Thames Water

Draft Water Resources Management Plan 2019

Technical Appendices

Appendix L: Water reuse

Table of contents

Figures

Tables

Appendix L.

Water reuse

- We have identified reuse of water as a feasible water resource 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). 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. 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), 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 flow augmentation option was established to support enhanced Teddington Direct River Abstraction (DRA) option. It is expected that the deployable output of such option could reach up to 268 Ml/d (Section D). The scheme is still undergoing development to ensure best mitigation measures for ecological (i.e. complying with the Water Framework Directive) and river navigation impacts are included in the design of this option.

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.2 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

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 RO 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 IPR. It is called indirect because the treated wastewater flows through a natural watercourse before being reused.

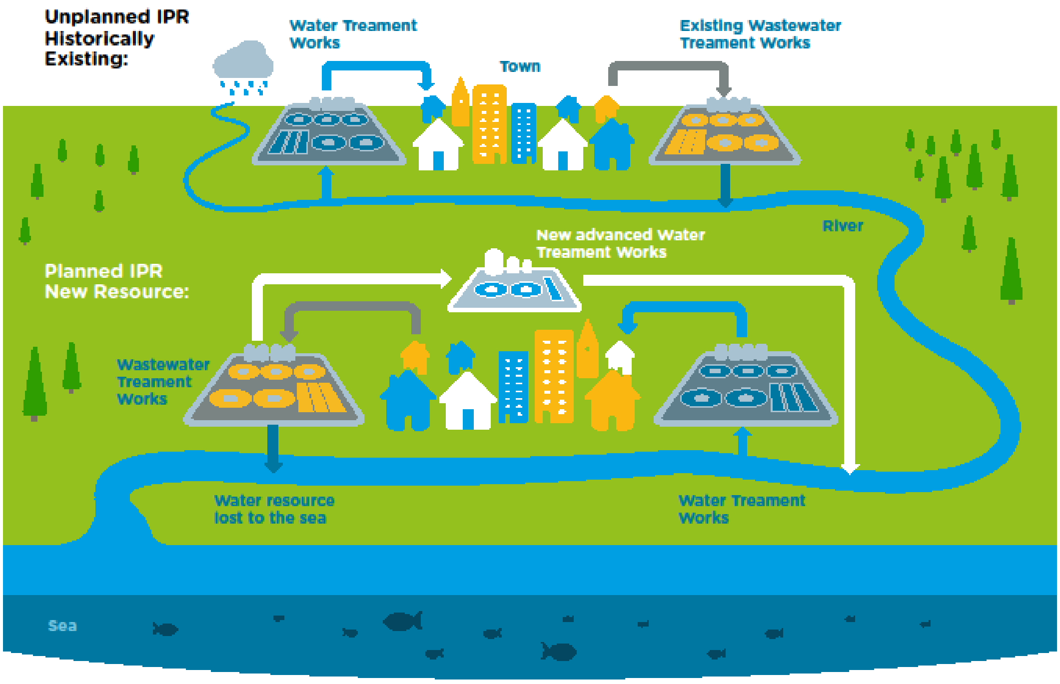
L.5 IPR occurs in a majority of rivers and catchments in the UK. Where IPR is already happening it is a function of historical growth and development of towns and cities around water supplies. As this recycling of water already exists it is called unplanned IPR.

L.6 In water stressed areas, such as the Thames catchment area, most of the available water resources have already been used. 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.7 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.8 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.9 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.10 To comply with the Catchment Abstraction Management Strategy (CAMS), as set by the Environment Agency[1], only wastewater sources which are not contributing to current water supply (i.e. unplanned IPR) and environmental health were selected. As an example, any 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.

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

L.11 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.12 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 Ml/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 Ml/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 Ml/d
Mogden WWTW effluent	River Thames upstream of Walton intake	50 to 200 Ml/d
Kempton South Sewer (raw wastewater)	River Thames upstream of Walton intake	50 Ml/d

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

L.13 More details on how these feasible options were identified can be found in the associated feasibility report[2]. In totality the maximum identified feasible volumes amounts to a maximum potential 816.5 Ml/d.

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

Why we have not included direct potable reuse?

L.14 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.15 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.16 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 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.17 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.18 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 Sections "Required water quality of the discharged reclaimed water to the environment" and "Proposed Treatment Trains").

L.19 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. Please refer to Appendix B and BB for further information on this potential impact.

L.20 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.21 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 DWSPs 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.22 In collaboration with Mott MacDonald[3] a methodology was developed to identify consented water quality parameters that could cause a risk to the environment and public health should 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.23 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.24 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.25 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

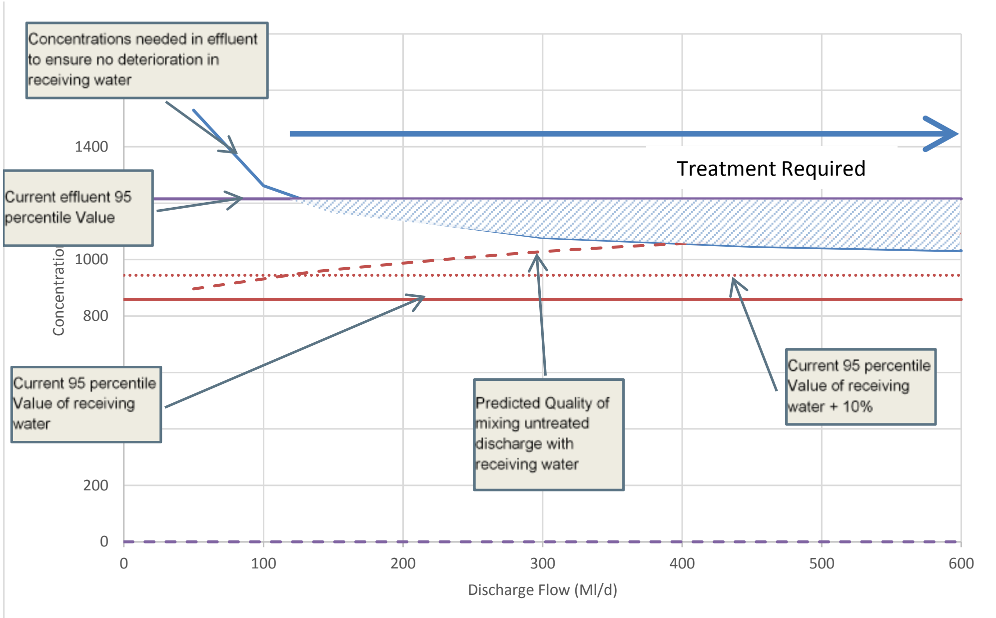
L.26 "No Deterioration" is a WFD related concept that aims to ensure that the status of a waterbody does not get worse. Where there is evidence to suggest that deterioration is occurring, *or could occur,* as a result of a discharge, a permit limit is calculated (and in the case of existing permits, 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.27 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

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

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 MacDonald[4]

L.28 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:

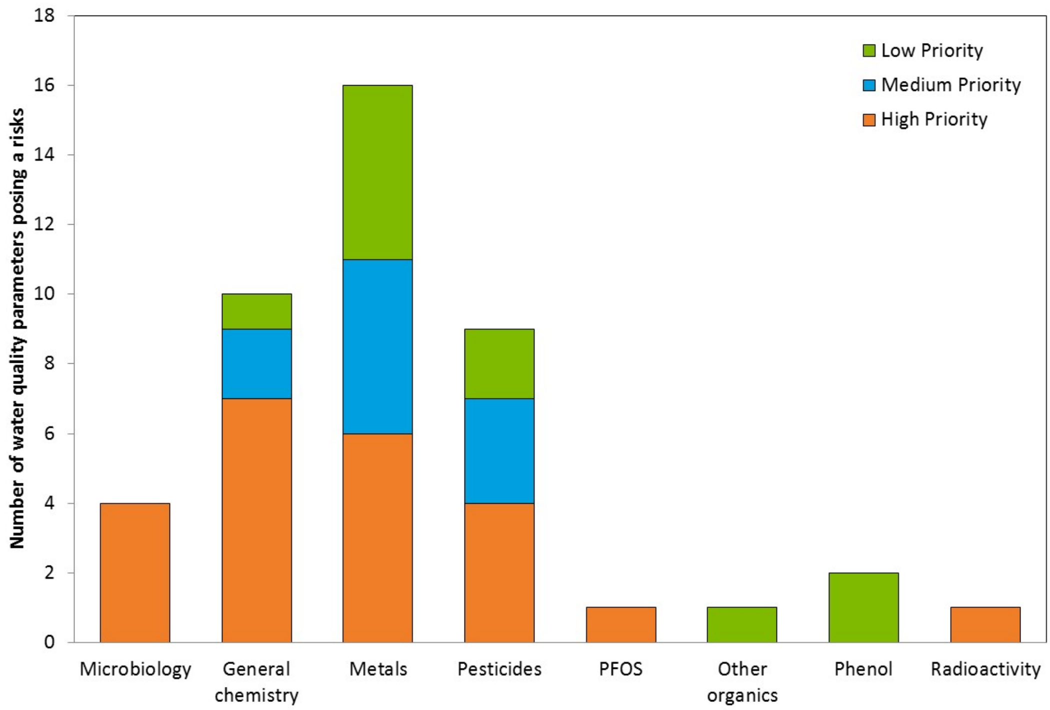
- High priority water quality parameters: where treatment is required to ensure compliance with a regulated parameter (either environmental or drinking water). For the parameter of concern:
  - There is an EQS / WFD standard and concentration is greater than 10% of respective values
  - There is a prescribed 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.29 This priority ranking allows to account for potential status improvement of the river to good ecological status (or above), if required.

L.30 More details of the methodology can be found in the associated report[4]. This report was reviewed by the Environment Agency, which found the approach to be sound. However, we 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.31 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



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

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	Coliform, E.coli, Enterococci, Giardia Reduced water quality in river Increased challenge to receiving drinking WTW
General chemistry	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	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	Carbendazim, Diuron, Mecoprop and Metaldehyde Exceedance of pesticide PCV
Perfluorooctane-sulfonic acid (PFOS)	Exceedance of the annual average EQS.
Radioactivity	Beta activity – exceed PCV on occasion. However, this elevated level might related to the naturally occurring potassium-40 isotope

L.32 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.33 Large scale IPR schemes required treatment trains comprising reverse osmosis (RO) followed by advanced oxidation. For smaller schemes, such as the 46.5 Ml/d IPR scheme proposed at Deephams WWTW, a RO-based treatment is not required to meet those standards for a standalone scheme.

L.34 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.35 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	Lower initial cost Likely easier to operate (could be based on conventional treatment technology)	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	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.	Higher initial cost Likely to be more complex to operate as innovative technology will be used.

L.36 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 nonidentified) water quality parameters. RO-based technology treatment followed by AOP has been assumed for all IPR water reuse schemes in WRMP19.

L.37 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.38 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. Please refer to Appendix B and BB for further information on this potential impact.

L.39 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.

Operating philosophy

L.40 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.

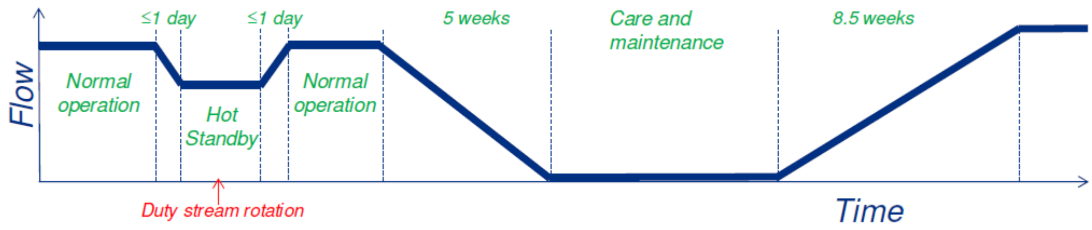
L.41 During the “hot standby” mode, a minimum flow (corresponding to the capacity of one stream) would be rotated around the different streams of the plant to maintain the availability to all the streams. This mode allows ramp up to normal operation (25%-100% of deployable output capacity) in less than a day, ensuring fast water resource availability should it be required, including drought periods and low river flow.

L.42 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.43 These modes were based on current Thames Water practices with regards to the Thames Gateway WTW.

L.44 An example of the modes of operation is shown in Figure L-4.

Figure L-4: IPR plant operational modes



IPR Research Programme

L.45 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.46 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.47 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.48 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 a research programme has been required?

L.49 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.50 We are responsible for the supply of wholesome water to our supply region. Wholesome water is defined in The Water Supply (Water Quality) Regulation 2016[5] 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.51 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 occur[6].

Increased risks from rising wastewater effluent into drinking water catchment

L.52 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 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 effluent[7]. 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 Thames[7]

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%

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

[6] 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.

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

L.53 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.54 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.55 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.56 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.57 As an example, from January to March 2010, we received 1,114 complaints about "smelly" drinking water from residents in North East London[8]. 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 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.58 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.

[8] http://dwi.defra.gov.uk/stakeholders/information-letters/2011/08-2011-annexa.pdf

Research programme packages

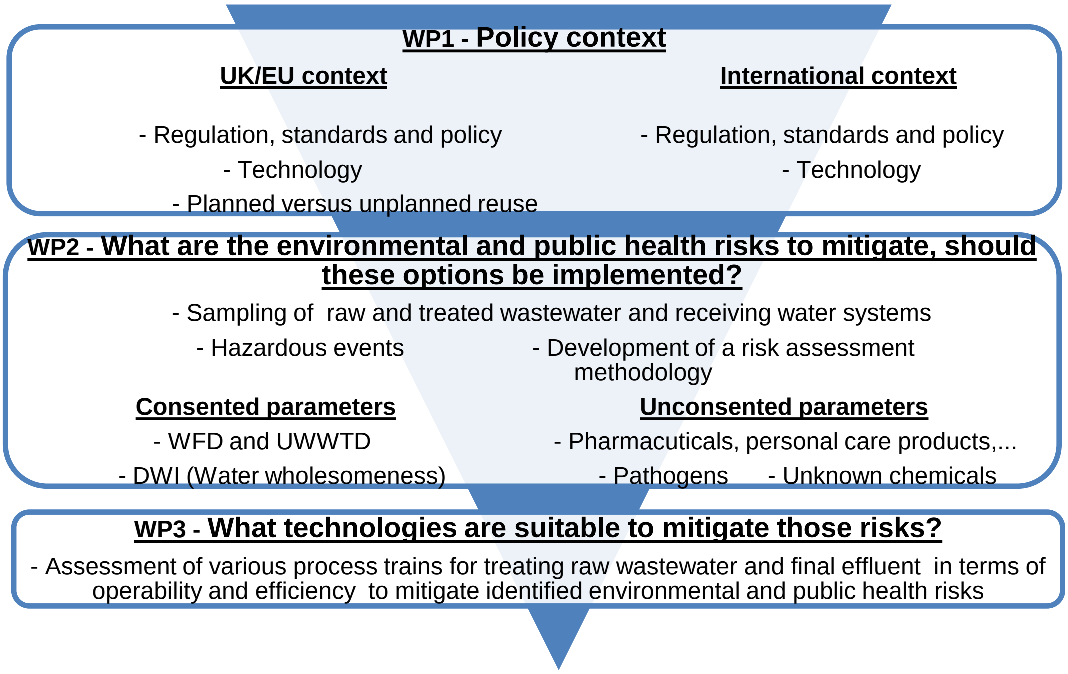
L.59 We have been conducting a comprehensive research programme to follow on from the research carried out for previous WRMPs. In 2014 we shared our programme with an independent expert review panel for comment. The panel included six acknowledged international experts in the field (David Cunliffe, Joan Rose, John Fawell, Clare Stacey, Mike Wehner and Paul Jeffrey) and was chaired by AMEC. The research programme follows their recommendations[9] so far as is reasonably practicable in term of timescale and cost. We have sought to understand worldwide IPR practice to inform our proposals.

The current research programme was divided into three work packages, which are summarised in Figure L-5.

[9] 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

L.60 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 draft WRMP19. However, any findings pre-publication of the draft 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.

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

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

WP1 – Policy context

L.61 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.62 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.63 This work package is now complete[10;11] and the findings are summarised below.

UK context

Regulations

L.64 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.

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

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

L.65 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 2016[5] 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.66 The Langford scheme, belonging to Essex and Suffolk Water, is the only example of planned IPR in the UK[12]. 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 Directive[13]. Hanningfield reservoir is also a designated SSSI.

L.67 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 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 fish[14]

L.68 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 reservoir[14].

The Langford scheme consists of treating final effluent[15] 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.69 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

[12] Scheme details available through this web link: http://www.reclaimedwater.net/data/files/252.pdf

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

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

[15] Note: The wastewater catchment of the associated WWTW is mainly from household sources.

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.70 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.71 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.

L.72 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.73 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.74 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.75 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.76 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.77 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 m^3/year to 140,000 m^3/year by reusing the highly treated wastewater of their factory from the steeping process[16]. 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 use[17]. 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.78 However, there are still some barriers to overcome. The main barriers for implementing IPR by water companies in the UK include:

- 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.79 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.80 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:

[16] 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

[17] 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

- 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.81 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.82 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.83 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.84 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.85 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.86 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.87 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 Oxford[18].

L.88 The assessment of environmental risks is based on the quantitative framework suggested by the European Commission in the Technical Guidance Document on Risk Assessment[19]. 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

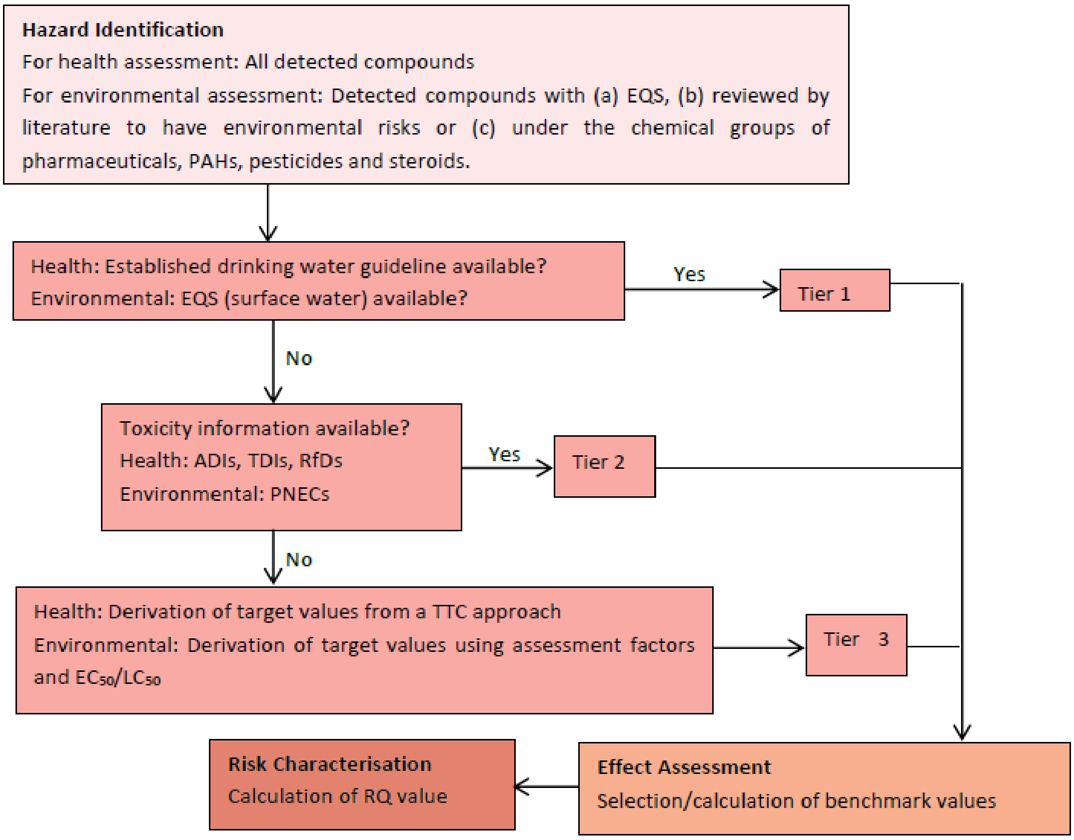
[18] Lee, Si Jia (2016), Indirect potable reuse in the United Kingdom – Risk assessment and technology choice, MSc thesis, School of Geography and the Environment, University of Oxford

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

number of compounds[20]. The methodology employed for the health risk assessment is adapted from the empirical framework applied by Etchepare and van der Hoek[21] as well as the approach used in the Australian Guidelines for Water Recycling[22].

L.89 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 approach[23], summarised in Figure L-6.

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



Source: Lee (2016)[18]

[20] 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

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

[22] NRMMC, 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

[23] 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 WTW[21].

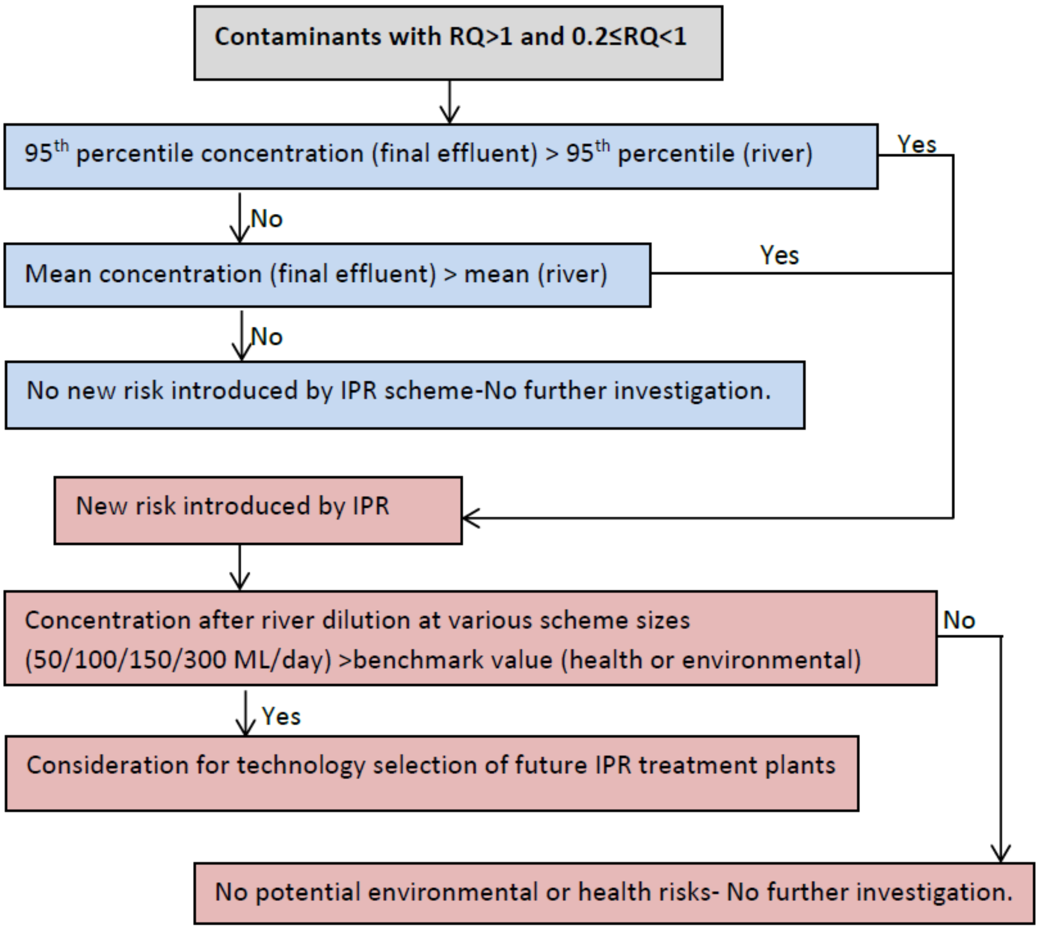
L.90 Any contaminants with a RQ ≥ 1 are contaminants that may pose environmental and health risks if effluent from the studied WWTWs was discharged into the receiving river without further treatment. Etchepare and van der Hoek[21] also advised further assessment for any contaminants with a RQ ≥ 0.2, which we have followed.

L.91 The concentrations of each contaminant with a RQ ≥ 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.92 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.93 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.94 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.95 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.96 However, this new method did not allow us to assess chemical removal to achieve no deterioration as defined in paragraph L.26 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	Clostridium, Coliform, E.coli, Enterococci, Cryptosporidium, Giardia	> 2-log removal required
General chemistry	BOD, Colour, turbidity, ammonia, nitrite, cyanide	> 60% removal required
Metals	Aluminium, zinc, iron, barium, copper, lead, molybdenum Nickel, manganese, mercury, lithium,	Between 70 and 99% removal required Between 10 and 55% removal required
Pesticide	AMPA, cypermethrin, diuron, glyphosate	> 70% removal required
PAH	Fluoranthene, Total PAH	> 75% removal required
Alkyphenol	Octylphenolmonoethoxylase	> 95% removal required
Hormones	17β-oestradiol, 17α-ethinyloestradiol	>99% removal required
Pharmaceuticals	Diclofenac, erythromycin Azithromicine, clarithromycin Carbamazepine, ciprofloxacin, fluoxetine	> 90% removal required Between 70 and 80% removal required Between 5 and 30% removal required
Disinfection by-product	Trihalomethane (chloroform, bromoform), N-nitrosodimethylamine (NDMA), haloacetic acid (dichloroacetic acid, trichloroacetic acid, chloroacetic acid), dimethylamine	Between 40 and 60% removal required, apart for trichloroacetic acid, which requires removal of > 80%
Bromodiesthers	PBDE-28, PBDE-47, PBDE-99, PBDE-100, PBDE-153, PBDE-154	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.98 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.99 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.100 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.101 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.102 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.103 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.104 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.105 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.106 It is expected that WP2 will be completed by March 2018 since we need to compile more complete datasets on some wastewater treatment locations.

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

L.107 The choice of treatment technology used for WRMP19 IPR options was determined by the discharge design standard approach. This work package aims to identify by identified risk 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.108 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 workshop[24]

L.109 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.110 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.111 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.112 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.113 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.

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

L.114 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.115 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.

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

L.116 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 only just complete.

L.117 Operational data from our current and historic studies were part of the conceptual design report written by Mott MacDonald[25].

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_2O_2) dosing and UV
Deephams WWTW (Pilot Plant)	May 2012 – August 2012	Final effluent	UF membranes followed by nanofiltration (NF) membranes and AOP (H_2O_2 + UV)
Deephams WWTW (Pilot Plant)	June 2008 – August 2012	Final effluent	UF membranes followed by AOP (H_2O_2 + UV)
Deephams WWTW (bench test)	June 2008 – August 2012	Final effluent	UF membranes followed by AOP (Ozone + H_2O_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
WRMP19[26]			
OFWRP (Pilot plant)	December 2016 - Ongoing	MBR effluent from full-scale OFWRP	RO membranes followed by AOP (H_2O_2 + UV)
OFWRP (Pilot plant)	December 2016 - Ongoing	MBR effluent from full-scale OFWRP	GAC process followed by AOP (H_2O_2 + UV)

[25] Mott MacDonald (2017), Thames Water WRMP19 Resource Options – Options operating philosophy, May 2017
[26] The pilot plant was handed over to Thames Water in October 2017.

Contaminants removal

L.118 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.

L.119 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.120 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.121 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 bromodiesthers (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.122 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.123 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.124 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.125 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.126 Pharmaceuticals and bromodiesther 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.127 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.128 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.129 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.130 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.131 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 for England and Wales between 2003 and 2015.

L.132 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.133 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.134 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" Section.

Further development work

L.135 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.136 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.137 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.138 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.139 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 EngD), 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.[27].

L.140 Key risks that have been considered include:

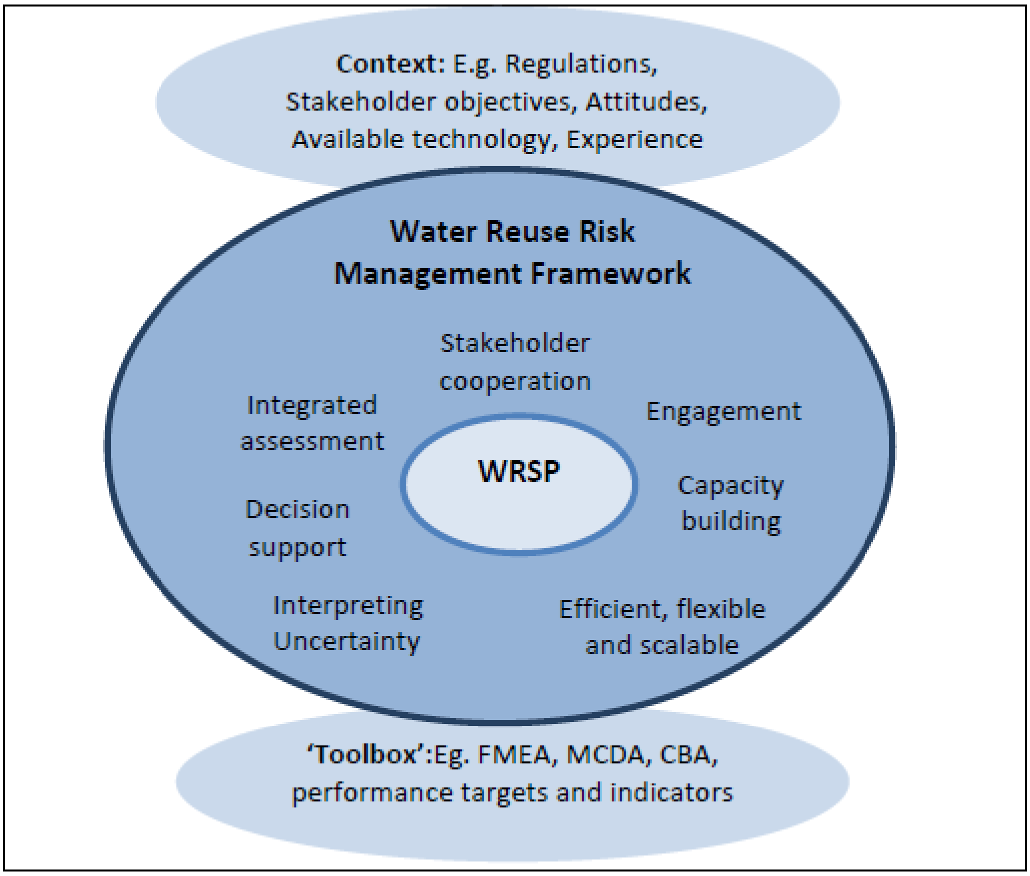
- Risk characterisation and decision support tools to interpret uncertainty
- Integration and prioritisation of risks, risk controls and operational monitoring
- Understanding technological performance and the capabilities of water professionals
- Communication and engagement with regulators, stakeholders and the public

L.141 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.

[27] 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

L.142 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 (WRRMF), operationalised through a water reuse safety plan. We are aiming to start the WRRMF for the one of the reuse options in spring 2018.

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



Source: Goodwin et al.[27]

IPR Pathogen fingerprint

L.143 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.144 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.145 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.146 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.147 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.148 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.149 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.150 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.151 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.152 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.153 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.154 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.155 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.156 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.157 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.158 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.159 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.160 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 and the continued operation of the OFWRP.

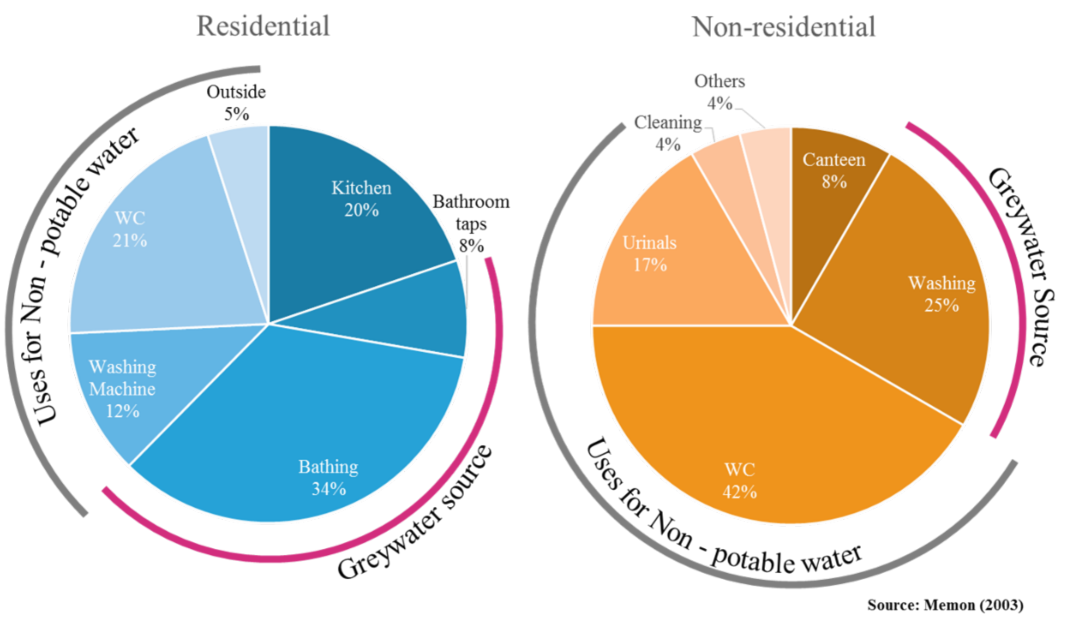
L.161 Following a multi-stage methodology, which screened out non-viable options, we concluded that the implementation of NPR (using a combination of greywater recycling and rainwater harvesting systems) could reduce drinking water demand by up to 33 Ml/d. The system would however need to be installed in a managed environment to reduce the possibility of misuse or cross-connections between the non-potable and potable networks.

L.162 The OFWRP has supplied non-potable water to the Queen Elizabeth Olympic Park since April 2012 and we are willing to continue operating the plant should customer demand exceed 200 m^3/day all year round. The plant has the potential to reduce drinking water demand by up to 574 m^3/day and becomes biologically unsustainable at low flows.

What is non-potable reuse?

L.163 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.164 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.165 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.166 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.167 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.168 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.169 A total increase in population is forecast in the Thames Water 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 Plan[28]. 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

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

March 2016, the government also extended this support offer to new settlements comprising between 1,500 and 10,000 new homes.

Non-potable water reuse feasible options

L.170 We have contracted a consortium of consultants and non-potable water system suppliers, led by Arup, to carry out a feasibility study of 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.171 The results of this study are summarised below and the details can be found in the full report[29].

L.172 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.173 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.

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

Option categories	Unit	Rainwater harvesting	Stormwater harvesting	Greywater recycling	Combined
Development Level – Individual Systems – Commercial only	Ml/d	0.3	-	4	5
Development Level – Individual Systems – Residential only	Ml/d	0.9	-	28	28
Development Level – Individual Systems –	Ml/d	1.2	-	32	33

[29] 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)

Option categories	Unit	Rainwater harvesting	Stormwater harvesting	Greywater recycling	Combined
Commercial & Residential					
Development Level – Mix of Systems – Commercial only	Ml/d		0.4	4	5
Development Level – Mix of Systems – Residential only	Ml/d		1.4	28	28
Development Level – Mix of Systems – Commercial & Residential	Ml/d		1.8	32	33
Development Level – Central System – Commercial & Residential – Commercial only	Ml/d		0.4	4	5
Development Level – Central System – Commercial & Residential – Residential only	Ml/d		1.4	28	28
Development Level – Central System – Commercial & Residential development – Commercial & Residential	Ml/d		1.8	32	33

Old Ford water recycling plant

L.174 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 are operating and maintaining the OFWRP and associated assets as a research initiative from 2012-2019.

L.175 The plant, which has a production capacity of 574 m^3/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.176 In cooperation with London Legacy Development Corporation (LLDC) we are communicating with potential future non-potable water customers to secure a stable and sustainable future non-potable water demand for the OFWRP. The inclusion of the OFWRP within the WRMP19 process would allow for security and funding for future operation and maintenance to produce a minimum of 200 m^3/day.

Lesson learned – our experience to date with Non-Potable Water

L.177 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), the blackwater recycling plant at Beddington Zero Emission Development (BedZED, South London 2008-12). We have also 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.178 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.179 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.180 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.181 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.182 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. 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.183 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 us, our customers and other operators

Is the inset regime a possible answer?

L.184 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.185 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 Thames Water). 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.186 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 on rainwater and/or greywater recycling 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.

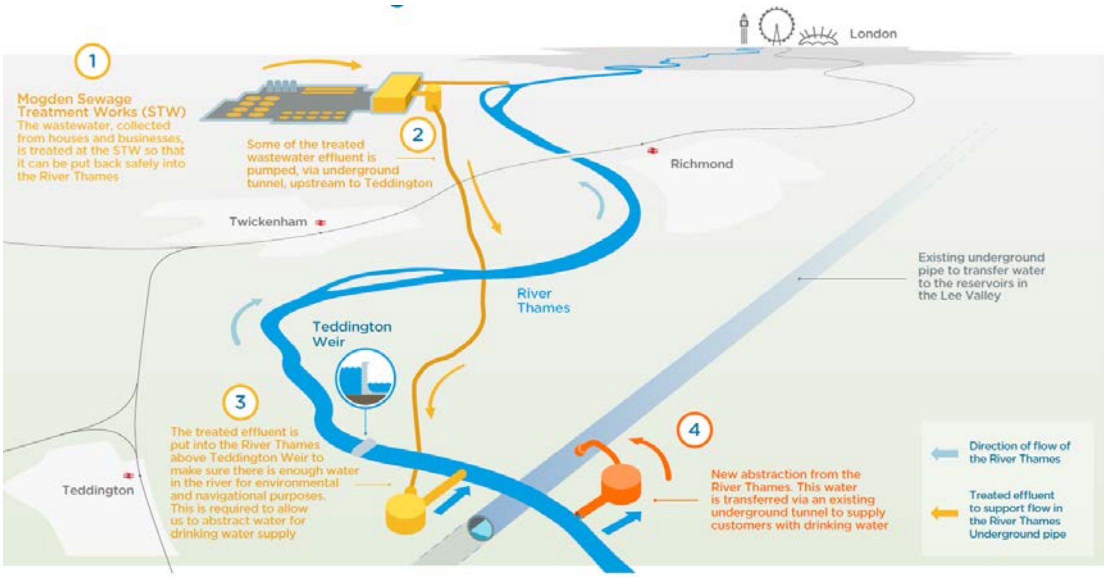
L.187 We are also proposing to continue the operation of the OFWRP, which could reduce drinking water demand on the Queen Elizabeth Olympic Park by 200 m^3/day as a minimum.

L.188 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.189 An environmental flow augmentation option was established to support enhanced Teddington DRA option. In this option, up to 268 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 the River Lee 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. It is therefore necessary to consider the environmental impact of the transferred effluent on the water body it discharges into as well as the impact of loss of freshwater that would normally flow into the upper River Thames estuary.

Figure L- 10: Teddington DRA option



Considerations when implementing Teddington DRA

L.190 The option has numerous benefits including the following:

- Increase of freshwater resource for abstraction. Without environmental flow augmentation, we would not be able to abstract more freshwater on the non-tidal River Thames whilst still complying with the catchment abstraction management strategy (CAMS)[1] requirements
- No change in risk to drinking water quality

L.191 However, some considerations need to be taken into account to ensure this option does not have detrimental impact on the environment (i.e. complying with WFD) and users of the River

Thames (e.g. impact on navigation). Please refer to Appendix B and BB for further information on this potential impacts.

Concluding Remarks for flow augmentation scheme

L.192 The Teddington DRA option has the potential to provide a deployable output of up to 268 Ml/d. The option requires the diversion of (or 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 could have detrimental ecological impacts if not managed properly. We are currently working with our stakeholders to ensure that the appropriate mitigation measures are included in the design of this option.

E. Public and Stakeholders Risk Perception

L.193 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 STREAM[30] EngD student from Cranfield University[31]. 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.194 OFWRP was used as the case study to assess stakeholder engagement.

Collaboration on risk management

L.195 Collaboration between stakeholders and learning opportunities are perceived as necessary to improve scheme governance.

L.196 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; and improving awareness, knowledge and capabilities. 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

30 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.

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

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.197 Full results can be found in Goodwin et al. (2017)[31].

The effect of media on public perception

L.198 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.199 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.200 More details can be found in Goodwin et al.[31].

Significance of message framing

L.201 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.

Multi-criteria stakeholder evaluations of risk intervention

L.202 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.

Concluding remarks for public and stakeholder risk perception

L.203 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.204 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.205 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.206 In promoting the choices of technology for IPR and non-potable water schemes we have will demonstrate high quality standards to reduce risk. This will be a key part of communicating any future reuse scheme to gain public acceptance.