of the detrimental impacts is possible or whether a smaller variant of the scheme would not cause deterioration. The investigations are listed below.

XX.8 Potential ecological effects requiring further research include:

- The increased risk of establishment of invasive non-native species population and the resilience of native fauna and flora;
- Sensitivity of the River Thames ecosystem to the discharges from the scheme at all times of the year;
- Climate change sensitivity and resilience of the ecosystems.

XX.9 Potential chemical effects require further research including exploring additional mitigation measures that may be required to protect the river or estuarine environment during operation of the scheme, namely:

- Sampling programmes (insoluble versus soluble concentrations of mercury and zinc in Mogden sewage treatment works effluent and olfactory inhibitors relevant to adult upstream salmonid migration);
- Risk from reduction in dilution of chemicals present in the freshwater river within the estuarine Tideway;
- Risk of elevated phosphate concentrations on plant growth;
- Potential additional evidence required including: pentachlorobenzene using lower detection limit methodology; continuous water temperature measurement in the freshwater River Thames both upstream of Hogsmill River and at Teddington Weir to establish baseline; continuous dissolved oxygen monitoring at Teddington Weir;
- Real-time European eel and elver run event recording;
- Assess the effects of the scheme on the water environment of the Upper and Middle Thames Tideway.

XX.10 Potential environmental mitigation measures (in addition to water temperature) including:

- Smelt spawning habitat and conditions in the estuarine Upper Tideway;
- Outfall design (including location) leading to minimal velocity increases and maintaining normal circulation patterns in the freshwater River Thames to maintain fish passage;
- Operational mitigation to reduce early commencement of saline ingress in the estuary in spring for successful smelt spawning;
- Treatment solution to match discharged dissolved oxygen to at least that of the receiving water;
- Potential for a multi-species fish pass at Teddington Weir.

XX.11 Potential navigation effects of the scheme require further research including: leakage through Richmond Sluice and navigation impacts below Richmond. This work would be undertaken in conjunction with the Port of London Authority.

XX.12 The outcome of the further studies into the Teddington DRA scheme will determine whether additional investigations would be appropriate for other reuse options in West London. In our draft WRMP19 we explained that a reuse scheme at Mogden is considered to be mutually exclusive with the Teddington DRA option. Furthermore, the Environment Agency in its representation on our draft WRMP19 noted a number of potentially significant detrimental environmental impacts associated with a new effluent discharge into the lower reaches of the freshwater River Thames linked to the Teddington DRA scheme. We will therefore review the outcome of the further studies of the Teddington scheme before determining whether additional work on other potential West London options would be appropriate.

Severn Thames Transfer (STT) scheme.

XX.13 Thames Water has undertaken preliminary work to investigate the feasibility of a transfer of water from the River Severn catchment to the Thames catchment in conjunction with United Utilities and Severn Trent Water, and engagement with regulators including Natural Resources Wales, the Environment Agency, Natural England and interested stakeholders the Group Against Reservoir Development (GARD), Canal and River Trust and the Cotswold Canals Trust. There remain a number of technical, environmental and regulatory issues that need further work. In collaboration with other water companies and regulators we will continue further work to examine these issues. Both Ofwat and the Environment Agency have requested in their representations to the further consultation on our revised draft WRMP19 that we continue to undertake further work to investigate a regional transfer from the River Severn, which Ofwat has suggested '*could potentially displace or delay other large supply-side options, or reduce the environmental impacts of new supply and enhance resilience'.*

XX.14 The further work builds on the collaborative work that has already been undertaken and is focused on five particular aspects of the scheme:

1) The availability of raw water in the River Severn for transfer to the River Thames during periods of drought and low flow. Water availability has been addressed through a detailed stochastic modelling study undertaken by Atkins. The Raw Water Transfer Feasibility Report concluded that, assuming these stochastic yields, the unsupported Severn Thames Transfer is not cost effective when compared with partially supported options that include flow augmentation support for the transfer during periods of drought and low flow. The results of Atkins stochastic modelling analysis have been appended to the Raw Water Transfers Feasibility Report published on our website and were shared with stakeholders for review and comment.
2) A detailed feasibility study has been undertaken examining the potential options available to support the Severn Thames Transfer. This substantial volume of work was led by Mott MacDonald and is detailed in the Raw Water Transfers Feasibility Report July 2018. The investigations confirmed the feasible options to include within the programme appraisal analysis for our revised draft WRMP19. The Executive Summary of the report is attached as Annex XX1. Earlier versions of the report have been published and shared with stakeholders for review and comment.
3) Work to understand the environmental implications of the Severn Thames Transfer support options, in particular the environmental mitigation requirements for Lake Vyrnwy releases and the Minworth effluent flow transfer to the upper reaches of the Warwickshire Avon. The ability of the River Thames to receive the transferred water without incurring WFD deterioration was also examined and a discharge point below Oxford was confirmed to prevent deterioration to upstream flow dependent habitat and irreversible changes to fluvial geomorphology. This work is detailed in the Severn Thames Transfer: Water Quality and Ecology Assessment Phase 2 Main Project Report October 2016, published on our website.

   The Vyrnwy Reservoir River Flow Support Scheme for Severn Thames Transfer: Environmental Assessment report was shared with Natural Resources Wales for review and comment in April 2018. The work was led by Ricardo Energy &

Environment in collaboration with Natural Resources Wales and the Environment Agency.

4) Work examining the water quality and invasive non-native species risks associated with transferring River Severn flow into the upper reaches of the River Thames, and the mitigation requirements to minimise the risks. The Severn Thames Transfer Water Quality and Ecology Assessment Phase 2 report is published on our website following extensive review and discussion with stakeholders and regulators. The investigations were led by HR Wallingford, with support from Cascade Consulting. A report on risk management of invasive non-native species is included as Appendix B to the Raw Water Transfers Feasibility Report.

5) The Raw Water Transfers Feasibility Report examined alternative conveyance options for the Severn Thames Transfer including both a pipeline conveyance route and the potential to restore the disused Cotswold Canals to transfer raw water from the River Severn into the River Thames. The work was undertaken by Mott MacDonald in close collaboration with the Cotswold Canals Trust. The investigation confirmed that the pipeline route is a much more cost effective option and would also be associated with less operational and water quality risks. A Conceptual Design Report has been prepared for the Deerhurst pipeline which has determined a feasible route for the pipeline and the next phase of the work would be to move to outline design stage. The conceptual design report is available for review by stakeholders within our offices but is not published on the website given potential national security concerns.

XX.15 We are committed to fully understanding the viability of the Severn Thames Transfer. Further development will be required by United Utilities, Severn Trent Water, Welsh Water, Thames Water, Natural Resources Wales, Natural England and the Environmental Agency. Funding is included within the WRMP19 and our company Business Plan to Ofwat. This work aligns with other work packages provided by United Utilities, Severn Trent and the Environment Agency. A common note has also been prepared and included describing the objective and high level activities for the Severn Thames Transfer between these named companies, with the support of Ofwat and Defra.

XX.16 To achieve governance for the future work programme, a River Severn ‘steering group’ (Water Resources West) has been set up in addition to the existing River Severn working group. This includes senior members of these companies, and will guide the development of these regional transfers.

Breakdown of the further work

XX.17 Based on the work completed to date we have a good understanding of the potential challenges that would be associated with a Severn Thames Transfer, as set out in Annex XX2. Further development of the transfer option will be achieved by building on the existing joint collaborative work that has been undertaken with Natural Resources Wales, the Environment Agency, Natural England, Welsh Water, United Utilities Water and Severn Trent Water.

XX.18 The further work will focus on:

1) understanding the magnitude of water losses that could occur during transfer and updating the stochastic modelling of yields for required drought return periods;
2) the changes that would be required to the regulation of the River Severn to ensure water is available for transfer when required and that the Severn Estuary Special Area of Conservation and Bristol Water are not detrimentally impacted by the increased upstream abstraction;
3) further environmental investigations and survey requirements for the River Severn flow augmentation options (e.g. Lake Vyrnwy reservoir); and
4) water quality issues associated with how River Severn algae behave when transferred into the River Thames.
5) Further consideration of the lead time to implement the option, taking account of timescales for changes to River Severn regulation

XX.19 As the potential recipients for the transferred water and hence needing to assure itself that the water supply provided would be secure and resilient to a wide variety of uncertain futures, this ongoing research will be led by the Water Resources South East companies in close liaison with Water Resources West. The details of the proposed programme of work are set out in Appendices XX3, XX4 and XX5 and these have been compiled in liaison with HR Wallingford, Ricardo Energy & Environment and the Centre for Hydrology & Ecology (CEH). These consultants have undertaken much of the work completed during AMP6 and have an excellent knowledge of the scheme and are well placed to continue to support the further ongoing programme of work.

XX.20 The above work will be included within our company Business Plan.

XX.21 Further work will also need to be undertaken by each of the donor companies to develop the feasible river augmentation and supporting options within their own supply areas, in order to release water that is currently used to supply customers so that it can be made available for the water transfer scheme. Currently, little information on the supporting options has been shared with the WRSE companies beyond a very high level scope. This will be required to ensure that the new supply is feasible, resilient in the face of future uncertainties and does not cause a detrimental impact on the environment. Costs for this work are not included in the programmes discussed above.

XX.22 It is highly likely that Ofwat would expect to see further work undertaken to investigate how the transfer scheme together with the required flow augmentation supporting schemes would be delivered under a Direct Procurement for Customers arrangement. No funding to facilitate further work in this area has been included in the current programme.

Annex XX1: Thames Water WRMP19 resource options - raw water transfers feasibility report executive summary

Purpose of the report

This feasibility report identifies and assesses the potential to augment water supplies in the Thames Basin through transfers of raw water from other catchments.

Introduction

The Thames Water (TW) Water Resources Management Plan (WRMP) was published in August 2014 (WRMP14) following approval from Defra. The plan set out the need for development of new resources, in addition to the implementation of a significant programme of demand management. Since then TW has undertaken detailed work to review and identify the best value resource options to ensure a secure supply of water in the future.

To reduce uncertainties and update options for the next WRMP in 2019 (WRMP19), a four-phase programme was developed. Mott MacDonald, in partnership with Cascade Consulting (now, Ricardo), completed Phase 1 of the programme; the findings were published in two reports in May and November 2015. The Phase 1 objective was to reduce the number of resource options carried forward from the WRMP14 constrained list, including reviewing rejected options; and to better target Phase 2 investigations by focusing on risks and uncertainties that are material to option selection.

Phase 2 has focused on conducting the investigations identified in Phase 1 so that the resource option screening can be finalised. The findings of these investigations are recorded in a number of feasibility reports for specific resource option types and in a number of cross option studies. This report focuses on identifying potential raw water transfer options and assessing their feasibility.

In total, 19 potential resource / support elements and 13 conveyance elements have been identified and studied in the feasibility assessment. Of the total 32 raw water

transfer elements studied, 12 are considered feasible within the criteria set. The approach taken to arrive at this decision is described below.

Approach to feasibility assessment

A common methodology has been applied across the water resource feasibility reports to assess and screen potential options. The methodology comprised three stages:

- Stage 1: options screened against absolute constraints shown in Table S.1
- Stage 2: the performance of the option is compared qualitatively against a number of criteria that differentiate between options of that type.
- Stage 3: the performance of the options is assessed in further detail (e.g. costing). Stage 2 and 3 criteria are shown in Table S.2.

Stage 1 applies a pass / fail approach to the criteria assessment, for the Stage 2 and 3 assessments a Red, Amber and Green assignment is used, where:

- Red – issue or constraint can't be overcome or will be challenging
- Amber – issue or constraint can be overcome
- Green – no constraint / issue

Table S.1: Stage 1 Criteria

Criteria
Property / legal criteria
Water Rights (regulatory or legal barriers)
Planning, socio-economic & environmental criteria
National / International nature conservation sites
National / International heritage sites
Potential impact on downstream abstractors
Water Availability
Engineering criteria
Resilience to drought
Source Quality (Treatability)

Table S.2: Stage 2 and 3 Criteria

Criteria	Stage 2 Criteria	Stage 3 Criteria
Property / legal criteria		
Ownership and site tenancies	Y	Y
Estimated land acquisition cost	Y	N
Planning, socio-economic & environmental criteria		
Planning policy & history	N	Y
Land use and land use quality	Y	Y
Floodplain encroachment (loss of floodplain / need for compensation storage)	Y	Y
Landscape character sensitivity	Y	Y
Views and visual amenity	Y	Y
Employment and local economy	N	Y
Nature conservation and biodiversity	Y	Y
Opportunity for biodiversity improvement	N	Y
Archaeology and the historic environment	Y	Y
Non-traffic impact of construction on local residents	Y	Y
Impact on residential dwellings	Y	N
Impact of construction on local traffic	Y	N
Recreational benefit	Y	N
Impact on recreation	Y	Y
Water resources & water quality	Y	Y
Engineering criteria		
Network reinforcement requirements	N	N
Material use and local availability	N	N
Variation of topographical levels	N	N
Length of conveyance	Y	Y
Normalised cost	N	Y
Pumping head	Y	N
Water source and availability	Y	Y
Cost / benefit of further investigation to validate yield	N	N
Water treatability / process complexity	N	Y
Access during construction and operation	Y	N
Resilience	Y	N
Power supply	N	Y
Connectivity to waste system	Y	N
Hydrogeological suitability	N	N
Construction complexity	Y	Y
Operational complexity	Y	N

Table S.3: Stage 2 and 3 Assessment Non Applicable Criteria

Criteria	Reasoning
Engineering Criteria	
Network reinforcement requirements	This criterion was developed to differentiate between individual options that would connect to different parts of the existing water supply network. The raw water transfer options support flows in the River Thames and so the criterion is not a significant differentiator.
Material use and local availability	This criterion is specific to new reservoirs
Variation of topographical levels	This criterion is specific to new reservoirs
Cost / benefit of further investigation to validate yield	This criterion is specific to groundwater options
Hydrogeological suitability	This criterion is specific to groundwater options

(Note: Criteria considered not applicable to both stage 2 and 3 are shown in grey text)

Option identification and definition

Stage 1 comprised option identification and assessment. The option identification included a review of all options considered during the WRMP14 study, responses to the Official Journal of the European Union (OJEU) notice issued by Thames Water, main historical options and options identified by recent / ongoing studies.

The options were split into resource / support and conveyance elements for assessment as defined hereafter:

- Water Resource / Support Elements
  - Support in upstream catchment (e.g. redeployment of Lake Vyrnwy)
  - Transfers of water within upstream catchments to facilitate option (e.g. transfer from Minworth STW to carrier water course in River Severn catchment)
  - Support in River Thames catchment (e.g. use of Abingdon Reservoir in conjunction with a Severn-Thames Transfer to augment deployable output)
- Conveyance Elements
  - All engineering works required to abstract flow from the carrier watercourse and transfer it to the receiving water in the Thames Water area (e.g. Thames Water reservoir or River Thames). Assessment will include water quality / ecology impacts on the receiving water.

The Stage 1 assessment focussed on the resource / support options to establish where water is available for transfer. The assessment was undertaken using absolute constraint criteria (Table S.1).

The resource elements that passed Stage 1 were developed in further detail in Stage 2 and conveyance elements were introduced. Element definition included identifying:

- Individual resource elements as per OJEU responses
- Further definition of potential support elements
- Definition of potential conveyance elements as identified in recent studies
- Resource parameters
- Nominal conveyance routes

The elements passing Stage 2 were further investigated in Stage 3. At this stage the mitigation requirements to overcome issues / constraints were considered and the elements were rated based on how difficult it is to provide mitigation / overcome constraints. In Stage 3 the normalised cost of each element was estimated and used in the Red / Amber / Green assessment.

Assessment results

The Stage 1, 2 & 3 assessment results are summarised in Table S.4 and Table S.5.

Table S.4 : Assessment Results – Resource / Support Elements

Element	Capacity (Ml/d)	Stage			Comment
		1	2	3	
Kielder Reservoir	Not defined	✓	✗		Rejected because its associated conveyance elements fail Stage 2 screening. These conveyance elements (existing canals and a new pipeline) are considered the only realistic ones.
Great Spring	Not defined	✗			Rejected as it has no longer been included as part of Welsh Water's offer, which includes other resources considered more cost effective by Welsh Water. It has not been offered by Network Rail, who own the abstraction licence, in response to TW's OJEU notice. Also concerns on water quality including risk of Cryptosporidium.
River Wye to Deerhurst	60.3	✓	✓	✓	Passed based on current offer from DC Welsh Water
CRT Bradley Groundwater	15	✗			This option was brought forward from WRMP14. Recent work by CRT has resulted in a new offer from CRT to provide water from the canal network to the River Cherwell. Therefore, Bradley Groundwater is rejected on the grounds that it is superseded by the new offer
CRT BCN Surplus (options for SWOX and LON)	15	✓	✓	✓	Use of surplus in the canal network to provide water through the Oxford Canal

Element	Capacity (Ml/d)	Stage 1	Stage 2	Stage 3	Comment
Minworth STW effluent to River Avon	115	✓	✓	✓	STT support option, passed
Minworth STW effluent transfer through existing canal network	75	✗			Initial assessment of the 75Ml/d canal transfer proposed by CRT (which would transfer tertiary treated final effluent from Minworth STW through the canal network and River Cherwell to the River Thames at Isis Lock in Oxford) indicates that the River Cherwell would be affected by the full volume of flow in low flow conditions, with an unacceptable impact on the flow regime, water quality and consequently the ecology. It is also assessed that transfer of the full 75 Ml/d to the River Thames at Isis Lock or Duke's Cut would have significant effects on ecology in low flow conditions due to the likely poor water quality and different water chemistry of the canal water / final effluent. Due to the assessed environmental impact and water quality concerns, it is considered unlikely that the EA would support the option. It is also noted that if the option were to go forward further discussions would be required with STWL to confirm the availability of water from Minworth STW. The option is rejected on the grounds of Water Rights and Source Water Quality (Treatability).
Mythe WTW unused part of licence	15	✓	✓	✓	STT support option, passed
Netheridge STW effluent	35	✓	✓	✓	STT support option, passed
Lake Vyrnwy	180	✓	✓	✓	STT support option, passed
Craig Goch Reservoir expansion	Not defined	✗			Rejected on National/ International Nature Conservation designations.
River Severn (unsupported)	Stochastic Yield 24-100	✓	✓	✓	Screened out at validation of the feasibility study as not cost effective in comparison with supported STT. However, an element of unsupported flow will be included in the partially supported STT options. Stochastic yield varies with overall STT transfer capacity. See validation section for more information.
Longdon Marsh reservoir to support River Severn abstraction	Reservoir volume 50/89/125 Mm^3	✓	✗		Rejected because of comparatively poor performance against other resource/ support elements on several criteria, including estimated land acquisition cost, flood plain encroachment, impact on residential dwellings and archaeology and the historic environment.
Use of a new Thames reservoir (as in reservoir report, if successfully promoted) to support River Severn abstraction and transfer	Not Defined	✗			WARMS2 modelling has shown that there is minimal Deployable Output benefit in discharging an STT pipeline directly to a new Upper Thames reservoir, rather than considering separate STT and reservoir options. Therefore, it is considered appropriate to assess the two options separately at Feasibility / Fine Screening stage and consider the combination of options through the Programme Appraisal process. The option is rejected on the grounds that there is negligible increase in water availability with a combined option compared with separate STT and reservoir options.

Element	Capacity (Ml/d)	Stage 1	Stage 2	Stage 3	Comment
Use of Farmoor Reservoir to support River Severn abstraction and transfer	Not Defined	✗			The option would transfer water direct to Farmoor. The River Severn and River Thames catchments would not be linked, abstraction would cease at Farmoor and previously abstracted water would remain in the river for abstraction at the London intakes. The option provides no appreciable deployable output benefit over discharging to the River Thames and is failed on the basis of water availability.
Redeployment of ST Abstractions at Shrewsbury	12	✓	✓	✓	Redeployment of existing River Severn abstraction at Shrewsbury. Abstraction at Shrewsbury currently serves Severn Trent Water customers in Shrewsbury and Oswestry. UU/STW have offered to provide a supply to Oswestry from Lake Vyrnwy using the existing aqueduct and UU treatment works, thereby reducing abstraction from the upper River Severn at Shrewsbury and leaving water in the river for abstraction at Deerhurst.
	30	✓	✓	✓	Additional redeployment of existing River Severn abstraction at Shrewsbury. Abstraction at Shrewsbury currently serves Severn Trent Water customers in Shrewsbury and Oswestry. UU/STW have offered to provide a supply to both Shrewsbury and Oswestry from Lake Vyrnwy using the existing aqueduct and a new pipeline to Shrewsbury, thereby reducing abstraction from the upper River Severn at Shrewsbury and leaving water in the river for abstraction at Deerhurst.

Note: STT support options Draycote and Hayden were previously offered by STWL but have been withdrawn and are therefore not included in this revision of the feasibility assessment. STWL also offered a Middle Severn option, but this option was rejected in Revision 1 of the feasibility report and has since been withdrawn by STWL, therefore it does not appear in this revision of the feasibility assessment.

Table S.5: Assessment Results – Conveyance Elements

Element	Capacity (Ml/d)	Stage 1	Stage 2	Stage 3	Comment
Oxford Canal to Farmoor Reservoir (SWOX)	15 (SWOX) TBC (LON)	n/a	✓	✓	Passed
Pipeline from Kielder Reservoir	Up to 300 to LON; 40 Ml/d to SWOX	n/a	✗		Rejected because of comparatively poor performance against other conveyances on several criteria including total pipeline conveyance length, pumping head, construction complexity and operational complexity.
Canals from Kielder Reservoir	45	n/a	✗		Rejection reasons include: The Water UK study concluded that the water from Kielder Reservoir is likely to be required by neighbouring areas; and the operational complexity associated with this conveyance is disproportionate to the limited DO benefit that could be achieved.

Element	Capacity (Ml/d)	Stage 1	2	3	Comment
Pipeline Deerhurst to Culham for 100 Ml/d transfer	100	n/a	✗		Rejected because the Deerhurst to Lechlade pipeline route for the same capacity is a significantly shorter route and had similar performance for other criteria.
Deerhust to Radcot 300/600 Ml/d	300-600	n/a	✗		Rejected as mutually exclusive of and less promotable on water quality and environmental grounds than the Deerhurst to Culham 300/600 Ml/d element.
Pipeline Deerhurst to Culham for 300/400/500 Ml/d transfer	300 - 500	n/a	✓	✓	Passed
Pipeline Deerhurst to Culham for 600 Ml/d transfer	600	n/a	✓	✗	Rejected as less promotable compared with other options due to environmental effects and cost.
Pipeline Deerhurst to Lechlade for 100 Ml/d transfer	100	n/a	✓	✓	Rejected at validation stage of feasibility report in comparison with larger transfers on basis of cost and adequate capacity given projected deficits.
Cotswold Canal 100 Ml/d	100	n/a	✓	✗	Rejected as it is mutually exclusive with the Deerhurst pipeline conveyances and was concluded to be overall less feasible than the latter. Performed worse on the key criteria of water resources and water quality, normalised cost, constructability and operability.
Cotswold Canal 300 Ml/d	300	n/a	✓	✗	Rejected as it is mutually exclusive with the Deerhurst pipeline conveyances and was concluded to be overall less feasible than the latter. Performed worse on the key criteria of water resources and water quality, normalised cost, constructability and operability.

As the assessment undertaken is high level there are inherent risks and uncertainties with the feasible options list, the main areas are as follows:

- Put and take arrangements – The feasibility assessment assumes that all flow put into a carrier watercourse can be abstracted for transfer (i.e. all flow from Lake Vyrnwy can be abstracted into the Deerhurst pipeline) albeit with an allowance for natural, environmental losses. A loss factor of 10% in the River Severn was assumed for feasibility assessment in Revisions 1 and 2 of the RWT feasibility report. Recent work by HR Wallingford indicated that this was conservative and losses are likely to be greater, particularly during low flow periods. Therefore, at validation stage (and later for program appraisal), a loss factor of 20% is used. This would then be subjected to sensitivity analysis if the STT is chosen for the plan. The EA has indicated that without further data and analysis of losses they would apply the published abstraction

licensing policy to any new licence at Deerhurst. Therefore, there remains a significant risk that water released to the River Severn from 3rd party support options would not be available for transfer when required by Thames Water.

- River Severn Losses - Investigations continue into appropriate loss assumptions for STT support options in the River Severn, involving discussions with EA and NRW around this issue.
- Agreement terms – Negotiations with third parties are ongoing to agree heads of terms.
- Regulatory requirements – Emerging guidance on metaldehyde may change mitigation requirements, the NRW / Welsh Government view on any Welsh options is yet to be confirmed.
- Treatment technology for water quality mitigation – It may not be possible to achieve the level of treatment required with the available technology and therefore negotiations may be required for a 'best available technology' approach. The Environment Agency has issued a position statement relating to Non-Native Invasive Species (INNS) and it is understood that further work by the EA is ongoing to develop an approach to INNS risk.
- Phasing – Further consideration of appropriate phasing will be required given better understanding of predicted demand in SWOX, possible sharing with neighbouring water companies such as Affinity Water and South East Water.
- Exact route of pipeline conveyances – The nominal routes defined to date are likely to change at later stages of design development to provide improved mitigation, operating efficiency etc.
- Exact site location in cases where site locations are flexible – Further work will be required to locate optimum sites for permanent and temporary works.
- Lake Vyrnwy STT Support Releases - Discussions continue with NRW in relation to water quality and ecology impacts of releases to the River Vyrnwy.

Validation

During Validation, the resource and conveyance elements that were assessed separately in stages 1 to 3, were considered in combination. The potential combinations are given in Table S.6.

Table S.6: Raw Water Transfer Combined Options

Resource(s)/Support(s)	Conveyance	Resource zones	Capacity (Ml/d)	Feasible List?	Comments
Oxford Canal options	Oxford Canal to Farmoor Reservoir	London, SWOX, SWA	15	✓	Passed feasibility assessment.
Unsupported STT to River Severn	Deerhurst to Lechlade	London, SWOX, SWA	100	X	Rejected at validation stage of feasibility report on cost grounds. The unsupported benefit will be accounted for in all STT support combinations.
	Deerhurst to Culham	London, SWOX, SWA	300/400/500	X	Rejected at validation stage of feasibility report on cost grounds. The unsupported benefit will be accounted for in all STT support combinations.
Partially supported STT with combinations of: Mythe, Lake Vyrnwy(60,148, 180 Ml/d), Shrewsbury (12, 30 Ml/d), Minworth STW, Netheridge, River Wye with the unsupported River Severn.	Deerhurst to Lechlade	London, SWOX, SWA	100	X	Rejected at validation stage of feasibility report on cost grounds
	Deerhurst to Culham		300/400/500	✓	Passed feasibility assessment.

Within the Fine Screening report, options will be compared against other option types using six dimensions that recognise the inter-connectedness and opportunities and constraints of the water cycle from source to tap covering a number of systems both man-made and environmental.

The six dimensions that will be applied at the fine screening stage for all water resource options include:

- Environment and social impacts and opportunities
- Cost
- Promotability
- Flexibility
- Deliverability; and
- Resilience

This feasibility report focuses on the water resource / support and conveyance elements of the raw water transfer options, whereas the fine screening report will take account of the other elements needed to provide an overall water supply option from resource to distribution, including both man made and environmental systems.

Options that are mutually exclusive (for example relying on the same ultimate source of water resource), where sufficient information is available, have been screened out at the feasibility stage. Mutual exclusivities between option types will be resolved at the fine screening stage.

Future Work

Each of the water resource option feasibility reports set out a range of large scale potential water resource options deemed feasible on a site selection basis. Further work would be required to reduce uncertainty and develop a deliverable option, should the raw water transfer options be included in the final Water Resource Management Plan. Further work would include:

- Continued discussions with Severn Trent Water, United Utilities, Dwr Cymru Welsh Water and Canal and River Trust to develop agreements for third party options
- Agreement of environmental mitigation for Vyrnwy releases with NRW
- Agreement of licensing arrangements with the EA and NRW including put and take arrangements and agreement on associated losses assumptions
- Further design development and permissions such as planning, land purchase etc
- Thames Water has committed to continue work on the Severn Thames Transfer. For further information see the Statement of Response Appendix J: Severn Thames Transfer – Further Work

Annex XX2: Water supply transfers to the South East region from the west

Key issues

Context

1. It would be wrong to characterise the situation as one of surplus in the west and need in the east, with a simple transfer to balance this out. United Utilities (UU), Severn Trent Water (ST) and Welsh Water all have to develop alternative sources of water to compensate for what would be transferred to the South East region – and those alternatives would have their own impacts which need to be accounted for (e.g. risk of Water Framework Directive deterioration in water bodies used for the transfer routes, risks to future security of supply in Severn Trent's donor area linked to the export of water to the South East, etc.).

Why the transfer is not required in our WRMP19 until the 2080s

2. The transfer does not feature in our plan until the 2080s for a number of reasons, but cost is one of the primary drivers as well as resilience. It is a more expensive option than the reservoir, and also is much higher risk in terms of guaranteeing water availability when needed during periods of drought and low flow. None of the WRSE companies have requested a water supply in the 2020s. Whilst Southern Water has a requirement for additional water resources in its Hampshire South zone, neither of the strategic water supply options in the West of the region (SESRO and Severn Thames Transfer) would be available in time to meet this need and instead Southern Water has identified that a desalination scheme is its preferred supply option. A number of stakeholders have asserted that the Severn Thames Transfer could be delivered much quicker than the 10 year plus lead time that Thames Water has indicated would be required to deliver the scheme. Little evidence has been presented in support of their assertions and the available information concurs with Thames Water's position. The Environment Agency in its representation on Thames Water's revised draft WRMP19 has stated that a 10 year lead time is too short and a substantial data collection exercise is first required to properly assess the potential environment impacts of the scheme. Allowing for the four year programme the EA has proposed would increase the lead time to a minimum of 14 years.

3. The earliest requirement for a strategic regional transfer is from Affinity Water, who has requested 100 Ml/d in 2037/38. None of the other WRSE companies have forecast a requirement for raw water in the current WRSE planning period to 2080.

4. Furthermore, none of the WRSE water companies support delivery of the Severn Thames transfer in isolation from the reservoir. Affinity Water has stated that it does not have the raw water storage that is required to efficiently generate reliable yield from the scheme[1].

[1] Alignment of Water Resources Management Plans (March 2019). Pauline Walsh (CEO Affinity Water) joint letter with Steve Robertson (CEO Thames Water) to Rachel Fletcher

Costs of a transfer

5. Severn Trent, United Utilities and Welsh Water provided us with the costs of making the water available, based on whatever margin they chose, plus the costs of developing new resources to replace what they make available.

6. Severn Trent and United Utilities provided us with a fixed fee for simply reserving the water – irrespective of whether we take it in a given year – plus a volumetric fee. These two numbers are currently all that we have sight of, and therefore have used as input in developing our plan. We then also have to factor in the cost of transferring the water from the River Severn, including raw water treatment at Deerhurst and transfer via a pipeline to the River Thames, and the subsequent re-abstraction from the River Thames, water treatment and distribution infrastructure costs within London.

7. Severn Trent and United Utilities also put together a joint proposal to allow redeployment of water currently abstracted at Shrewsbury and, when they were aware that the option had not been selected in the plan until the 2080s, we had a discussion to help them better understand our costs, as they thought that we may have made an error in how we used the information they provided us. They accepted, once we had talked this though, that we had not.

8. Since the consultation on our draft WRMP19, Severn Trent has submitted lower costs for their Third Party water supply options. United Utilities has not updated its costs and we are still waiting for further cost information from Welsh Water. In the absence of definitive third party costs from Welsh Water we have had to make our own assumptions to ensure that the option was fully considered in our WRMP19. This has used capex and opex estimates provided by Welsh Water for the development of resources to replace the River Wye resource that is to be transferred and we have made our own assessment of the costs for the transfer pipeline from the River Wye to the inlet of the raw water treatment works at Deerhurst.

Risk and uncertainty associated with the transfer

Losses en route

9. There is a Hands-off Flow (HOF) constraint at Deerhurst on the lower River Severn to protect the Severn Estuary Special Area of Conservation. The problem with that is that it makes it a very risky option for the WRSE, because we can't have any confidence in how much of the water going into the transfer can be taken out. In its recent abstraction licensing strategy policy for the River Severn catchment (March 2019) the EA has indicated that the HOF constraint at Deerhurst will be increased by a large amount to protect the River Severn estuary. This will significantly reduce the unsupported element of the River Severn flow available for transfer and as such will further reduce the yield of the scheme and increase its relative cost.

10. This also raises the question of whether this arrangement would represent value for money for our customers, who would in effect be paying for the costs of protecting the environment in the upstream catchment during periods of lower flows; plus the costs of any uncontrolled losses to other abstractors incurred between the start and end of the catchment.

11. We sought agreement from the EA that any transfer would instead have to use a 'put and take' arrangement, which they weren't prepared to agree to, and have asked us to look at

scenarios of 10, 20, 30 and 40% losses to ascertain what would represent a reasonable / acceptable level of loss. We have used a central figure of 20% losses within our base modelling, which was discussed and agreed with the EA. The EA considers that 10% losses, used in our draft WRMP19 modelling, is too low.

Coincident drought

12. Another unresolved issue is that there is no clear agreement of how we would resolve the question of a drought affecting both the South East and western areas, as occurred during the drought of 1976. Ofwat has asserted that 'actual droughts tend to be local in nature' (personal correspondence between David Black and Colm Gibson 4th July 2018). There is no evidence to support Ofwat's assertion, and leading industry research suggests a contrary view. Professor Jim Hall (Oxford University) was funded by NERC to look at drought risk under climate change (the MaRIUS[2] project). As part of that work, CEH Wallingford found that droughts in the Thames and Severn regions are going to be more coincident in the future as a result of climate change[3]. A major drought in both the Severn and Thames catchments at the same time is projected to increase by 56% in the near future (2022-2049) and 135% in the far future (2072-2099).

13. On the question of whether the use of Lake Vyrnwy storage reservoir in Mid Wales (and other sources of support) gets around that problem, the answer is that it doesn't fully address the issue. The transfer would have an unsupported element – what is in the river before the HOF comes into play, and this would be affected by drought. The support doesn't provide enough to compensate fully for lower levels during a drought in the unsupported bit.

Increasing vulnerability of our existing ageing storage reservoir stock

14. A number of our existing raw water storage reservoirs are more than 100 years old. Work undertaken by engineering consultants W S Atkins and AECOM has identified that there is an increasing risk that these assets will need to be taken out of supply in response to unplanned maintenance requirements. If the volume of the existing raw water storage capacity is reduced the yield of the Severn Thames Transfer will be impacted accordingly because there is reduced capacity to store the water that is transferred and increasing reliance and drawdown is placed on the remaining storage reservoirs.

Impact on the upper Thames

15. Phosphorous from the agricultural lower Severn catchment contributes to high algal loading, which risks changing the characteristics of the upper Thames. Algal loads are increasing in any case due to climate change, but a transfer could potentially further increase our exposure to this risk, to which we are particularly vulnerable because of our reliance on surface water abstraction (80% in London and 40% in SWOX – the latter still high enough to make us concerned).

[2] Managing the Risks, Impacts and Uncertainties of drought and water Scarcity, NERC funded research project
[3] Rudd A.C., Bell V.A. and Davies H.N., Severn Thames Transfer Study Final Report July 2018, Centre for Ecology & Hydrology 2018

16. CEH Wallingford is researching this for us – this is at the leading edge of work in this area – it is a high risk that arguably is not properly appreciated. Any problems would, of course, relate to the affected works and the water they treat from other sources, not just what would have been transferred. From the initial work that it has undertaken to date[4], CEH has stated:

    'Recommended option

    Based on our current understanding, we believe that the construction of a deep reservoir with artificial mixing in the middle Thames provides the best option for future drinking water supply and flow support for the River Thames during drought periods. It is a tried and tested solution that is under the full control of Thames Water, which makes it the most robust option. The Severn-Thames transfer also provides a viable water resources option, but there are more potential environmental problems associated with this, in terms of algal proliferation and inter-basin species transfers, and could be ineffective if the Severn region is also in drought.'

Other issues:

Potential wider environmental benefits of low opex solutions

17. Lower opex solutions – like a reservoir – do have the advantage of being effective for use in non-drought conditions to support the wider environment and facilitate (with new connectivity) the use of transferred water to relieve pressure on other sources (e.g. vulnerable chalk streams and other water courses). The opex cost ratio of the transfer in comparison to the reservoir (at P50 cost confidence) is approximately 3.3 to 1 which illustrates the significantly higher running costs of the transfer.

Customer preferences

18. Transfers are customers' least-favoured solutions - they perceive them as an unwanted over-reliance on another region for their water. The reservoir option is more preferred – all the deliberative customer research meetings that we undertook on our draft WRMP19 selected the reservoir in preference to other water supply options, even the customer research that we undertook in Abingdon, the area closest to the proposed reservoir site.

[4] Centre for Ecology and Hydrology (2018), Natural Environment Research Council, Briefing note on the impact of the Draft Water Resources Management Plan 2019, Dr Mike Bowes & Dr Alex Elliott

Annex XX3: HR Wallingford: Scope of work for understanding the magnitude of water losses that could occur from river augmentation releases to the River Severn and the changes that would be required to the regulation of the River Severn

1 Introduction

Building on work undertaken for WRMP 2019, Thames Water Utilities Ltd. (TWUL) has requested HR Wallingford to provide a high level scope for additional assessment of a supported Severn Thames Transfer (sSTT) option to carry through to WRMP 2024.

TWUL are to continue to explore a sSTT option through the WRMP 2024 planning cycle and has identified the following aspects which could be considered in greater depth than work previously completed:

- Water quality
- Scheme losses
- Regulation of the River Severn

A considerable body of evidence has been amassed on a sSTT scheme over the past 25 years. Building on initial assessments (WS Atkins, 1993a, 1993b; Cascade, 2011) HR Wallingford has more recently contributed water quantity and quality modelling to this body of work, including:

- Water quality modelling of a the River Thames (HR Wallingford, 2008), and the Severn Thames transfer (HR Wallingford, 2016a);
- Water resources modelling of the River Severn, including stochastic, climate change, and demand scenarios, and the likelihood of coincident drought between the River Severn and River Thames (HR Wallingford, 2016b, 2016c);
- Assessing the potential physical and operational losses from a release of water from the Upper Severn for abstraction at Deerhurst (HR Wallingford, 2018);
- Assessing the regulation and resources of the River Severn under the impacts of climate change (HR Wallingford, 2014);
- Assessing the resilience of the River Severn as a source for Bristol Water (ongoing).

To improve the understanding of feasibility of any potential scheme, both quantity and quality modelling require integration and systematic testing against a range of scenarios. Any additional modelling should focus on answering the following question:

> "When a transfer from the River Severn to the River Thames is required by Thames Water, is the water readily available, and can it be provided without negatively impacting the environment, or any other stakeholders?"

Collaboration with a range of stakeholders is therefore essential for a successful sSTT scheme. Stakeholder engagement, the identification of metrics valued by individual stakeholders, testing of scenarios which best capture this information, and creative communication of results, should be the basis for any further work. Enabling stakeholders to readily interrogate results of modelled scenarios and view the trade – offs between metrics of interest to them, and other parties, would be a valuable tool to support the dialogue of initiating such a potentially complex scheme.

Provision of results via an interactive dashboard would enable all stakeholders to examine the results of the modelling. Presenting results in this manner could provide stakeholders, such as the Environment Agency, Natural Resources Wales, Bristol Water, and TWUL, a holistic view of a sSTT scheme, the River Severn, and the River Thames. The integrated modelling approach has the potential to benefit multiple stakeholders. For example, scenarios exploring regulatory options for the River Severn at Bewdley and Deerhurst could be developed and tested, and modelling could be used to improve the understanding of the resilience of the River Severn as a source for Bristol Water.

Outlined in this document is a potential approach to undertaking this work. HR Wallingford are at the leading edge of UK water resources, with a portfolio of both research projects commissioned by UKWIR to inform industry guidance, and consultancy projects supporting water companies in their planning process. The combination of leading academic approaches and a strong foundation in industry practicalities enable HR Wallingford to support TWUL in assessing a potential sSTT scheme.

If TWUL were to commission HR Wallingford to complete this work, a detailed scope, programme, and budget, would be drawn up and agreed with TWUL prior to the commencement of any work.

2 Recommended updates to existing models

HR Wallingford has carried out extensive hydrological, water resources, and water quality modelling of the River Severn and River Thames, and are well placed to support on any further investigations. Existing integrated hydrologic, water resources, and water quality models relevant to the study area which were either developed by HR Wallingford, or are held by HR Wallingford, are shown in Figure 1, with a brief description of the model and modelled run periods summarised in Table 7. However, in order to integrate water quality with water quantity a number of updates to the existing models are required. These are listed in Table 8 to Table 10, alongside the reasoning behind their recommendation.

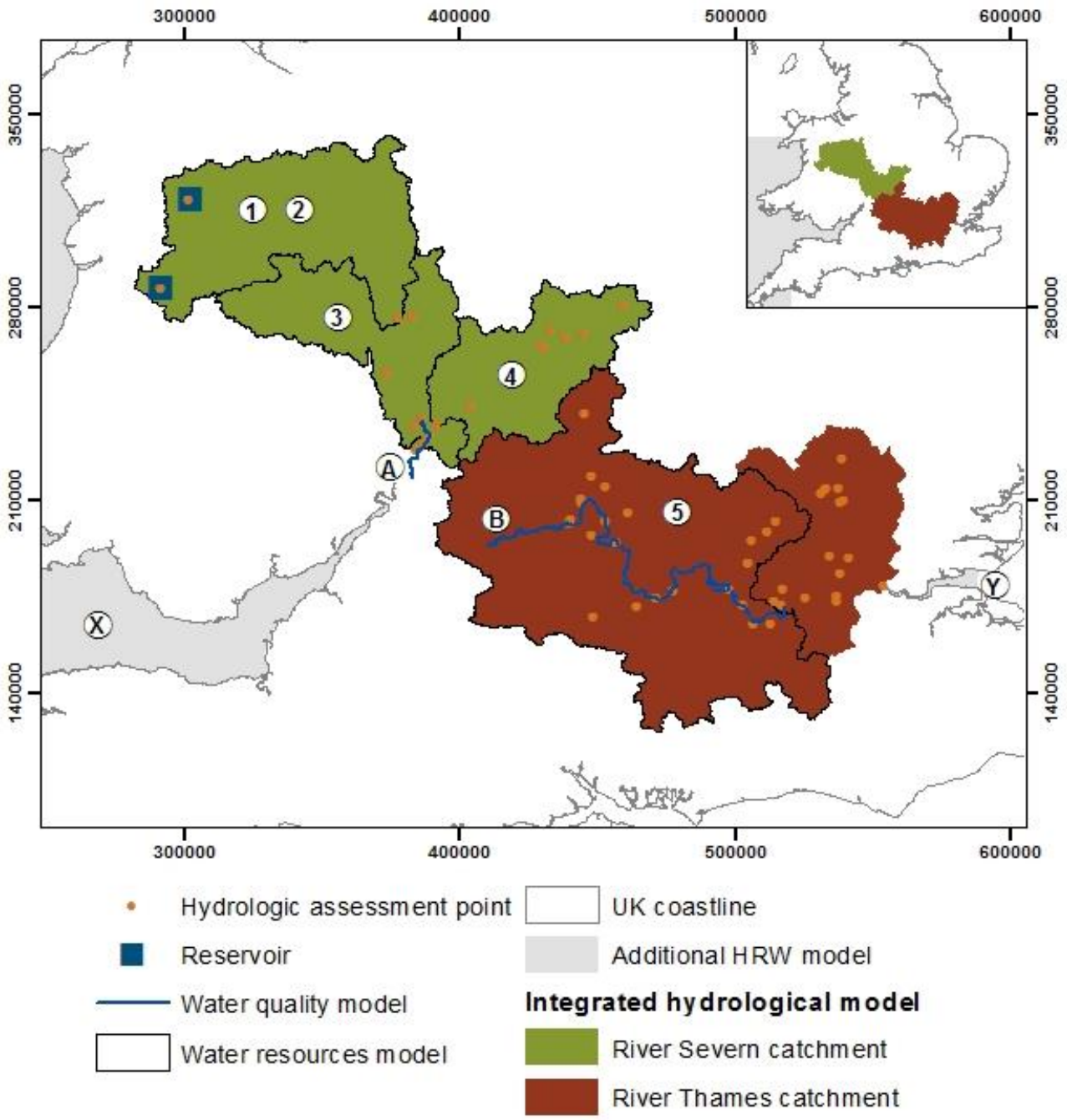

Figure 1: Existing models either developed by HR Wallingford (labels explained in Table 7)

Note: Hydrologic assessment points are locations in the Kestrel-IHM where flows have been exported. It should be noted that Kestrel-IHM has been developed in a flexible manner, so that flows can easily be exported for any model cell.

Table 7: Summary of existing models held by HR Wallingford

Model type	Label*	Description	Modelled periods
Integrated hydrologic model	Greenarea in Figure 1	Kestrel-IHM model developed by HR Wallingford for the River Severn at Hawbridge catchment (HR Wallingford, 2016b), running on daily time steps.	• 1910 – 2015 historic • 15,600 years stochastic weather • 2,000 years synthetic droughts • 100 sets of climate change factors for 2080s (Medium Emission scenario; UKCP09), the process for updating with UKCP18 factors would be straightforward.
	Red area in Figure 1	Kestrel-IHM model developed by HR Wallingford using internal research funding for the River Thames catchment, running on daily time steps.	• 2010 – 2015 historic
Water Resources model	1	XRAM model of the Upper Severn developed by the Environment Agency and AMEC (detailed in AMEC, 2014). HR Wallingford obtained the spreadsheet for HR Wallingford (2016b) work.	• 1964 – 2011 historic
	2	Kestrel-WRM model developed by HR Wallingford for the River Severn at Bewdley catchment (2016b), representing key water resource system components for the key application of modelling river regulation, running on daily time steps.	• 1910 – 2015 historic • 15,600 years stochastic weather • 2,000 years synthetic droughts • 100 sets of climate change factors for 2080s (Medium Emission scenario; UKCP09) • All above scenarios for deployable output and recent actual demand scenarios.
	3**	Kestrel-IHM artificial influences model for the River Severn between Bewdley and Deerhurst developed by HR Wallingford (2016b) to account for Severn Trent Water abstractions and discharges.	• 1910 – 2015 historic • 15,600 years stochastic weather • 2,000 years synthetic droughts • 100 sets of climate change factors for 2080s (Medium Emission scenario; UKCP09) • All above scenarios for deployable output and recent actual demand scenarios.
	4**	Kestrel-IHM post processing script developed by HR Wallingford (2016b) to account for abstractions and discharges in the River Avon catchment.	• 1910 – 2015 historic • 15,600 years stochastic weather • 2,000 years synthetic droughts • 100 sets of climate change factors for 2080s (Medium Emission scenario; UKCP09) • All above scenarios for two demand scenarios; recent actual, and a design scenario reflecting Severn Trent Water's planning assumptions for WRMP 2014.
	5	Kestrel-WRM model developed by HR Wallingford (ongoing internal research) for the River Thames catchment upstream of Teddington,	• 1910 – 2015 historic

Model type	Label*	Description	Modelled periods
		and the Lee Valley. This model is currently being migrated to Kestrel-NXS (i.e. a dynamically linked Kestrel-IHM and Kestrel-WRM model), with computational efficiency capable of running the modelled periods outlined in for the Kestrel-IHM model described in the row above.	
Water quality and hydraulic model	A	InfoWorks RS version 12.5 model of the River Severn developed by HR Wallingford (2016a) using cross-section data from Environment Agency ISIS model files. The model runs on daily time steps.	2007, 2010, 2011
	B	InfoWorks RS version 12.5 model of the River Thames from Farmoor to Teddington developed by HR Wallingford (2016a) from a previously existing ISIS model (HR Wallingford, 2008). The model runs on daily time steps.	2003, 2004, 2011
Other models	X	DECC Severn Estuary Bristol Channel model developed by HR Wallingford for the government to investigate tidal power options and explore potential ways of preventing foreshore loss if tidal power in place.	Representative spring-neap periods.
	Y	Thames 2D Base Model developed by HR Wallingford for the Environment Agency and the Port of London Authority. The model is used to help understand and predict the effects of natural evolution, development, and dredging schemes.	• Mean spring tide + mean daily river flow (65 m3/s) • Mean spring tide + 1in100yr daily river flow (800 m3/s) • Large flood tide + mean daily river flow (65 m3/s)

** See Figure 1 for location of models.*

*** Not in the format of Kestrel-WRM, but could easily be migrated.*

Table 8: Recommended updates to existing water quality models

Update to water quality modelling (InfoWorks RS)	Justification
Migration from InfoWorks RS to InfoWorks ICM to create one model.	Future proofing existing model. InfoWorks ICM was in its infancy when this model was developed, HR Wallingford have since used InfoWorks ICM extensively in a wide range of riverine locations, including the UK. InfoWorks ICM offers significant functionality and working enhancements on InfoWorks RS while maintaining the essential core functionality. The majority of InfoWorks RS users have migrated to InfoWorks ICM, making it one of the standard river modelling applications in the UK. There are tools within InfoWorks ICM for importing InfoWorks RS models although there is still a significant convert and check' process to ensure that both the InfoWorks RS and InfoWorks ICM models give the same answers. It is also recommended that the grid size be made coarser as part of this process so as run time is reduced.
Representation of the following: • Diffuse inputs • Alkalinity • Transfer of saline water • Water quality changes in pipeline • Algal blooms	The process associated with these elements were not included (or in case of algal blooms, need improving) in the original model, but may be desired by TWUL.
Inclusion of the River Avon	As Severn Trent Water Ltd. are exploring options to support a sSTT by discharging to the River Avon for abstraction at Deerhurst, extending the water quality model to cover the River Avon would be beneficial.
Use of a screening tool to simulate water quality metrics of multiple scenarios before filtering to a library to run through InfoWorks ICM.	Whilst the hydrological and water resources models developed by HR Wallingford can simulate long time series, the water quality models are computationally more expensive, and thus, limited in the model time period they can simulate. In order to systematically test a potential sSTT to a wide range of scenarios, a development of screening tool is recommended. The screening tool would be calibrated against historic data, and appended to the hydrological and water resources modelling component. Analysis of all runs will be carried out to identify which runs should be input to the more detailed InfoWorks ICM model.
Updating to include the most recent water quality data.	The data in this model is currently missing the most recent three years of data. It is recommended that these data are updated, where possible.

Table 9: Recommended updates to existing water resources models

Update to water resources modelling (Kestrel-WRM)	Justification
Extension to include the River Avon and the Lower Severn	At present, the water resources model covers the River Severn from the upper reservoirs to the Bewdley gauge, accounting for regulation processes at Bewdley. To thoroughly test regulation and operation scenarios, water resources models of the Lower Severn and River Avon should be included. At present, the abstractions and discharges from these catchments are applied in post-processing scripts. The task to convert these scripts to a Kestrel-WRM model would not be intensive.
Updating to include latest abstraction and discharge information	The abstraction and discharge data in this model is currently missing the most recent three years of data. It is recommended that these data are updated, where possible.

Table 10: Recommended updates to existing hydrological models

Update to hydrological model (Kestrel-IHM)	Justification
Updating to include the latest rainfall and PET data.	The rainfall and PET data in this model is currently missing the most recent three years of data. It is recommended that these data are updated, where possible.
Update to include the latest climate change evidence	UKCP18 climate change evidence is scheduled for release in November 2018. Inclusion of this data should be anticipated for any work informing WRMP 2024.

3 Initial scope of technical work

3.1 Overview

A staged approach to assessing a sSTT scheme is recommended. Such an approach ensures that review stages of the project are clearly defined, and both TWUL and HR Wallingford are afforded points at which the most efficient and beneficial methods can be reassessed if necessary. As more information becomes available, either through model development or discussions with stakeholders, a phased approach can also allow amendments to scope, budget, and programme at a timely manner. The phases suggested by HR Wallingford are outlined below:

- Scoping phase
- Model update phase
- Model and screening tool development phase
- Scenario testing phase

3.2 Scoping phase

Table 11: Summary of scoping phase*

	Scoping phase
Objective	This phase will inform the modelling approach, through liaison with stakeholders and review of the most recent literature, to identify the key priorities and metrics of all parties involved.
Tasks	• Liaise with stakeholders to assess priorities and metrics of importance. • Potential stakeholders include the Environment Agency, Natural Resources Wales, Severn Trent Water, Bristol Water, and TWUL. • Review of most up to date literature. • Review of most up to date data.
Deliverable	A brief technical note of recommended model improvements to capture the most important metrics for all stakeholders, dealing with one round of comments within two working weeks of receiving all comments.
Working days*	20

* *These elements are indicative, and will be finalised if HR Wallingford are commissioned to undertake this work.*

3.3 Model update phase

Table 12: Summary of model update phase*

	Model update phase
Objective	Update existing models (see Table 8 to Table 10 for recommendations). Potential updates are outlined below, but any updates would also be informed by the findings of the scoping phase.
Tasks	• Data preparation. • Update Kestrel-IHM gridded hydrological model models of the River Severn and River Avon with latest data. Recalibration is not included in budget estimates. • Conversion of existing water quality and hydraulic InfoWorks RS models of the River Severn and River Thames to InfoWorks ICM models for benefits described in Table 8, and merging River Severn and River Thames models into one model. • Making the water quality model grid size coarser. Calibration will be reviewed, but recalibration is not included in budget estimated.

	Model update phase
	• Process and analyse new UKCP18 climate change evidence for the River Severn. It should be noted that HR Wallingford are currently undertaking similar analyse for TWUL on the River Thames, which would also be used to inform this assessment.
Deliverable	A brief technical note on process and results of updating existing models, dealing with one round of comments within two working weeks of receiving all comments.
Working days*	35

* *These elements are indicative, and will be finalised if HR Wallingford are commissioned to undertake this work.*

3.4 Model, screening tool, and dashboard development phase

Table 13: Summary of model, screening tool, and dashboard development phase*

	Model, screening tool, and dashboard development phase
Objective	Development of integrated water quality and quantity modelling, accompanied by a screening tool as a solution to the computation expense incurred by water quality modelling, and a dashboard to enable interrogation of results by all stakeholders. Potential developments are outlined below, but any developments will be informed by the findings of the scoping phase and the model update phase. Developments may require additional data (e.g. inclusion of new reaches in the InfoWorks ICM model).

Tasks	• Data preparation.
	• Development of Kestrel-IHM to represent bank storage.
	• Development of Kestrel-WRM to cover the extent of the Lower River Severn and River Avon.
	• Extending InfoWorks ICM model of the River Severn further upstream.
	• Including the River Avon in the InfoWorks ICM model.
	• Including the Gloucester and Sharpness Canal in the InfoWorks ICM model.
	• Including, or improving, the following processes in the InfoWorks ICM model. An indicative costing of modelling two of the processes has been included in the budget estimate. Calibration approaches will depend on data availability, and will be defined in further detail should TWUL commission HR Wallingford to complete this task.
	  ○ Diffuse inputs
	  ○ Transfer of saline water
	  ○ Water quality changes in pipeline
	  ○ Algal blooms
	• Development of a water quality screening tool, potentially using the Kestrel-IHM framework. A thorough assessment of the tools ability to recreate InfoWorks ICM model outputs will be carried out.
	• Development of dashboard to enable all stakeholders to visualise results. A potential method of displaying results is shown in Figure 2. Using a display similar to this, stakeholders could filter all results from a scenario based on a metric range of value to them. The rose plot displays the full range of values that satisfy the filtered range, whilst the lines on the rose plot show the results for a selected scenario. Successful development of such a dashboard would be an iterative process, requiring input from all stakeholders.

Deliverables	• Report on water resources model and water quality model, dealing with one round of comments following a meeting with the River Severn Working Group (and/or other stakeholders).
	• A prototype of a dashboard tool enabling rapid visualisation of model and interrogation of model results for all stakeholders.
	• Meeting with the River Severn Working Group (and/or other stakeholders) – if not HR Wallingford offices, venue to be decided upon, organised, and covered, by TWUL to present findings to date and discuss visualisation tool. Meeting to cover:
	  ○ Acceptability of tool
	  ○ Scenarios to be developed

	Model, screening tool, and dashboard development phase
	○ Additional metrics / information which would be of value
Working days*	95

* *These elements are indicative, and will be finalised if HR Wallingford are commissioned to undertake this work.*

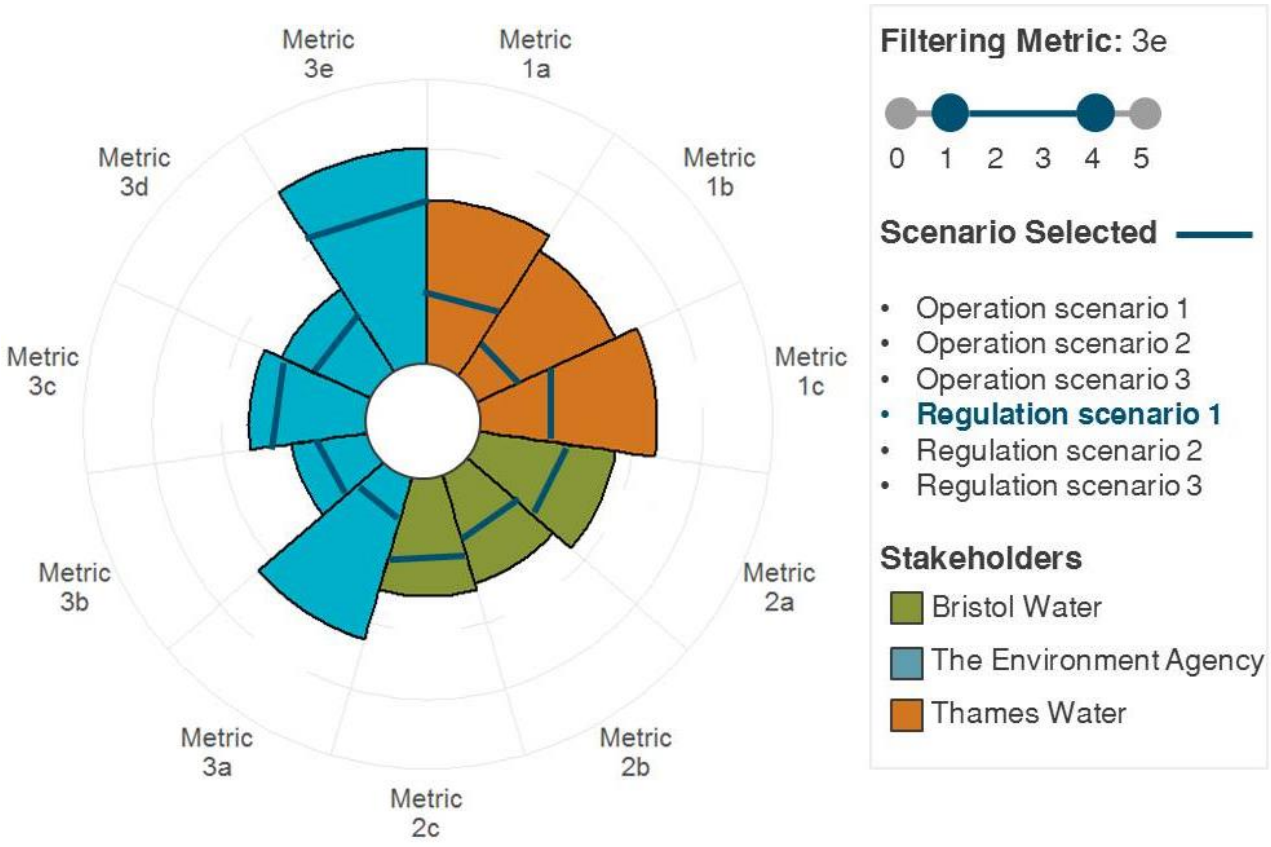

Figure 2: Potential interactive dashboard visualisation of results from scenario testing phase

Note: Metrics and stakeholders presented are for presentation only.

3.5 Scenario testing phase and final reporting

Table 14: Summary of scenario testing phase and final reporting*

	Scenario testing and final reporting phase
Objective	The final phase of work will reflect on discussion with the River Severn Working Group (and other stakeholders) to refine the interactive dashboard and develop scenarios or value to all stakeholders. Potential tasks are outlined below, but any work will be informed by the previous phase of work, and discussions with stakeholders.
Tasks	• Update dashboard to reflect outcomes of River Severn Working Group meeting. • Development of scenarios based on River Severn Working Group meeting, to include: ○ Operational scenarios ○ Drought scenarios ○ Stochastic scenarios ○ Optimisation of abstraction and discharge points

	Scenario testing and final reporting phase
	• Run scenarios through Kestrel-IHM, Kestrel-WRM, and water quality screening tool to filter scenarios for detailed input to InfoWorks ICM model. • Run selected scenarios through InfoWorks ICM model. • Analyse results. • Report on models.
Deliverable	Reporting of results dealing with one round of comments within two working weeks of receiving all comments
Working days*	60

* *These elements are indicative, and will be finalised if HR Wallingford are commissioned to undertake this work.*

4 Deliverables

A summary of the deliverables outlined in Section 3 is provided below. These deliverables are dependent on the scope of work TWUL undertake, and will be finalised if HR Wallingford are commissioned to undertake this work. All model development and reporting will follow HR Wallingford quality assurance procedures (see Section 5).

Technical notes and reports

- Scoping phase technical note: A brief technical note of recommended model improvements to capture the most important metrics for all stakeholders.
- Model update phase technical note: A brief technical note on process and results of updating existing models, including analysis of new UKCP18 evidence.
- Modelling report: A report detailing the water quality, water resources, and water quality screening tool development phases, scenario development, results of modelling, and discussion of implications for a sSTT scheme.

Models, tools, and data

- A water quality model of the River Severn, River Avon, and River Thames migrated to InfoWorks ICM. The extent of the water quality model may also be updated to include the Gloucester and Sharpness Canal. A number of processes may be included, or updated, as part of the work, these include, but are not limited to, diffuse inputs, transfer of saline water, water quality changes in pipeline, and algal blooms.
- A water resources model of the River Severn, River Avon and River Thames in Kestrel-WRM.
- An integrated hydrological model of the River Severn and River Avon in Kestrel Kestrel-IHM.
- Representative sample of UKCP18 evidence for the River Severn and the River Severn.
- Results pack from UKCP18 analysis, provided in a format compatible with HR Wallingford's Climate Change and WRMP tool developed as part of the UKWIR project of the same name. This will allow TWUL staff to interrogate and visualise results and select scenarios based on user-defined metrics.
- Scenarios developed in collaboration with TWUL and several other stakeholders, including, but not limited to, the Environment Agency, Natural Resources Wales, Severn Trent Water, and Bristol Water. Scenarios may include, but are not limited to, operational scenarios, regulation scenarios, and climate change scenarios.

- A water quality screening tool to identify which scenarios should simulated using the InfoWorks ICM model. The discrepancy in run times between models built using the Kestrel suite and InfoWorks ICM mean that such a tool would enable a systematic, but targeted, testing of water quality models.
- A dashboard tool enabling rapid visualisation and interrogation of model results for all stakeholders.

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Document information

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22 Jun 2018	01-00	ABM	TEJ	CJC	

Annex XX4: Ricardo Energy & Environment: Environmental Investigations and Survey Requirements for Severn Thames Transfer flow augmentation options.

This Technical Note sets out the likely scope of investigations and surveys that would be required should the River Severn river flow support options be required to be progressed in the future.

1. Vyrnwy Flow Support Scheme

The requirements for further investigations and monitoring work have been set out in the report issued in February 2018 to Natural Resources Wales on the environmental assessment of the Vyrnwy Flow Support option.

Element	Tasks	Outcome
1. Discharge from Vyrnwy Reservoir to Afon Vyrnwy		
a	Review operating pattern from TW water resources simulation model to determine magnitude and pattern of change in flow regime	Consideration of engineering practicalities for operating against this pattern, and the requirements for any mitigation measures immediately downstream of the dam.
b	Review raw water quality (mainly DO and temperature) and its variability, at times of likely scheme operation based on Thames Water's water quality continuous monitoring data at Vyrnwy Reservoir. Continue water quality continuous monitoring to establish comprehensive baseline against different reservoir discharge rates (and to compare to ecological monitoring survey evidence). Assess risks of hydraulic scour to the river bed/channel and impact on flora/fauna – site walkover survey and river channel cross-section survey for first 1km of Afon Vyrnwy to confirm risk assessment and inform mitigation measures. Carry out series of flow trials and monitor hydrology, hydraulics, geomorphology, water quality and ecology before, during and after the trials to assess effects immediately downstream of the dam.	
c	Review requirements for operational controls and associated mitigation measures with NRW, UU and Severn Trent Water as appropriate.	
2. Downstream Afon Vyrnwy to the River Severn Confluence		
a	Continue water quality continuous monitoring at agreed sites with NRW to establish comprehensive baseline against different flow conditions (and to compare to ecological monitoring survey evidence).	Consideration of hydrological, ecological and water quality effects in the Afon Vyrnwy against appropriate reference conditions
b	Scope and agree with NRW (and EA if applicable) the additional monitoring and/or modelling required to reduce uncertainty in the existing environmental assessment: 1. Carry out series of flow trials and monitor hydrology, hydraulics, water quality and ecology before, during and after the trials to assess effects on the Afon Vyrnwy. Include video and photographic evidence at key locations (joint effort with NRW). 2. Carry out ecological and water quality monitoring at	

	targeted flow conditions and relevant times of year in the affected river reach + suitable control site (e.g. on the Afon Tanat). 3. Carry out hydrological, geomorphological and river cross-section surveys to inform hydrological and hydraulic modelling of effects on flow regime, river channel characteristics and relevant fish habitat. Consultation with NRW has indicated that the main water bodies and fish species to focus upon are: • GB109054049880 from Lake Vyrnwy Reservoir to the confluence with Afon Cownwy for brown trout • GB109054049720 from the confluence with Afon Cownwy to the waterfall at Dolanog for brown trout • GB109054049720 from downstream of the waterfall at Dolanog to the confluence with Afon Tanant • GB109054049852 for brown trout, Atlantic salmon, European eel, lamprey and sea lamprey • GB109054049800 from the confluence with the Afon Tanat to the River Severn confluence for bleak, brook lamprey, bullhead, chub, dace, European eel and roach. Targeted electric fishing surveys required at key sites to be agreed with NRW under different specified hydrological conditions (July to September) to improve confidence in the assessment of potential effects of the flow support scheme. A proportion of the surveys must be fully quantitative in order to calibrate semi-quantitative surveys. No timed electric fishing surveys should be undertaken as this method provides less statistically robust data. A 2 year fish survey programme should suffice. This will inform a quantitative fish assessment. For lamprey-specific electric fishing surveys, monitoring of optimal and sub-optimal habitat with adequate coverage of the study area in one year should be undertaken. The data can then be used to establish the status of lamprey within the full hydrological zone of influence and identify if any further monitoring is required. If this monitoring confirms the very low densities suggested by the existing data, then no further monitoring would need to be undertaken. However, if greater densities are recorded, some additional monitoring would need to be undertaken alongside the other fish surveys. Monitoring should be undertaken in September/October at all optimal and sub-optimal sites identified during a preliminary walkover survey. For macroinvertebrates, spring and autumn baseline surveys are required (ideally under conditions likely to arise during scheme operation) to inform analysis to species level (rather than the biotic index level currently available). 2 year survey programme should suffice. This will inform a quantitative impact assessment. The flow trials and surveys will inform: a) hydraulic modelling to assess implications to river channel characteristics and fish habitat. b) water quality mixing model to assess effects on key water quality parameters important for aquatic ecology.	

There is a risk that the releases from Vyrnwy Reservoir direct to the Afon Vyrnwy will not be acceptable environmentally and that instead an alternative option to release water via the UU Vyrnwy Aqueduct, new raw water pipeline and discharge to the River Severn downstream of the Afon Vyrnwy confluence. If this option is required to be investigated the following scope of work would be required:

Element	Tasks	Outcome
1. Discharge to River Severn		
a	Review operating pattern from water resources simulation model to determine magnitude and pattern of change in flow regime	Consideration of engineering practicalities for operating against this pattern, and the requirements for any mitigation measures immediately downstream of the discharge point
b	Review raw water quality (mainly DO and temperature) and its variability, at times of likely scheme operation based on existing EA water quality monitoring data. If necessary, carry out some site-specific water quality continuous monitoring to establish a baseline against different discharge rates (and to compare to ecological requirements) to inform the need for any mitigation measures. Assess risks of hydraulic scour/local velocity increases to the river bed/channel and impact on flora/fauna – site walkover survey and river channel cross-section survey (ADCP survey) to establish baseline velocity profile for first 5km downstream of the discharge point to inform the need for any mitigation measures. Review available fish data and agree scope of a localised fish survey to establish the species and populations in the vicinity of the discharge point to determine any mitigation measures, in particular in respect of designated species (e.g. salmon, lamprey, eel). Carry out riparian environmental walkover survey and aquatic ecology survey of the proposed new discharge point to establish any sensitive habitats and species (e.g. Protected Species, Priority Species/Habitats, SAC features) that could be affected by the construction of the discharge facility.	
c	Scope and agree with EA the modelling required to support assessment of the effects on river water quality (and consequent effects on ecology). It is not anticipated that hydraulic modelling would be required but a contingency allowance should be made for this possible requirement. Carry out environmental assessment of the flow discharge and construction of the discharge facility, including consideration of the field survey findings and the need for mitigation measures. Carry out HRA and WFD assessments	
d	Review requirements for operational controls and associated mitigation measures with EA.	
2. Pipeline from the Vyrnwy Aqueduct to the River Severn		
a	Agree scope of environmental surveys with EA, Natural England, Historic England, local planning authorities. Carry out Phase 1 habitat survey, Great Crested Newt survey and other species-specific surveys to establish the ecological	Consideration of hydrological, ecological, landscape, recreation, local community and heritage effects of the

	baseline of the pipeline corridor. Review any effects on hydrology and the aquatic environment via a targeted walkover survey of the pipeline corridor (including river crossings and the possible effects on wetland habitats). Carry out heritage assets walkover survey in dialogue with Historic England. Review available groundwater and hydrological data to assess potential risks of groundwater impedance to wetland habitat and/or risks to water quality and flooding/drainage, with particular reference to designated European and national conservation sites. Carry out HRA and WFD assessments. Carry out environmental assessment using all SEA topic areas.	pipeline construction and operation.

Technical note prepared by:

Dr Martin Ferreira, Trevor Wade and John Sanders

Ricardo Energy & Environment

6 July 2018

Annex XX5: Centre for Ecology and Hydrology: Scope for algal studies for Severn Thames Transfer.

1 Further algal growth experiments (Lead: Dr. Mike Bowes)

It is imperative that we study how River Severn algae behave when transferred into the Thames when each river has differing chlorophyll and nutrient concentrations. Initial ongoing studies funded by Thames Water have shown that this is not an issue when nutrient and chlorophyll concentrations are similar. However, we suspect that we could get major algal bloom problems in the lower Thames when the two rivers are out of sync in terms of algal biomass. If the Severn algae are blooming and the Thames isn't, then the water transfer scheme would introduce large amounts of algal biomass into a nutrient rich stretch of the River Thames. If the Thames is blooming, and the Severn isn't, then the transfer would introduce nutrients (particularly phosphorus and silicon) into the mid-Thames which would relieve the nutrient limitation of the algae and exacerbate the bloom. CEH have tried to capture this in our present Thames Water-funded microcosm study, but unfortunately there have not been any periods of significant algal growth in either river over the last two years.

Proposal 1. We propose to carry out some more microcosm studies in the lower Severn and mid-Thames in spring / early summer, if high chlorophyll concentrations occur in either river. This would provide growth rates of algae, diatoms and cyanobacteria in each river, and vitally, growth rates of the River Severn plankton community when transferred into the middle Thames. This project would only be carried out if an algal bloom actually occurs. We will be prepared to deliver this at short notice if algal conditions become suitable.

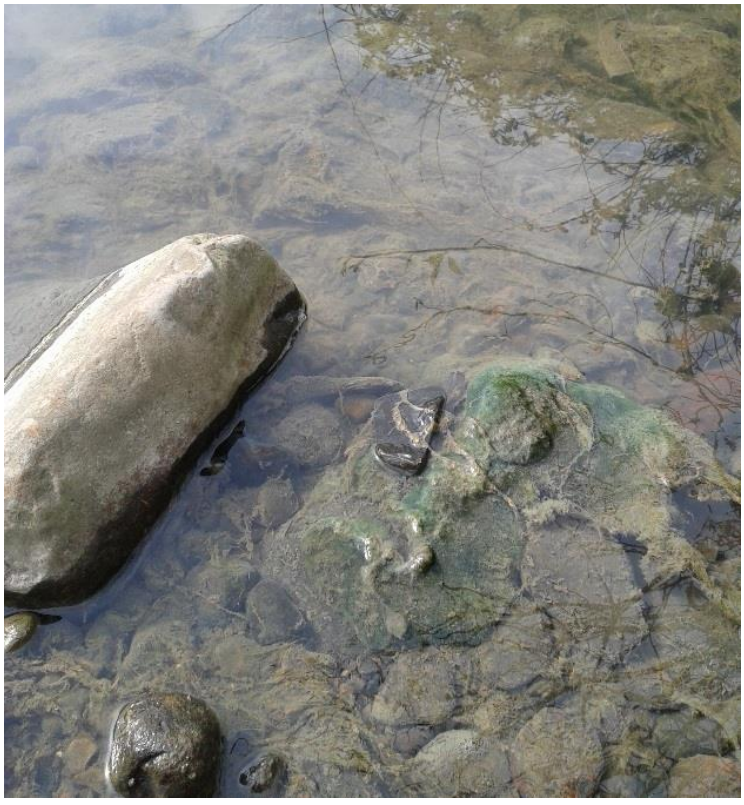
Proposal 2. Lab microcosm studies. CEH will utilise their dialysis membrane microcosms within their controlled temperature lab facilities, to mimic the impact of blooms in either the Severn or mid-Thames. Water from the Thames will be cooled to ~17oC in full light, to allow the diatom community to grow rapidly (mimicking a spring bloom with accompanying nutrient depletion). Nutrient concentrations will be then increased by (1) increasing P, N and silicon concentrations and (2) by adding river water from the Lower Severn, to simulate the proposed water transfer. The impact on diatom, algal and cyanobacterial growth rates will be quantified by flow cytometry (Read et al., 2014). In the second experiment, River Severn water will be transported to our controlled temperature labs and a bloom allowed to develop. This water and algae will then be added into a bulk sample of Thames water to simulate the water transfer, and phytoplankton growth rates measured by flow cytometry. These experiments will determine if there is a risk of increased chlorophyll levels in the lower Thames due to the transfer scheme.

2 Impact of pipe transfer (Lead: Dr. Mike Bowes)

As outlined in the CEH Briefing Note5, pipe transfers and culverts can greatly alter the plankton community, shifting from algae to bacteria. This has caused problems for other water companies, with the Environment Agency failing WFD monitoring sites due to the

[5] Centre for Ecology and Hydrology (2018), Natural Environment Research Council, Briefing Note on the impact of the Draft Water Resources Management Plan 2019, Dr Mike Bowes & Dr Alex Elliott

presence of what they term “sewage fungus”. This has led to costly CSO investigations by the water company, as it is assumed by the EA that this grey biofilm (see photos below) is caused by excess nutrients, rather than a lack of light within pipes and culverts. CEH have already used our flow cytometry technique to help water companies demonstrate that the presence of this aesthetically unappealing biofilm is due to shading and increase in bacterial numbers, and not sewage contamination.



“Sewage Fungus” at culvert and pipe outlets in County Durham

Proposal 3. CEH will take samples from the inputs and outputs of similar pipe transfers within the Thames Water region (or other water companies if needed), or simulate in the lab, by recreating the light, temperature and transit time conditions for the proposed water transfer. The algae and bacterial community would again be characterised by CEH's flow cytometry technique, to assess how the transit time of the proposed transfer may affect the community composition of the River Severn water. This experiment and monitoring will determine if sewage fungus is likely to be a problem at the transfer point in the mid-Thames, and we could investigate the impact of different pumping rates / pipe residence times.

3 River water quality and ecological modelling using QUESTOR (Lead: Dr Michael Hutchins)

QUESTOR is a 1D eutrophication model of water flows and quality in river networks (Hutchins et al., 2016). It splits the river into reaches of approximately 2km lengths. The model is primarily used to simulate and predict phytoplankton blooms and dissolved oxygen response. QUESTOR has been used to represent future change for example to consider issues of climate (Hutchins et al., 2016) or increased water demand (Hutchins and Bowes, 2018). Interventions to reduce nutrient loads and light input to the river have also been evaluated (Hutchins et al., 2018). It represents inputs from tributaries and sewage effluents (flows and pollutant concentrations of N, P, suspended sediment and BOD). Other artificial influences such as abstractions and weirs are also included.

3.1 Proposed work with QUESTOR river model

- Model water flows and water quality impacts (nutrients, dissolved oxygen, chlorophyll) at daily time-step in the River Thames of a transfer of 180 M L/d (2.083 m3/s) to the Thames at Culham.

- Model water flows and water quality impacts at daily time-step in the River Thames of a transfer of 148 Ml/d (1.713 m3/s) to the Thames at Culham.

- Model water flows and water quality impacts at daily time-step in the River Thames of a transfer of 60 Ml/d (0.694 m3/s) to the Thames at Culham.

- For the middle option (148 Ml/d), model the water flows and water quality impact of introducing the water at Lechlade instead of Culham.

- Model abstraction at a constant daily rate (to be advised by Thames Water) at a new reservoir in Abingdon and assess the impact on water flows and water quality in the River Thames.

For each of these 5 scenarios the model will otherwise use present day water management (i.e. present day abstraction rates at Farmoor, present day rates of sewage effluent returns). These are already set up in the model. We will assess impacts of each of the scenarios at a set of locations downstream and compare them to present day conditions. The Thames model is split into reaches approximately 2 km in length. The present day baseline climate conditions on which QUESTOR has been tested and is currently based are 2009-12.

The QUESTOR model is very flexible, and we would be able to run it for any River Severn water transfer scenarios that Thames Water suggest. For instance, we could investigate -

- The impacts of varying the water transfer rates through the year on chlorophyll, DO and nutrients.
- The impacts of droughts of different magnitudes on water quality and chlorophyll.
- We can also link the model to PROTECH water quality outputs and model the impact of reservoir discharges from Farmoor or the proposed Abingdon reservoir on the lower River Thames.
- We can do all the above under future conditions that are different to present day: i.e. changes in flow (wetter/drier) water temperature (hotter/colder), improved sewage treatment for phosphate, change in riparian management (planting/felling trees)

4 Invasive species and Environmental DNA (Lead: Dr Daniel Read)

There is always a concern that inter-basin water transfers result in the spread of nuisance species from one catchment to another. CEH can offer environmental DNA screening of the Severn and Thames, using our in-house sequencing facilities, to identify the presence / absence of a range of aquatic species. For example, we could use seasonal bulk DNA water sampling in both rivers to identify if particular species (i.e. invasive or problem species, such as quagga mussels, killer shrimp etc.) were present, using an established PCR technique. The cost would be approximately £5k for one species (including sampling costs), and £2k for each additional species of concern.

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