

Thames Water Final Water Resources Management Plan 2019

Technical Appendices

Appendix L: Water reuse

Table of contents

A.	Introduction	2
B.	Planned indirect potable reuse	2
	What is indirect potable reuse?	2
	Our planned IPR water supply options	3
	Considerations when implementing large-scale IPR	7
	IPR research programme.....	15
	IPR concluding remarks.....	41
C.	Non-potable reuse	41
	What is non-potable reuse?	42
	Our non-potable water reuse options for new developments.....	43
	Old Ford water recycling plant (OFWRP)	45
	Lesson learned – our experience to date with non-potable water.....	46
	What's next – the challenge of implementing a non-potable system?	47
	Concluding remarks non-potable water	48
D.	Environmental flow augmentation	48
	Our draft WRMP19 position	49
	Investigations summary – post dWRMP19 submission	50
	Common understanding between the Environment Agency and Thames Water	54
	Research programme scope	55
	Concluding remarks for flow augmentation scheme.....	60
E.	Public and stakeholders risk perception	60
	Collaboration on risk management	60
	The effect of media on public perception.....	61
	Significance of message framing	62
	Multi-criteria stakeholder evaluations of risk intervention	62
	Concluding remarks for public and stakeholder risk perception.....	62
Annex 1:	Assessment of Deephams Reuse option	64
	Option description	64
	Assessment of option to date	65

Figures

Figure L-1: Planned indirect potable reuse.....	3
Figure L-2: Spreadsheet tool's output graph	9
Figure L-3: Number of identified water quality parameters that may pose a risk if not removed	10
Figure L-4: IPR plant operational modes	15
Figure L-5: Research programme work packages	19
Figure L-6: Three-tiered approach for benchmark values identification	26
Figure L-7: Flow diagram indicating the methodology for risk assessment after calculation of RQ	27
Figure L-8: A conceptual water reuse risk management framework	39
Figure L-9: Water use by use type, non-potable supply and demand.....	42
Figure L-10: Teddington DRA option	49
Figure L-11: Deephams Reuse schematic	64

Tables

Table L-1: Feasible planned IPR options for WRMP19.....	5
Table L-2: Summary of high priority water quality parameters and impact associated on the environment and public health across studied sites	11
Table L-3 : Water reuse technology strategies - advantages and disadvantages	12
Table L-4: Proportion of wastewater effluent in the Rivers Lee and Thames ⁸	17
Table L-5: Research programme timeline	19
Table L-6: Trade effluent proportion (TE %) in incoming wastewater to WWTW by volume and population equivalent (PE).....	25
Table L-7: Number of parameters posing an environment or public health risk per contaminants' category.	28
Table L-8: Summary of risks parameters identified across sites and required contaminant removal...29	
Table L-9: Summary of schemes where IPR technologies have been assessed	34
Table L-10: Non-potable water reuse feasible options.....	45
Table L-11: Investigation summary table.....	51
Table L-12: WRMP14 and WRMP19 option flows summary.....	68

Appendix L.

Water reuse

- We have identified the use of wastewater (water reuse) to support water resources as a feasible option for our Water Resource Management Plan 2019 (WRMP19). We have reviewed three distinct reuse systems each producing a multiple of supply-demand options to be considered deriving the preferred plan.
- Firstly we have included supplementing abstracted potable water resources (termed **planned indirect potable reuse**) where we consider additional risks to drinking water and the environment from the return of additional wastewater volumes.
- Secondly we have examined the creation and management of **non-potable water** to reduce the demand for potable water in applications such as toilet flushing and landscape irrigation. Non-potable water reuse systems must take into account and endeavour to avoid the potential for misuse and misconnection.
- Thirdly our reuse system includes the transfer of wastewater into new environmental discharges specifically to facilitate increased abstraction. This is termed **flow augmentation**. This results in no change in risk to drinking water but we must maintain or improve ecological status of the receiving river in creating options for the plan.
- For Indirect Potable reuse five sub-options were identified with a combined maximum deployable output of 816.5 Ml/d (Section B below). Due to the nature of this water resource (wastewater), we have developed risk assessment methodologies to ensure risks to the environment and public health are identified and risk mitigation techniques included. We have tested different technologies to assess their operability and efficiency at eliminating those risks. Based on the risks identified and the trialled technologies' performance it is proposed that reverse osmosis membranes followed by advanced oxidation processes should be included in all planned water reuse treatment schemes, whatever their deployable output. This supports our aim to continue achieving high compliance with drinking water regulations and promote schemes that will gain widespread public acceptance. The suitability of our approach to assess and mitigate risks was confirmed by Professor Jennifer Colbourne, former Chief Inspector of the Drinking Water Inspectorate. However, further work is required in the domain of understanding the presence of pathogens as well as relating our approach to the current regulatory risk assessment (Drinking Water Safety Plan).
- Concerning the non-potable water reuse option (Section C below), potable water demand could be reduced by up to 33 Ml/d by implementing a combination of greywater recycling and rainwater/stormwater harvesting systems in new developments across London's 38 opportunity areas (as defined in the London Plan).

A. Introduction

- L.1 With increasing freshwater scarcity in South East England, the use of wastewater to support water resource augmentation is becoming increasingly attractive for water resource planners. This Appendix L summarises our approach to the feasibility of implementing water reuse within WRMP19, including:
- Planned indirect potable reuse (IPR) – IPR was identified as an option to increase water resources (Section B below);
 - Non-potable reuse (NPR) – NPR was identified as an option to decrease water demand from customers (Section C below); and
 - Using wastewater for environmental flow augmentation to support additional upstream freshwater abstraction (Section D).
- L.1 Note: This appendix does not aim to repeat what was provided in our Water Resource Management Plan 2014 (WRMP14), unless it is to:
- Remind the reader of the context of the work
 - Update results from the research introduced in Appendix L of WRMP14
- L.2 This Appendix was reviewed after public consultation of the draft WRMP19 as part of the final WRMP19 process.

B. Planned indirect potable reuse

- L.3 This section sets out our approach to establishing the scale for possible IPR within our water resource zones (WRZs). We have determined our preferred treatment technology based on establishing and exploring new approaches to environmental and public health risk. Controlling the identified and possible future risks is best achieved using our preferred technology of Reverse Osmosis and Advanced Oxidation treatment of pre-treated wastewater. We believe such a treatment system will also be most acceptable to the public. We have made this decision based on extensive research and with reference to worldwide best practice.

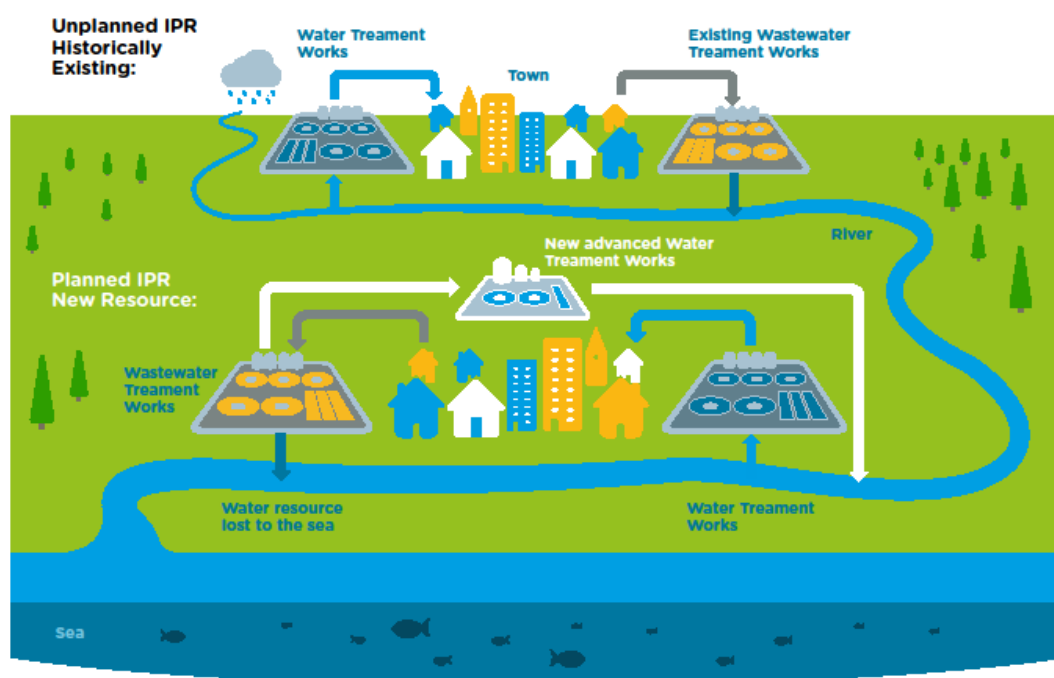
What is indirect potable reuse?

- L.4 In the United Kingdom, as in many countries, wastewater is treated and then discharged into a river or watercourse. This water then combines and blends with the natural river flow. Further downstream, water may then be abstracted for treatment and supplied as drinking water. This is called indirect potable reuse (IPR). “Indirect” indicates that the treated wastewater flows through a natural watercourse before being reused.
- L.5 IPR occurs in a majority of rivers and catchments in the UK. Where IPR is already happening it is a function of historical growth and development of towns and cities around water supplies. As this recycling of water already exists it is called unplanned IPR.
- L.6 In water stressed areas, such as the Thames catchment area, most of the available water resources have already been used. An example of this would be Oxford and London. Oxford is located upstream of London and its drinking water is sourced from the River Thames. In Oxford, wastewater is treated at sewage treatment works and then returned into the River Thames or

one of its tributaries. Water is abstracted from the River Thames near London, and is treated and put into London water supply.

- L.7 In water stressed areas, such as the Thames catchment area, most of the available water resources for drinking water supply have already been 'used'. To try and abstract more water from the watercourses could cause environmental damage. In these instances, water resource options may include options for planned IPR.
- L.8 Planned IPR occurs when wastewater effluent, that would not normally be available to support water supplies, is treated to an appropriate level and transferred to another place, where it can then be used to support the water available for drinking water supplies.
- L.9 Figure L-1 shows the differences between planned and unplanned IPR. In this instance wastewater effluent, that would normally be lost to the sea, is further treated and returned upstream in the same river. Here it can now supplement the water available for abstraction.

Figure L-1: Planned indirect potable reuse



Our planned IPR water supply options

- L.10 Thirteen wastewater source locations were identified through a review of our wastewater assets, including sewers and pumping stations for raw wastewater mining options as well as wastewater treatment works (WWTW), for screened wastewater or effluent mining.
- L.11 To comply with the Catchment Abstraction Management Strategy (CAMS), as set by the Environment Agency¹, only wastewater sources which are not contributing to current water supply (i.e. unplanned IPR) and environmental health were selected. As an example, any

¹ <https://www.gov.uk/government/collections/water-abstraction-licensing-strategies-cams-process>



wastewater sources contributing to the River Thames above Teddington weir were screened out to fulfil the above and to conform to the Environment Agency non-consumptive position for this part of the river basin.

L.12 The 13 options were examined using a series of factors to assess their potential as future planned IPR options. These factors included:

- Volume of wastewater available for reuse during drought conditions
- Planning, socio-economic and environmental impact, e.g. planning policy and history, land availability, potential impact on downstream abstractors, potential impact on nature conservation and biodiversity, potential impact on historic, archaeological and heritage sites
- Engineering criteria, e.g. requirement for network reinforcement, reclaimed water discharge location and distance from source, treatability of wastewater, and cost
- Property and legal factors, e.g. ownership of sites and tenancies where options could be implemented, cost estimated or land acquired

L.13 From the 13 options, five were identified as feasible. These options are summarised in Table L-1. The main reasons for screening out the eight other options were:

- The mutually exclusivity between options, where two or more options were using the same wastewater source. The best performing options was therefore chosen, based on cost and feasibility to implement (including land availability requirement for future extension, waste disposal routes and treatment, reclaimed water conveyance, and planning and social impact)
- Conveyance complexity due to significant conveyance length and number as well as type of pipeline crossing options.

Table L-1: Feasible planned IPR options for WRMP19

Wastewater source	Receiving water body	Flow capacity
Beckton WWTW effluent	River Lee flood channel upstream of the King George V intake or directly to the King George V or William Girling reservoir	50 to 380 MI/d
Deephams WWTW effluent	River Lee flood channel upstream of the King George V intake or directly to the King George V or William Girling reservoir	46.5 MI/d
Crossness WWTW effluent	River Lee flood channel upstream of the King George V intake or directly to the King George V or William Girling reservoir	50 to 190 MI/d
Mogden WWTW effluent	River Thames upstream of Walton intake or Lockwood/Banbury Reservoirs	50 to 200 MI/d 212 MI/d
Kempton South Sewer (raw wastewater)	River Thames upstream of Walton intake	50 MI/d

Note: MI/d stands for megalitre per day. 1 megalitre is equivalent to 1,000,000 litres

L.14 More details on how these feasible options were identified can be found in the associated feasibility report². In totality the maximum identified feasible volumes amounts to a maximum potential 816.5 MI/d.

² Mott MacDonald (2017), Thames Water WRMP19 Resource Options, Water Reuse Feasibility Report (<https://www.thameswater.co.uk/wrmp>)

- L.15 Within our preferred plan in Section 11 we have included the Deephams Re-Use option, being delivered in 2030. In Annex 1 a description and assessment of this option has been considered, describing the deployable output, environmental impacts, flow effects to Hackney Marshes, effect of discharging re-use effluent and impact on navigable channels.

Why have we not included direct potable reuse?

- L.16 Direct potable reuse (DPR) occurs when wastewater is treated to drinking water standards and is either blended with water from other sources at the WTW or in the drinking water network, without discharge to an environmental buffer. Direct potable reuse is relatively uncommon. Examples include the Windhoek DPR plant in Namibia, where treated wastewater has been blended with potable water for more than 40 years, and the Wichita Falls and Big Spring in Texas, with more DPR schemes to be expected in the future in the USA.
- L.17 There are some benefits from implementing DPR:
- The highly treated wastewater is not subject to potential environmental contamination and an environmental permit for discharge is not required
 - All treated wastewater will serve as drinking water. If returned to an environmental buffer some of the treated wastewater could be lost through evaporation or infiltration, or not abstracted
 - The scheme would likely cost less as the treated wastewater would not be subject to further abstraction and treatment costs
- L.18 However, there are various reasons for not proposing a DPR scheme. These include:
- Removal of barriers in a widely applied multi-barrier approach:
 - The environment buffer contributes to mitigate risks from chemical and microbial contaminants
 - Dilution of the treated wastewater by the environmental buffer will reduce contaminant concentrations
 - Removal of these contaminants will start in the environment, either by sedimentation, adsorption or photolysis
 - Lack of knowledge: the UK is far behind countries such as the USA, Australia, Namibia and Singapore in terms of planned water reuse and does not have the knowledge to operate water reuse plants for potable water applications. For most of the countries cited above, water reuse started many years ago with the implementation of Non-Potable Reuse (NPR) systems. Once enough knowledge about the technology used has been gained, IPR and then DPR were implemented. In the UK, while unplanned IPR is common place, NPR plants are still rare, although there are a number of schemes now in planning. This is discussed later.
 - Reduction of reaction time: in the event of treatment failure, the reaction time to avoid contaminated water entering the drinking water supply system will be reduced.
- L.19 For those reasons, we are not promoting the implementation of a DPR scheme until the more widely practised option of IPR has been more widely practised in the UK.

Considerations when implementing large-scale IPR

- L.20 An IPR scheme involves the diversion of treated wastewater from one location to another, with the discharge location being a surface water body within the catchment of a drinking water treatment works (WTW). This new discharge may affect water quality of this surface water body and may pose risks to the environment and public health. It is thus paramount to assess the required water quality of the discharged water needed to mitigate those risks. A consistent discharge standard risk assessment methodology allowed identification of 44 water quality parameters that are present on one or more wastewater effluents that would require reduction before being discharged to the new location in an IPR scheme. The same methodology was applied across all WRMP options. Due to the nature of some water quality parameters, a RO-based treatment train followed by advanced oxidation process (AOP) was considered for all IPR schemes (See subsections 'Required water quality of the discharged reclaimed water to the environment' and 'Proposed treatment trains').
- L.21 The use of this new water resource means that less freshwater is likely to reach the Middle Thames Tideway. The inclusion of RO technology would also lead to the potential discharge of a brine stream. This could have an impact on the salinity gradient of this reach of the tidal River Thames, and thus its ecology. It has to be noted that this could be true with other proposed WRMP19 options, including desalination and DRA options. Our study concluded that IPR brine discharges are unlikely to have an ecological impact. We have established that reduction of freshwater greater than 15-20% (275-366 Ml/d) in the Middle Thames Tideway could potentially create an ecological impact.
- L.22 Please refer to Appendix B and BB for further information on this potential impact.
- L.23 Finally, the water reuse plant is unlikely to be operated continuously, but on a requirement for extra resource basis at times of low flow. For this reason an operating philosophy was identified to ensure the plant is kept operational at all times, alternating nine months of "care and maintenance" mode (when it is unlikely this resource would be required) with three months of "hot standby" (where the plant is operated and supplies a minimum flow, ready to ramp up to full flow in less of a day).

Required water quality of the discharged reclaimed water to the environment

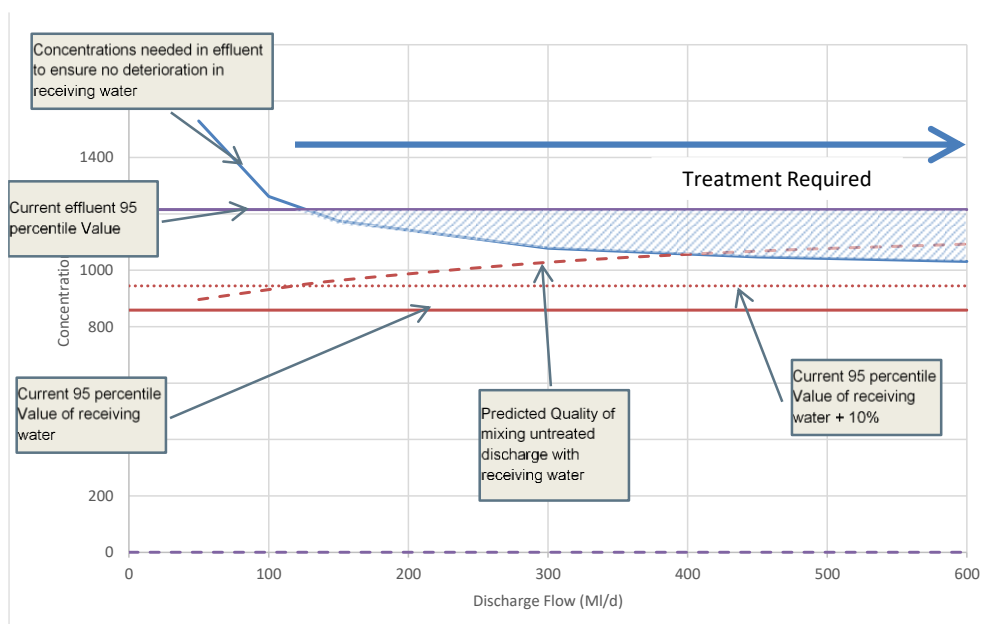
- L.24 Any IPR scheme will involve the discharge of treated wastewater effluent into a surface water body (river or surface reservoir) which is used for abstraction of drinking water. Consequently, IPR may have an impact on the environment and public health. It is therefore important to understand such risks and establish appropriate water quality standards needed to mitigate them. This section describes our standard methodology and is based on interpretations of environmental legislation and the drinking water safety plans (DWSP) used to protect public health. We identified 44 parameters that require removal through any IPR scheme. Of these 23 were considered high priority. For large scale IPR schemes the treatment system needed to control those risks was deemed to be RO followed by advanced oxidation.
- L.25 In collaboration with Mott MacDonald³ a methodology was developed to identify consented water quality parameters that could cause a risk to the environment and public health should

³ Mott MacDonald (2017), Thames Water WRMP19 - Discharge Standard Cross-option Study Volume 1: Methodology, May 2017 (<https://www.thameswater.co.uk/wrmp>)

final effluent from treated wastewater (before accounting for any additional treatment) be discharged into the considered river/reservoir prior to re-abstraction. The methodology was designed such that it is applicable to all WRMP19 water resource options where a water discharge to the environment occurs. This consistent approach thus applies to the Teddington and River Lee DRA schemes, and the Severn-Thames transfer.

- L.26 Two overarching assumptions were made, namely:
- There should be no material deterioration in the quality of the water with respect to environmental conditions
 - There should be no material deterioration in the catchment risk positions (i.e. increased risk) associated with the DWSPs
- L.27 Based on these assumptions, a spreadsheet tool was developed to assess the required water quality for each potential discharge of treated wastewater (design standards) to comply with the Water Framework Directive (WFD) requirement for achieving/maintaining good status of the water body and to not compromise our DWSP (and hence the removal through a potential IPR plant).
- L.28 Benchmark water quality (i.e. maximum contaminants' concentration to achieve in the environment after discharge) used in the spreadsheet were:
- The environmental quality standard (EQS) required by the WFD and the Environment Agency to meet good ecological status (environmental risks)
 - The drinking water consent as set by the Drinking Water Inspectorate and any maximum/alert concentration allowed for abstraction as indicated in our DWSP
- L.29 "No Deterioration" is a WFD related concept that aims to ensure that the status of a waterbody does not get worse. Where there is evidence to suggest that deterioration is occurring, *or could occur*, as a result of a discharge, a permit limit is calculated (and in the case of existing permits, a new limit is calculated). The formal assessment guidance states that "no determinand in the proposed discharge must be predicted to cause deterioration beyond the current class boundary in the receiving water". The Environment Agency may allow a within class deterioration of up to 10% in the mean and 90th (or 95th) percentile of the current water quality (for each individual determinand).
- L.30 The tools have been developed to reflect the Environment Agency's River Quality Planning (RQP) model software, which was previously used to define discharge permits to river. Once developed, water quality results from the sampling are entered into the spreadsheet tool and consented water quality parameters, for which treatment is required (and to which extent), are identified. An example of the tool's output graph is provided in Figure L-2, and presents the concentration of a parameter as a function of discharge flow. The graph identifies the treatment required at different discharged flows to ensure no deterioration of quality in the receiving watercourse (in this example for flow > 125 Ml/d). The spreadsheet tool will be updated on a regular basis whilst sampling continues that may identify new risks.

Figure L-2: Spreadsheet tool's output graph



Source: Mott MacDonald⁴

L.31 The results for each water quality parameter have been assessed and scored with respect to the need for treatment. This assessment established different priority considerations as follows:

- High priority water quality parameters: where treatment is required to ensure compliance with a regulated parameter (either environmental or drinking water). For the parameter of concern:
 - There is an EQS / WFD standard and concentration is greater than 10% of respective values
 - There is a prescribed concentration or value (PCV) and concentration of discharge is greater than 50% of respective value
- Medium priority water quality parameters: The concentration is less than 50% of respective PCV value
- Low – Treatment is required to ensure there is “no material deterioration” in the receiving water quality. And:
 - No EQS / WFD standard or concentration is less than 10% of respective values
 - No PCV

L.32 This priority ranking allows to account for potential status improvement of the river to good ecological status (or above), if required.

L.33 More details of the methodology can be found in the associated report⁴. This report was reviewed by the Environment Agency, which found the approach to be sound. However, we

⁴ Mott MacDonald (2017), Thames Water WRMP19 - Discharge Standard Cross-option Study Volume 1: Methodology, May 2017 (<https://www.thameswater.co.uk/wrmp>)

agree with the Environment Agency that the method is likely to be conservative and requires sensitivity analysis to be carried out to assess water quality uncertainty.

- L.34 The application of this methodology has identified 44 water quality parameters that require removal through any IPR scheme. 23 high priority water quality parameters, 10 medium priority that may require consideration and 11 low priority water quality parameters. Figure L-3 summarises the number of water quality parameters as a function of their type. Table L-2 summarises the high priority water quality parameters identified and their associated impact on the environment and public health.

Figure L-3: Number of identified water quality parameters that may pose a risk if not removed

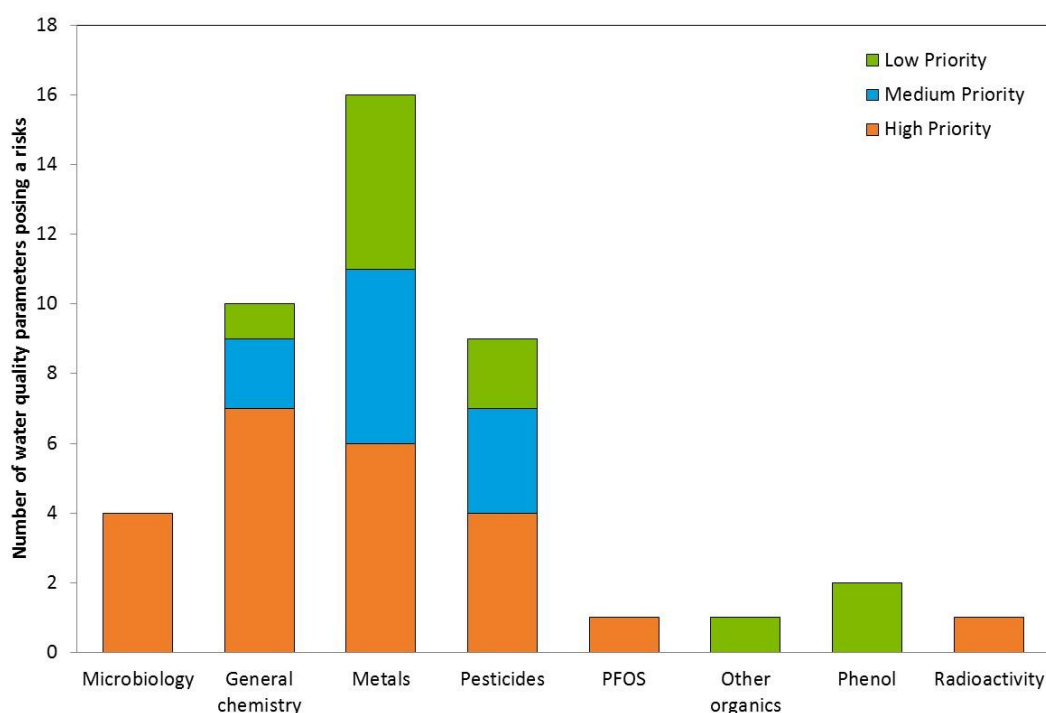


Table L-2: Summary of high priority water quality parameters and impact associated on the environment and public health across studied sites

Parameters	Potential impacts
Microbiology	<ul style="list-style-type: none"> Coliform, E.coli, Enterococci, Giardia Reduced water quality in river Increased challenge to receiving drinking WTW
General chemistry	<ul style="list-style-type: none"> Biochemical oxygen demand – Reduced water quality in river. Ammonia - Reduced water quality in river and could cause fish depletion. Presence of ammonia could be good where chloramine is used to disinfect the water, reducing requirement for ammonium sulphate dosing. However, WTW disinfecting the drinking water with chlorine would experience additional chlorine demand, which could lead to disinfection control problem. Nitrate/ nitrite – Eutrophication of water course. Potential of increased algal challenge at WTW. Exceedance of PCV, which could lead to WTW not able to abstract this water. Chloride & sodium – Concentration could become > 50% of PCV in the river. Potential taste complaints Cyanide – Exceedance of EQS in final effluent Colour – Reduced water in river and adverse impact to WTW's processes. Potential to form increase disinfection by-product in WTW treated water Phosphate - Eutrophication of watercourse. Potential of increased algal challenge at WTW.
Metals	<ul style="list-style-type: none"> Copper, Lead, Manganese, Nickel and Zinc Reduced water quality in river. Exceedance of EQS for copper. Exceedance of PCV for Manganese for one option. Concentration of some parameters in the river could become > 50% of PCV.
Pesticides	<ul style="list-style-type: none"> Carbendazim, Diuron, Mecoprop and Metaldehyde Exceedance of pesticide PCV
Perfluorooctane-sulfonic acid (PFOS)	<ul style="list-style-type: none"> Exceedance of the annual average EQS.
Radioactivity	<ul style="list-style-type: none"> Beta activity – exceed PCV on occasion. However, this elevated level might related to the naturally occurring potassium-40 isotope

L.35 Each reuse option has different water quality requirements (we term this the design standard) before return to the environment which in turn will change depending on the volume of water returned. Following the determination of those design standards, a treatment train was selected for each scheme to meet those standards.

- L.36 Large scale IPR schemes required treatment trains comprising reverse osmosis (RO) followed by advanced oxidation. Small schemes may not require RO-based treatment to meet those standards.
- L.37 However, as the size and the number of IPR schemes increase, some of the contaminant concentrations in the river would increase. Those increased challenges would necessitate specific treatment systems to be deployed eventually. In the case of chloride, there is a high level concentration within the Beckton catchment and for which removal is required due to the restriction on chloride concentration to the River Lee. For metaldehyde and hydrophilic organic compounds that are poorly removed by RO membranes (or GAC process) an AOP is eventually required.
- L.38 Two strategies were thus considered, both with advantages and disadvantages for the choice of treatment technologies for initially small scale IPR schemes with strong likelihood to require expansion in future. These strategies are summarised in Table L-3.

Table L-3 : Water reuse technology strategies - advantages and disadvantages

	Advantages	Disadvantages
Strategy 1 – Lowest cost technology is implemented until high cost technology is required	<ul style="list-style-type: none"> • Lower initial cost • Likely easier to operate (could be based on conventional treatment technology) 	<ul style="list-style-type: none"> • The scheme is likely to be replaced by a RO scheme in the future as the size or number of the schemes increase, increasing future cost. • No lesson learned from design and operation for a larger scheme • Risk of unknowns
Strategy 2 – Highest cost technology is implemented from outset	<ul style="list-style-type: none"> • Lesson learned from design and operation for a larger scheme • Higher capacity to treat for unknown water quality parameters that could pose risks to the environment and public health. 	<ul style="list-style-type: none"> • Higher initial cost • Likely to be more complex to operate as innovative technology will be used.

- L.39 As it is likely that the size and number of operating schemes will increase over the years, a RO-based treatment train would likely be required to mitigate risks from identified (and non-identified) water quality parameters. RO-based technology treatment followed by AOP has been assumed for all IPR water reuse schemes in WRMP19.
- L.40 Therefore discussion within the remainder of this document covering operating philosophy and salinity impact refers to RO only based schemes.

Impact on environment – salinity

- L.41 Any water resource scheme that reduces the net flow within the River Thames will change the dynamics of the tidal reaches of the Thames. If less flow of fresh water is interacting with seawater then some upstream stretches of the tidal Thames would see more saline water. Additional abstractions including those supported by water reuse do ultimately create such conditions – although this is not a 1 to 1 volume relationship as proportions of the abstracted waters are still returned to the river. Our studies described below have suggested that the salinity impacts become of concern when the net reduction in freshwater flow reaches 275-366 MI/d (equivalent to 15-20%) – based on current ecological baselines. Please refer to Appendix B and BB for further information on this potential impact.
- L.42 Following the publication of our WRMP19 Water reuse feasibility report², the Environment Agency requested a desktop study to establish the potential of cumulative impacts of feasible WRMP19 options (water reuse, desalination and direct river abstraction) on the receptors in the Middle Thames Tideway, with an emphasis on the ecological receptor communities. The possible effects investigated included:
- Immediate, local salinity effects
 - Longer term spatial effect on salinity in the wider Thames Tideway
 - Local changes in tidal level
- L.43 The main concerns include the decrease of fresh water flow in the Thames Tideway, as well as the discharge of brine from reverse osmosis membrane process, both used for water reuse and desalination schemes.
- L.44 The findings of the investigation are included in Ricardo's report "Middle Thames Tideway – Cumulative effects of re-use, desalination and DRA WRMP19 options"⁵, the main conclusions are as follows:
- Brine discharges would be diluted with STW effluent and the potential for local salinity impacts on the Middle Tideway for individual options is minor to negligible as local salinity levels are not expected to exceed background levels. Any resulting effects would be localised and not have a significant effect on the local ecology.
 - Cumulatively, the Middle Tideway resource options may result in a potential moderate exacerbation of normal patterns of salinity ingress, changing local salinities within the Middle Tideway. The magnitude of change is difficult to predict but the initial view is that **if** options which decrease freshwater inputs to the Middle Tideway including a reduction of freshwater discharges are greater than 15-20% (275-366) MI/d it could substantially affect the normal salinity patterns. Potentially sensitive ecological receptors in the estuarine habitats of the Middle Tideway include no (current) national or international designated habitats but at least ten different protected species. Of these, it is anticipated that at highest moderate, probably reversible impacts would occur on brown/sea trout, bullhead, European smelt (fish) and the swollen spire snail. In addition, a moderate, probable reversible impact is anticipated as a result of disruption of communities through displacement of individual species within the community mosaic due to individual species salinity preferences. In both instances,

⁵ Ricardo (2017), Middle Thames Tideway – Cumulative effects of re-use, desalination and DRA WRMP19 options

reversibility is considered to occur over the short to medium term, depending on the mobility and life cycle of individual species and how often the schemes are switched on.

- The implementation of some WRMP19 schemes could be decades away. The future ecological baseline of the Thames Tideway is difficult to forecast, with climate and other changes (e.g. implementation of the Tideway Tunnel) known to influence the future qualities of associated watercourses. A Marine Conservation Zone (MCZ) is proposed for the Thames Tideway for European smelt, European eel and tentacled lagoon worm, which could result in a minor impact in the future. Furthermore, recovery of the Thames estuary may have allowed more sensitive species to re-establish and a moderate impact could result in the future. Climate change (sea level rise, drier summers and potentially lower summer freshwater inputs) may also result in more routine and stronger saline ingress in the summer period and resilient communities would have to adapt to this regardless of the implementation of future water resource schemes
- Uncertainties in the assessment include a requirement to improve confidence in the exact predicted change in local salinities through development of a tideway model; and the absence of primary research evidence for salinity tolerances of some sensitive species (e.g. swollen spire snail). Provision of such evidence is unlikely to result in a significant improvement in prediction of the expected results.
- The effect of any changes in water level from [desalination] abstraction is considered likely to be offset by tidal inflow, resulting in no material impact on associated intertidal habitats.

- L.45 Furthermore, there is a future risk that development of total resource capacity in the Middle Tideway could reduce freshwater flows to an extent that would require the desalination options to be designed for sea water membrane technology (to match the increase in abstraction salinity). This has an impact of reducing plant recovery rate (80% for brackish water membrane to 68% for seawater membranes) and increasing plant capex and opex.
- L.46 More detailed analysis will be undertaken to substantiate this initial review and confirm the net reduction in freshwater flow point before change in salinity pattern, taking into account the added return flow to the environment from WWTW effluent (due to increase potable water demand).

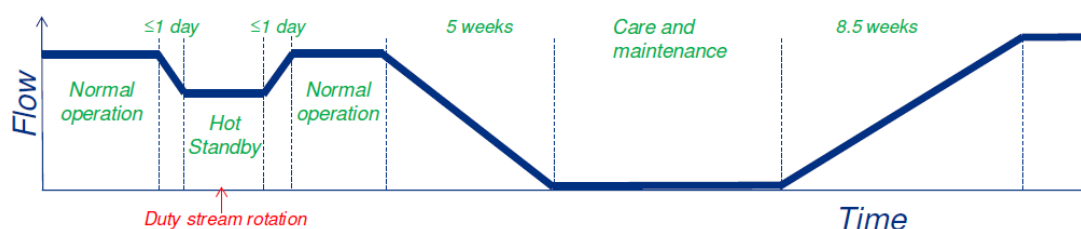
Operating philosophy

- L.47 It is not intended to operate the IPR scheme(s) continuously, but assumed that the IPR plant(s) will be on a “hot standby” mode for three months (April, May, June), and a “care and maintenance” mode for the remaining nine months of the year. It is important that our IPR options include such provisions within the modelling to establish the optimal plan. This allows the plant to be ready to ramp up to normal operation during drier months (April to August). This minimum utilisation scenario aimed at reducing risks of plant process deterioration such as membrane processes and loss of staff knowledge, risks that could occur if the plant was fully decommissioned when not required.
- L.48 During the “hot standby” mode, a minimum flow (corresponding to the capacity of one stream) would be rotated around the different streams of the plant to maintain the availability to all the

streams. This mode allows ramp up to normal operation (25%-100% of deployable output capacity) in less than a day, ensuring fast water resource availability should it be required, including drought periods and low river flow.

- L.49 When the plant is not needed for long periods of time, it would be placed in “care and maintenance” mode, where the flow will be reduced or stopped and the membranes put in preservative solution. This does not mean that the plant will be shut down as essential maintenance activities would occur during that period as well as ensuring that any mechanical and electrical parts remain in working order. It is estimated that eight and a half weeks will be required to ramp up the plant from the care and maintenance mode to normal operation and five weeks to ramp down the plant from normal operation to care and maintenance mode. Figure L-4 summarises the IPR plant operational modes.
- L.50 These modes were based on current Thames Water practices with regards to the Thames Gateway WTW.
- L.51 An example of the modes of operation is shown in Figure L-4.

Figure L-4: IPR plant operational modes



IPR research programme

- L.52 The remainder of Section B of this Appendix is concerned with articulating the IPR research programme. We are aware from previous WRMP submissions of the considerable public interest regarding planned reuse schemes. This necessitated us going beyond applying the discharge design methodology for options appraisal based primarily on consented parameters used within WRMP19^(2&4) and seeking to better articulate in measurable terms what constitutes wholesome drinking water in the context of an increased quantity of water reuse within water resources and emerging environmental and health concerns. In doing so we aim to put a fuller range of water quality parameters we have measured into a form of comparative framework to evaluate what mitigations, in the form of treatment technology and/or regular monitoring, may be appropriate.
- L.53 We have undertaken extensive water quality sampling of our wastewater sources and compared those against the receiving water environment – sampling for parameters that are not routinely carried out within the industry. We have piloted and continue to evaluate numerous treatment systems to understand performance and reliability. We have reviewed international practice to inform our position and supported numerous published academic papers.

- L.54 Our current assessment has highlighted further risks associated with non-consented parameters such as disinfection by-products, pharmaceuticals and other organics not part of previous discharge design standard.
- L.55 Based on our research to date an effective particulate and microbiological barrier in the form of an ultrafiltration (UF) membrane is required. A RO (RO) barrier is needed for inorganic materials (chloride, some dissolved metals) removal. For effective pesticide removal an additional advanced oxidation stage (AOP) is necessary. Our work on removal of the pesticide AMPA has indicated that GAC cannot replace the RO as an effective barrier ahead of AOP. RO followed by AOP also provides a demonstrable effective barrier against pharmaceutical and hormone risks.

Why has a research programme been required?

- L.56 We wish to better articulate what might constitute water wholesomeness in the context of increased levels of recycled water and therefore risks from such water sources within our abstracted water. Our particular focus is on parameters that are not explicitly consented at prescribed concentrations but which nevertheless are still covered under our statutory obligations.

Drinking water wholesomeness

- L.57 We are responsible for the supply of wholesome water to our supply region. Wholesome water is defined in The Water Supply (Water Quality) Regulation 2016⁶ as water that does not contain:
- Any micro-organism (whether or not a consented parameter) or parasite, or any substance at a concentration or value which would constitute a potential danger to human health
 - Any substance (whether or not a consented parameter) at a concentration or value which, in conjunction with any other substances it contains which would constitute a potential danger to human health
 - Concentration or values of consented parameters in excess of or, as the case may be, less than, the prescribed concentrations or values
- L.58 This is a duty we take very seriously, achieving water quality compliance at customers' taps greater than 99.96% over the last few years against an aspirational target of 100%. 100% compliance remains a very stretching target to achieve. Our current strategy aims to proactively identify the risks to water quality in order to implement mitigation measures before failures occur⁷.

Increased risks from rising wastewater effluent into drinking water catchment

- L.59 As described earlier some wastewater is already being recycled as part of unplanned IPR systems and our WTWs are designed to treat that water. In a review of river and wastewater

⁶ Drinking water Inspectorate (2016), The Water Supply (Water Quality) Regulations 2016 (<http://www.legislation.gov.uk/uksi/2016/614/contents/made>)

⁷ Note: A proportion of failures are due to customer side plumbing which is largely outside of our control; in 2016 a third of failures were due to customer side issues. Mitigation measures include our lead pipe replacement programmed and targeted mains flushing to address iron accumulation.

flows it was identified that the two main rivers from which we abstract fresh water for the drinking water supply of London each contain a certain proportion of effluent⁸. The proportions of effluent within the River Lee and River Thames at the lowest abstraction point are summarised in Table L-4.

Table L-4: Proportion of wastewater effluent in the Rivers Lee and Thames⁸

River	Last abstraction point on the river	Percentage of effluent in river at average flow	Percentage of effluent in river in drought conditions
River Lee	High Maynard reservoir intake	39%	81%
River Thames	Surbiton intake	18%	55%

- L.60 It is important to understand that the make-up of the influent to different WWTW may be significantly different. Some wastewater comes from catchments which have a large range of different industries discharging into the sewers or commercial companies may tanker specific waste or trade effluent to a wastewater site. In other catchments there may be a large amount of surface water drainage and capture of rainfall run-off which brings potentially different contaminants and some dilution, whilst some wastewater catchments have very little or no surface water dilution.
- L.61 This means that wastewater effluents from different sources could have different risks in terms of chemicals and contaminants which could present a problem when discharged into the environment or when used as a source of water for drinking water treatment.
- L.62 Consequently, the introduction of planned IPR in one (or more) of our drinking water catchments without controls could compromise the wholesomeness of the drinking water supplied. The resources to be recovered derive from large wastewater catchment areas that include diverse people and traders. Thus, their addition within the drinking water catchment would create water quality risks to the environment and public health if not managed properly.
- L.63 The development of the discharge design methodology and its application allowed us to appraise the extent of the risks associated with the increased concentration of consented parameters and how to mitigate them. However, it does not mean that wholesomeness of the drinking water will not be compromised due to unconsented parameters increasing risk. These parameters may not be considered in our DWSP at the moment as are normally not or at low concentration in surface water bodies.
- L.64 As an example, from January to March 2010, we received 1,114 complaints about “smelly” drinking water from residents in North East London⁹. Investigation concluded that the taste and odour was caused by minute trace of two chemicals, called 2-EDD and 2-EMD, originating from resin manufacturing and which had entered at Rye Meads WWTW. These chemicals were not removed through conventional wastewater treatment and ended up in the River Lee, which is the main raw water source in North East London for drinking water. This event was exacerbated by the reduced dilution of Rye Meads sewage effluent in the small river receiving the discharge

⁸ Cascade Consulting (February 2016), Sewage effluent composition in the freshwater River Thames, River Lee and Lower River Severn, *Confidential report*

⁹ <http://dwi.defra.gov.uk/stakeholders/information-letters/2011/08-2011-annexa.pdf>

and a changed operating philosophy of the storage reservoir due to a maintenance requirement, increasing the proportion of sewage effluent at the inlet of the WTW. Whilst these chemicals, which are not consented either through the WFD and the Drinking Water Inspectorate, did not pose a risk to the environment and public health at the concentration detected, other compounds may cause harm to the environment and public health. It is thus appropriate for the research to extend the risk assessment to unconsented parameters.

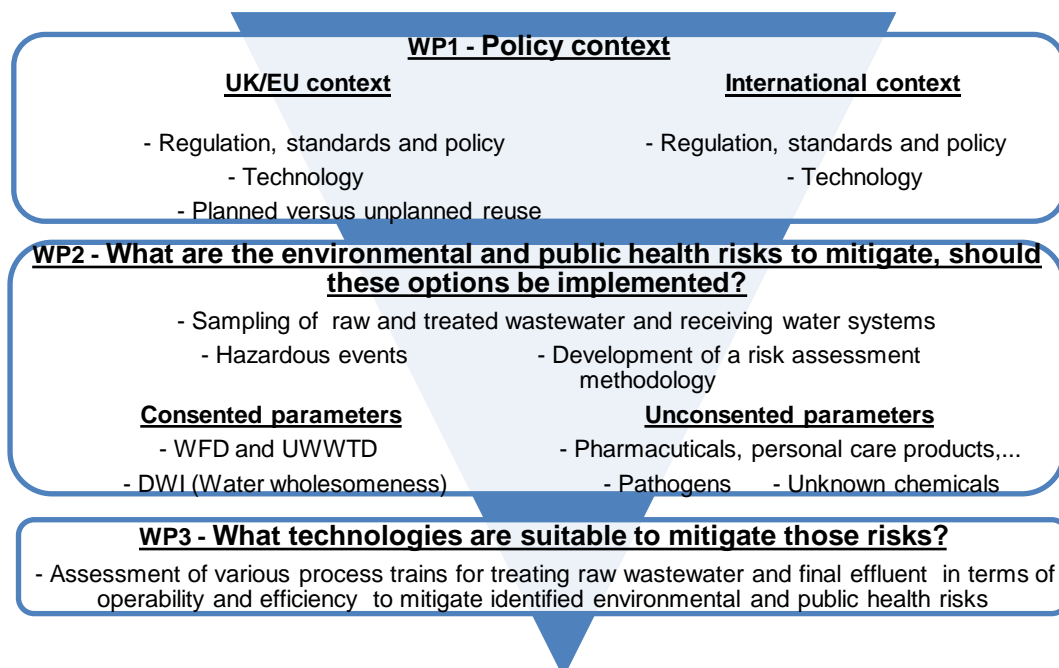
- L.65 This research programme allows identifying what mitigation measures should be put in place to mitigate risks associated with the implementation of IPR and ensure drinking water wholesomeness is not compromised.

Research programme packages

- L.66 We have been conducting a comprehensive research programme to follow on from the research carried out for previous WRMPs. In 2014 we shared our programme with an independent expert review panel for comment. The panel included six acknowledged international experts in the field (David Cunliffe, Joan Rose, John Fawell, Clare Stacey, Mike Wehner and Paul Jeffrey) and was chaired by AMEC. The research programme follows their recommendations¹⁰ so far as is reasonably practicable in term of timescale and cost. We have sought to understand worldwide IPR practice to inform our proposals.
- L.67 The current research programme was divided into three work packages, which are summarised in Figure L-5.
- L.68 Table L-5 indicates the timeline required for this research programme to be completed. It is likely that this programme will be completed after the publication of the final WRMP19. However, any findings pre-publication of the final WRMP19 have been used to inform the constrained option lists. In summary we have sort to articulate the policy context, more clearly set out the risks we wish to mitigate and confirmed the final treatment technology.

¹⁰ AMEC (2014), Inception Review of Thames Water Indirect Potable Reuse Plans for the planning horizon as detailed in the 2014 rdWRMP – Draft report of the Independent Expert Review Panel, August 2014

Figure L-5: Research programme work packages



Note: WFD: Water Framework Directive; UWWTD: Urban Wastewater Treatment Directive; DWI: Drinking Water Inspectorate

Table L-5: Research programme timeline

Work Package	Timeline					
	WRMP14	2015	2016	2017	2018	2019
WP1 – Policy context						
WP2 – Risks						
WP3 – Technology						

WP1 – Policy context

- L.69 This work package aimed at understanding the worldwide, national or regional policy context with regards to water reuse schemes. This includes a review of current regulation and technology used throughout existing water reuse schemes.
- L.70 Whilst there are no water regulations in the UK or the European Union (EU) for potable water reuse schemes, worldwide policies are highly influenced by specific drivers such as supply security, population growth, environmental benefits, etc. Existing regulations vary from one region to another, with some adopting parameter based policy, while others implement a risk-based approach. Treatment varies from low to high technologies. As such there is no overriding approach and requirements for implementing an IPR scheme are considered on a case by case basis.

L.71 This work package is now complete^{11;12} and the findings are summarised below.

UK context

Regulations

- L.72 Water quality requirements for discharges to water courses in Europe are largely governed by the Urban Wastewater Treatment Directive (UWWTD) and the WFD. There is no specific regulation regarding potable water reuse in either the UK or the EU, although Article 12 of the UWWTD states that “treated waste water shall be reused whenever appropriate”. It follows that there are no water quality criteria specifically for planned IPR. The WFD sets out to achieve good chemical and ecological status for specified water bodies by 2027. The Priority Substances Directive, a daughter directive of the WFD, will contain standards for emerging parameters that may influence IPR treatment technology selection. It should be noted that emerging parameters may also have implications for all future water treatment technology, regardless of the potable reuse context. The applicability of legislation will depend on the nature of the environmental buffer to which reclaimed water is intentionally discharged. Requirements might therefore be dictated by more advanced treatment required for UWWTD sensitive areas or ecological status objectives of the WFD, including for priority substances.
- L.73 Drinking water in the UK requires DWSP to be developed and submitted to the Drinking Water Inspectorate as part of the regulatory process. In England, Regulation 27 of the Water Supply (Water Quality) Regulations 2016⁶ requires water companies to carry out a risk assessment for each treatment works. This includes water source, catchment and connected supply. The assessment must be based on the World Health Organisation’s (WHO) Water Safety Plan (WSP) methodology and reported to the regulator.

Application to IPR schemes

- L.74 The Langford scheme, belonging to Essex and Suffolk Water, is the only example of planned IPR in the UK¹³. For this scheme, regulation and permitting were framed around the potential to impact on riverine, estuarine and reservoir environments. These include ecologically important areas with the Blackwater Estuary being a designated Site of Special Scientific Interest (SSSI), Ramsar site and a candidate ‘special area for conservation’ under the European Commission Habitats Directive¹⁴. Hanningfield reservoir is also a designated SSSI.
- L.75 Although there were some objections to the temporary scheme implemented in 1997, public resistance to the permanent scheme (commissioned in 2002) came about largely through perceptions of the potential impact to the estuary where the wastewater is normally discharged. It was thought that reduced flows to the estuary could increase siltation. For this reason several

¹¹ Thames Water (April 2015), Policy context for worldwide wastewater reuse – For drinking water augmentation, Version 3: Final, Company confidential

¹² WRc (April 2015), Indirect potable reuse scheme international survey, Report reference: UC10672.03, Company confidential

¹³ Scheme details available through this web link: <http://www.reclaimedwater.net/data/files/252.pdf>

¹⁴ Wishart, S. J. Mills, S. W. and Elliott, J. C. (2000) Considerations for Recycling Sewage Effluent in the UK. Journal CIWEM

directives, including the Conservation of Wild Birds Directive and the Habitats Directive, had a bearing on the scheme's approval. Scheme-specific community engagement and monitoring requirements included:

- Establishing a siltation steering group for the estuary
- Monitoring over-wintering wildfowl and waders and endocrine impact on fish¹⁵

L.76 For the permanent scheme, the Environment Agency required that the wastewater was discharged to the river (3km upstream) and not directly to the large Hanningfield reservoir¹⁵.

The Langford scheme consists of treating final effluent¹⁶ through Densadeg and Biofor processes followed by ultraviolet (UV) disinfection. The reclaimed water is then discharged in the River Chelmer, upstream of the abstraction point of the Hanningfield reservoir and Langford WTW. Public health risks associated with the Langford scheme would be covered by the requirement for a DWSP. It is not clear if any additional risk assessment or risk management activities have been required for this scheme.

Worldwide context

L.77 A review of the policy context for worldwide IPR schemes shows that a range of potable reuse configurations are possible and scheme design is influenced by local characteristics. Such local characteristics include geological, social or political variables. Some schemes have benefited from the use of large groundwater basins for treatment and storage, whilst others rely on short lengths of river or no environmental buffer at all. Even in regions with well-established reuse schemes, like California, the policy and regulation tend to be developed on a case-by-case basis. For example, there are established regulations for aquifer recharge but not for potable reuse via a reservoir. The complexity of ownership and proximity of infrastructure can also have a bearing on the development of scheme designs. Some schemes have developed new statutory bodies and others benefit from national government oversight. Drought, water security and projected population growth are key drivers for developing water reuse policy and regulation. Both stakeholder collaboration and community engagement, particularly regarding source control, can also inform scheme governance requirements.

L.78 Although a trend towards using RO-based treatment trains has emerged since the early 2000s (starting with Torreele in 2002), there has still been a diverse mix of technologies employed in this time period. A number of plants not employing RO in this timeframe include upgrades to older plants such as Windhoek in 2002, Occoquan in 2005 and Gwinnett County in 2006. Technology used includes, for example, a combination of UF membrane followed by biological activated carbon/GAC and ozone (or vice versa), or a combination of filtration followed by activated carbon, ion exchange and chlorination.

L.79 Since 2011, all the constructed schemes reviewed for this report use RO as the main treatment technology. Most of these schemes are for managed aquifer recharge. Furthermore two of these, both in Texas, are DPR schemes, while the other two (Perth and San Diego) do not yet supply potable water.

¹⁵ Lunn, M. 2014. The pitfalls to promoting reuse. Powerpoint Presentation given to Thames Water, 10/10/2014

¹⁶ Note: The wastewater catchment of the associated WWTW is mainly from household sources.

- L.80 A number of schemes have required the reclaimed water to be drinking water quality before it is discharged to an environmental buffer. Other schemes have framed the water quality discharge standards around improving the existing quality of environmental waters. Water quality compliance varies considerably both in the number of parameters and the limit values. The regulations for the Western Corridor scheme in Australia include nearly four hundred parameters, whilst discharge to the River Llobregat in Spain must meet only six consented parameters.
- L.81 A number of the schemes promote the benefits of providing a saline intrusion barrier or NPR applications and do not necessarily focus on highlighting the potable reuse context.
- L.82 Other schemes have implemented risk-based approaches to scheme appraisal and operational management. In Europe, a WSP approach has been extended to reuse in both Berlin and Torreele. The Australian Guidelines for Water Recycling inform the regulatory risk based requirements for the Western Corridor and Perth.
- L.83 Generally, having established non-potable standards may help provide confidence to move along the water reuse continuum towards potable reuse. The majority of schemes reviewed had non-potable standards in place prior to implementing a potable reuse scheme. A number of the reviewed schemes also include a large component of NPR.

Discussion – The UK is on the path to move towards potable reuse

- L.84 In the UK, guidance on implementation of rainwater harvesting and greywater recycling for non-potable applications have been published since 1999 through the Water Regulations Advisory Scheme (WRAS) and the British Standards Institution. However, we are still at the emergence of implementing water reuse, with most of the schemes being at local scale (including single household, new housing and commercial development, factory, etc.) and generally not being communicated to the wider public, reducing the potential to gain confidence in developing water reuse schemes and moving toward higher risk water reuse schemes such as IPR.
- L.85 Nonetheless, appetite for non-potable and potable reuse schemes is increasing in the UK, with a big push from commercial and industrial companies. For example, Bairds Malt Ltd, which produces malt in their factory in Wiltham, reduced their water consumption from 250,000 m³/year to 140,000 m³/year by reusing the highly treated wastewater of their factory from the steeping process¹⁷. Aquabio also installed a water reuse system at Cucina Sano food production facility (near Boston) where all the wastewater from the factory is highly treated and blended with the incoming water main for potable use¹⁸. New commercial or residential developments wishing to obtain the Building Research Establishment Environmental Assessment Method (BREEAM) accreditation, which proposes an assessment framework with regards to building sustainability, will have to reduce water consumption through the lifetime of a building.
- L.86 However, there are still some barriers to overcome. The main barriers for implementing IPR by water companies in the UK include:

¹⁷ Kysten Moore (2017), Experience with wastewater treatment and reuse back into the malting (steep) process, 1st Water Reuse Europe Conference on Innovation in Water Reuse, Bruges, Belgium, 9th-10th October 2017

¹⁸ Phil Lynch (2017), Wastewater to potable water reuse in the UK food industry, 1st Water Reuse Europe Conference on Innovation in Water Reuse, Bruges, Belgium, 9th-10th October 2017

- Lack of dedicated regulations for IPR. Water companies are highly regulated and must provide wholesome water to their customers as well as discharging treated wastewater, which is not harmful to the environment
- Multiple regulators to engage with (Environment Agency, Drinking Water Inspectorate, the Water Services Regulation Authority (Ofwat) and the Department for Environment, Food and Rural Affairs). Each of these regulators (and divisions) will have their own requirements, which may conflict when assessing water reuse schemes
- Water and wastewater providers/department fragmentation, with each provider/department also having their own requirements
- Public perception – This is discussed in Section E

L.87 Due to the diverse worldwide approach in terms of regulation (list of consented parameters or risk management approach) and applied technologies, and the specific UK context, we decided to design our own approach. This includes the identification of environmental and public health risks to be mitigated (consented and non-consented – WP2 below) and the choice of fit-for-purpose treatment technology (see WP3 below).

WP2 – Identification of environmental and public health risks to be mitigated

- L.88 This work package aims to identify the environmental and public health risks that an implemented IPR scheme should mitigate. The sub-tasks of this work package included:
- WP2.1 – Sampling of wastewater treatment plants and environmental water bodies
 - WP2.2 – Review of hazardous events within WWTW catchment
 - WP2.3 – Risk identification (consented and unconsented water quality parameter)

WP2.1 – Sampling of wastewater treatment plants and environmental water bodies

- L.89 Continuing the work that informed WRMP14, an extensive sampling programme has been carried out to understand water quality characteristics of both the IPR source water (i.e. incoming wastewater and final effluent of Beckton WWTW, Deephams WWTW and Mogden WWTW) and environmental water body at potential point of discharge (i.e. River Lee, William Girling reservoir and River Thames). We decided to not sample Crossness WWTW as it was unlikely that the Crossness IPR scheme would be chosen as the first IPR scheme to be implemented.

- L.90 The water quality parameters (274 in total) for which samples are analysed include:
- Microbiological compounds, including somatic coliphage
 - Nutrient and physical chemistry
 - Inorganic chemistry
 - Pesticides
 - Volatile Organic carbon and disinfection by product
 - Steroids hormones and other endocrine disruptors compounds (EDCs)
 - Polycyclic aromatic hydrocarbons
 - Polychlorinated biphenyls
 - Pharmaceuticals
 - Personal care products
 - Other chemicals
- L.91 Water quality parameters include all the parameters consented under the WFD and associated daughter directives, and under the Water Supply (Water Quality) Regulation. It also includes unconsented parameters, also known as contaminants of emerging concern, which are often cited in worldwide IPR regulation or in literature. Since WRMP14 further samples have been taken on a monthly basis since January 2016. The sampling programme will end in December 2017.
- L.92 Pathogens (including viruses), apart from consented microbiological compounds and parameters used as indicators of pathogen presence, were not analysed as part of this sampling campaign.

WP2.2 – Review of hazardous events within WWTW catchment

- L.93 While sampling indicates background water quality characteristics of wastewater (incoming wastewater and final effluent of a WWTW), it does not account for release of hazards into the WWTW catchment associated with human activities and natural events. This includes pollution incidents due to legal (or illegal) traders' activities, flooding and storm run-off, fires and spills.
- L.94 Discharges from legal traders into sewers are consented by Thames Water. Traders are given guidelines which they must adhere to when discharging their effluent to sewers. Overall, for the options being looked into for WRMP19, trade effluent forms a very small proportion of the total flow to a WWTW (2.77% by volume being the greatest for Mogden in 2015) (Table L-6). It has to be noted that the trade effluent proportion within the incoming wastewater has been decreasing over recent years and is likely to continue to do so. Industries listed in the trade effluent consents varied from light industrial, which includes laundrettes and car washes, to metals and chemical processing plants and hospitals.

Table L-6: Trade effluent proportion (TE %) in incoming wastewater to WWTW by volume and population equivalent (PE)

WWTW	TE % by volume	TE % by PE
Beckton	0.82	3.77
Deephams	1.69	5.14
Mogden	2.77	6.03
Crossness	0.97	2.29

Note: 2015 data

WP2.3 – Risk identification

Risk assessment – consented and unconsented water quality parameters

- L.95 The aim of this risk assessment was to understand the potential risks to the environment and public health for both consented and unconsented water quality parameters. As discussed in WP1 – Policy context, there is not a common approach towards water quality risks, with implemented schemes using more or less stringent water quality standards or risk assessment. The WHO (and subsequently the EU) is tending towards the use of risk assessment, such as WSPs, for the protection of drinking water. Whilst the comparative discharge design methodology used across all WRMP options represents a business-as-usual type of approach to consented parameters, the risk assessment presented here is quite novel. It has the benefit of allowing the assessment of risks linked to more unconsented parameters. This method was developed in collaboration with the University of Oxford¹⁹.
- L.96 The assessment of environmental risks is based on the quantitative framework suggested by the European Commission in the Technical Guidance Document on Risk Assessment²⁰. This approach has been commonly employed in the literature to evaluate the ecological hazard from exposure to micropollutants in wastewater, although studies at present are limited to either a specific category of micropollutants (e.g. organic contaminants, EDCs) or a small number of compounds²¹. The methodology employed for the health risk assessment is adapted from the

¹⁹ Lee, Si Jia (2016), Indirect potable reuse in the United Kingdom – Risk assessment and technology choice, MSc thesis, School of Geography and the Environment, University of Oxford

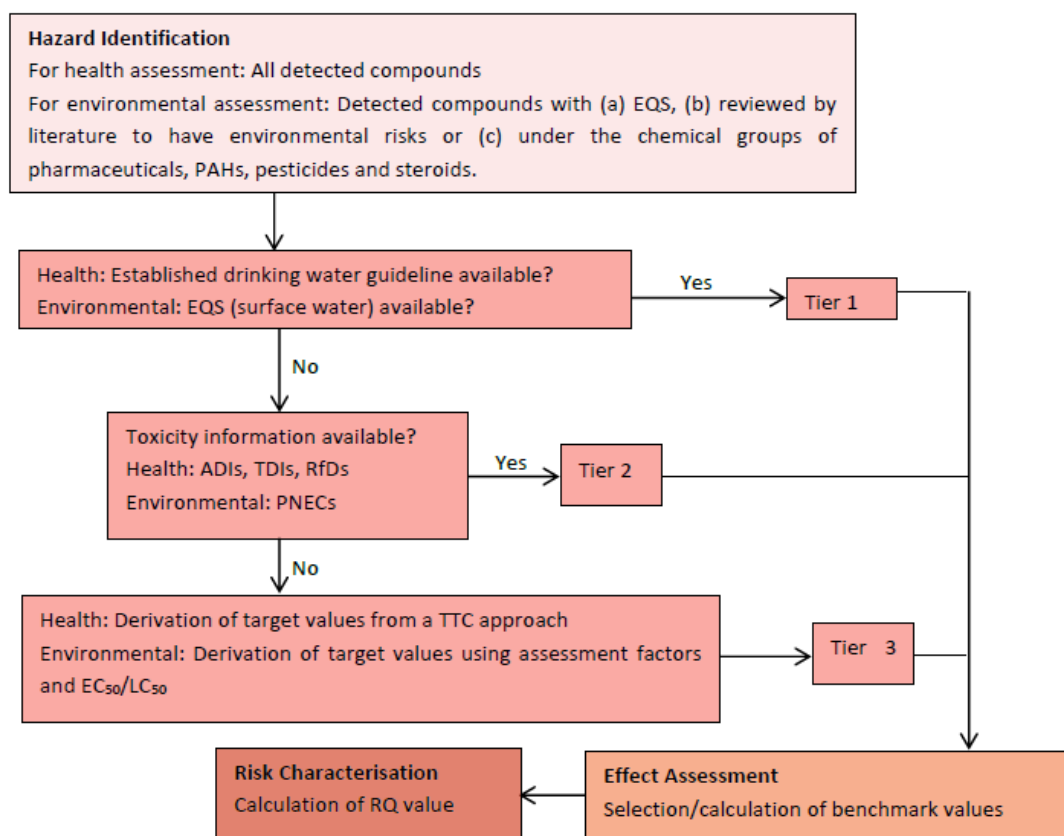
²⁰ European Commission (2003), Technical Guidance Document on Risk Assessment, European Commission, Luxembourg (https://echa.europa.eu/documents/10162/16960216/tgdpart1_2ed_en.pdf)

²¹ Thomaidi, V. S., Stasinakis, A. S., Borova, V. L., & Thomaidis, N. S. (2015), Is there a risk for the aquatic environment due to the existence of emerging organic contaminants in treated domestic wastewater? Greece as a case-study, Journal of Hazardous Materials, 283, 740–747

empirical framework applied by Etchepare and van der Hoek²² as well as the approach used in the Australian Guidelines for Water Recycling²³.

- L.97 The method rests upon the calculation of a risk quotient (RQ), which is the ratio between the 95th percentile concentration of identified contaminants in final effluent (obtained from sampling) and an environmental or a health benchmark value, respectively for the environmental and the health assessments. The benchmark values were selected (or calculated) following a three-tiered approach²⁴, summarised in Figure L-6.

Figure L-6: Three-tiered approach for benchmark values identification



Source: Lee (2016)¹⁹

- L.98 Any contaminants with a $RQ \geq 1$ are contaminants that may pose environmental and health risks if effluent from the studied WWTWs was discharged into the receiving river without further

²² Etchepare, R., & van der Hoek, J. P. (2015), Health risk assessment of organic micropollutants in greywater for potable reuse, *Water Research*, 72, 186–98

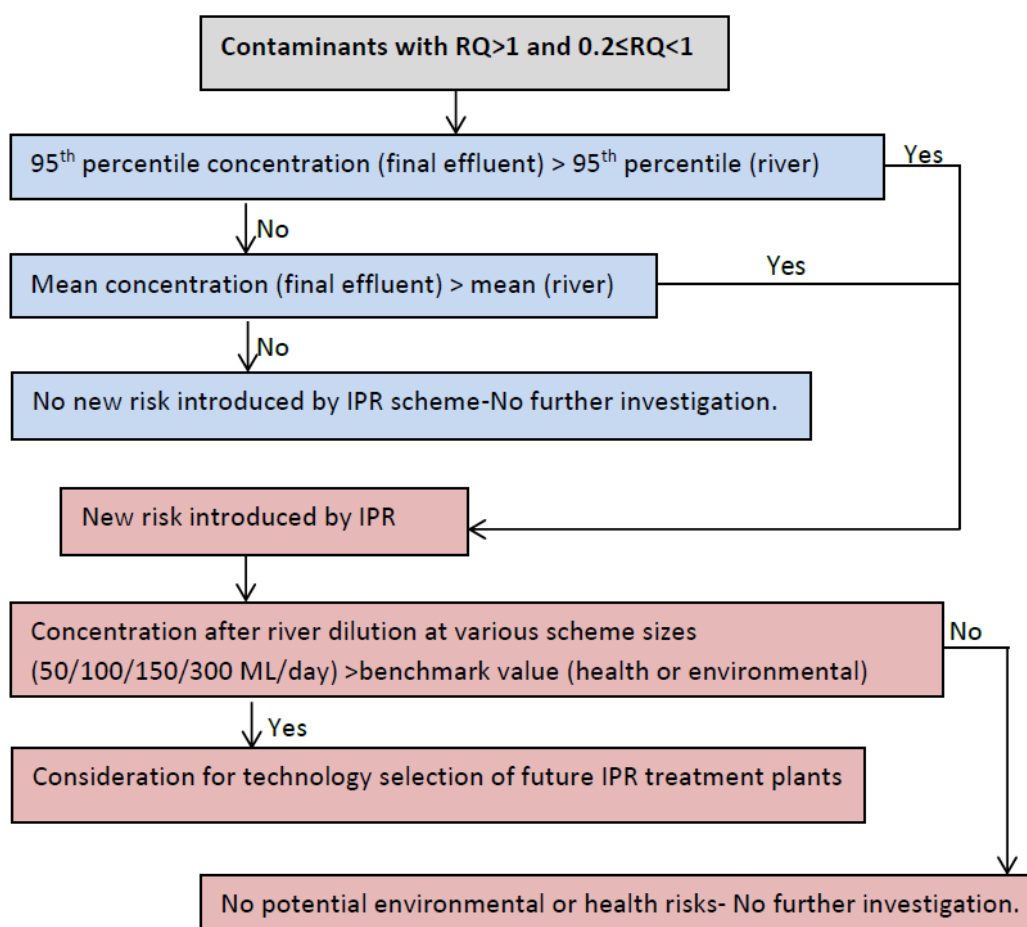
²³ NRMCC, EPHC, & NHMRC, (2008), *Australian Guidelines for Water Recycling: Augmentation of Drinking Water Supplies (Phase 2)*, Natural Resource Management Ministerial Council, Environmental Protection and Heritage Council and the National Health Medical Research Council: Canberra, Australia

²⁴ Note that detected compounds with a pH-corrected n-octanol-water partition coefficient (Log-D) > 3 were not included in the health risk assessment as they are more likely to be removed by conventional water treatment process included activated carbon adsorption stage, process that is used currently in our WTW²².

treatment. Etchepare and van der Hoek²² also advised further assessment for any contaminants with a $RQ \geq 0.2$, which we have followed.

- L.99 The concentrations of each contaminant with a $RQ \geq 0.2$ were compared with the river water quality. When a contaminant concentration was lower than the one measured in the river, this compound was removed from the risk list. However, if contaminants' concentration in the river were already above the Tier 1 environment benchmark value, the contaminants were kept in this list. This is to account for the fact that concentration of some contaminants in the river might not meet EQSs for good ecological status. As a water company we should work towards improving the river quality so far as is reasonably practicable.
- L.100 The final steps of the method were to assess the effects of various dilution factors by the receiving river to determine contaminants which remain toxic after the dilution of the WWTW effluent by the river water.
- L.101 The full method is summarised in Figure L-7.

Figure L-7: Flow diagram indicating the methodology for risk assessment after calculation of RQ



Source: Lee, Si Jia (2016), *Indirect potable reuse in the United Kingdom – Risk assessment and technology choice*, MSc thesis, School of Geography and the Environment, University of Oxford

Summary of key risk parameters identified across studied sites

- L.102 Among the 274 parameters analysed for in our IPR sampling programme, 151 were attributed an environmental benchmark value and 153 were attributed a health benchmark value. Across the studied sites, 33 parameters were identified to pose a risk to the environment and 26 parameters were identified to pose risks to public health after dilution of the effluent by the river. Table L-7 and Table L-8 summarise the number of parameters posing a risk to the environment and public health. Note a substance may exhibit both environmental and health risks hence our lists are not mutually exclusive. This work to date has also created benchmark removal requirements for any IPR treatment scheme allowing us to compare the various treatment technologies.
- L.103 This assessment has highlighted further risks associated with non-consented parameters such as disinfection by-products, pharmaceuticals and other organics not part of the previous discharge design standard.
- L.104 However, this new method did not allow us to assess chemical removal to achieve no deterioration as defined in paragraph L.29 when both the RQ < 0.2 and current river concentration are below benchmark values. This is the case for chloride, phosphate, metaldehyde and PFOS, for example, which were identified as risks using the discharge design methodology. It is clear that in the future, and with further discussion with our regulators, a combination of the discharge design methodology and the risk assessment used in this work package may be required to ensure all risks are adequately accounted for.

Table L-7: Number of parameters posing an environment or public health risk per contaminants' category.

	Environmental risks from WWTW	Health risks from WWTW
Microbiology	2	6
General chemistry	2	4
Metals	6	5
Pesticide	2	3
PAH	2	0
Alkylphenol	1	0
Hormones	2	2
Pharmaceuticals	7	0
Disinfection by-product	2	6
Bromodiesthers	6	0

Table L-8: Summary of risks parameters identified across sites and required contaminant removal

Category	Parameters	Maximum required contaminant removal
Microbiology	<ul style="list-style-type: none"> Clostridium, Coliform, E.coli, Enterococci, Cryptosporidium, Giardia 	<ul style="list-style-type: none"> > 2-log removal required
General chemistry	<ul style="list-style-type: none"> BOD, Colour, turbidity, ammonia, nitrite, cyanide 	<ul style="list-style-type: none"> > 60% removal required
Metals	<ul style="list-style-type: none"> Aluminium, zinc, iron, barium, copper, lead, molybdenum Nickel, manganese, mercury, lithium, 	<ul style="list-style-type: none"> Between 70 and 99% removal required Between 10 and 55% removal required
Pesticide	<ul style="list-style-type: none"> AMPA, cypermethrin, diuron, glyphosate 	<ul style="list-style-type: none"> > 70% removal required
PAH	<ul style="list-style-type: none"> Fluoranthene, Total PAH 	<ul style="list-style-type: none"> > 75% removal required
Alkyphenol	<ul style="list-style-type: none"> Octylphenolmonoethoxylase 	<ul style="list-style-type: none"> > 95% removal required
Hormones	<ul style="list-style-type: none"> 17β-oestradiol, 17α-ethinyloestradiol 	<ul style="list-style-type: none"> >99% removal required
Pharmaceuticals	<ul style="list-style-type: none"> Diclofenac, erythromycin Azithromicine, clarithromycin Carbamazepine, ciprofloxacin, fluoxetine 	<ul style="list-style-type: none"> > 90% removal required Between 70 and 80% removal required Between 5 and 30% removal required
Disinfection by-product	<ul style="list-style-type: none"> Trihalomethane (chloroform, bromoform), N-nitrosodimethylamine (NDMA), haloacetic acid (dichloroacetic acid, trichloroacetic acid, chloroacetic acid), dimethylamine 	<ul style="list-style-type: none"> Between 40 and 60% removal required, apart for trichloroacetic acid, which requires removal of > 80%
Bromodiesthers	<ul style="list-style-type: none"> PBDE-28, PBDE-47, PBDE-99, PBDE-100, PBDE-153, PBDE-154 	<ul style="list-style-type: none"> Between 80 and 95% removal required

Note: The above is a summary of general risks, i.e. not all the risks will be present at all sites.

Are there other risks?

- L.105 The current approach taken allows understanding of the risks associated with the measured chemicals and microbial community present in the water, i.e. the chemicals and the microbial community that we have analysed for.
- L.106 With over 200 pathogens listed as potentially harmful to humans and over 132 million organic and inorganic chemicals listed on the chemical abstract registry (this number increases by 15,000 per day), it is impossible to assess the risks associated with the presence of all these parameters. It has to be noted that the majority of these parameters however will not be relevant to the UK as some pathogens are more prevalent in tropical countries and many of the chemicals mentioned are confined to research. These parameters are referred to here as the unknown knowns, known unknowns and unknown unknowns, summarised below:
- Unknown knowns are the chemicals and pathogens for which there is a probability for them to be present in the final effluent. However, they might be difficult to analyse for, with sometimes no method developed in the UK, or the analysis of these parameters is developed within a research centre such as a university. For example this is the case for viruses, for which few laboratories are able to analyse.
 - Known unknowns are the chemicals and pathogens whose presence we are aware of, but their presence cannot be quantified due to their variability. For example, this could be chemicals derived from disinfection process such as UV where the targeted chemicals are cut into smaller unknown molecules.
 - Unknown unknowns are the chemicals and pathogens whose presence we are not aware of as they might not have been created yet. This can also include mutated bacteria or viruses, which originally were not harmful to humans.
- L.107 Furthermore, there is growing concern with regards to the presence of microplastics in wastewater effluent and freshwater. Microplastics originate from a wide range of sources, including various domestic products such as cosmetics and synthetic clothing microfiber resulting from abrasion during washing. It is likely that those microplastics would pass through conventional wastewater treatment as they are not designed to remove small particles. The chronic effect of microplastics on human is unknown and yet to be defined. More research is required in this field, including the understanding of microplastics removal enhancement through wastewater treatment.
- L.108 Antimicrobial resistance is another growing concern. Due to the excessive use of medicines, some pathogens have become resistant to currently available treatment and are likely to be present in WWTW effluent. Therefore, it's preferable that those pathogens are removed by proposed IPR technology to ensure they are not present in greater quantities in the drinking water supply.

Discussion on water quality risk research

- L.109 WP2 is aimed at identifying water quality parameters that could pose risks to the environment and/or public health in the context of IPR. This includes:
- An extensive sampling (analysis of 274 water quality parameters) of wastewater (settled sewage and final effluent) and environment water bodies (river and surface reservoir) associated with the proposed schemes
 - A review of the different wastewater catchments to define hazardous events
 - The development of risk assessment methodologies to identify risks to mitigate.
- L.110 Whilst the sampling allows us to define the water quality baseline for each sampled WWTW and surface water body (river and surface reservoir), it does not allow us to account for hazardous events. A review of trade effluent shows that risks associated with traders' activities are present in all wastewater catchments studied but they represent a small volume proportion compared to the influent flow to the WWTWs. This does not mean that pollution accidents could not happen (illegal traders discharge to the sewer, flooding, storm run-off, fires and spills) and mitigation should be put in place to ensure an IPR scheme acts as an effective ultimate barrier. Other mitigations will take the form of communication with the trade effluent team and the operations team of the WWTW, and monitoring at the inlet of IPR advanced treatment plants for specific risk indicators.
- L.111 A risk assessment methodology was developed to identify water quality parameters (consented and non-consented) that could pose a risk to the environment and public health. This methodology was applied for all feasible schemes using sampling data. The exception was the Crossness IPR scheme, for which no water quality data are available. Twenty-six water quality parameters were identified as posing a risk to public health and 33 water quality parameters were identified as posing a risk to the environment. These parameters include microbiological compounds, inorganic compounds such as metals and salts, and organic compounds such as pharmaceuticals, disinfection by-product and hormones. This assessment has identified a range of removal requirements needed to reduce those risks and thus identify an appropriate treatment system.
- L.112 While the sampling has been extensive, it does not allow us to develop the full lists of chemicals and microbial community present in the water that could be a risk to human health. Control measures (technology or monitoring) chosen to remove risks identified through the risk assessment should also be able to mitigate the unknown risks.
- L.113 The sampling is now completed. However, due to the large amount of data, more analysis is required to complete WP2.

WP3 – What technologies are suitable to mitigate those identified risks?

- L.114 The choice of treatment technology used for WRMP19 IPR options was determined by the discharge design standard approach. This work package aims to identify the most robust technology to mitigate those risks determined in our research programme WP2. We therefore seek to more clearly articulate those emerging contaminant risks and appropriate mitigations levels that should be provided. Our on-going assessment continues to support the choice of RO followed by advanced oxidation as the core treatment requirement.
- L.115 The sub-tasks of this work package included:
- WP3.1 – IPR workshop
 - WP3.2 - Assessment of technologies – from bench-scale to full-scale

WP3.1 – IPR workshop²⁵

- L.116 In autumn 2015, we organised a workshop, which was run by WRc and was attended by 37 people. Attendees included experts in water reuse, wastewater and water treatment, and regulations, all drawn from Thames Water, different consultancies and universities.
- L.117 The aim of the workshop was to review the contaminants which were considered potential risks to meeting the requirements of current water industry public health and environmental standards, if planned IPR were implemented. In addition, the workshop also aimed to identify treatment options to mitigate the potential future risks as nominated by the workshop attendees.
- L.118 The workshop identified that most of the potential risks to the environment (to comply with the Environment Agency EQSs and the WFD) could be removed through optimised existing or enhanced WWTP, or through catchment management. The remaining risks, if existing, could be mitigated using ozonation, activated carbon or membrane processes.
- L.119 Similarly, the risks that could compromise existing DWSPs of downstream WTPs were often dealt with adequately via traditional WTP or WWTP treatment options. Instances which did require additional treatment upstream of the WTP did raise the potential for new risks to be introduced, for example risks associated with bromate (ozonation of WWTP effluent) and acid neutralising capability (desalination of WWTP effluent without remineralisation). These issues will need to be investigated further.
- L.120 The final stage of the workshop raised the issue of risks from emerging compounds, i.e. compounds that currently are not monitored or targeted for treatment at WTW or/and WWTW. Such compounds may become an issue in the future due to their increasing concentration in the water system and the potential treatment requirements to deal with these compounds. It was recorded from the workshop that chemical properties of these emerging compounds would determine the propensity of a process to remove these compounds. Without knowing these chemical properties, the attendees leaned toward the consensus that a combination of RO and AOP is the treatment method most likely to remove most emerging contaminants. Membrane bioreactors (MBRs) were mentioned as another option that could remove some of these emerging contaminants.

²⁵ WRc (2016), Thames Water indirect potable reuse workshop, Report reference UC11443.02 (March 2016)

WP3.2 – Assessment of technologies – from bench-scale to full-scale

- L.121 Over the last 10 years, different treatment processes were trialled to assess their suitability to remove parameters that could pose a risk to the environment and public health. Table L-9 summarises the different schemes from which water quality and operational data has been gathered in researching IPR technologies.
- L.122 Since WRMP14 was completed our technology focus has concentrated on the evaluation of MBRs for raw wastewater treatment followed by RO (RO) membranes and AOP. This allowed us to continue to evaluate disinfection by product risks and better understand RO brine characterisation and re-hardening needs for RO permeates.
- L.123 We have also examined a modified biological configuration for our MBRs to study if low nitrate levels can be achieved (denitrifying). We have also evaluated a GAC and advanced oxidation treatment following the denitrifying MBR. This provides a contrasting IPR scheme without using RO membranes. This has necessitated making further investment in pilot equipment and the evaluation of those completed pilot plants is on-going with plant commissioning completed in October 2017.
- L.124 Operational data from our current and historic studies were part of the conceptual design report written by Mott MacDonald²⁶.

²⁶ Mott MacDonald (2017), Thames Water WRMP19 Resource Options – Options operating philosophy, May 2017

Table L-9: Summary of schemes where IPR technologies have been assessed

Location	Trial period	Source water	Technology
WRMP14			
Deephams WWTW (Pilot Plant)	June 2008 – May 2012	Final effluent	UF membranes followed by RO membranes and AOP (combination of hydrogen peroxide (H ₂ O ₂) dosing and UV)
Deephams WWTW (Pilot Plant)	May 2012 – August 2012	Final effluent	UF membranes followed by nanofiltration (NF) membranes and AOP (H ₂ O ₂ + UV)
Deephams WWTW (Pilot Plant)	June 2008 – August 2012	Final effluent	UF membranes followed by AOP (H ₂ O ₂ + UV)
Deephams WWTW (bench test)	June 2008 – August 2012	Final effluent	UF membranes followed by AOP (Ozone + H ₂ O ₂)
Swindon WWTW (Full-scale)	February 2007 – August 2012	Final effluent	Disc filter followed by GAC
BedZED (Full-scale)	July 2008 – January 2012	Raw wastewater (from residential building)	Septic tank followed by MBR and adsorption media (Bone char adsorption media or GAC)
Old Ford Water Recycling Plant (OFWRP) (Full-scale)	October 2011 - Ongoing	Raw wastewater from Northern Outfall Sewer	Primary treatment consists of septic tanks and 1 mm screens. The screened wastewater is then treated through MBR and GAC processes to be finally disinfected with sodium hypochlorite. Since April 2012, polyaluminium chloride is dosed to the biological process to remove phosphorus. Since February 2017, a carbon source is dosed to the screened wastewater for improved denitrification
WRMP19²⁷			
OFWRP (Pilot plant)	December 2016 - Ongoing	MBR effluent from full-scale OFWRP	RO membranes followed by AOP (H ₂ O ₂ + UV)
OFWRP (Pilot plant)	December 2016 - Ongoing	MBR effluent from full-scale OFWRP	GAC process followed by AOP (H ₂ O ₂ + UV)

Contaminants removal

- L.125 Based on our research to date an effective particulate and microbiological barrier in the form of an UF membrane is required. A RO barrier is needed for inorganic materials (chloride, some dissolved metals). For effective pesticide removal an additional advanced oxidation stage (AOP) is necessary. Our work on removal of the pesticide AMPA has indicated that granular activated carbon (GAC) cannot replace the RO as an effective barrier ahead of AOP. RO followed by AOP also provides a demonstrable effective barrier against pharmaceutical and hormone risks.

²⁷ The pilot plant was handed over to Thames Water in October 2017.

- L.126 Microbiological compounds were generally well removed with 2 to 5-log removal achieved post-UF membranes for all measured compounds. RO and advanced oxidation allowed further log removal (combined and on their own). It has to be noted that GAC promotes regrowth of bacteria with up to 2-log increase observed.
- L.127 As expected, UF membranes are efficient at removing suspended solids (80 to 98%), with MBR being most effective of UF membranes evaluated. Results include:
- Any inorganic compounds in solid form such as aluminium, copper and iron, with average removal varying between 40 and 80% when treating final effluent and between 75 and 98% through MBR.
 - Any organic compounds in the solid or colloids form (or adsorbed on solids).
- L.128 However, as anticipated, UF membranes were ineffective at removing dissolved compounds, including dissolved metal, nitrate, nutrients, pesticide, pharmaceuticals, etc. However in MBR form we observed better removals for some pesticide (cypermethrin (87%), glyphosate (88%)), PAH (circa. 90%), alkenylphenol (circa. 95%), HAAs (circa. 90%), hormones (circa. 90%) and bromodiethers (circa. 80%). It also provides a partial removal of pharmaceuticals (circa 50%). The intensive biological process within the MBR is the likely explanation; although we remain concerned that the results may not apply at larger scale MBRs with lower sludge ages.
- L.129 Among the post-UF treatment studied (RO, GAC and Advanced Oxidation), the RO process was the only treatment that achieved the inorganic removals identified in our risk assessment (see Table L-2 and Table L-8). This specifically proved essential for chloride, some dissolved metals (zinc, barium, lead, mercury etc.) and nutrients such as phosphorus and nitrogen compounds. In the case of nutrients such as nitrates and phosphorus from wastewater it is more appropriate to modify the biological treatment process of wastewater treatment (for all sites except Deephams WWTW).
- L.130 With regards to pesticides neither the GAC nor the RO (including pre-treatment) could achieve the pesticide removal required by our risk assessment. The addition of an AOP process is necessary. However, due to the low removal of AMPA by GAC, RO process followed by AOP was the only train to achieve the targeted removal for AMPA.
- L.131 PAH and alkylphenol removals through the different technologies were difficult to assess as there were only few occasions when the observed concentration was above the benchmark value. Results show that these compounds are well removed through biological process (>99% removal through an MBR) and may pose risks on a rare occasion.
- L.132 RO followed by AOP was the only treatment train to achieve the >99% removal required to meet environmental standards for hormones in our risk assessment. It is noted that such a high removal requirement may not become a future likely standard.
- L.133 Pharmaceuticals and bromodiester were generally well removed by a combination of GAC followed by AOP or RO followed by AOP, achieving required removal. Again AOP is required as neither RO nor GAC could remove all pharmaceuticals without the AOP.

Proposed treatment trains

- L.134 Based on the risks identified in WP2 and results from the technologies assessment in this work package, the treatment proposed for any reuse schemes would include:
- Gross and fine screens – to remove gross solids, such as wipes, cotton buds, hair, fibres, leaves etc. as a pre-treatment to an MBR. A fine screen would also be required if final effluent is the source for IPR as secondary clarifiers are generally not covered, allowing solids such as leaves to be present. These solids could damage the UF membrane
 - For any schemes where raw wastewater is used as an IPR source water, an MBR would be utilised. An MBR is a combination of biological and UF membrane processes used to remove nutrients, solids, organic and inorganic substances as well as to provide a full or partial barrier for pathogens such as cryptosporidium and other viruses
 - For any schemes where final effluent from WWTW is used as a water reuse source, an UF membrane process is used to remove solids, some organic and inorganic substances and to provide a full or partial barrier for pathogens such as Cryptosporidium and other viruses
 - A RO membrane process to remove most of the dissolved organic and inorganic substances, including unknown knowns, known and unknown unknowns. This is also an extra barrier against pathogens
 - An AOP used to destroy any organic chemicals that would pass through the RO. It will also act as an extra barrier with regards to pathogens.
 - A remineralisation process to ensure the water is re-hardened
- L.135 The GAC process in place of the RO process was not retained as it has a lower propensity to remove hydrophilic compounds such as metaldehyde and dissolved inorganic compounds. Furthermore, a cost analysis shows that replacing a RO process with a GAC process will not decrease the cost of the treatment due to lower water quality post-GAC, compromising the organic removal efficiency of the following AOP. This means that the AOP post-GAC, to achieve the same efficiency as an AOP post-RO, will require a higher number of UV reactors (increase in capital expenditure) and a higher energy and chemical consumption (higher operational costs) compared to an AOP post-RO. The proposed treatment is the most effective and lowest cost solution to maintain wholesome water.

Discussion

- L.136 In this work package, we have assessed the performance of different technologies with regards to the removal of contaminants identified as potential risks to the environment and public health. This has allowed us to define best treatment train for an IPR scheme. This includes RO and AOP, which confirmed the treatment train assumed for WRMP19 costing.
- L.137 This treatment choice is also supported by the panel of experts that carried out a review of identified risks to the environment and public health and potential treatment to mitigate them. While these experts confirmed that most of the risks could be controlled either by enhancing contaminants' removal through existing WWTW or dealt with at WTW, RO followed by AOP is the most effective barrier to deal with emerging and unknown contaminants.

Validation of our approach

- L.138 Our approach to identification and mitigation of risk was reviewed by Professor Jennifer Colbourne MBE, Visiting Professor, Centre for Environmental Engineering, University of Surrey, who was the Chief Inspector of the Drinking Water Inspectorate for England and Wales between 2003 and 2015.
- L.139 Professor Colbourne confirmed the suitability of our approach based on design standard methodology enhanced by consideration of novel risks. On reviewing our evidence, she agreed that reverse osmosis treatment would be necessary to have confidence that wide range of varying risks associated with planned indirect potable reuse could be mitigated in order to secure the safety of drinking water at all times.
- L.140 Professor Colbourne considered that further data was needed in order to understand the pathogen risks associated with the increased discharge of final wastewater effluent upstream of the abstraction point. At present she considered that this aspect of the risk assessment was based on generic knowledge rather than catchment specific data, which if available would enable the refinement of the design of mitigation of the public health risk in respect of disinfection. In particular, she considered that the need for ultraviolet irradiation, as an alternative to chlorination, could not be adequately assessed without such data.
- L.141 While being content with the approach, Professor Colbourne highlighted a possible gap in the current methodology, namely, how did it relate to the current regulatory risk assessment (Drinking Water Safety Plan) for the water supply system. She recommended a review of the existing Drinking Water Safety Plan and data about the performance of existing control measures. She emphasized that securing the safety of drinking water quality was far wider than a consideration of the water quality data and parameters used for compliance monitoring and included operational maintenance and asset performance information. We have noted her suggestions and included them in our 'Further development work' subsection below.

Further development work

- L.142 From the research carried out to date, gaps have been identified, including:
- Water quality gaps such as the understanding of pathogens presence and global water toxicity of the influent (link to unknown contaminants), and negative impact of treatment on water quality (e.g. disinfection by-products production during IPR treatment)
 - Impact of chosen treatment train on the environment – what do we do with the waste stream and how we ensure that the produced water is not too pure for the flora and the fauna
 - Monitoring of the influent, between treatment train (on-line and off-line) – to ensure that influent water quality is within design specification and treatment trains are capable to treat the influent and remove identified risks.
- L.143 These gaps could have been identified earlier if a wider risk assessment was already in place. One of the drawbacks of the risk assessment methodologies used is the focus on environmental and public health risks associated with (known) influent water quality as well assessing which treatment could be used to mitigate them. Therefore, there is a need to develop a broader dimension of risk and meet the requirement to develop a water reuse safety plan.

- L.144 The further work proposed below is needed to assist in the design and implementation of any IPR schemes and thus provide greater confidence to our regulators that we are taking any steps to identify and mitigate any risks associated with the scheme we plan to implement.

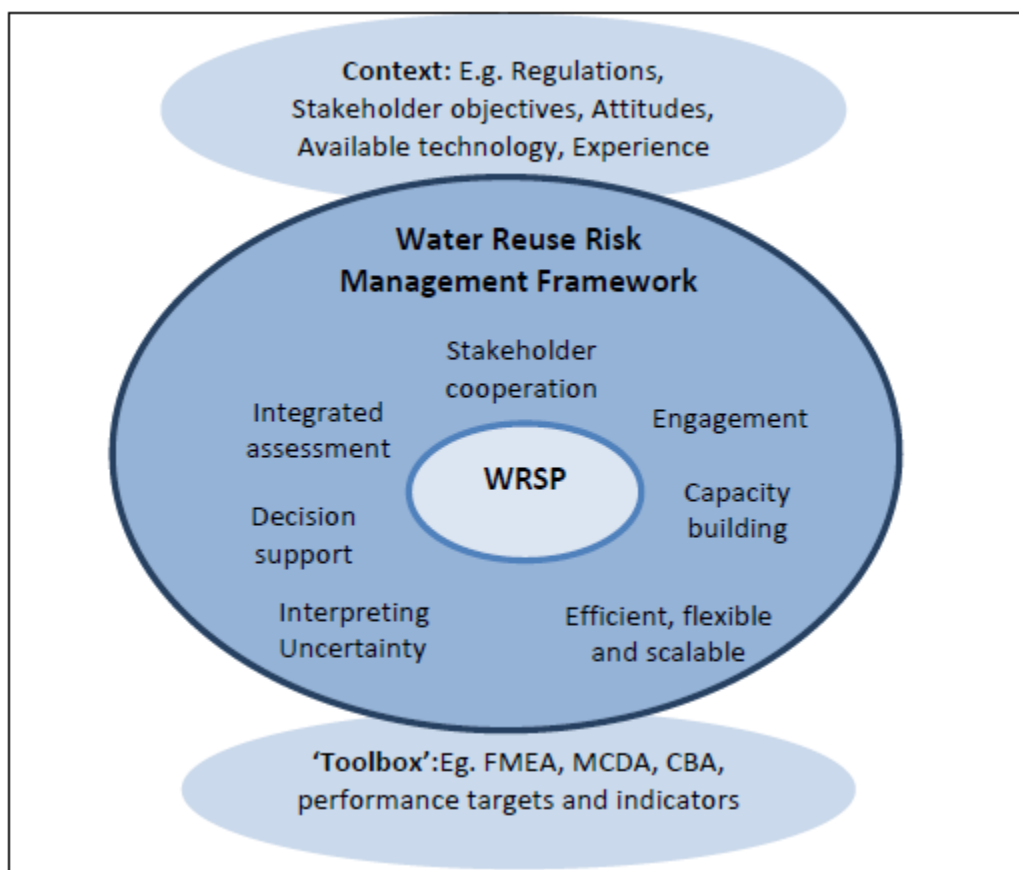
Water reuse risk management framework

- L.145 Under Regulation 27 of the Water Supply (Water Quality) Regulations 2016, water suppliers must carry out a risk assessment of each of their WTWs and connected supply to ensure control measures are put in place to mitigate those risks. This risk management approach is based on the WHO's WSP (Drinking Water Inspectorate, 2009). To comply with this regulation we have implemented the WSP approach throughout our drinking water systems.
- L.146 The WSP is also receiving increasing attention as a recommended risk management approach for water reuse through a range of research programmes, guidelines and standards. In collaboration with Cranfield University (through the sponsorship of a STREAM Engineering Doctorate), a comprehensive review of the numerous conceptual modifications of the approach – including the Sanitation Safety Plan, the Water Cycle Safety Plan (WCSP), and even a dedicated Water Reuse Safety Plan (WRSP) – was carried out, highlighting a number of key risk considerations for further developing the WRSP approach. More details can be found in Goodwin et al.²⁸.
- L.147 Key risks that have been considered include:
- Risk characterisation and decision support tools to interpret uncertainty
 - Integration and prioritisation of risks, risk controls and operational monitoring
 - Understanding technological performance and the capabilities of water professionals
 - Communication and engagement with regulators, stakeholders and the public
- L.148 It was proposed to modify the existing WSP approach and its overarching risk management framework, in order to adapt it for water reuse, to include aspects such as supporting communication and engagement with the public, stakeholders and governing bodies, and improving decision support mechanisms to better account for uncertainty, risk interactions and risk prioritisation. These aspects are not unique to water reuse, but require a greater degree of attention than is afforded in current WSP guidance.
- L.149 As with the WSP, a WRSP approach should be encompassed within a broader risk management framework. This will help establish risk management principles and ensure that objectives are suitable for the context. Like the WHO's Framework for Safe Drinking Water, the risk management framework for reuse would guide scheme managers in setting targets and routinely assessing management performance. For water reuse, important risk considerations extend beyond public health outcomes, and an overarching risk management framework must therefore reflect and facilitate broader contexts and objectives for water reuse schemes. The findings of this study highlight that a more integrated systems approach to risk management for water reuse, encapsulated within a risk management framework and operationalised through the WRSP, would help scheme managers to better anticipate potential risks and opportunities. Figure L-8 presents the developed conceptual water reuse risk management framework

²⁸ D. Goodwin, M. Raffin, P. Jeffrey, H. M. Smith (2015), Applying the Water Safety Plan to water reuse: Towards a conceptual risk management framework, *Environmental Science: Water Research and Technology*, 1(5), pp. 709-722

(WRRMF), operationalised through a water reuse safety plan. We are aiming to start the WRRMF for one of the reuse options in summer 2018.

Figure L-8: A conceptual water reuse risk management framework



Source: Goodwin et al.²⁸

IPR Pathogen fingerprint

L.150 The implementation of IPR would lead to the increase of wastewater effluent discharging into a drinking water catchment (i.e. surface water body). Wastewater effluents have a higher pathogen concentration than the surface water body, potentially increasing the pathogen load on our WTWs. To understand pathogen distribution for the current wastewater and water system and how IPR would change this distribution, we are proposing to undertake a pathogen fingerprint. This study aims to answer the following questions:

- What are the current microbial risks to human health associated with our current activities (river abstraction, surface reservoir, WTWs and network)?
- Is an implemented IPR scheme likely to control those microbial risks to human health?

L.151 To evaluate these risks, we propose to assess current and future pathogen fingerprints from source to tap under different scenarios: business as usual and IPR. Water sampling will be carried out through the full water cycle, including WWTW's influent and effluent, surface water body, WTW's influent, process steps effluent and produced drinking water. Pathogens in

samples will then be analysed by the University of Surrey using technologies which are both currently available and in development.

- L.152 The data will be analysed to form a pathogen fingerprint and risks will be identified (if existing) for the different scenarios. The research started in autumn 2017 and will last for a year to assess any seasonal variation. This work will feed into the WRRMF.

IPR Water quality patterns

- L.153 The current water quality data are mainly aggregated to average, minimum (5th percentile) and maximum (95th percentile). As discussed in the Operating philosophy, it is unlikely that the plant will be operated all year around. It is, therefore, necessary to understand water quality patterns to ensure that risks and their prevalence are considered when the plant is likely to be operated.
- L.154 Furthermore, we should understand whether one or few parameters could be used as surrogates instead of carrying out analysis for a vast amount of compounds. This would reduce cost of analysis and could become an “ally” with regards to influent on-line monitoring for example. This work was started in summer 2017.

IPR Monitoring

- L.155 Within the context of the WRRMF, on-line monitoring is a key part of mitigating water quality risks and identifying any treatment processes failure. This is something we will need to establish before we build any IPR scheme.
- L.156 We are proposing to review available on-line/off-line technologies and assess their performance and suitability to manage IPR schemes. This could include monitors to measure water toxicity, pathogen or other chemicals relevant to IPR. This work will start in spring 2018.

IPR Remineralisation

- L.157 RO membranes enable a quasi-pure water stream to be obtained, almost entirely free of organic and inorganic substances and with an acidic pH. If not re-hardened, this water could harm the fauna and the flora of the environment where the reclaimed water will be discharged.
- L.158 Through the use of jar tests, we will assess the remineralisation requirement as well as the blending ratio between reclaimed water and surface water.
- L.159 Furthermore, discharging high purity water may impact on downstream water treatment plant assets. For example, a certain level of alkalinity would be required for coagulation processes to work effectively. Lower alkalinity (and pH) could also have a detrimental effect on our water mains. This research started in autumn 2017 and will last for a year to assess seasonal variation.

Waste stream management

- L.160 The RO membrane waste stream, which will require disposal, contains all the contaminants present in the RO feed. This is called the RO concentrate. Depending on the size of the IPR plant and the WWTW, the RO concentrate can either be returned to the head of the associated WWTW or sent to a nearby WWTW, or discharged to a river after treatment if required.

- L.161 The requirement for the RO concentrate disposal will be assessed through this workstream to ensure risk minimisation for the WWTW process and the environment. This research started in autumn 2017 with the commissioning of the pilot RO plant and will last for a year to assess seasonal variations.

IPR concluding remarks

- L.162 Planned IPR (IPR) is the reclamation of wastewater effluent that would be potentially lost to the sea as a water resource. Once treated, the reclaimed water is discharged within a drinking water catchment (i.e. river or surface water reservoir).
- L.163 We have identified five IPR sub-options with a combined maximum deployable output of 816.5 Ml/d. Due to the nature of this water resource (wastewater), we have developed risk assessment methodologies to ensure risks to the environment and public health are identified and mitigation techniques included. Risks identified include microbiological compounds, inorganic compounds (chloride, cyanide, nutrients such as phosphorus and nitrogen compounds and metals) and organic compounds (pesticides, solvent, disinfection by-product, hormones, pharmaceuticals and other organics).
- L.164 We have tested different technologies to assess their operability and efficiency at eliminating these risks. Based on the risks identified and the trialled technologies' performance it is proposed that RO membranes followed by AOPs should be included in all water reuse treatment schemes, whatever their deployable output. This supports our aim to continue achieving high compliance with drinking water regulations.
- L.165 Further research is however required as risks associated with "unknowns" (i.e. compounds we did not analyse for) could not be derived from current research. We would also look at developing and applying a water reuse risk management framework to ensure that any risks associated with the implementation of IPR are accounted for.

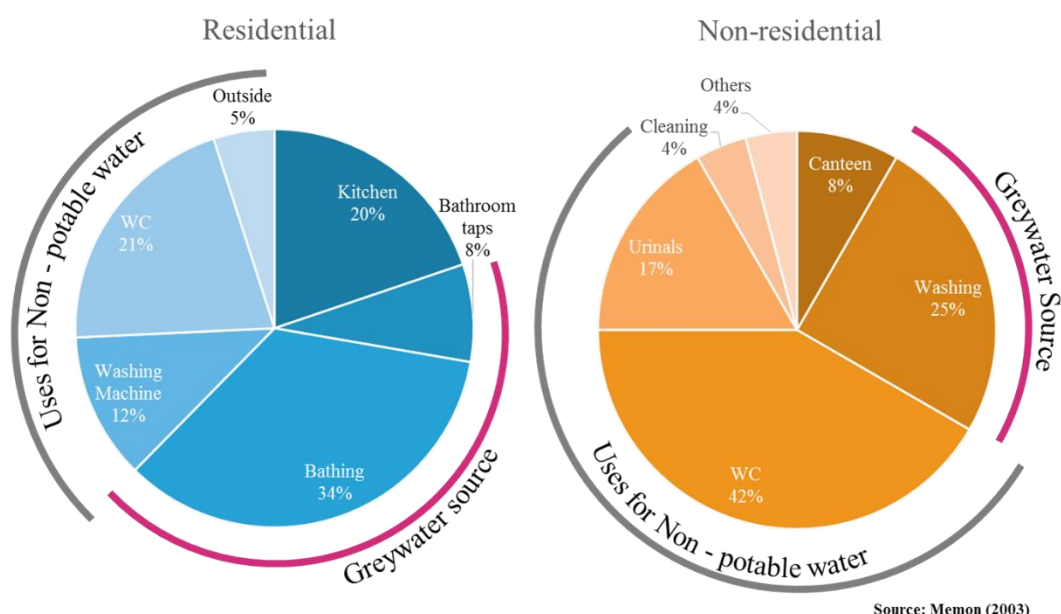
C. Non-potable reuse

- L.166 As part of WRMP19 we have examined the creation and management of non-potable water to reduce the demand for potable water in applications such as toilet flushing and landscape irrigation. NPR systems must consider and seek to eliminate the risk from misuse or misconnection. The large anticipated demand for new housing offers the opportunity to influence developments to incorporate non-potable water systems.
- L.167 For the first time, we have included NPR options as part of our WRMP19 demand management programme. We have included costed options for the implementation of NPR systems in new developments.
- L.168 Following a multi-stage methodology, which screened out non-viable options, we concluded that the implementation of NPR (using a combination of greywater recycling and rainwater harvesting systems) could reduce drinking water demand by up to 33 Ml/d. The system would however need to be installed in a managed environment to reduce the possibility of misuse or cross-connections between the non-potable and potable networks.

What is non-potable reuse?

- L.169 Residential or commercial water demand is made up of various uses that can be met by water that has a lower quality level than that necessary for potable (drinking) water purposes. For households (residential units), approximately 33% of the water supplied is used to flush toilets and run washing machines. Similarly for commercial (non-residential) developments, approximately 60% of the water demand is for non-potable purposes including flushing toilets and urinals (Figure L-9).

Figure L-9: Water use by use type, non-potable supply and demand



- L.170 Some of this demand could be met by a non-potable water supply, resulting in a significant reduction in the demand for potable water.

L.171 Non-potable water can originate from different sources:

- Rainwater – Rainwater is captured from roofs and treated to meet non-potable water standards (rainwater harvesting)
- Stormwater – Rainwater captured from pedestrianised surfaces and road run-offs, and treated to meet non-potable water standards (stormwater harvesting)
- Greywater – Water from baths, showers and bathroom sinks collected and treated to meet non-potable water standards (greywater recycling)
- Blackwater – Wastewater, including municipal and industrial wastewater, and rainwater run-off (from combined sewers) collected and treated to high quality standards (blackwater recycling)

L.172 Although various systems are available in the market, an NPR system normally comprises:

- Collection pipes and pre-treatment storage
- Water treatment systems to improve water quality
- Storage for treated non-potable water
- Dual plumbing and pumping system for the supply of non-potable water separate from the potable water supply systems.

L.173 In addition to the above, the greywater systems require dual plumbing of the drainage system to capture the water from showers, baths, sinks and washing machines.

L.174 Non-potable solutions in the UK are implemented at different scales, from single buildings to large housing/commercial development (decentralised/semi-centralised supply). In the UK, most of the systems are implemented at individual building scale, often driven by the desire from the building owner to achieve sustainability certification (e.g. BREEAM). Implementation at a larger scale is less common and operated under a managed environment. Non-potable systems are generally easier to install in new developments rather than retrofitting to an existing building due to the cost impact of retrofitted dual pipe plumbing.

Our non-potable water reuse options for new developments

Opportunity for non-potable water reuse

L.175 A total increase in population is forecast in our supply area of more than 2 million people by 2045 with high population growth predicted in London, Oxfordshire, Swindon and Slough. In London, the majority of this growth is expected to occur within the 38 Strategic 'Opportunity Areas' (OAs) identified in The London Plan²⁹. These OAs are large brownfield sites that are suitable for major redevelopment. To achieve its target of one million new homes by 2020, the Government is also supporting a new wave of garden cities, towns and communities of at least 10,000 homes (e.g. Bicester, Basingstoke, Didcot, Ebbsfleet). In March 2016, the government also extended this support offer to new settlements comprising between 1,500 and 10,000 new homes.

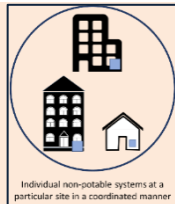
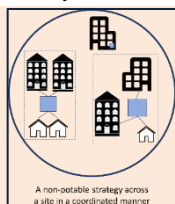
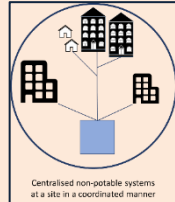
²⁹ Mayor of London (2016), The London Plan – The spatial development strategy for London consolidated with alterations since 2011, March 2016

Non-potable water reuse feasible options

- L.176 We have undertaken a feasibility study, with a consortium led by Arup, to assess the potential for implementing NPR within the 38 OAs in London. The feasibility study aimed to identify a credible non-potable demand reduction estimate based on the total opportunities available. This was achieved across the OAs using a multiple stage approach:
- Stage A – The available yield, estimating the volume of NPR assuming all non-potable demand is met
 - Stage B – The technical yield, estimating the volume of NPR based on ability of new developments to meet their non-potable water demands
 - Stage C – The allowable yield, estimating the volume of NPR that can be achieved once regulation, standards, policies, perception, deliverability and performance are met, addressed and accounted for. These are the feasible options
 - Stage D – The economically effective yield, which is the volume of NPR that could be delivered economically, in comparison with other demand management options being considered in the WRMP19 Demand Management Options Screening Report. These options are those identified in the WRMP19 constrained options list
- L.177 The results of this study are summarised below and the details can be found in the full report³⁰.
- L.178 The study found that up to 33 Ml/d of water could be saved through the implementation of NPR, by harvesting rainwater and stormwater, and/or recycling greywater (combined source). 27 options for each opportunity area were put forward for assessment in the WRMP19 Demand management options screening report. The breakdown of NPR options by different developments is categorised and summarised in Table L-10.
- L.179 Cost analysis in Stage D identified the recycling of greywater with rainwater/stormwater harvesting as more cost effective than recycling greywater or harvesting and reusing rainwater and stormwater alone.

³⁰ Ove Arup & Partner Ltd (2017), Non-potable water reuse as a demand management option for WRMP19 – Options appraisal report, June 2016 (<https://www.thameswater.co.uk/wrmp>)

Table L-10: Non-potable water reuse feasible options

Option categories	Building type	Unit	Rainwater harvesting	Stormwater harvesting	Greywater recycling	Combined
Development Level – Individual NPR Systems  <small>Individual non-potable systems at a particular site in a coordinated manner</small>	Commercial only	MI/d	0.3	-	4	5
	Residential only	MI/d	0.9	-	28	28
	Commercial & Residential	MI/d	1.2	-	32	33
Development Level Mix of NPR Systems  <small>A non-potable strategy across a site in a coordinated manner</small>	Commercial only	MI/d	-	0.4	4	5
	Residential only	MI/d	-	1.4	28	28
	Commercial & Residential	MI/d	-	1.8	32	33
Development Level – Central NPR System  <small>Centralised non-potable systems at a site in a coordinated manner</small>	Commercial only	MI/d	-	0.4	4	5
	Residential only	MI/d	-	1.4	28	28
	Commercial & Residential	MI/d	-	1.8	32	33

Old Ford water recycling plant (OFWRP)

- L.180 The OFWRP is the UK's largest blackwater recycling facility, providing a water resource for non-potable applications, including toilet flushing and irrigation on the Queen Elizabeth Olympic Park (QEOP). Jointly funded by the Olympic Delivery Authority (ODA) and Thames Water, the facility was set up as part of the ODA's strategy to reduce potable water consumption across the park by 40 per cent. The OFWRP currently supplies 13 customers through a dedicated 4 km non-potable network. We have operated and maintained the OFWRP and associated assets since February 2012, supplying on average 75 million litres a year of recycled, non-potable water.
- L.181 The plant, which has a production capacity of 0.574 MI/day, also provided an opportunity for us to perform detailed research into aspects of non-potable water provision (technical, financial, social and regulatory etc.) that is of growing local and national interest.
- L.182 We are contracted to operate the OFWRP and supply non-potable water to our customers to February 2019. We have looked at different options with regards to the fate of the plant post-

February 2019, including the continuation of operating and maintaining it. However, after careful consideration, we took the decision that the operation of the OFWRP by ourselves should be stopped post-February 2019. Reasons for this decision are:

- Poor alignment with future non-potable water promotion initiatives, which will focus on greywater recycling and rainwater harvesting NPR system (as described above)
- Uncertainty with regards to potential customer demand for non-potable water on the QEOP
- Poor operational fit to our existing business process
- Uncertainty with regards to long term funding and financial viability

L.183 However, the operation of the Old Ford Water Recycling system has been tremendously valuable for both us and other involved parties in terms of design, operation, risk management, customer and stakeholder engagement and public perception. We have learned a considerable amount and it has directly led to us promoting non-potable water at scale within the WRMP19.

Lesson learned – our experience to date with non-potable water

L.184 As explained above, we have supplied non-potable water derived from raw sewage (blackwater) from the OFWRP to the QEOP since 2012. We have also built and operated a greywater recycling plant at the Millennium Dome (1999) and a blackwater recycling plant at Beddington Zero Emission Development (BedZED, South London 2008-12). Finally, we have funded a greywater recycling plant at a mosque/community centre (Wapping 2015). The following summarises the lessons learned from implementing and operating those schemes.

L.185 Use of non-potable water reduces drinking water demand. As an example, water consumption is reduced by more than 75 million litres every year on the Olympic Park thanks to the non-potable water supply from the OFWRP. The different schemes have been reliable and resilient as long as they are operated and maintained correctly. For example, the OFWRP meets 100% of the required water quality standards and has availability higher than 95%.

L.186 However, NPR technology (especially with regards to a blackwater recycling plant such as the OFWRP) can be quite complex to operate and requires skilled operators. Furthermore, running a plant that contains both water and wastewater assets poses a considerable challenge for a water company when aligning with its asset maintenance systems and protocols.

- L.187 Non-potable water poses a risk to public health if not used as intended (for example if drunk). Pipe cross-connections between different water networks are of particular concern. To reduce those risks, we have developed and implemented tools such as:
- Applying a bespoke reuse WSP to identify and manage risk
 - Producing high quality water safe enough to be used for non-potable applications
 - Requiring a strict adherence to WRAS guidance for clear labelling of non-potable assets and network
 - Providing inductions and safety briefings to all non-potable water facility managers
 - Requiring end users to perform dye and pressure testing for intermittent use systems
- L.188 Our current risk management approach favours non-household customers with large water demand for non-potable water supply schemes. Residential developments pose considerable cross-connection and misuse risk spread over a large number of potential intervention points. At present there is no proven low cost risk management technique that addresses our concerns. We encourage the installation of non-potable systems provided they are properly implemented and maintained. However their increased use poses a considerable water quality compliance risk to us.
- L.189 Furthermore, we have concerns over the ability of such systems to provide long term water reduction performance. Because of a lack of ownership from the customers, two of the implemented schemes, namely the greywater recycling plant at the Millennium Dome and the BedZED water recycling plant, were decommissioned once contracts between us and the customers ended. This will be also the case for the Old Ford Water Recycling Plant. Furthermore, new developments are rarely built by the subsequent owners and future Thames Water customers. This means that non-potable water systems could be installed in new developments but not operated/maintained correctly, decreasing its efficiency at reducing water demand through these development. Reducing company investment in infrastructure to meet growing population demands based on demand reduction schemes such as non-potable systems must be considered a risk until the requirement for maintaining and using such schemes for the long term is clarified and confirmed.

What's next – the challenge of implementing a non-potable system?

- L.190 For any NPR system options identified in WRMP19, a sustainable operating model must be developed to ensure that:
- The NPR scheme is performing as it should in the short, medium and long term (water quality and demand reduction)
 - Cross-connection risk between potable and non-potable water supplies is effectively managed
 - The implementation of NPR schemes is beneficial for our customers, us and other operators

Is the inset regime a possible answer?

- L.191 The inset regime allows a third party (now termed new appointments and variations (NAV)) to become a new service provider within an existing water company's region. Most of the new developments (either within the London OAs or new green villages/towns) would qualify as potential inset sites.
- L.192 Successful applicants provide water and/or sewerage services for a specific area, typically a new or large development. They do not generally produce the drinking water or treat the wastewater. Therefore there are bulk supply connection arrangements between the NAV and the wholesaler (such as us). In this arrangement we and the NAV trade bulk water and wastewater services but the NAV remains accountable for water quality issues at the customer tap. The inset regime also opens the opportunity to create the incentive and performance accountability for NPR schemes. This would allow the NAV to innovate on the non-potable water treatment system and control regime and be held accountable by the Drinking Water Inspectorate. We could, in principle, seek to reward the NAV with a lower cost water supply should they maintain raw water demand; with appropriate penalties should they fail.

Concluding remarks non-potable water

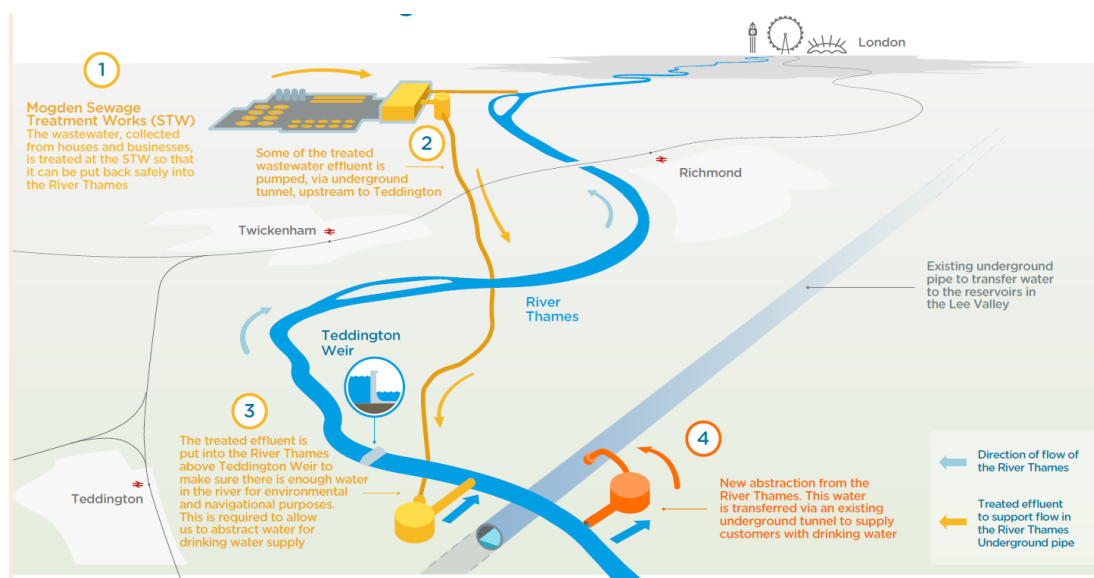
- L.193 Non-potable water supplies to customers reduce the demand for potable water in applications such as toilet flushing and landscape irrigation. We have identified the use of greywater recycling in combination with rainwater or stormwater harvesting as the most sustainable option. This could reduce drinking water demand by up to 33 Ml/d from new commercial and residential developments. We are well aware from our own experience that NPR systems must consider the risk from misuse or misconnection.
- L.194 All options will require effective management controls to ensure that risks linked to the misuse of non-potable water or linked to cross-connections between the non-potable and potable water supply are mitigated.

D. Environmental flow augmentation

- L.195 An environmental flow augmentation option was assessed to support enhanced Teddington direct river abstraction (DRA). In this option, up to 300 Ml/d of tertiary treated effluent from Mogden WWTW would be transferred to above Teddington Weir to allow further upstream abstraction of freshwater from the River Thames. This is termed environmental flow augmentation. The abstracted water will be transferred to two reservoirs in the Lee Valley Reservoir Chain, the Lockwood Reservoir or Banbury Reservoir, via the Thames-Lee tunnel. Figure L-10 summarises the key aspects of this option. In this instance water is reused purely for the purposes of enabling the additional upstream abstraction. Without environmental flow augmentation, we would not be able to abstract more freshwater on the non-tidal River Thames whilst still aiming to comply with the catchment abstraction management strategy (CAMS) ¹, the Lower Thames Operating Agreement (LTOA) and the Lower Thames Control Diagram (LTCD) requirements.

- L.196 For this option to be feasible, considerations need to be taken into account to ensure this option does not have detrimental impact on the environment (e.g. complying with WFD) and users of the Thames (e.g. impact on navigation).

Figure L-10: Teddington DRA option



Our draft WRMP19 position

- L.197 The Teddington DRA option was considered feasible and was part of our preferred plan³¹. However, our dWRMP19 reported that the WFD compliance of a Teddington DRA option was uncertain. The dWRMP reported that the uncertainty concerned the development and agreement of the extent and purpose of further mitigation to ensure compliance with WFD objectives for ecology, notably maintaining the current Good WFD status for fish and invertebrates in the estuarine Thames Upper transitional WFD water body (GB GB530603911403).
- L.198 Regarding uncertainty, compliance with Habitats Regulations Assessment (HRA) and WFD requirements, paragraph 11.48 of the dWRMP Technical Report states:

'A significant programme of further work is currently under way to understand the potential for Teddington DRA to affect ecological status or potential, and to identify the design, operation and mitigation measures that would be required in order to make the scheme compliant with the WRPG. We fully expect this work to be concluded by the submission of our final plan, and that the potential ecological issues raised to date can be resolved.'

- L.199 Regarding the SEA impact of the preferred programme, paragraph 10.254 of the dWRMP Technical Report states:

³¹ <https://corporate.thameswater.co.uk/About-us/Our-strategies-and-plans/Water-resources/Our-draft-Water-Resources-Management-Plan-2019>

‘In deciding upon the preferred plan we have noted the potential concerns regarding the need to identify further mitigation measures associated with the DRA_Teddington scheme to ensure no deterioration against WFD status of the Upper Tideway. With this uncertainty yet to be resolved we agree that it is prudent to defer the delivery of the scheme until 2030 to allow extra time for investigation.’

- L.200 Please refer to Appendix B and BB for further information on this potential impact. To reduce/remove the uncertainty described above, further investigations were undertaken post dWRMP19 to understand the impact of the Teddington DRA on the River Thames upstream and downstream of Teddington Weir. The results are presented below.

Investigations summary – post dWRMP19 submission

- L.201 HR Wallingford was commissioned to model the impacts on the freshwater and estuarine tideway of different options by varying the ratio between the discharged water flow and the river water flow post- potential abstraction³².
- L.202 This includes assessing impacts on water levels, salinity, current velocity, sediment, dissolved oxygen, temperature, nutrient and chemicals. The modelling results are summarised in Table L-11.
- L.203 The modelling results were used to inform the potential impacts on ecology (including fisheries and benthic invertebrates) and navigation. Mitigation options for the impacts have been investigated.
- L.204 The modelling results, impacts and mitigation options have been reviewed by both the EA and the Port of London Authority (PLA).
- L.205 These investigations identified that the main impact would be an increase in water temperature in the freshwater River Thames locally above Teddington Weir and in the estuarine upper Thames tideway as a consequence of discharging treated effluent at Teddington.

³² HR Wallingford (2018) Thames Tideway Impacts of DRA (WRMP Option 3) Modelling and analysis of impacts in the Upper Thames Tideway. Ref DER5714-RT001-R04-00. Report to Thames Water 15 March 2018
HR Wallingford (2018) Thames Tideway Impacts of WRMP Task 2: Modelling and analysis in the lower freshwater River Thames. Ref DER5714-RT002-R04-00. Report to Thames Water 15 March 2018

Table L-11: Investigation summary table

Investigated parameters	Modelling summary for estuarine Thames Tideway downstream of Teddington Weir	Modelling summary for the freshwater River Thames upstream of Teddington Weir	Potential ecological / navigation impacts	Proposed mitigation
Water level	Reduction in minimum water level of up to 0.18 m, with largest reduction downstream of Richmond Weir	No significant change (less than 1 mm)	<ul style="list-style-type: none"> May restrict navigation, including accessibility for the PLA's Harbour Service Launches, other emergency vessels and commercial services. Increase of period of time where navigation is restricted by up to 30 min/day, with largest increase on shoals between Richmond and Kew. May influence sport and recreational activities with increase number of incidents and near misses. May impact PLA's ability to maintain the required water level between Teddington and Richmond due to increase lock leakage 	<ul style="list-style-type: none"> An initial assessment of the likely increased leakage through Richmond Weir and lock has concluded this is not expected to be significant – No mitigation required. Further work is required to identify mitigations for the reduced water level downstream of Richmond and its impact on river users.
Salinity	Increase in average and maximum salinity of up to 1.25 ppt and 1.7 ppt respectively, with largest increase between Putney bridge and Tower Bridge	Not applicable	<ul style="list-style-type: none"> May influence smelt spawning. May change distribution of freshwater fish within the upper (estuarine) Thames Tideway. May influence estuarine invertebrate infauna community. May influence swollen spire snail population. 	<ul style="list-style-type: none"> Restricting the operation of the scheme in March would alleviate the effects on Smelt spawning. Further work required to validate assumption made for the modelling.
Intertidal exposure	Increase in intertidal exposure of up to 1.6%	Not applicable	<ul style="list-style-type: none"> May influence elver migration. 	<ul style="list-style-type: none"> Further work required.
Current speed/ River flow	Increase in maximum peak current speed to 0.15 m/s	Reduced flow velocity in the river between the intake and the outfall. An eddy is predicted between the outfall and Teddington weir	<ul style="list-style-type: none"> May influence Atlantic Salmon and Sea Trout migration May influence elver migration 	<ul style="list-style-type: none"> Alternative outfall designs have been developed that reduce the eddy effect between the outfall and Teddington weir



Investigated parameters	Modelling summary for estuarine Thames Tideway downstream of Teddington Weir	Modelling summary for the freshwater River Thames upstream of Teddington Weir	Potential ecological / navigation impacts	Proposed mitigation
Suspended sediment	Changes in the time-average suspended sediment concentrations, generally below 10 mg/l, with the largest changes in the vicinity of Greenwich. Instantaneous maximum differences in suspended sediment concentrations are below 30 mg/l	Not applicable	<ul style="list-style-type: none"> Unlikely to have an impact 	
Sediment flux	Changes of about 2% to sediment flux, which is considered negligible in terms of morphological change	Not applicable	<ul style="list-style-type: none"> Unlikely to have an impact 	
Dissolved oxygen	Reduction in dissolved oxygen in the upper tideway landward of Richmond Weir. Beyond Chiswick the option is not predicted to impact on dissolved oxygen under any flow condition.	Not Applicable	<ul style="list-style-type: none"> May influence fauna 	<ul style="list-style-type: none"> Additional oxygenation at Mogden STW to increase dissolved oxygen in effluent

Investigated parameters	Modelling summary for estuarine Thames Tideway downstream of Teddington Weir	Modelling summary for the freshwater River Thames upstream of Teddington Weir	Potential ecological / navigation impacts	Proposed mitigation
Temperature	Increase of river temperature at Teddington Weir of up to 3°C for high probability scenarios and up to 8°C for low probability scenarios, with temperature returning to background value around 30 km below Teddington	Increase of river temperature at Teddington Weir of up to 3°C for high probability scenarios and up to 8°C for low probability scenarios	<ul style="list-style-type: none"> • May influence smelt • May influence Atlantic Salmon and Sea Trout migration • May influence estuarine invertebrate infauna abundance • May influence timing of emergence of new species • May promote invasive non-native species such as quagga mussel (competitively advantaged over native benthic molluscs) 	<ul style="list-style-type: none"> • Two mitigation options have been investigated: operational mitigation by reducing the deployable output and engineering solutions to reduce the temperature of the effluent prior to discharge. • Further work required
Phosphate	Increased concentrations in the Teddington to Richmond reach	Not applicable	<ul style="list-style-type: none"> • May influence flora and fauna 	<ul style="list-style-type: none"> • Further work required
Nitrate	Increased concentrations in the 13 km between Teddington Weir and Chiswick and reduced concentrations seawards of Chiswick.	Not applicable	<ul style="list-style-type: none"> • May influence flora and fauna 	<ul style="list-style-type: none"> • Further work required
Chemicals	Potential increase of organic and inorganic compounds	Potential increase of organic and inorganic compounds	<ul style="list-style-type: none"> • Non-compliance with WFD EQS requirement • May influence Atlantic Salmon and Sea Trout migration (masking of olfactory cues) 	<ul style="list-style-type: none"> • Advanced treatment of Mogden WWTW effluent investigated – zinc, mercury and pentachlorobenzene concentrations above EQS. • Further work required

Common understanding between the Environment Agency and Thames Water³³

- L.206 The findings were discussed at meetings with the Environment Agency on 1 May 2018 and consequently on 13 July 2018 and a common understanding of the water environment effects of the Teddington DRA option between the EA and Thames Water was drafted. Based on these further discussions since the dWRMP position, both parties agree that the compliance with WFD objectives of a Teddington DRA option remains uncertain.
- L.207 Uncertainty remains, in a WFD context, around the required extent of temperature mitigation of a Teddington DRA option. Research to date has not been sufficient to satisfactorily determine the required extent or to identify a viable mitigation option to deliver this. In consequence, a Teddington DRA option cannot be considered a feasible option³⁴ in a proposed WRMP programme at this time.

Background to the position

- L.208 WFD³⁵ standards for water temperature in rivers are listed as not greater than a 3°C temperature increase³⁶ compared with background temperature³⁷. Although the standards apply to discharges with environmental permit conditions relating to thermal discharge³⁸, it is considered by Thames Water and the Environment Agency that these standards should be used as a guide to the thermal sensitivity of the Thames ecosystem to DRA discharges at all times of the year. This guide approach³⁹ is in acknowledgement of the following:
- Neither Thames Water nor the Environment Agency has experience of this type of option given the magnitude of its size, either in its operation or its environmental effects.
 - The Environment Agency note that the standards are in the context of small discharges to large rivers. When considering the permitting of thermal discharges⁴⁰, the Environment Agency advocate allowing for a mixing zone for the discharge across and along the river, within which targets may be exceeded. In line with

³³ Thames Water and Environment Agency: Common understanding of the water environment effects of the Teddington Direct River Abstraction (DRA) option. Statement following meeting with the Environment Agency on 13 July 2018

³⁴ Environment Agency and Natural Resources Wales (2017) Water Resources Planning Guideline Section 6.11 states: *You should confirm that there is no risk of deterioration from a potential new abstraction or from increased abstraction at an existing source before you consider it as a feasible option.*

³⁵ UK transposition of the WFD: Water Environment (Water Framework Directive) (England and Wales) Regulations 2017. <http://www.legislation.gov.uk/uksi/2017/407/contents/made>
Defra's Direction to the Environment Agency: The Water Framework Directive (Standards and Classification) Directions (England and Wales) 2015 (see Table 6 for temperature standards for rivers):
http://www.legislation.gov.uk/uksi/2015/1623/pdfs/ukiod_20151623_en_auto.pdf

³⁶ Up to 3°C increase (or decrease) is applicable to both Cyprinid and Salmonid rivers at Good WFD status

³⁷ Expressed as an annual 98th percentile, i.e. 98 values out of 100 must comply with this standard and only 2 out of 100 can exceed it for compliance to be retained, with all values across a year considered relevant.

³⁸ It is noted that the current Mogden STW environmental permit does not include thermal conditions for discharge of treated effluent into the estuarine Thames Tideway at Isleworth Ait, and that in permitting in general, thermal conditions relate typically to power station cooling discharges.

³⁹ Noting this may become a requirement should the Environment Agency include thermal discharge conditions in the environmental permit for a DRA scheme at the time of permitting.

⁴⁰ BEEMS-SAR-008, Thermal standards for cooling water from new build nuclear power stations

international good practice, some 75% of the width of the river should be outside the mixing zone so that an unpolluted corridor remains for fish migration.

- A DRA option is of larger scale than the standards are set for, with potential for whole river replacement⁴¹ for several months⁴². In this case there would be no such mixing zone, just a step change from background conditions to impacted conditions, across the full width of the freshwater River Thames local to the outfall⁴³.
- L.209 Indeed, a more precautionary objective may be appropriate in considering an ecologically acceptable temperature increase from a DRA option compared with background temperature in the freshwater River Thames and estuarine Tideway. The Environment Agency indicate that **zero temperature increase** would be such a precautionary objective. In regulatory and practical terms zero increase would need defining further⁴⁴.
- L.210 Mitigation approaches considered by us at present are based on either reducing/ temporarily suspending the rate of DRA operation, or cooling of treated effluent prior to discharge. At present the review of mitigation options and their effectiveness is not able to identify a robust temperature mitigation package that could be included in option design to meet the more precautionary objective. With further development of operational controls, a technically feasible cooling system could meet the guide standards, noting that the resulting temperature increase is not confirmed as ecologically acceptable. As such, the compliance with WFD objectives of the Teddington DRA option remains uncertain.
- L.211 We will continue to undertake research on both: 1) the sensitivity of the Thames ecosystem to DRA discharges at all times of the year; and 2) potentially viable mitigation approaches. The climate change sensitivity and resilience of these will be included in the research.

Research programme scope

- L.212 In order to lift up the uncertainty surrounding the Teddington DRA option with regards to its effect on the Thames ecosystem, the following research programme scope will potentially be undertaken in AMP7 in support of WRMP24. This research programme will appraise:
- The ecological effect, including further research on how this option may affect non-native species population (fauna and flora) and the resilience of native fauna and flora
 - The chemical effect, ensuring compliance with WFD and concentration of olfactory inhibitors relevant to adult upstream salmonid migration
 - The physical effect, including the impact on this option on smelt spawning habitat

⁴¹ 300MI/d DRA abstraction and discharge operating at times of a 300MI/d Teddington Target Flow through the Lower Thames Operating Agreement

⁴² On a low return frequency of 1:50 years or more rarely

⁴³ As identified through 2D hydrodynamic modelling of the outfall undertaken for Thames Water for indicative DRA outfall designs to date.

⁴⁴ For example this could relate to a 0.3°C variance as measured at a continuous water temperature monitoring sonde in the River Thames downstream of a DRA outfall upstream of Teddington Weir, in comparison with a partner sonde continuously measuring background freshwater river temperature located in the River Thames upstream of the Hogsmill River confluence, with data collected for compliance assessment every 15 minutes. Of these 15 minute data at the downstream sonde, 98% could need to be within plus or minus 0.3°C of the background sonde at times of operation of a DRA option.

- The navigation effect, including leakage through Richmond Sluice and navigation impacts below Richmond.

L.213 Required environmental mitigation will be investigated further to determine its feasibility, practicability and cost.

Ecological effect

Enhancing establishment of invasive non-native species

L.214 Four invasive non-native species (INNS) are reported to be present around the Teddington Weir (Thames 21): the quagga mussel, zebra mussel (Ponto-Caspian INNS), the Asiatic clam and the Himalayan balsam. In addition to those, Chinese mitten crab and Japanese knotweed are reported downstream of the Isleworth Ait location where Mogden WWTW final effluent is discharged to. The further research will mainly focus on the risk of enhanced establishment for new colonising Ponto-Caspian INNS.

L.215 Ponto-Caspian INNS success to colonise our river can be attributed to different factors⁴⁵:

- The South East of England has a similar climate to the Ponto-Caspian region
- The species tolerance to wide temperature (especially the coldest temperature), oxygen and salinity ranges
- The species ability to resist to drought
- Their omnivorous opportunistic feeding
- Their rapid reproduction
- The presence of one INNS will promote the invasion of other INNS (i.e. invasional meltdown)
- Their establishment may be promoted in polluted environment and disturbed habitat

L.216 The presence and abundance of Ponto-Caspian species can have tremendous negative effects on an ecosystem by changing its energy flow and impacting on its biotic and abiotic components, including fisheries.

L.217 Zebra and Quagga mussel presence for example lead to a change of water chemistry, including a reduction in concentration of calcium, alkalinity and turbidity; and an improvement of water transparency promoting the growth of benthic plant. The later results in nutrient concentration reduction. On the other hand, it changes the food web change, by reducing the stock of phytoplankton and consequently impacting on zooplankton eaters such as perch, pike, pikeperch, bullhead, cyprinid and eel or unionid molluscs.

L.218 Temperature, salinity, oxygen and habitat stability are four factors that will be altered by the implementation of the Teddington DRA scheme without suitable mitigation. It is thus paramount to minimise the effect of this change.

L.219 We propose first to undertake targeted survey to better understand the abundance of Ponto-Caspian species above the Teddington weir, in the Richmond to Chiswick reach as well as in the Lee Valley Reservoirs chain where the water would be transferred to. This will include

⁴⁵ Gallardo, B., Aldridge, D.C., 2013, Review of the ecological impact and invasion potential of Ponto-Caspian invaders in Great Britain, Cambridge Environmental Consulting

sampling over several years of the river for INNS as well as assessing current WFD physico-chemical, biological and hydro-morphological indicators.

L.220 Similar research will be carried out for invasive non-native plants.

L.221 Output of this research should inform on the following:

- Current presence of INNS species
- Influence of parameters promoting the propagation of INNS species
- The design requirement for potential environmental mitigation

Fish migration/passage

L.222 Without confirmation of effective mitigation, fish (salmonids and European eel) migration/passage may be affected by the following:

- Change in flow/ velocity pattern
- Increase of temperature
- Decrease of oxygen level
- Presence of olfactory inhibitors that could interact with the environmental cue, disturbing fish migration

L.223 While the first three above points can be mitigated through engineering solutions, the last point requires assessment of how these inhibitors could disturb migration and is discussed further in the 'Chemical effect' subsection below.

L.224 The extent of this study will be defined through collaboration with fish biologists. This is considered to include a combination of fish databases review to assess the abundance of the fish during their migration, real-time monitoring (Temperature and dissolved oxygen upstream/downstream of the Hogsmill River and face of Teddington Weir), engineering design and modelling.

L.225 Output of this research should inform on the following:

- Current presence of migrating fish
- The design requirement for potential environmental mitigation

Smelt (and other endangered species) spawning and juvenile

L.226 Smelts start to spawn around March when the temperature of the water reaches 10°C. Later spawning can occur as long as the temperature remains below 15°C. Smelt spawning occurs in the Thames reach between Teddington Lock and Wandsworth Lock, with juveniles and adults found seaward of this reach all year round. Smelt are sensitive to salinity variation, with spawning occurring in areas with low salinity.

L.227 Concerns were raised with regards to the potential detrimental effect that the Teddington DRA option could have on European smelt. Further research is thus required to ensure that any effect could be mitigated. The research may include a combination of database review, real-time monitoring of salinity, species survey and modelling. The modelling should assess if an operating strategy for the scheme would allow decreasing salinity ingress during the spawning season.

L.228 Output of this research should inform on the following:

- Current smelt population
- Current salinity pattern, how the smelt population accommodate change in salinity and how the scheme could alter salinity

L.229 Our proposed mitigation to avoid salinity ingress during smelt spawning is to turn the scheme off during March. This research aims to confirm that the proposed mitigation is suitable.

Chemical effect

Compliance with Water Framework Directive

L.230 To ensure compliance with the Water Framework Directive, it is proposed to treat Mogden effluent through advanced treatment processes before discharge into the River Thames above Teddington weir. The current treatment option comprises of the following steps:

- Ferric addition – This will precipitate phosphate
- Nitrifying sand filter – This will reduce the biological oxygen demand, suspended solids and ammonia.
- Mechanical filter – Additional polishing steps to ensure compliance with the probable discharge permit.

L.231 Modelling, based on the Environment Agency Horizontal Guidance Note 1 (H1D1), shows that this would be suitable to meet concentration below the EQS value apart for mercury, zinc and pentachlorobenzene^{2&3}. It has to be noted that the modelling included only the total concentration of zinc and mercury and as such did not differentiate between the solid part, which would be removed by the proposed treatment and the soluble part. Furthermore, the EQS for pentachlorobenzene is 0.07 µg/l, which is lower than the limit of detection currently in force by the laboratory carrying the analysis for us. It is therefore possible/likely that there is in fact no issue relating to pentachlorobenzene,

L.232 We will perform further sampling to understand the soluble and solid fraction of the metals as well as identifying a laboratory able to measure pentachlorobenzene below the EQS.

L.233 Furthermore, the effect of Mogden WWTW effluent discharge reduction on the environment should be assessed to understand if further treatment is required to ensure WFD status is not compromised by reducing the flow at Isleworth Ait. Phosphate and nitrate were identified as two parameters that may increase.

Other chemical effects

L.234 A sampling campaign will assess the presence of olfactory inhibitors (currently not consented) in the Mogden WWTW effluent that could influence fish migration.

L.235 The impact of water quality at the abstraction point on our DWSP will also be investigated to ensure compliance with Regulation 27 of the Water Supply (Water Quality) Regulations 2016.

L.236 Output of this research should inform on:

- The scheme influence on the WFD status of the affected river stretches and the required treatment to ensure no deterioration in WFD status.

- The olfactory inhibitors could affect fish migration.
- The effect on our DWSP
- The mitigation required to comply with the WFD and DWSP requirements

Physical effect

- L.237 There is concern from the Environment Agency for sediment pumping within the middle estuary. Research to assess how sedimentation within the middle estuary is affected will be carried out.
- L.238 The PLA's response to the scheme indicates that the reduction in water level could impact on navigation and the management of Richmond lock and weirs. The impact of decreased water level on the Richmond lock and weirs was modelled and was found negligible. However, the PLA's experience of maintaining the level during low water period suggests the contrary. This has the potential to impact on the PLA's ability to maintain the required water level, as stated in Section 88 of the Port of London Act 1968. As such, further modelling will be carried out. With regards to navigation between Battersea and Richmond Lock, it is recognised that the option would reduce the accessibility for the PLA's Harbour Service Launches (HSL). The PLA's HSL undertake a safety and enforcement role, being required to respond to any navigational incidents within their operational area at any time and at all states of the tide. The scheme could increase the response time by an hour. The reduction of water level will also impact on commercially operating vessels (i.e. Cass V passenger vessels and tugs with tows), with some passenger services becoming no longer viable to operate as a scheduled service. Finally, this may impact on sport and recreational activities, for which less area of the Thames will be navigable. Mitigation, including communication with stakeholders, will be investigated to minimise the impact of this option on users of the Thames.

Environmental mitigation

- L.239 Environmental mitigations required to minimise the effects of the Teddington DRA option on fish migration and passage include:
- Confirmation that the proposed level of treatment of Mogden WWTW effluent is suitable to ensure WFD compliance (i.e. no deterioration) in all affected river stretches.
 - The design of the Teddington DRA outfall to ensure minimal velocity increases and maintain normal circulation patterns in the freshwater River Thames.
 - The design of an innovative solution to address the temperature difference between the treated final effluent and the River Thames. The use of cooling towers with heat exchangers or heat pump within Mogden WWTW vicinity are deemed not feasible due to the large footprint required and the increased capital costs.
 - Identification of operating strategy to minimise salinity ingress and mitigate potential effects on smelt.
 - Identification of mitigations to reduce impacts of reduced water level between Battersea and Richmond Lock on users.

Concluding remarks for flow augmentation scheme

- L.240 The Teddington DRA option has the potential to provide a deployable output of up to 268 Ml/d. The option requires the diversion of part of Mogden WWTW final effluent upstream in order to augment environmental flows downstream of the new abstraction point. The option requires a number of issues to be mitigated, related to impact on navigation and ecology of the downstream River Thames. The assessed risks with regards to navigation are minimal. The option would have detrimental ecological impacts if not managed properly. We have carried out further investigation to identify where the challenges are and how these could be mitigated. However, considering the EA guidance that any mitigation should achieve zero temperature uplift, we have concluded that the Teddington DRA option is now not feasible and therefore it does not feature in our final WRMP19 feasible options list. We will continue to undertake research to investigate the potential to mitigate the effects of the scheme on ambient river temperature as well as other impacts such as salinity and flow pattern that could affect the River Thames ecosystem.

E. Public and stakeholders risk perception

- L.241 Over the past few years we have undertaken research with customers, both qualitative and quantitative, to build an understanding of customers' views and concerns on water reuse. We have continued this research over the past four years by funding a STREAM⁴⁶ Engineering Doctorate student from Cranfield University⁴⁷. The aims of the research were to understand the nature of stakeholder engagement with risk management of water reuse schemes and to critically evaluate how different expectations might be assimilated to enhance governance and scheme design.
- L.242 OFWRP was used as the case study to assess stakeholder engagement.

Collaboration on risk management

- L.243 Collaboration between stakeholders and learning opportunities are perceived as necessary to improve scheme governance.

46 STREAM is the Industrial Doctoral Centre (IDC) for the Water Sector funded by the Engineering and Physical Sciences Research Council (EPSRC) and companies who sponsor research projects.

47 G. Goodwin (2017), From risk to safety management: Stakeholder engagement for water reuse scheme governance, EngD thesis, Cranfield University.

- L.244 In this research, data from semi-structured interviews were used to evaluate how stakeholders perceive risk management and governance challenges, and to understand their preferred solutions for addressing them. Three main governance challenges were perceived by stakeholders as:
- Developing mutual understandings of diverse expectations
 - Clarifying roles and responsibilities
 - Improving awareness, knowledge and capabilities.
- L.245 This component of the research found stakeholders perceived that collaboration and learning opportunities (focused on risk and risk management activities) had the potential to help overcome these challenges. In particular, common risk management activities were perceived as providing opportunities for forging informal networks and for informal modes of collaboration. This research indicated that more learning-by-doing based engagement had the potential to help facilitate dialogue around divergent objectives, help build relationships and maintain trust. Finally, the research implied that collaborative and learning processes could help the governance of schemes become more responsive to changing risks and stakeholder dynamics.
- L.246 Full results can be found in Goodwin et al. (2017)⁴⁷.

The effect of media on public perception

- L.247 The public is increasingly engaging with information about water reuse proposals through the internet. Though there are benefits to engaging the public online, there may also be challenges associated with media bias or online advocacy. This research qualitatively examines the public response to online news reporting of the IPR proposal for London. It aims to explore how perceptions of water management problems, risk and trust in the management of recycled water supply might be influenced by the media. The analysis found no evidence that the media's framing of a single news event describing a water reuse scheme proposal for London had a strong influence on online responses. Instead, people's perceptions of more general causes of water management problems, environmental values and prior knowledge of the water cycle were plausibly more influential. Though constrained by limitations on the applicability of the findings, this study suggests that online comments can help highlight themes describing positive sentiments towards the principles of water reuse and to the specific reuse proposal. Moreover, individual media events can offer useful opportunities for water resource planners, public relations experts and academics to explore the impact of different issue-specific framings, such as popular knowledge of the water cycle and areas of confidence in water safety initiatives to manage perceived risks.
- L.248 There is a need for further exploration of how to message the themes around water safety initiatives and how the short-term benefits might affect public support for water reuse schemes. There is also a need to build understanding of how public engagement methods can be developed that sufficiently engage with diverse concerns, particularly regarding broader concerns linked to perceptions of water resource management. Finally, this study also raised a number of other avenues for future research, particularly related to theoretical, methodological and practical aspects of using online platforms and social media to support public engagement research.
- L.249 More details can be found in Goodwin et al.⁴⁷.

Significance of message framing

- L.250 We also explored methods of public communication and, in particular, evaluated the impact of message framing on public attitudes towards NPR. To achieve this, an embedded sub-study was carried out to explore the pros and cons of engaging stakeholders with the risk management of water reuse schemes using video animations. This study provided evidence that showed survey respondents who were initially opposed to higher exposure uses for non-potable recycled water responded positively to short video animations framed in terms of water quality compliance. This finding contributed to existing knowledge through helping to isolate focal characteristics of risk management messages about water reuse. Moreover, the findings showed that, overall, the video messages improved the participant's trust in authorities to safely manage recycled water schemes. Through the conceptualisation of a message framing typology, this study advanced the understanding of public responses to information and corroborated benefits to communicating about recycled water safety within a specific water resource context.
- L.251 More details can be found in Goodwin et al.⁴⁷.

Multi-criteria stakeholder evaluations of risk intervention

- L.252 By using the multi-criteria evaluation method, we explored and assessed stakeholders' perceptions and preferences for how risk management and recycled water end-uses might influence decision-making. The case study results showed that stakeholders favoured risk reductions over both cost savings and potable water savings. Using the stakeholders' importance preferences, the multi-criteria evaluation prioritised an upgrade from the existing water treatment processes in the case of connecting new recycled water end-uses to the scheme. Conversely, the study found that stakeholders' responses to agreement statements favoured existing risk management practices, with more stakeholder engagement to help control risk. The two different evaluation methods gave differing accounts and, therefore, the findings indicated analytical advantages to method triangulation. As the stakeholders prioritised health risk reductions, the inclusion of quantitative health risk information in the multi-criteria evaluation pointed to more conservative risk management interventions. The findings indicated that the evaluation method might influence decision making but that differences in stakeholders' perceptions were more useful for delineating the boundaries around acceptable options. The findings implied that a benefit of the multi-criteria method is that it encourages stakeholders to deliberate the reasoning behind their preferences to help account for uncertainty and risk complexities.
- L.253 More details can be found in Goodwin et al.⁴⁷.

Concluding remarks for public and stakeholder risk perception

- L.254 Water reuse is a feasible technological approach for addressing urban water management challenges. It is acknowledged that stakeholder acceptance is an important ingredient for water reuse scheme success. However, less is known about how to engage stakeholders with the aim of reducing risks and promoting safety.



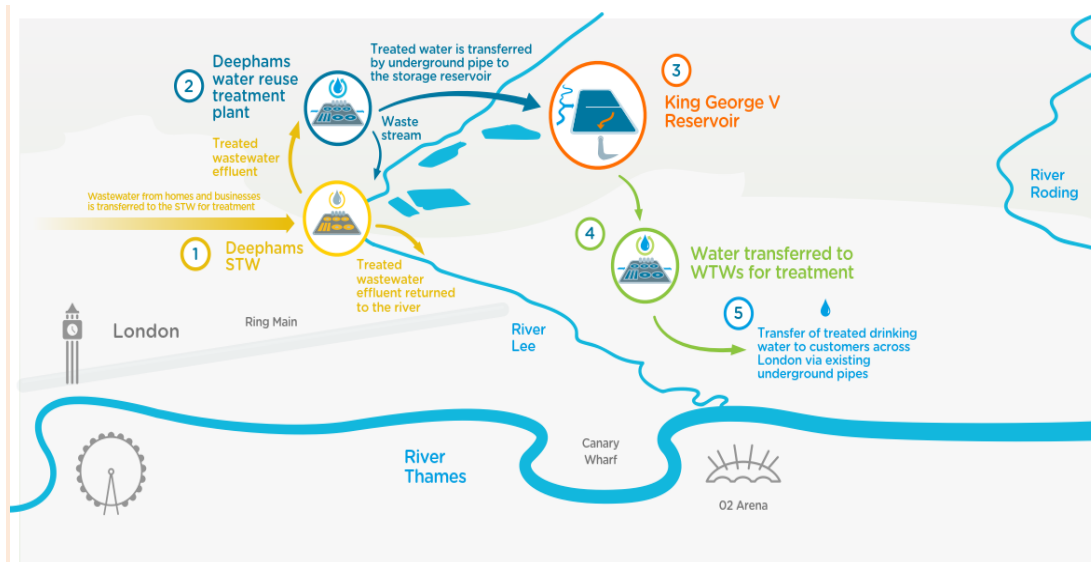
- L.255 Collaboration with stakeholders on risk management and more learning-by-doing based engagement had the potential to help facilitate dialogue around divergent objectives, help build relationships and maintain trust.
- L.256 Furthermore, members of the public are more likely to accept the risks associated with water reuse schemes as long as water companies maintain water quality compliance. Minimising risk was also more important for stakeholders, rather than mitigating cost and decreasing water stress.
- L.257 In promoting the choices of technology for IPR and non-potable water schemes we will demonstrate high quality standards to reduce risk. This will be a key part of communicating any future reuse scheme to gain public acceptance.

Annex 1: Assessment of Deephams Reuse option

Option description

- L.258 The Deephams Reuse option will treat 66Ml/d of effluent from Deephams Sewage Treatment Works (point 1 on Figure L-11 below) using an advanced treatment process (point 2) and then convey the treated water, 46.5Ml/d, by means of an underground pipe, to a discharge location on the Enfield Island Loop of the River Lee Diversion upstream of the intake for the King George V Reservoir (point 3). This option will supplement the raw water supply in the Lee Valley reservoirs which is then subject to water treatment (point 4) before going into supply (point 5), providing an additional 45Ml/d Deployable Output benefit to London.

Figure L-11: Deephams Reuse schematic



- L.259 The proposed reuse treatment plant will be within the Deephams STW boundary located adjacent to the west side of the William Girling Reservoir. The water reuse treatment plant will consist of the following treatment processes: screens, ferric dosing, ultrafiltration, reverse osmosis, advanced oxidation and remineralisation. The treated water will then be pumped, via a buried pipeline, to the Enfield Island Loop channel increasing the amount of water available for abstraction to the King George V Reservoir. The waste stream system will be returned to the Deephams STW inlet works for treatment.
- L.260 It is assumed that a “put and take” arrangement with the Environment Agency could be established to ensure an additional abstraction rate to the King George V Reservoir of 46.5Ml/d to match the upstream river discharge.
- L.261 An alternative option is to put the treated water direct into the King George V reservoir, but this would give less opportunity for mixing and dilution.

Assessment of option to date

- L.262 The extent of assessment of Deephams STW Reuse undertaken for WRMP 2019 is set out in the Water Reuse Feasibility Report⁴⁸.
- L.263 This includes Thames Water 2014 WRMP assessments for reuse options of 25MI/d and 60MI/d. The WRMP 2014 assessment included a 95MI/d option, at the time the EA indicated that it would not support a 95MI/d option and this option was screened out of programme appraisal.
- L.264 The WRMP 2019 Deephams reuse option taken forward to programme appraisal established a yield of 46.5MI/d, the reduction provides a 12.5MI/d allowance for the Hoddesdon Transfer and reflected the WRMP14⁴⁹ and previous⁵⁰ studies around sewage flow at Deephams STW. Further relevant evidence since WRMP14 includes review of reliable minimum sewage flows at Deephams STW based upon further modelling conducted for a potential Lower Lee direct abstraction scheme⁵¹. Discussion has been held with the Environment Agency on the subjects described in the sections below to confirm the findings taken from previously published reports and further work carried out, including any requirement for mitigation that may be required for the Hackney Marshes.
- L.265 The rationale for the WRMP19 scheme deployable output is summarised in Section 1 below.

⁴⁸ Thames Water (2018) Thames Water WRMP19 Resource Options: Water Reuse Feasibility Report. January 2018 report prepared for Thames Water by Mott MacDonald and Cascade Consulting. Available at: <https://corporate.thameswater.co.uk/-/media/Site-Content/Thames-Water/Corporate/AboutUs/Our-strategies-and-plans/Water-resources/Document-library/Thames-Water-reports/Redacted-Water-Reuse-Feasibility-Report-February-2018.pdf>.

⁴⁹ Thames Water (2012) Lower Lee Options Summary Report December 2012 Report prepared for Thames Water by Atkins.

⁵⁰ Thames Water (2012) Deephams Effluent Planned Reuse Scheme Investigation Phase 1-Potential Impact on Flows in the Salmon and Pymmes Brook and River Lee. Draft Report prepared for Thames Water by URS.

⁵¹ Thames Water (2017) Lower Lee Direct River Abstraction (DRA), 10 April 2017, Technical note prepared for Thames Water by Atkins.

L.266 A Deephams STW Reuse options report was prepared in 2012 for WRMP14, including environmental effects⁵². Other than re-statement of options appraisal for WRMP19, no additional bespoke technical assessments have been undertaken of the environmental and social effects specific to the option since WRMP 2014. Further relevant evidence since WRMP14 includes the AMP6 National Environment Programme (NEP) water resources investigation of the sustainability of Thames Water's Lower Lee abstraction licences. That work is currently ongoing, with Phase 3 impact assessment concluded and ongoing work limited to mitigation measures development and options appraisal. At WRMP19 the Environment Agency has noted several of the key issues highlighted in the 2012 Deephams STW Reuse options report, and the current understanding of those issues, as informed by relevant studies since WRMP14 are summarised for:

- Section 2: Assessment of environmental impacts from reduction in effluent contribution to flow in the river, especially water quality
- Section 3: Consideration of mitigation of potential flow effects in the River Lee at Hackney Marshes
- Section 4: Consideration of the effect of discharging reuse effluent into the Lee at the reuse outfall
- Section 5: Suitability of remaining flow in the navigable channels downstream of Deephams STW to maintain their statutory obligations for water level management (Lee Navigation below Tottenham Locks and associated spur canals, basins and wharfs)

Section 1: WRMP19 Scheme deployable output

- L.267 The Deephams Reuse option deployable output is calculated using the same assumptions employed for the Atkins modelling for Lower Lee Direct River Abstraction options. Simplistically, the water available is 140MI/d⁵³ of which 100MI/d is considered forward flow to pass over Three Mills Lock, from the River Lee to the tidal Lee for the 81% of the time the Lee is not tide locked (i.e. 81MI/d), leaving a balance of 59MI/d. In addition, the calculation needs to take account of the Hoddesdon transfer from Deephams STW, which currently operates at approximately 12.5MI/d, thus reducing the water available for reuse to 46.5MI/d. If at a later stage, Thames Water proposed to restore the capacity of the Hoddesdon transfer scheme to 25MI/d, this would have a knock-on effect reducing the Deephams reuse scheme to 34MI/d.
- L.268 The Deployable Output (DO) for the 46.5MI/d scheme was estimated by interpolation⁵⁴ as being 45MI/d, on the basis that the DO of the previous 60MI/d option was assessed at 58MI/d.

⁵²Thames Water (2012) Lower Lee Options Summary Report December 2012 Report prepared for Thames Water by Atkins.

⁵³ 140MI/d water availability comprises Deephams DWF excluding sewer infiltration which is estimated to be 120MI/d plus 20MI/d of river flow inferred by factoring 2012-2015 low flows to 1921 low flows.

⁵⁴ At the time of estimating the 45MI/d DO WARMS2 modelling had not been undertaken, however, subsequent WARMS2 modelling undertaken in July 2018, identified a higher DO of 48MI/d.

WRMP14 Scheme size assessment

L.269 At WRMP 14 Deephams reuse and Lower Lee river abstraction option sizes were considered in a 2012 report by Atkins⁵⁵. The assessment scenarios were based on Historic (gauged), Naturalised (N), Recent Actual (RA) and Fully Licensed flows for the CAMS assessment period 1990 – 2007. The historic flows are derived from gauged data at Lea Bridge and Low Hall, whilst the other flow scenarios are synthetic scenarios derived by the Environment Agency. Three flow reduction values from a reuse option were considered (35, 84, 127 MI/d) and also a corresponding set of flow reductions including a further 25MI/d reduction for the Hoddesdon transfer (60, 109, 152MI/d). The potential for impacts assessment included; water quality, hydrology, hydraulics / navigation and hydro-ecology. The report concluded that:

- *“there was broad consensus amongst the various studies that the residual flows from the 84 – 127 MI/d re-use scheme scenarios could lead to a large adverse change in the hydrological regime of the Lower Lee downstream of Tottenham Locks and throughout the Hackney Marshes reach. In both the short and long term, the impacts would be large and would fundamentally change the character and ecology of the river. The larger volume re-use schemes are likely to lead to deterioration of the ecology of the waterbody and constrain the achievement of Good Ecological Potential.*
- *None of the re-use schemes however would be expected to have an adverse impact on navigation for most or all of the time.*
- *The EFI threshold analysis suggests that the effect of a re-use volume of 60 MI/d, and higher, would be to increase non-compliance, and therefore there would be an increased risk that the resulting river flow would be insufficient to support aquatic ecology. The hydraulic modelling results also suggest that under a 60 MI/d re-use scheme, river flow would begin to drop below 100 MI/d cut-off identified in the tidal reach. This suggests that at a re-use scheme of 60 MI/d or higher could be difficult to implement without adverse ecological effects.*
- *By contrast the changes in extent, frequency and duration of flow conditions below the guidelines from the historic flows for the 35-55 MI/d re-use schemes are comparatively small. The effect of smaller volume schemes is principally to increase stress already apparent during drought periods. The analysis undertaken shows that a re-use scheme of 35-55 MI/d has limited impact above historic flows, confirming the drought order EAR assessment of a 50 MI/d scheme as having a Minor magnitude of hydrological impact.*
- *Despite the limited potential for impact, there is still a risk that even this smaller-scale re-use scheme could lead to deterioration in the ecology of the water body. The potential for impact could be mitigated through some in-channel measures to encourage ecological resilience.”*

L.270 The Atkins Lower Lee Option Summary Report also notes “The addition of the Hoddesdon transfer volumes (25 MI/d) in considering the cumulative effect on reduction of effluent

⁵⁵ Thames Water (2012) Lower Lee Options Summary Report December 2012 Report prepared for Thames Water by Atkins.

discharge from Deephams suggests that in association with the smallest re-use scheme (35 MI/d), the total reduction in discharge would be 60 MI/d. This is at the upper range of schemes given the potential impact on flows to the River Lee.” With the Hoddesdon Deployable Output now reduced to 12.5MI/d the upper range of 60MI/d flow reduction referred to in the 2012 Atkins report is consistent with the 46.5MI/d Deephams reuse scheme proposed at WRMP19.

- L.271 The WRMP14 Options Appraisal produced two option conceptual design reports for treated output capacities of 25MI/d and 60MI/d. The option DO’s were stated as being the same as the reuse plant output. The WRMP14 options assumed that the RO process waste stream would need to be discharged via a pipeline to the Beckton catchment for treatment. The WRMP19 options proposed that this may not necessarily be the case, but requires further clarification to confirm. The following table summarises the option flows.

Table L-12: WRMP14 and WRMP19 option flows summary

	FE Abstraction (MI/d)	Treatment Output (MI/d)	DO (MI/d)	Deephams Discharge net reduction (MI/d)	Total river flow reduction (incl. Hoddesdon)	
					12.5MI/d	25MI/d
WRMP14	39	25	25	33	45.5	58
WRMP14	94	60	60	80	92.5	105
WRMP19	66	46.5	45	46.5	59	71.5*

*Note * - an increase in the Hoddesdon transfer flow would further reduce the reuse option capacity.*

Section 2: Assessment of environmental impacts from reduction in effluent contribution to flow in the river, especially water quality

- L.272 The Deephams STW Reuse options report included consideration of hydrological and water quality changes from various scale reuse options, including previous investigations⁵⁶.
- L.273 The hydrological analysis in the report summarised the change in flow relative to historic flows and representation of recent actual abstraction rates, from the Lower Lee by Thames Water, using the Environmental Flow Indicators (EFI) approach in the Environment Agency’s Water Resources GIS tool undertaken for Thames Water⁵⁷. The 60MI/d reuse scheme was assessed

⁵⁶ Thames Water (2012) Deephams Effluent Planned Reuse Scheme Investigation Phase 1-Potential Impact on Flows in the Salmon and Pymmes Brook and River Lee. Draft Report prepared for Thames Water by URS
Thames Water (2012) Environmental Assessment of the Lower Lee Drought Order. Report to Thames Water by Cascade consulting.

⁵⁷ Thames Water (2012) Hydrological analysis of the re-use options. Technical Note to Thames Water prepared by Atkins.

with a relatively small reduction in flow compared with the historic flow regime⁵⁸. It is noted that the EFIs are a national screening tool devised by the Environment Agency, to help identify waterbodies at risk of abstraction pressure. They are not an indicator of environmental impacts *per se*, and further detailed investigations are always recommended to increase the confidence in the level of impacts caused by abstraction.

- L.274 The water quality analysis in the report summarised a wide range of previous studies. The reduced quantity of final effluent from Deephams STW was considered in previous assessments to potentially improve the water quality of the River Lee at Lee Bridge, with regards to phosphorus and ammonia. The report noted that the potential effects on dissolved oxygen levels are difficult to predict without using a water quality hydrodynamic modelling approach. The reduced flow, from the reduction in final effluent was considered, with uncertainty, to potentially result in reduced dilution during storm events. This is with respect to urban runoff into the watercourses together with intermittent discharges from combined sewer overflows. These assessments pre-dated the upgrades to Deephams STW (completed in 2017) including the increase in storm sewage storage capacity and other AMP5 investment by Thames Water in urban pollution management. Further investigation was recommended.
- L.275 For the AMP6 NEP investigation an InfoWorks ICM model was built, calibrated/validated and used in scenario testing including for the influence of Deephams STW. The model included continuous STW discharges, urban runoff and intermittent CSO discharges with assessment against WFD status concentration thresholds and fundamental intermittent standards, both for physico-chemical water quality determinands. The extensive continuous water quality monitoring dataset was also reviewed. Testing of increasing flow for various abstraction reduction scenarios showed⁵⁹ limited concentration change or change in compliance rate from increasing flows; noting that flow reduction was not included as a scenario in the AMP6 NEP investigation.
- L.276 On this basis, WRMP19 has concluded that flow effects from reduction in effluent contribution to flow in the river are minor, with potential effects on wetted habitat suitability limited to key reaches (see Section 3 below). Associated water quality effects from reduction in effluent contribution will continue to require investigation as more appropriate water quality datasets become available following the AMP5 Thames Water investment in wastewater assets and infrastructure. A 46.5MI/d Deephams reuse option is not considered to lead to WFD status deterioration risk. Such investigation would be planned as part of the planning and permitting stage of a scheme. Where it is considered that treated effluent from Deephams STW currently mitigates the effects of other water quality pressures then the applicability and sustainability of such mitigation requires review in the context of a reduction in effluent contribution.

⁵⁸ The H60 and RA60 scenarios which include Deephams STW reductions of 60MI/d, including an allowance for a Hoddesdon transfer scheme and in total correspond well with a 46.5MI/d reuse scheme and maximum practical Hoddesdon transfer of 10-15MI/d.

⁵⁹ Thames Water (2018) Lower Lee Flow Investigations Phase 3 - Impact Assessment Report. Final report version 2 to Thames Water April 2018 prepared by Cascade Consulting and Atkins.

- L.277 On this basis, WRMP19 has concluded that flow and water quality effects in the River Lee downstream of Deephams STW from a 46.5MI/d reuse scheme remain a minor adverse effect, being;
- Minor adverse effect for SEA criterion 4.1 Water topic objective to avoid adverse impact on surface and groundwater levels and flows, including when this impacts on habitats and/or navigation.
 - Minor adverse effect for SEA criterion 4.2 Water topic objective to protect and enhance surface and groundwater quality and protect and enhance estuarine waterbodies.
- L.278 The Environment Agency has noted more work is needed⁶⁰, by the Environment Agency, to determine what best possible WFD good ecological potential⁶¹ in the lower River Lee could be within its constraints as a heavily modified water body. In this context, a reuse scheme should be assessed for WFD compliance in terms of whether it compromised the effectiveness of planned mitigation in delivering these objectives, once established, in discussion with the Environment Agency.

Section 3: Consideration of mitigation of potential flow effects in the River Lee at Hackney Marshes

- L.279 The Hackney Marshes reach has been previously identified, and remains, a key reach downstream of a Deephams STW re-use scheme, as it is flow dependant and morphologically diverse, responding to changes in flow in the River Lee. Other downstream reaches are predominantly level dependant i.e. the reaches are more responsive to changes in water level than flow.
- L.280 The Atkins report considered 35MI/d, 84MI/d and a 127MI/d reuse options, reviewed in Section 1, and built a hydraulic model of the Hackney Marshes reach to assess the potential changes in velocity compared with the historic baseline as a result of the proposed re-use schemes. Of these, the Atkin's assessment of the 35MI/d option (closest in size to the 46.5MI/d option included in WRMP19) concluded this as unlikely to cause significant deterioration in WFD classification in any of the watercourses, but could potentially prevent WFD objectives being met without mitigation. Feasible mitigation options were considered more likely for this scheme.
- L.281 Atkins⁶² derived minimum flow guidelines for the Hackney Marshes reach based on the minimum depth and velocity requirements for Chub and Dace as key target species for this river, as well a minimum wetted width to ensure the 'bank-foot' width of the Hackney Marshes stayed wet. Testing of the reuse options in the Deephams STW Reuse options report using R-

⁶⁰ Environment Agency comments on the draft Deephams Effluent Re-use Scheme Investigation [URS 2012 for Thames Water] issued to Thames Water 24/2/2012

⁶¹ Using technically feasible measures, without incurring excessive costs or compromising the designated uses of the water body leading to its classification as heavily modified (in RBMP1 this was listed as flood protection and urbanisation)

⁶² Environment Agency (2012) River Lee Good Ecological Potential Study. Report for the Environment Agency by Atkins.

HEFT⁶³ shows that there is a reduction in habitat condition for Chub and Dace along the Hackney Marshes reach, although the changes in extent, frequency and duration of flows below the guidelines from the historic flows are small. The Deephams STW Reuse options report recommends mitigation, in the form of targeted in-channel enhancements and changes to bank-side management to help increase the ecological resilience to drought periods and increase or maintain the ability to recover during non-drought years.

- L.282 The flow dependent reach of Hackney Marshes is upstream of the confluence of the Flood Relief Channel, and consequently the Hackney Marshes reach. Review of flows in this reach, for the AMP6 NEP investigation identify that the flow regime is significantly truncated compared to a natural flow regime. Low flows are artificially high, as a consequence of Deephams STW effluent contribution⁶⁴. High flows are artificially low, as a consequence of flood flows being transferred to and conveyed by the Flood Relief Channel⁶⁵. As such the flow regime of the River Lee in the Hackney Marshes reach is artificial. HEFT was updated for the AMP6 NEP investigation, including additional cross-sections and revision of the flow guidelines to include for additional fish species, reported as Barbel. The updated baseline HEFT shows much less flow sensitivity in the Hackney Marshes than reported in the 2012 Deephams STW Reuse options report. Testing of increasing flow for various abstraction reduction scenarios shows limited ecological value from increasing flows; noting that flow reduction was not included as a scenario in the AMP6 NEP investigation.

⁶³ 'Rapid Hydro Ecological Flow Thresholds' (R-HEFT). The H60 and RA60 scenarios which include Deephams STW reductions of 60MI/d, including an allowance for a Hoddesdon transfer scheme and in total correspond well with a 46.5MI/d reuse scheme and maximum practical Hoddesdon transfer of 10-15MI/d.

⁶⁴ Using the daily flow series 2006-2017 developed for the AMP6 NEP investigation, Q95 low flow at the Hackney Marshes is 297MI/d. Without the flow additions from Deephams STW, Rye Meads STW and Low Maynard Reservoir overspill or the flow reductions from Thames Water's Lower Lee abstractions Q95 low flow at the Hackney Marshes would be 153MI/d.

⁶⁵ Using the daily flow series 2006-2017 developed for the AMP6 NEP investigation, Q10 high flow at the Hackney Marshes is 769MI/d. With the flows conveyed by the Flood Relief Channel Q10 high flow at the Hackney Marshes would be 1,400MI/d.

L.283 On this basis, WRMP19 has concluded that in-channel enhancements in the Hackney Marshes to increase resilience to flow changes from a 46.5Ml/d reuse scheme remain a potential mitigation option. However, it is noted that such mitigation would be subject to options appraisal and detailed design as part of the planning and permitting stage of a scheme. The WRMP19 assessment includes the scheme as compliant with the objectives of the Water Framework Directive⁶⁶ and in the SEA Environmental Report⁶⁷, for selected relevant criteria:

- Moderate adverse effect for SEA criterion 1.1 Biodiversity, flora and fauna topic objective to conserve and enhance biodiversity, including designated sites of nature conservation interest and protected habitats and species (with particular regard to avoiding the effects of over-abstraction on sensitive sites, habitats and species).
- Minor adverse effect for SEA criterion 4.1 Water topic objective to avoid adverse impact on surface and groundwater levels and flows, including when this impacts on habitats and/or navigation.
- Minor adverse effect for SEA criterion 4.2 Water topic objective to protect and enhance surface and groundwater quality and protect and enhance estuarine waterbodies.

Section 4: Consideration of the effect of discharging reuse effluent into the Lee at the reuse outfall

L.284 In a WFD context, WFD⁶⁸ standards for water temperature in rivers are listed as not greater than a 3°C temperature increase⁶⁹ compared with background⁷⁰, with such standards applying to discharges with environmental permit conditions relating to thermal discharge⁷¹. In the absence of environmental permit conditions only upper values for temperature are used as a supporting element to fisheries water body status.

L.285 Several continuous water quality monitoring stations are located in the River Lee catchment, including in the River Lee Diversion/Flood Relief Channel and at Deephams STW final effluent. These include Thames Water operational monitoring equipment used as part of abstraction control and equipment deployed by Thames Water for the AMP6 Lower Lee National Environment Programme (NEP) water resources investigation. Analysis of the River Lee data as part of the AMP6 investigation identify a normal river water temperature regime local to the

⁶⁶ Thames Water (2018) Revised Draft Water Resources Management Plan Appendix BB Water Framework Directive Compliance Assessment.

⁶⁷ Thames Water (2018) Revised Draft Water Resources Management Plan Appendix B Strategic Environmental Assessment Appendix E Option Element Assessments.

⁶⁸ UK transposition of the WFD: Water Environment (Water Framework Directive) (England and Wales) Regulations 2017. <http://www.legislation.gov.uk/ukxi/2017/407/contents/made> Defra's Direction to the Environment Agency: The Water Framework Directive (Standards and Classification) Directions (England and Wales) 2015 (see Table 6 for temperature standards for rivers): http://www.legislation.gov.uk/ukxi/2015/1623/pdfs/ukxi0d_20151623_en_auto.pdf.

⁶⁹ Up to 3°C increase (or decrease) is applicable to both Cyprinid and Salmonid rivers at Good WFD status

⁷⁰ Expressed as an annual 98th percentile, i.e. 98 values out of 100 must comply with this standard and only 2 out of 100 can exceed it for compliance to be retained, with all values across a year considered relevant.

⁷¹ It is noted that neither the current Deephams STW environmental permit nor the current Rye Meads STW environmental permit includes thermal conditions for discharge of treated effluent into the River Lee catchment, and that in permitting in general, thermal conditions relate typically to power station or large industrial cooling discharges.

Enfield Island Loop. Further downstream in the Flood Relief Channel, under low river flow conditions, the artificial wide, concrete channel exerts a significant influence on the river water temperature leading to wide diurnal fluctuations including high daytime temperatures and low night time temperatures.

- L.286 Mitigation measures are under development with the Environment Agency, as part of the AMP6 investigation, including retaining more flow along part of the flood relief channel to improve resilience to these effects. It is noted that a Deephams Reuse scheme would not reduce flow in the effected reaches and would therefore not exacerbate these effects.
- L.287 Local to the proposed Deephams Reuse discharge point, low river flow has been determined, as part of the AMP6 investigation to be c.170MI/d (Q95 low flow statistic 2006-2017 from derived daily flow). It is noted that this reach has a fairly stable low flow regime as river flow is augmented by Rye Meads STW effluent (permitted dry weather flow 110MI/d, estimated by Thames Water (SOLAR data) to grow from 74.3MI/d in 2016 to 84.1MI/d by 2031), and is not subject to high flows as these are conveyed by the Flood Relief Channel and not by the Enfield Island Loop.
- L.288 To date Deephams STW final effluent temperature data have not been reviewed for their difference to measured data in the Lee Flood Relief Channel local to the planned reuse outfall. However, noting the reuse scheme discharge rate of c.46.5MI/d and the local Q95 flow of c.170MI/d, for every 1.0°C difference in temperature between the effluent and river water, the scheme would change water temperature by 0.2°C. The extent of difference would be lower at higher river flows. This does not account for any changes in effluent temperature as consequence of the additional treatment processes of the reuse plant or the effects of piping – both of which would be expected to lower effluent temperature closer to ambient prior to discharge. The scale of change in river temperature anticipated by the scheme is minimal, and without compromise to WFD standards.
- L.289 It is also noted that there are existing pressures on water temperature downstream, exerted by the physical nature of the flood relief channel and its poor habitat value. The zone of influence of any water temperature changes is short – the c.100m distance between the reuse outfall and the King George V Reservoir intake and the c.420m between the existing King George V Reservoir intake and the downstream confluence of the Enfield Island Loop (of the River Lee Diversion) and the Flood Relief Channel.

Section 5: Suitability of remaining flow in the navigable channels downstream of Deephams STW to maintain their statutory obligations for water level management

- L.290 Deephams STW discharges into Salmons Brook, a tributary of Pymmes Brook which flows into the River Lee Navigation locally downstream of Tottenham Locks. Upstream of Tottenham Locks water level for navigation in the River Lee Navigation is managed by Canal & River Trust without the flow augmentation provided by Deephams STW.
- L.291 For Thames Water, Atkins developed a low flow hydraulic model of the Lower Lee to assess the impacts of the re-use scheme on water levels and the use of the river for navigation. This was undertaken in association with [former] British Waterways, who steered the model development to ensure that the Lower Lee (navigation) system was being simulated appropriately at low flows.

- L.292 The 2012 Atkins report assessed the impact of reuse schemes (35, 84, 127 MI/d) on navigation in the River Lee,

“a 1D ISIS hydraulic model of the River Lee (Lower Lee) developed for the London Development Agency’s Lower Lee Valley Regeneration Strategy in 2005 was supplied by the Environment Agency for this study. The model contains detailed survey information, including changes made within the river system over the course of the construction of the Olympic Park. It also includes the impounding structures, constructed at Three Mills Island by British Waterways (now the Canal and Rivers Trust) in 2008.

This hydraulic model has been supplemented by Atkins using information from other models. British Waterways’ ISIS model covering the Regents Canal, Hertford Canal, the Limehouse Cut, and the Lee Navigation was used to update the model’s representation of the Lee Navigation structures and Limehouse Cut channel characteristics. The Environment Agency’s L09_L10 ISIS model was used to extend the Lower Lee model from Lee Bridge to Tottenham Locks, and the location of discharge from the Deephams STW was added.”

- L.293 The impact of the reuse schemes was assessed at 6 locations:

- 1) Old Ford Locks (Tottenham – Old Ford Locks reach)
- 2) Lee Bridge Sluices (Tottenham – Old Ford Locks reach)
- 3) Bow Locks (Limehouse cut and Old Ford - Bow Locks reach)
- 4) Three Mills Lock
- 5) River Lee at A12 road bridge (tidal lock limit of Three Mills)
- 6) River Lee at Carpenters Road

- L.294 The report concluded that:

- *“The results of the hydraulic model show that none of the re-use schemes would be expected to have an adverse impact on navigation for most or all of the time.*
- *The 127 MI/d scheme could lead to levels falling by 1 cm below suitable levels upstream of the Three Mills Lock for 1% of the time period modelled.”*