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South East Strategic Reservoir Option Gate 1 submission – Technical Annex B1

Appendix A6 Water Quality (River and Reservoir)

Thames Water Utilities Ltd.

14 May 2021

5201137-013

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Client	Thames Water Utilities Ltd.
Project	South East Reservoir Strategic Option (SESRO)
Job number	5201137
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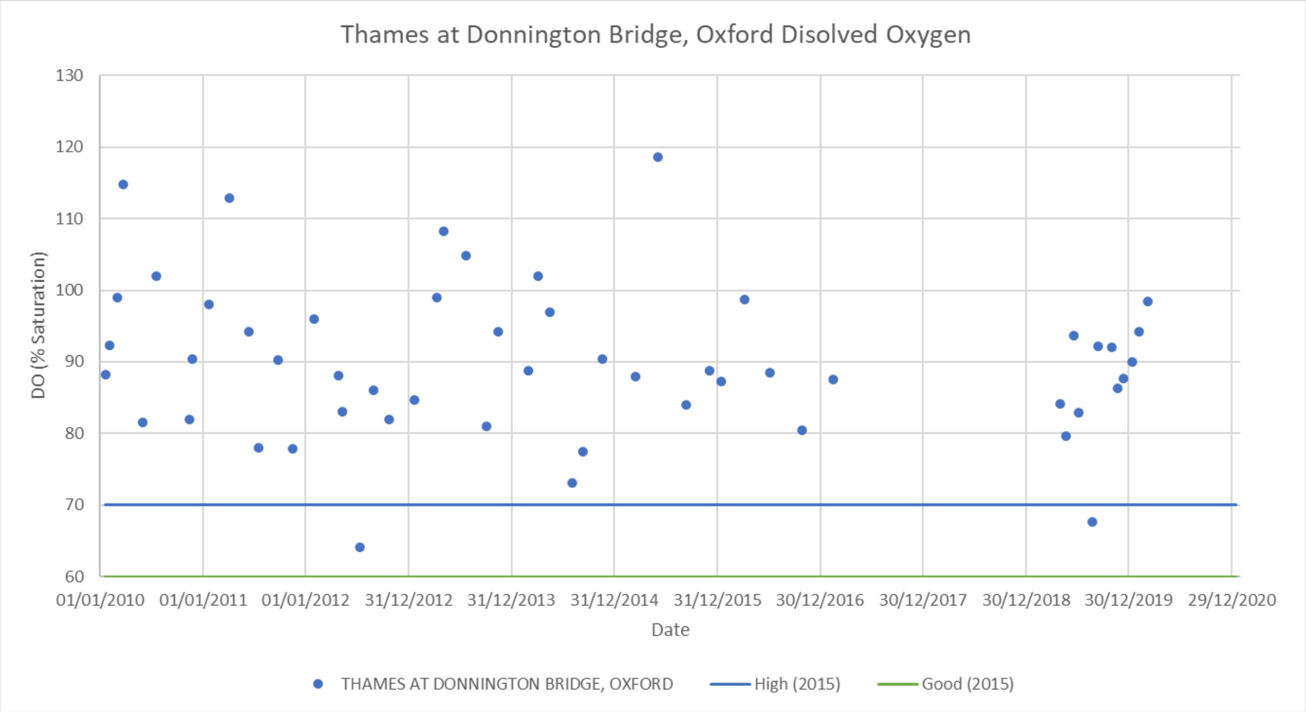
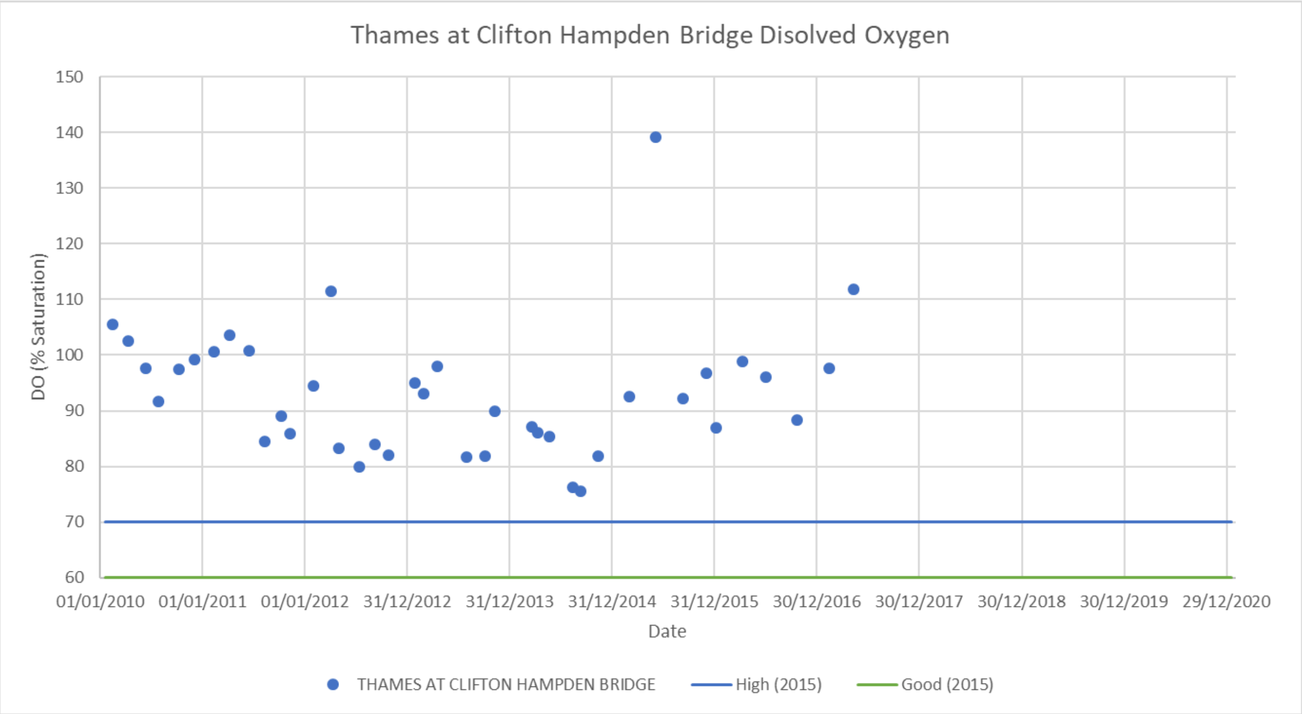
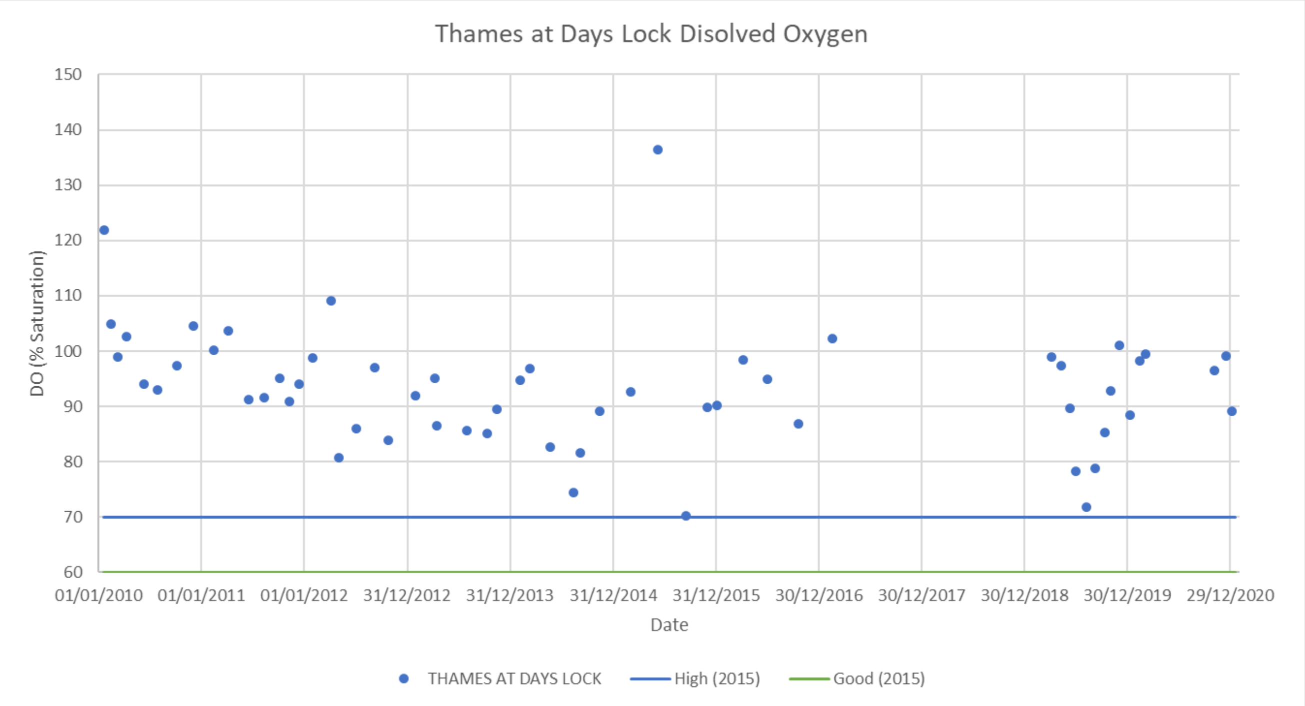
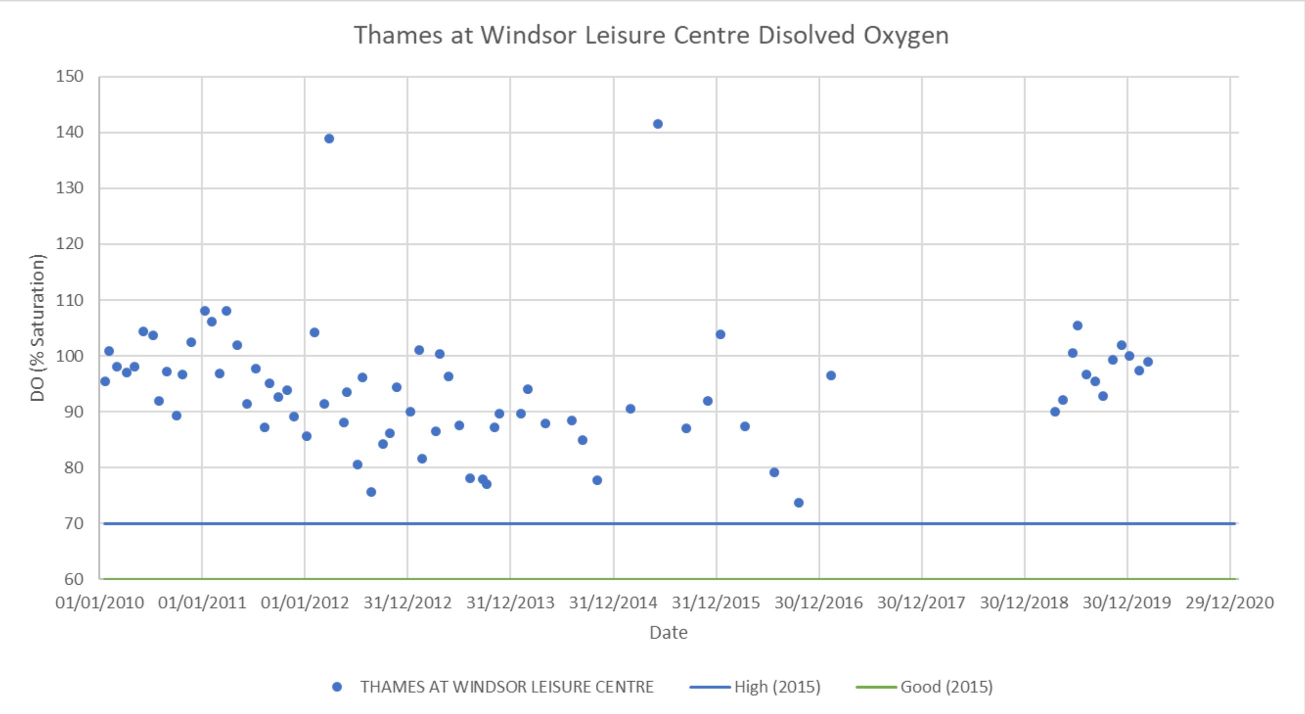
A6.1. Environment Agency Water Quality Data Between 2010 and 2021

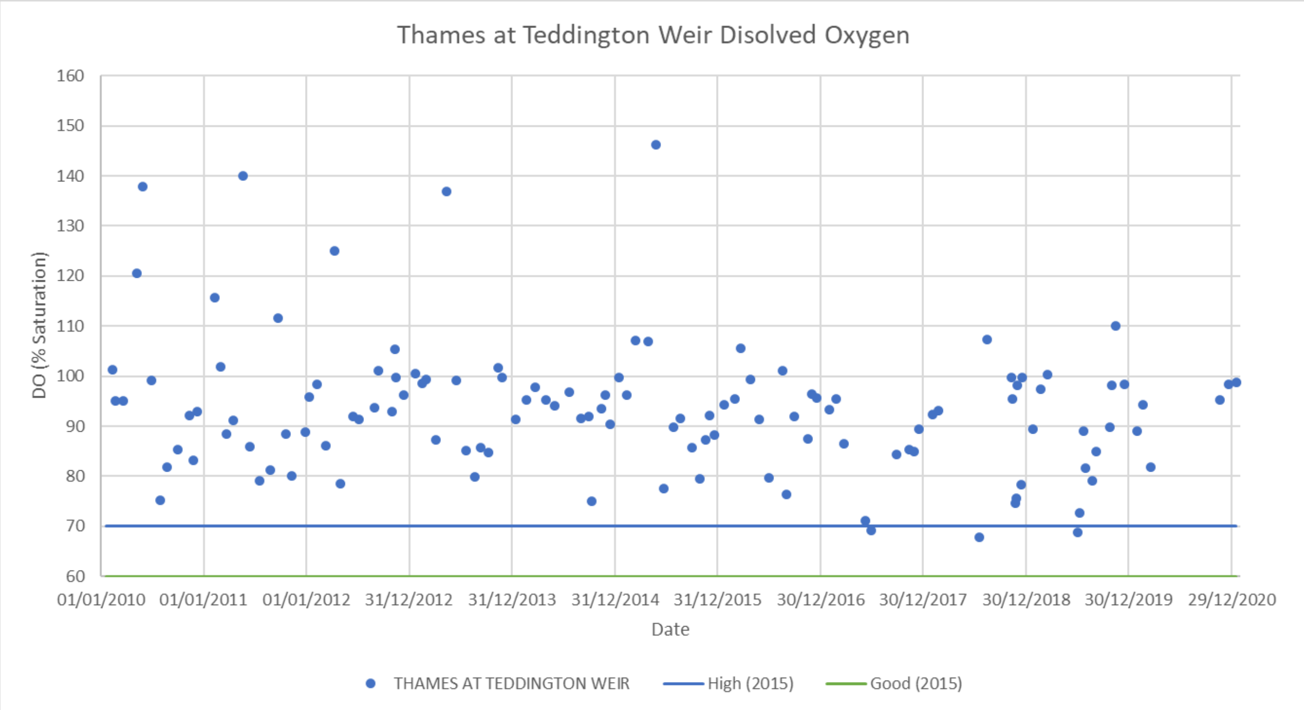
A6.1.1. Dissolved Oxygen



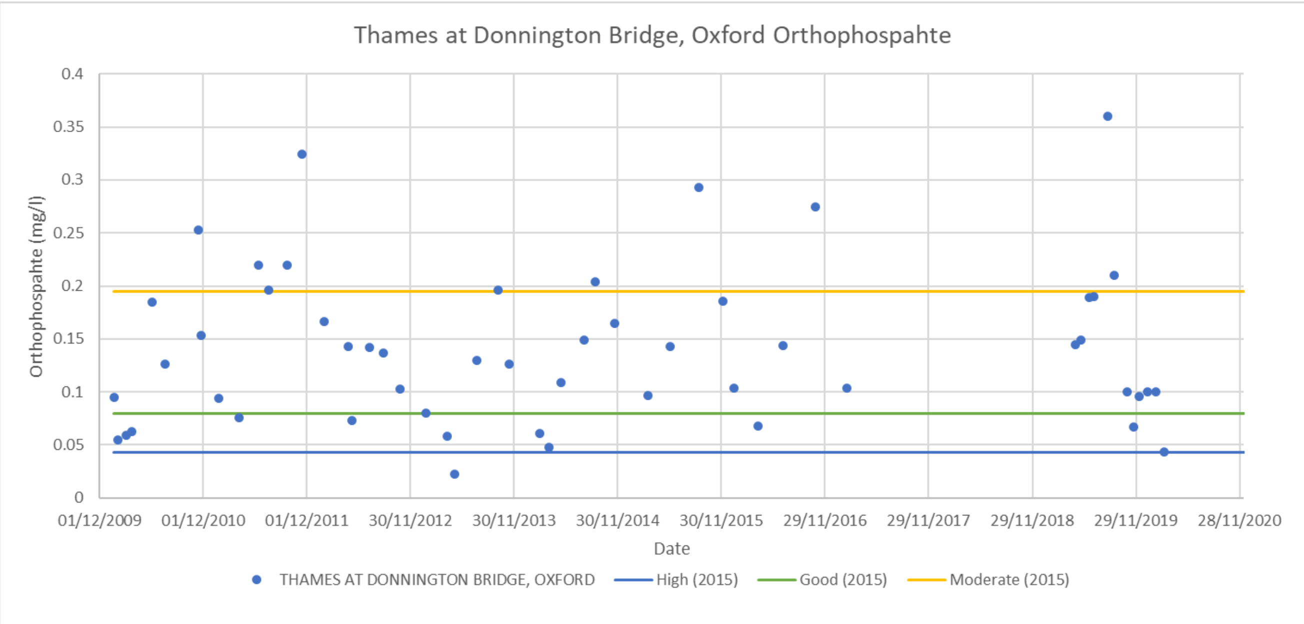


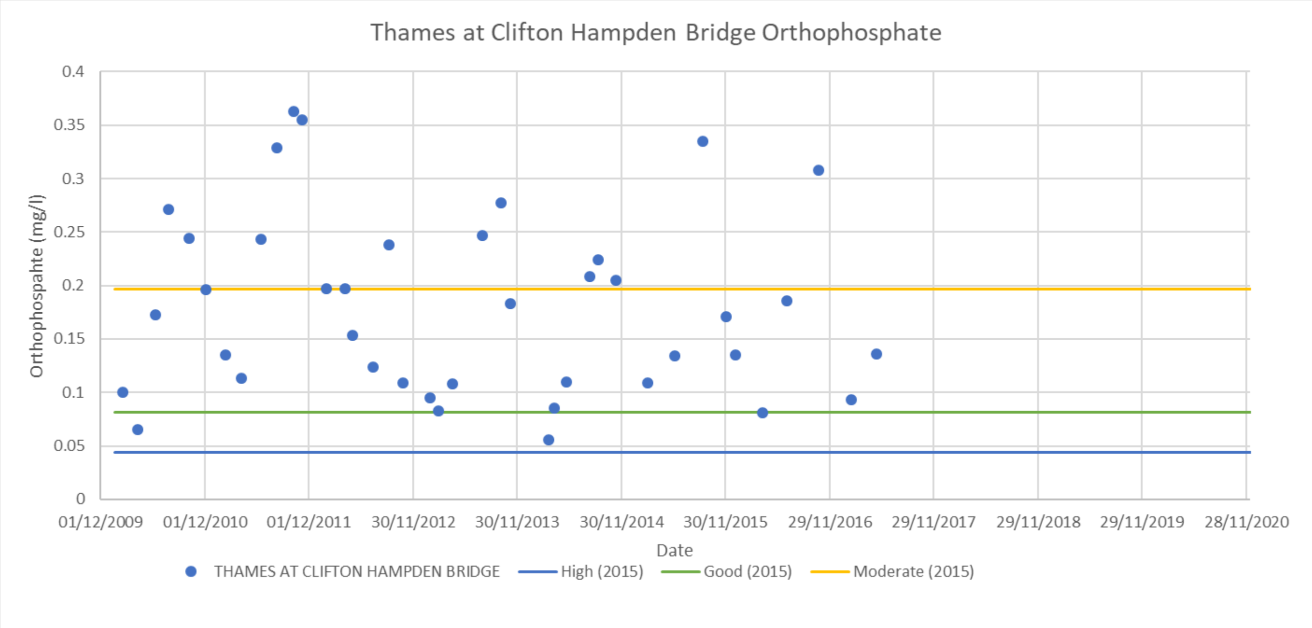

Thames at Days Lock Disolved Oxygen
150
140
130
120
110
100
90
80
70
60
DO (% Saturation)
01/01/2010 01/01/2011 01/01/2012 31/12/2012 31/12/2013 31/12/2014 31/12/2015 30/12/2016 30/12/2017 30/12/2018 30/12/2019 29/12/2020
Date
THAMES AT DAYS LOCK
High (2015)
Good (2015)

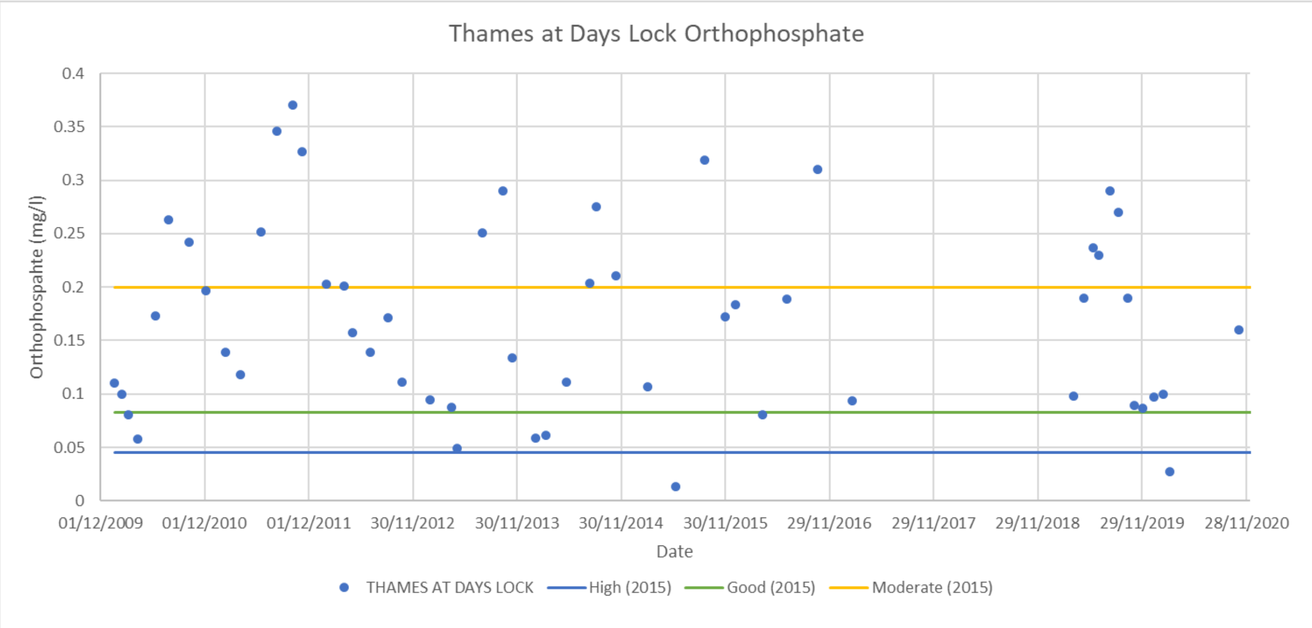

Thames at Windsor Leisure Centre Disolved Oxygen
150
140
130
120
110
100
90
80
70
60
DO (% Saturation)
01/01/2010 01/01/2011 01/01/2012 31/12/2012 31/12/2013 31/12/2014 31/12/2015 30/12/2016 30/12/2017 30/12/2018 30/12/2019 29/12/2020
Date
THAMES AT WINDSOR LEISURE CENTRE
High (2015)
Good (2015)

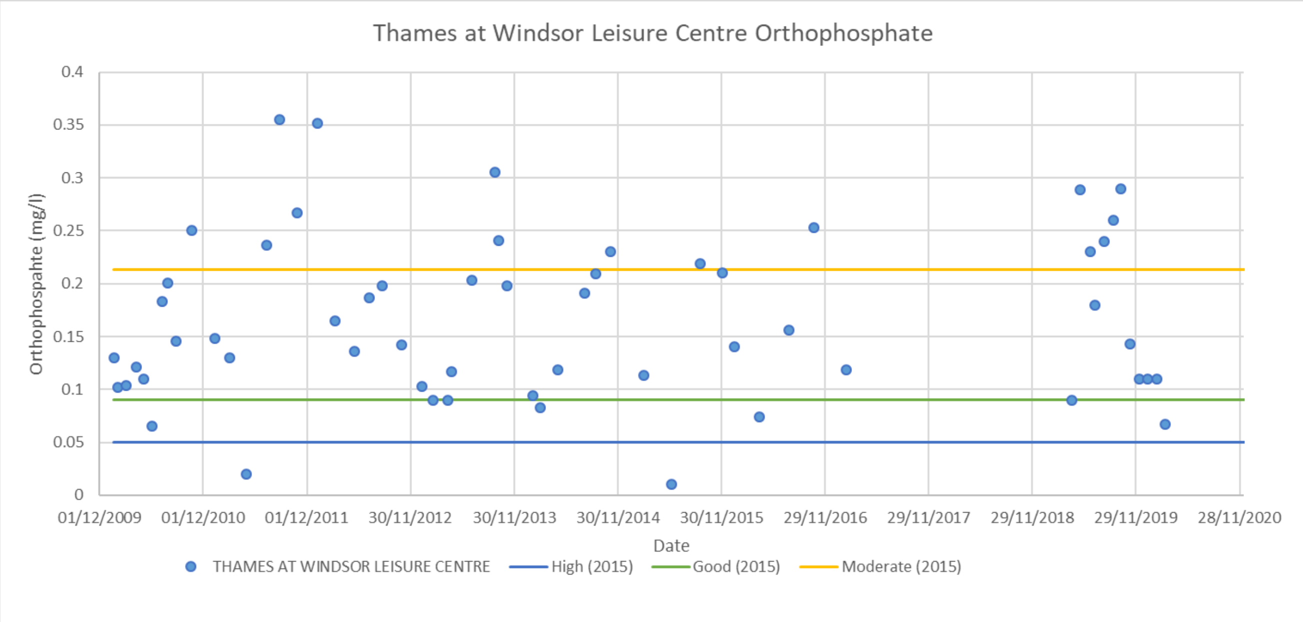


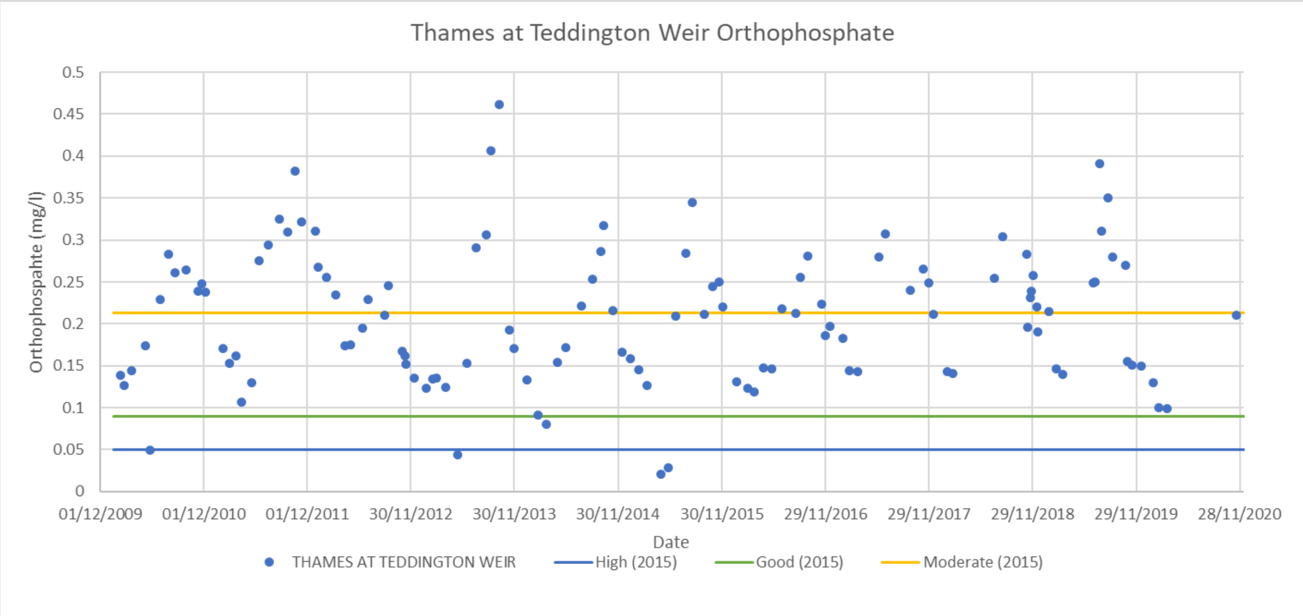
A6.1.2. Orthophosphate



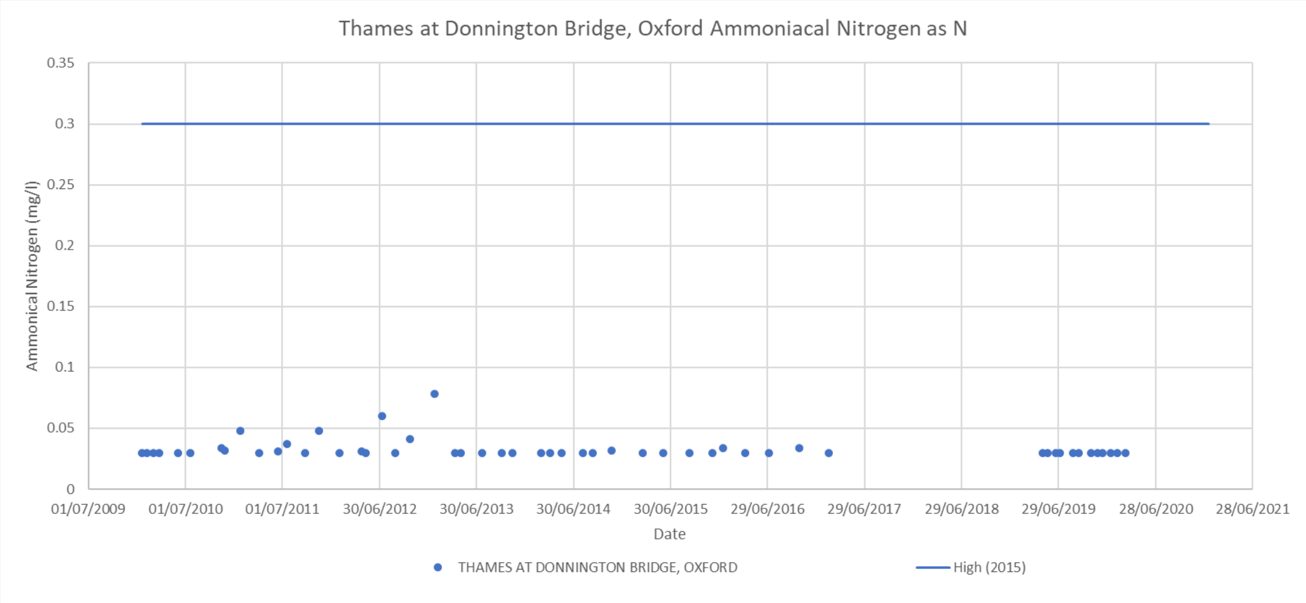

Thames at Clifton Hampden Bridge Orthophosphate
Orthophospahte (mg/l)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01/12/2009
01/12/2010
01/12/2011
30/11/2012
30/11/2013
30/11/2014
30/11/2015
29/11/2016
29/11/2017
29/11/2018
29/11/2019
28/11/2020
Date
THAMES AT CLIFTON HAMPDEN BRIDGE
High (2015)
Good (2015)
Moderate (2015)

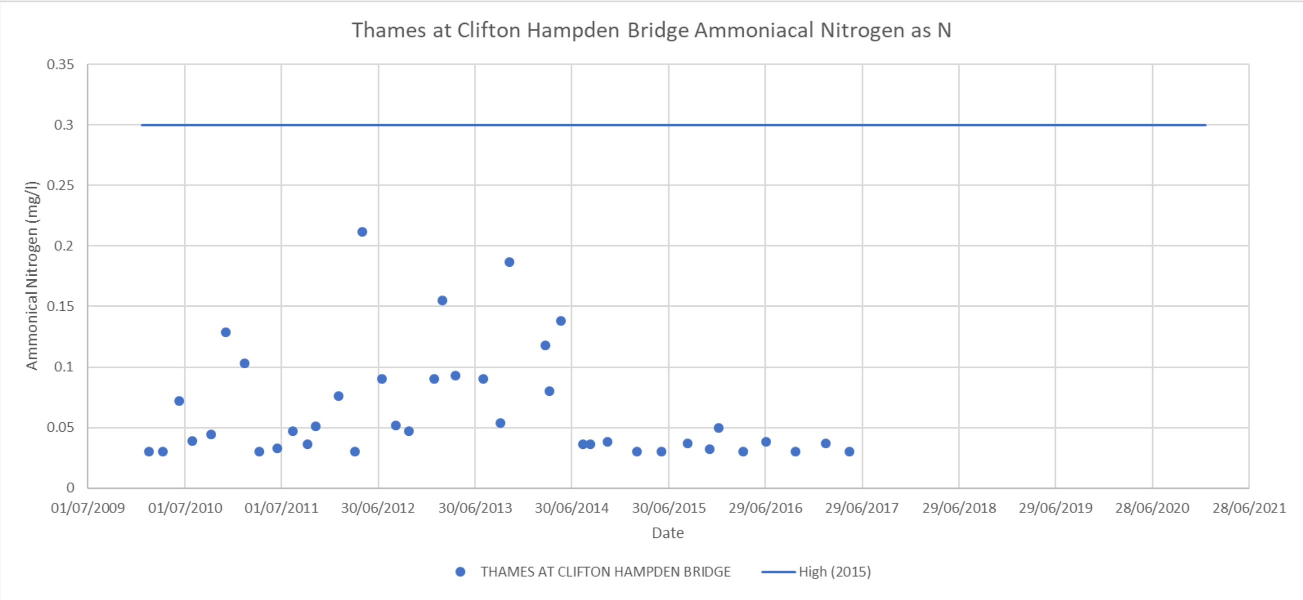

Thames at Days Lock Orthophosphate
Orthophospahte (mg/l)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01/12/2009
01/12/2010
01/12/2011
30/11/2012
30/11/2013
30/11/2014
30/11/2015
29/11/2016
29/11/2017
29/11/2018
29/11/2019
28/11/2020
Date
THAMES AT DAYS LOCK
High (2015)
Good (2015)
Moderate (2015)

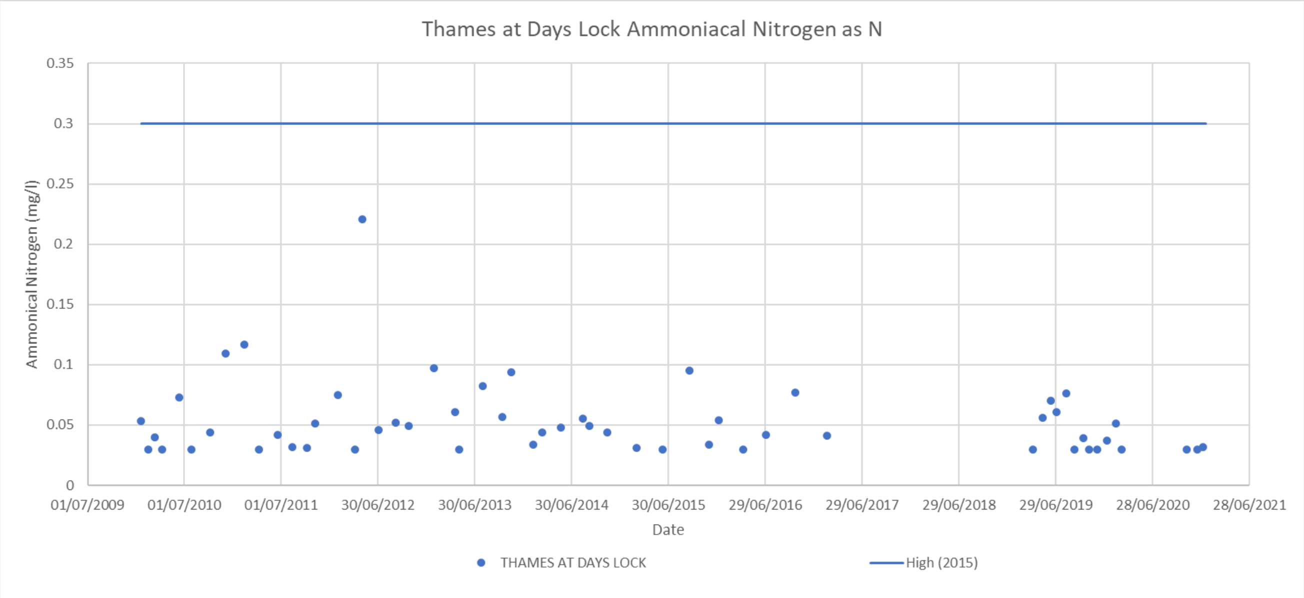

Thames at Windsor Leisure Centre Orthophosphate
Orthophospahte (mg/l)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01/12/2009
01/12/2010
01/12/2011
30/11/2012
30/11/2013
30/11/2014
30/11/2015
29/11/2016
29/11/2017
29/11/2018
29/11/2019
28/11/2020
Date
THAMES AT WINDSOR LEISURE CENTRE
High (2015)
Good (2015)
Moderate (2015)

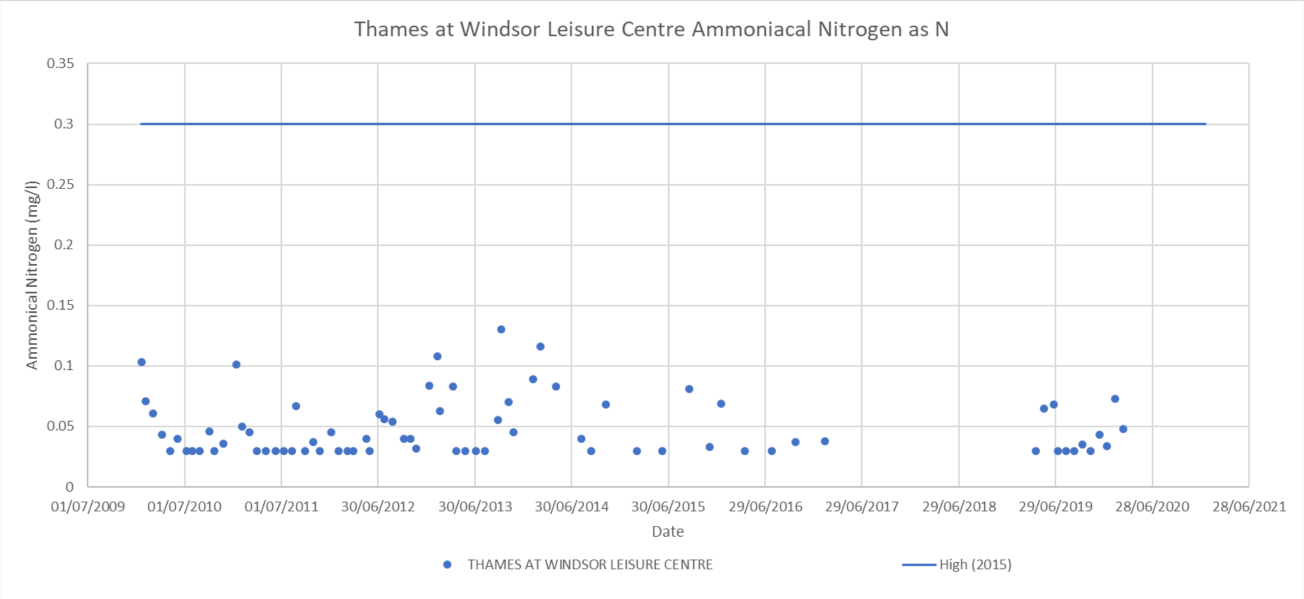

Thames at Teddington Weir Orthophosphate
Orthophospahte (mg/l)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01/12/2009
01/12/2010
01/12/2011
30/11/2012
30/11/2013
30/11/2014
30/11/2015
29/11/2016
29/11/2017
29/11/2018
29/11/2019
28/11/2020
Date
THAMES AT TEDDINGTON WEIR
High (2015)
Good (2015)
Moderate (2015)

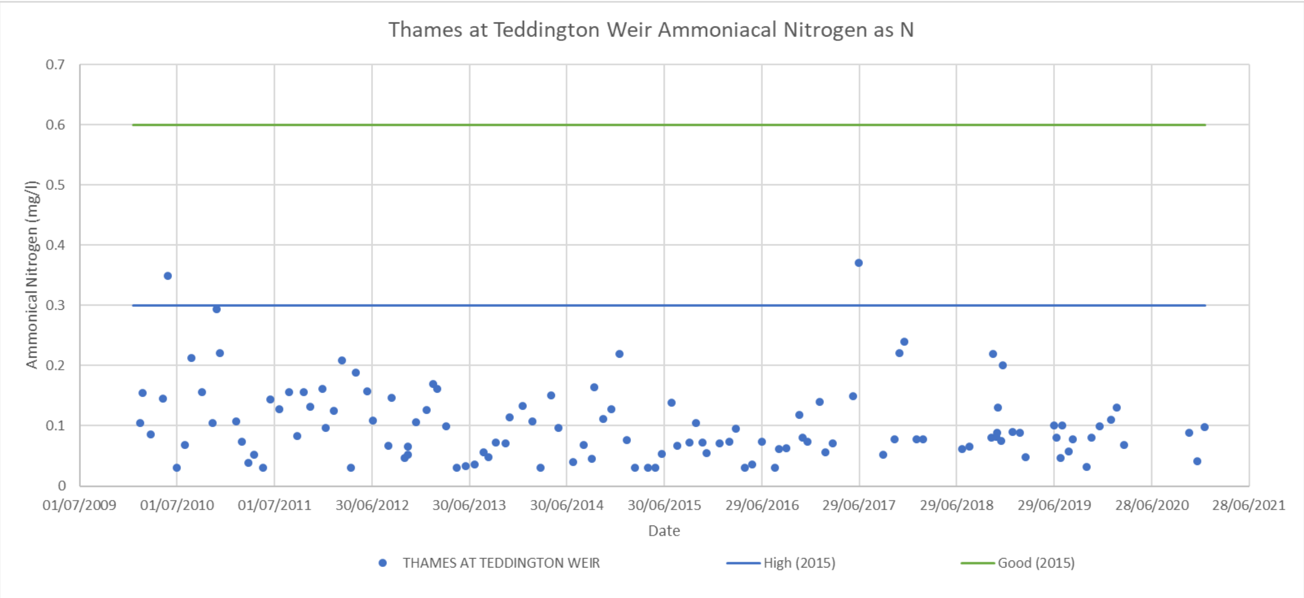
A6.1.3. Ammoniacal Nitrogen as N



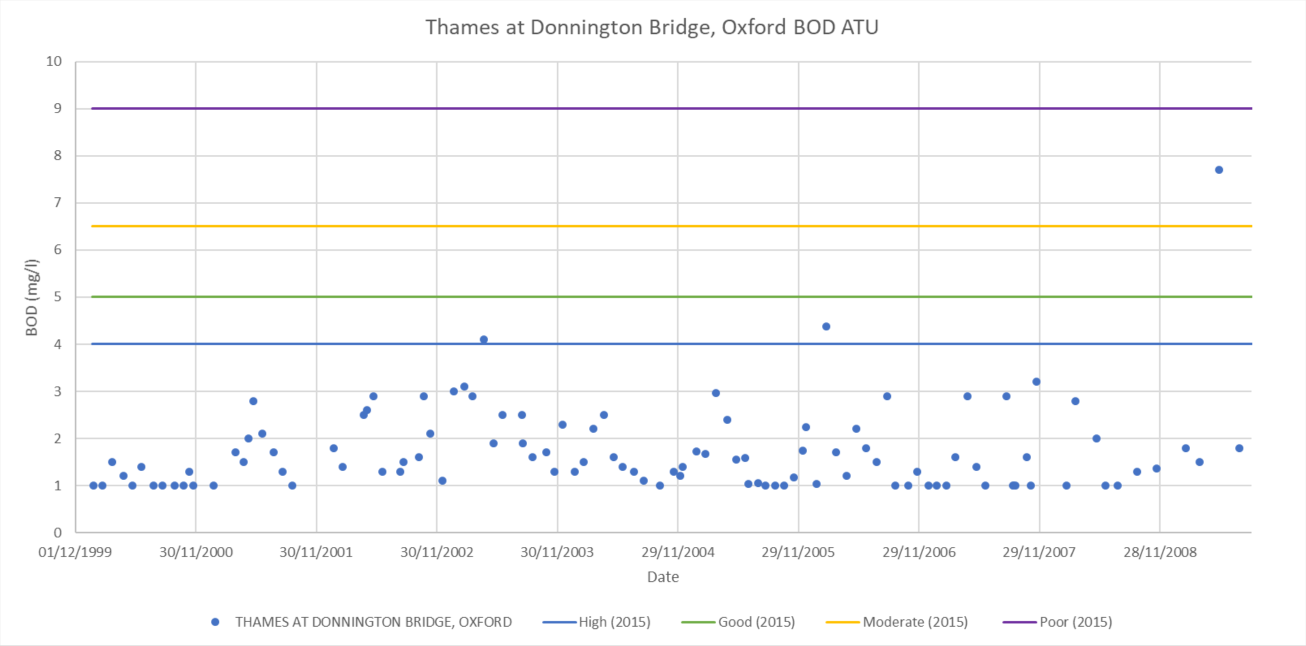



Thames at Days Lock Ammoniacal Nitrogen as N
Ammonical Nitrogen (mg/l)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01/07/2009
01/07/2010
01/07/2011
30/06/2012
30/06/2013
30/06/2014
30/06/2015
29/06/2016
29/06/2017
29/06/2018
29/06/2019
28/06/2020
28/06/2021
Date
THAMES AT DAYS LOCK
High (2015)

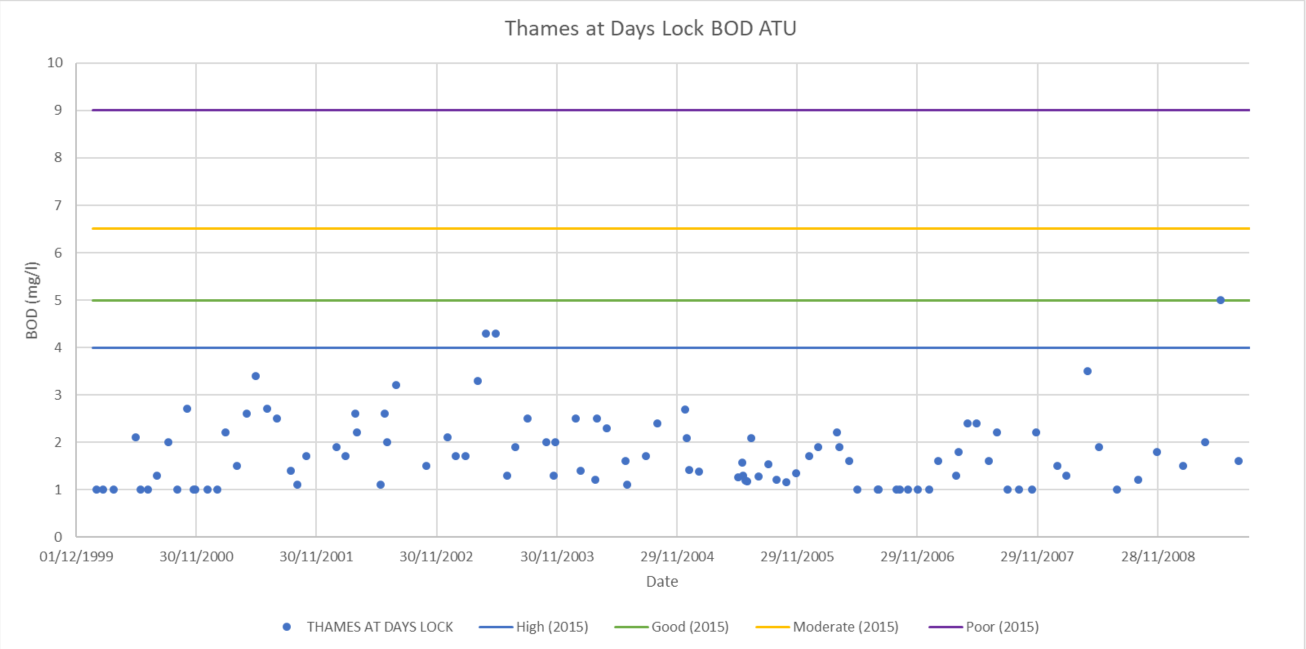

Thames at Windsor Leisure Centre Ammoniacal Nitrogen as N
Ammonical Nitrogen (mg/l)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01/07/2009
01/07/2010
01/07/2011
30/06/2012
30/06/2013
30/06/2014
30/06/2015
29/06/2016
29/06/2017
29/06/2018
29/06/2019
28/06/2020
28/06/2021
Date
THAMES AT WINDSOR LEISURE CENTRE
High (2015)


Thames at Teddington Weir Ammoniacal Nitrogen as N
Ammonical Nitrogen (mg/l)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
01/07/2009
01/07/2010
01/07/2011
30/06/2012
30/06/2013
30/06/2014
30/06/2015
29/06/2016
29/06/2017
29/06/2018
29/06/2019
28/06/2020
28/06/2021
Date
THAMES AT TEDDINGTON WEIR
High (2015)
Good (2015)

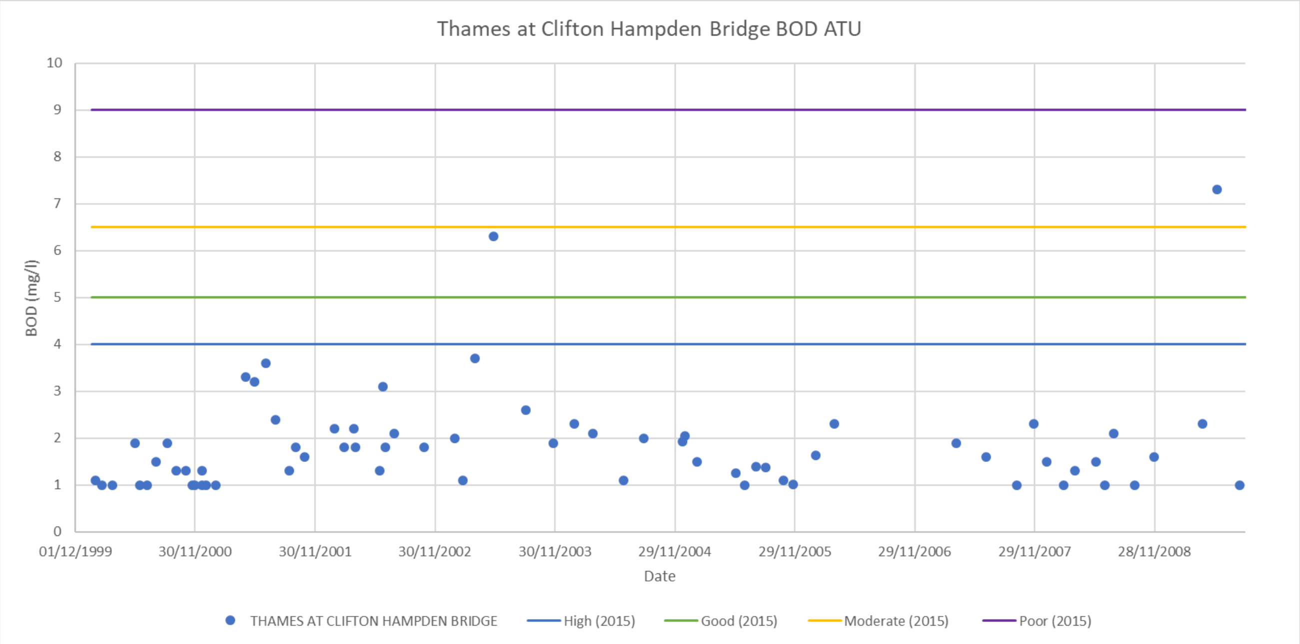
A6.1.4. BOD

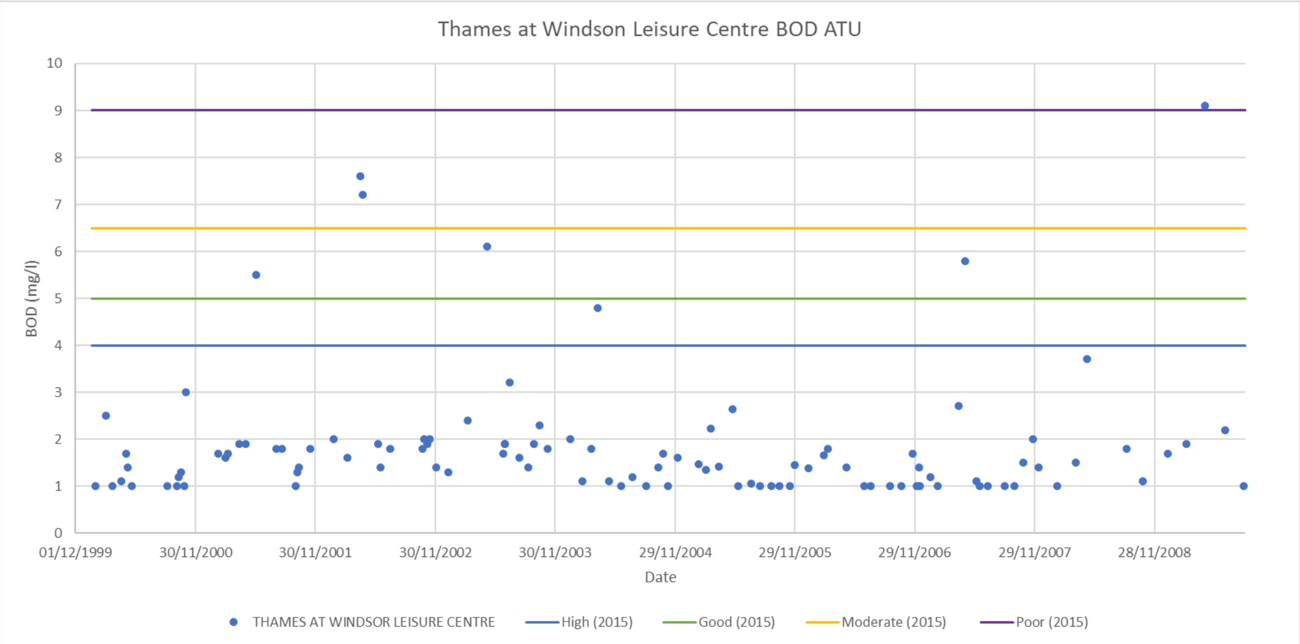


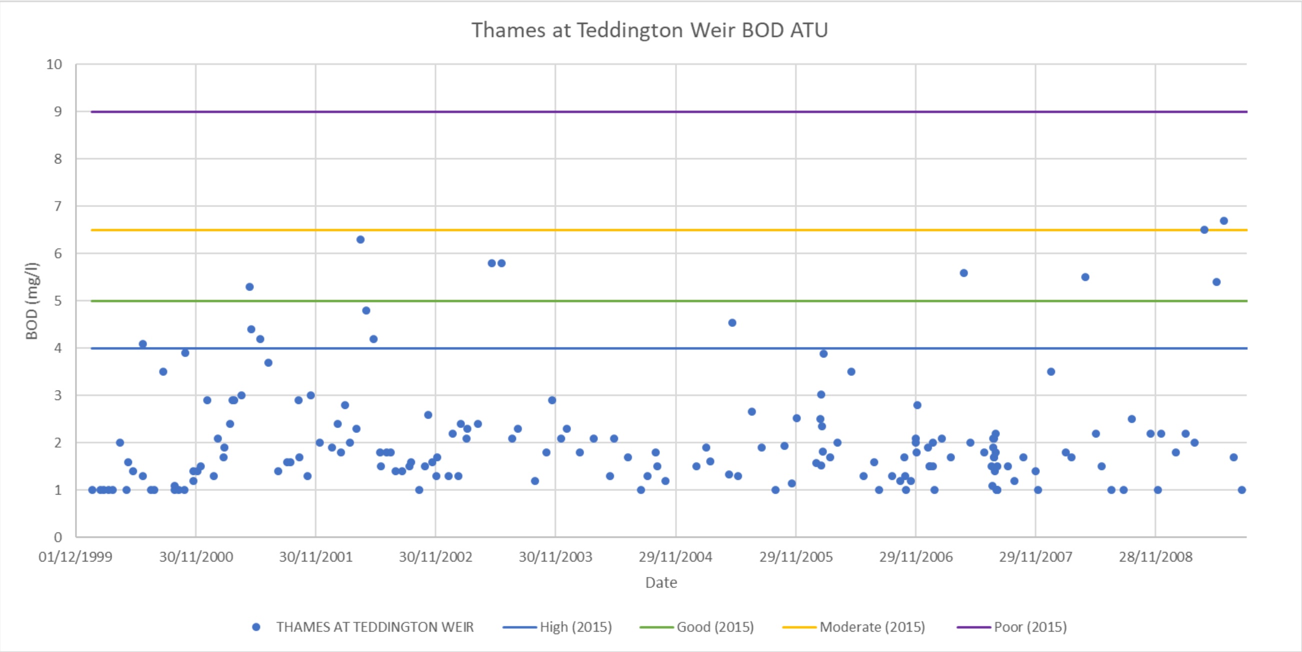
Thames at Donnington Bridge, Oxford BOD ATU
BOD (mg/l)
10
9
8
7
6
5
4
3
2
1
0
01/12/1999
30/11/2000
30/11/2001
30/11/2002
30/11/2003
29/11/2004
29/11/2005
29/11/2006
29/11/2007
28/11/2008
Date
THAMES AT DONNINGTON BRIDGE, OXFORD
High (2015)
Good (2015)
Moderate (2015)
Poor (2015)



Thames at Days Lock BOD ATU
BOD (mg/l)
10
9
8
7
6
5
4
3
2
1
0
01/12/1999
30/11/2000
30/11/2001
30/11/2002
30/11/2003
29/11/2004
29/11/2005
29/11/2006
29/11/2007
28/11/2008
Date
THAMES AT DAYS LOCK
High (2015)
Good (2015)
Moderate (2015)
Poor (2015)


Thames at Clifton Hampden Bridge BOD ATU
BOD (mg/l)
Date
01/12/1999
30/11/2000
30/11/2001
30/11/2002
30/11/2003
29/11/2004
29/11/2005
29/11/2006
29/11/2007
28/11/2008
THAMES AT CLIFTON HAMPDEN BRIDGE
High (2015)
Good (2015)
Moderate (2015)
Poor (2015)


Thames at Windson Leisure Centre BOD ATU
BOD (mg/l)
Date
01/12/1999
30/11/2000
30/11/2001
30/11/2002
30/11/2003
29/11/2004
29/11/2005
29/11/2006
29/11/2007
28/11/2008
THAMES AT WINDSOR LEISURE CENTRE
High (2015)
Good (2015)
Moderate (2015)
Poor (2015)


Thames at Teddington Weir BOD ATU
BOD (mg/l)
10
9
8
7
6
5
4
3
2
1
0
01/12/1999
30/11/2000
30/11/2001
30/11/2002
30/11/2003
29/11/2004
29/11/2005
29/11/2006
29/11/2007
28/11/2008
Date
THAMES AT TEDDINGTON WEIR
High (2015)
Good (2015)
Moderate (2015)
Poor (2015)

A6.2. SIMCAT SAGIS Modelling Report

A6.2.1. Introduction

The SAGIS-SIMCAT modelling presented in this Appendix aims to assess the potential impact of the South East Strategic Reservoir Option (SESRO) in Oxfordshire on Water Framework Directive (WFD) compliance in the downstream River Thames and risks to drinking water at downstream water treatment works as part of the Gate 1 work. This will provide an initial assessment of key issues and help define the requirements for further, more detailed water quality modelling work which may form part of Gate 2.

The following chemicals, already included within the SAGIS databases, were modelled. These present risk of WFD non-compliance and/or risk to drinking water.

1. WFD physico-chemicals suite: total phosphorus (P), orthophosphate[1], nitrate, ammonia, biochemical oxygen demand (BOD);
2. Metals suite: total copper, total zinc, total nickel, total cadmium, total lead, total mercury; and
3. Organics suite: di-(2-ethylhexyl)phthalate (DEHP), anthracene, benzo-[a]-pyrene, benzo-[b]-fluoranthene, benzo-[k]-fluoranthene, benzo-[ghi]-perylene, fluoranthene, indeno-[1,2,3-cd]-pyrene, naphthalene, nonylphenol;

The scope for the Gate 1 SAGIS-SIMCAT modelling was shared with the Environment Agency on 18/12/2020, who confirmed on 09/02/2021 that the proposed work was sufficient for the purposes of Gate 1 and could proceed. The current SAGIS-SIMCAT model, as used by the Environment Agency for their permitting work, was used for the modelling.

Possible interactions between SESRO and other SROs and non-SROs (e.g. Severn Thames Transfer and operation of Farmoor reservoir) are not considered in this element of the work.

[1] In this context orthophosphate is assumed to be equivalent to soluble reactive phosphorus in relation to WFD compliance

A6.2.2. Model set up

A6.2.2.1. Structural modifications to SAGIS model: River Thames

Figure A6.2-1 shows the SAGIS-SIMCAT model area along with key features. The river stretch marked in black is downstream of the outfall from SESRO and, therefore, potentially affected by reservoir abstractions and releases.

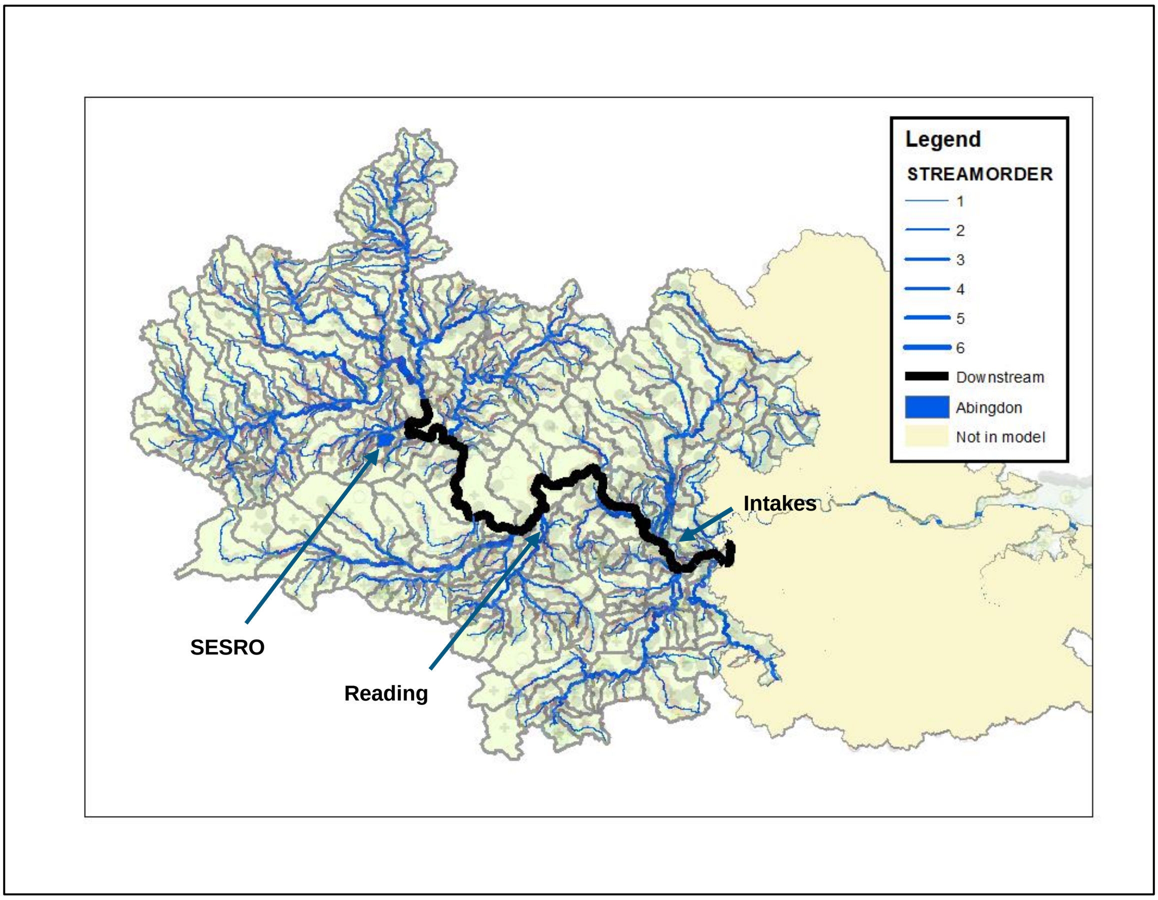


Figure A6.2-1 – Model area showing location of SESRO and the stretch of river potentially affected by its operation

SESRO was added to the model as a new lake feature, along with reservoir intake and outfall features as shown in Figure A6.2-2.

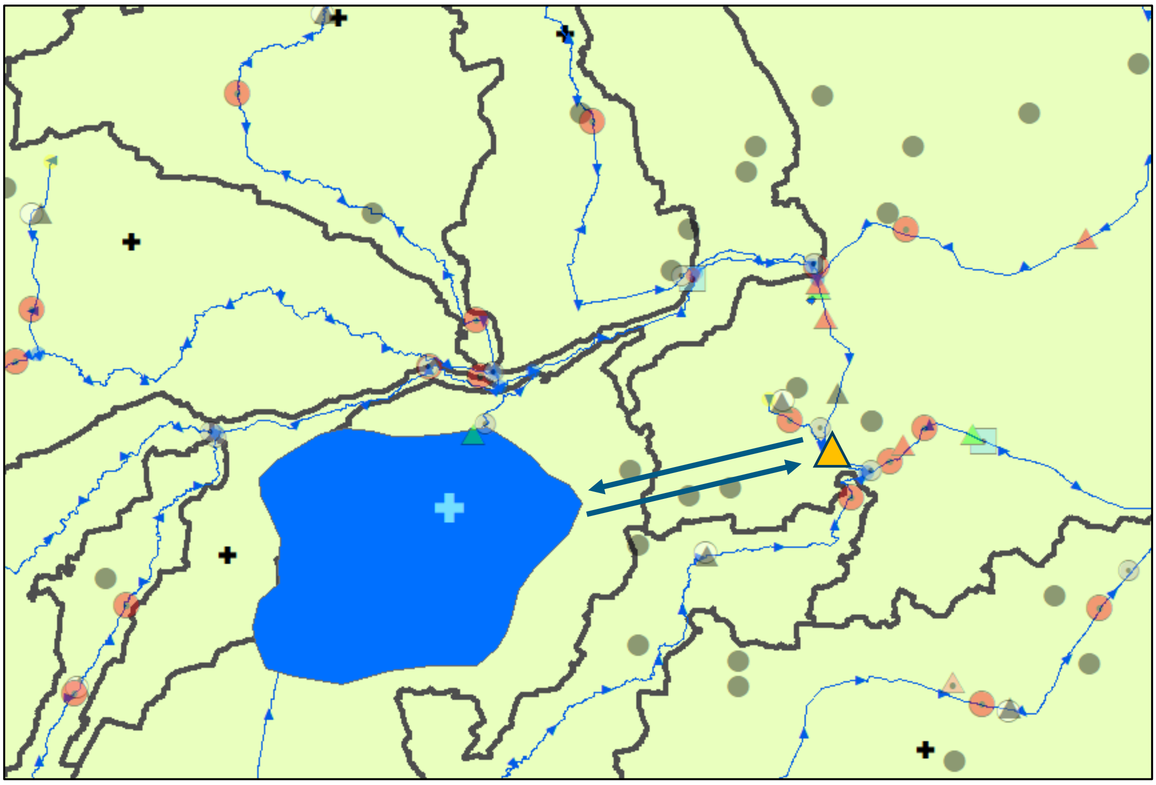


Figure A6.2-2 – Model location of intake and release point from the reservoir (triangle shows intake and outfall)

A reservoir volume of 150 Mm³ (150,000 Ml) was used as the preferred design option. Inputs of water pumped to the reservoir from the River Thames and released back to the river were based on outputs from the reservoir hydrological modelling work (see Appendix A5) for the period 1960–2000. This period was applied as it includes a wide range of hydrological conditions and aligns with the data period upon which river flows in the SAGIS model were originally based (using outputs from Lowflows 2000). More detail about the operating regime of SESRO are provided in Technical Annex B1 (Environmental Assessment Report) Section 4 (Hydrology).

The transfer volumes applied are shown in Table A6.2-1 below. Within each month, a correlation coefficient was applied in relation to river flow whereby transfer flows are increased or decreased depending on the position of daily river flows on the flow duration curve.

Table A6.2-1 – Modelled inflows and outflows (1960-2000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average monthly flow												
Inflow	220.36	109.38	82.30	29.75	1.94	4.92	2.41	5.72	40.47	103.48	105.44	232.11
Outflow	14.66	10.52	6.31	11.5	19.55	63.9	119.71	190.18	193.90	149.51	86.3	33.3
Correlation coefficient												
Inflow	0.01	0.27	0.05	0.07	0.02	0.12	0.09	0.36	0.71	0.40	0.18	0.12
Outflow	−0.26	−0.23	−0.20	−0.24	−0.27	−0.4	−0.28	−0.61	−0.51	−0.50	−0.38	−0.30

A6.2.2.2. Structural modifications to SAGIS model: River Ock

Revisions were made to the representation of the River Ock because watercourse modifications will be required to bypass the reservoir. The catchment area of the river was reduced by the proposed area of reservoir (estimated area was 9.5 km² within the dam wall). There are no proposed discharges from SESRO into the River Ock catchment, but it was assumed that runoff from the outer wall of dam will flow into the river. The length of Cow Common Brook was increased by 3 km to take account of the eastern and western watercourse diversions (see more detail in Technical Annex B3, Water Framework Directive assessment).

A6.2.2.3. Consolidation of observed data

Current data in the pre-existing SAGIS model (used for Environment Agency planning) is for the period 2010–2012. Further data on organic chemicals from subsequent Chemical Investigations Programme (CIP) studies was, however, incorporated to improve the dataset (although the data from 2014–2016 does not align in terms of period, this was considered preferable to having no data). The only chemical for which a substantial improvement in the dataset was achieved was for benzo-[a]-pyrene (other CIP data updates were for chemicals not included in this work).

Within the available time for this work, it was not possible to undertake a more wide-ranging update of the data; for example, making use of further data on organic chemicals collected by the Environment Agency, later monitoring for the CIP and by Thames Water.

In addition, 'At Permit' values for Total P for sewage works were obtained from the Environment Agency (using data from an 'At Permit' SIMCAT model provided by them).

A6.2.3. Model results

A6.2.3.1. Model calibration

Model calibration for water quality was carried out using standard tools developed by UKWIR; calibrated model outputs for the stretch of river downstream of the reservoir for key chemicals are shown in Figure A6.2-3 and Figure A6.2-4. The observed data available within the modelled area for each of the chemicals is summarised in Table A6.2-2 along with comments on the reliability of the calibration. The amount of data and reliability of the calibration process varied between chemicals and, for many of the organic chemicals, no observed data was available. In general calibration was good, apart from the calibration for ammonia for which underprediction occurred at some monitoring stations.

Table A6.2-2 – Summary of calibration data and outputs

Chemical	Data points	Comments
Total P	11	Data only allowed limited calibration
Orthophosphate	270	Good calibration achieved
Nitrate	274	Good calibration achieved
Ammonia	279	Reasonable calibration achieved but some overprediction
BOD	73	Good calibration achieved
Total Copper	12	Observed river water quality data allowed only limited calibration
Total Zinc	120	Good calibration achieved
Total Cadmium	4	Insufficient observed water quality data for meaningful calibration
Total Mercury	1	Insufficient observed water quality data for meaningful calibration
Total Lead	5	Insufficient observed water quality data for meaningful calibration
Total Nickel	13	Observed river water quality data allowed only limited calibration
Benzo-a-pyrene	45	Moderate calibration achieved
Di-(2-ethylhexyl)phthalate	3	No calibration possible as no observed river water quality data
Nonylephenol	0	No calibration possible as no observed river water quality data
Naphthalene	0	No calibration possible as no observed river water quality data
Indeno-[1,2,3-cd]-Pyrene	0	No calibration possible as no observed river water quality data
Fluoranthene	0	No calibration possible as no observed river water quality data
Benzo-[ghi]-perylene	0	No calibration possible as no observed river water quality data
Benzo-[k]-fluoranthene	0	No calibration possible as no observed river water quality data
Benzo-[b]-fluoranthene	0	No calibration possible as no observed river water quality data
Anthracene	0	No calibration possible as no observed river water quality data

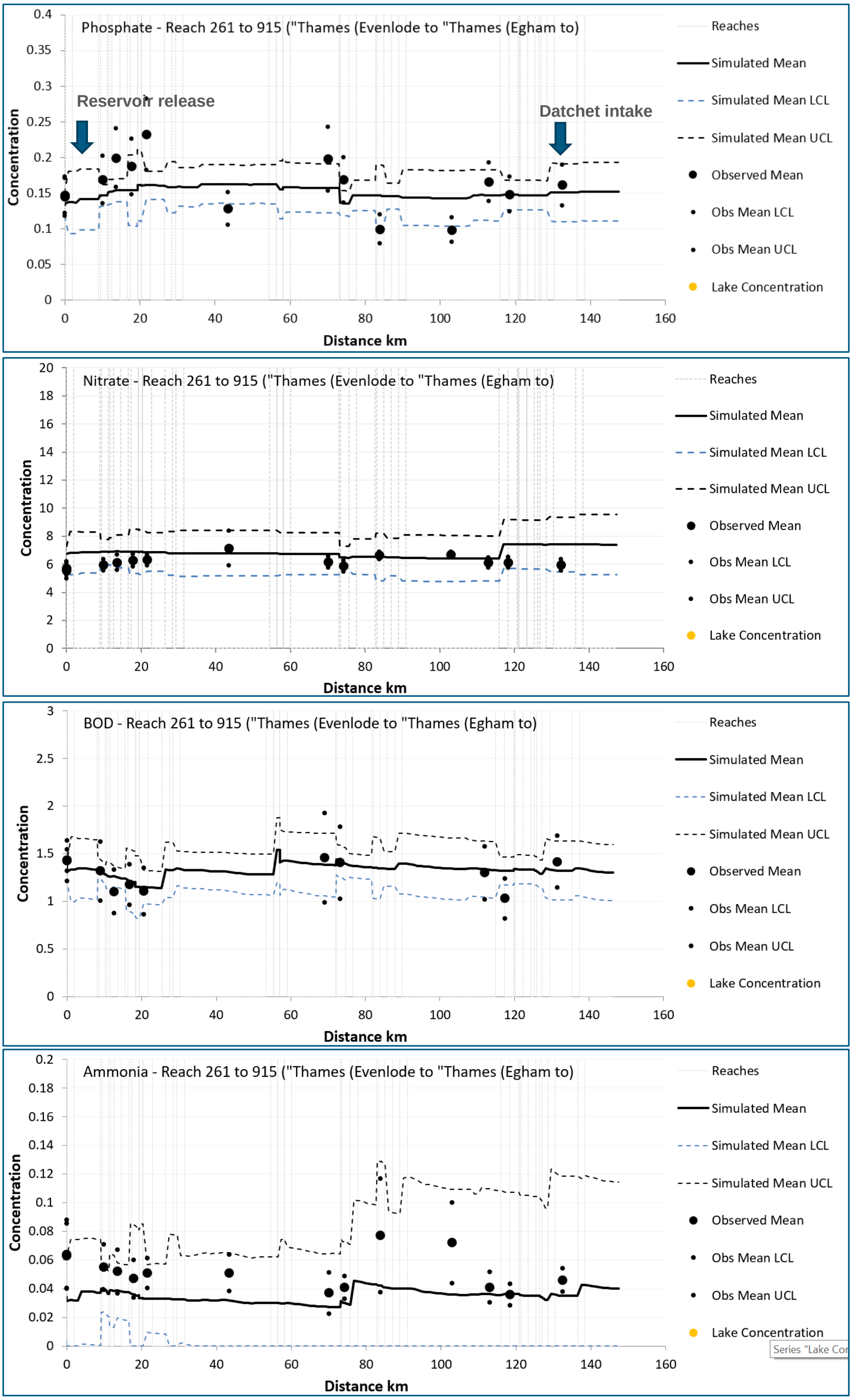
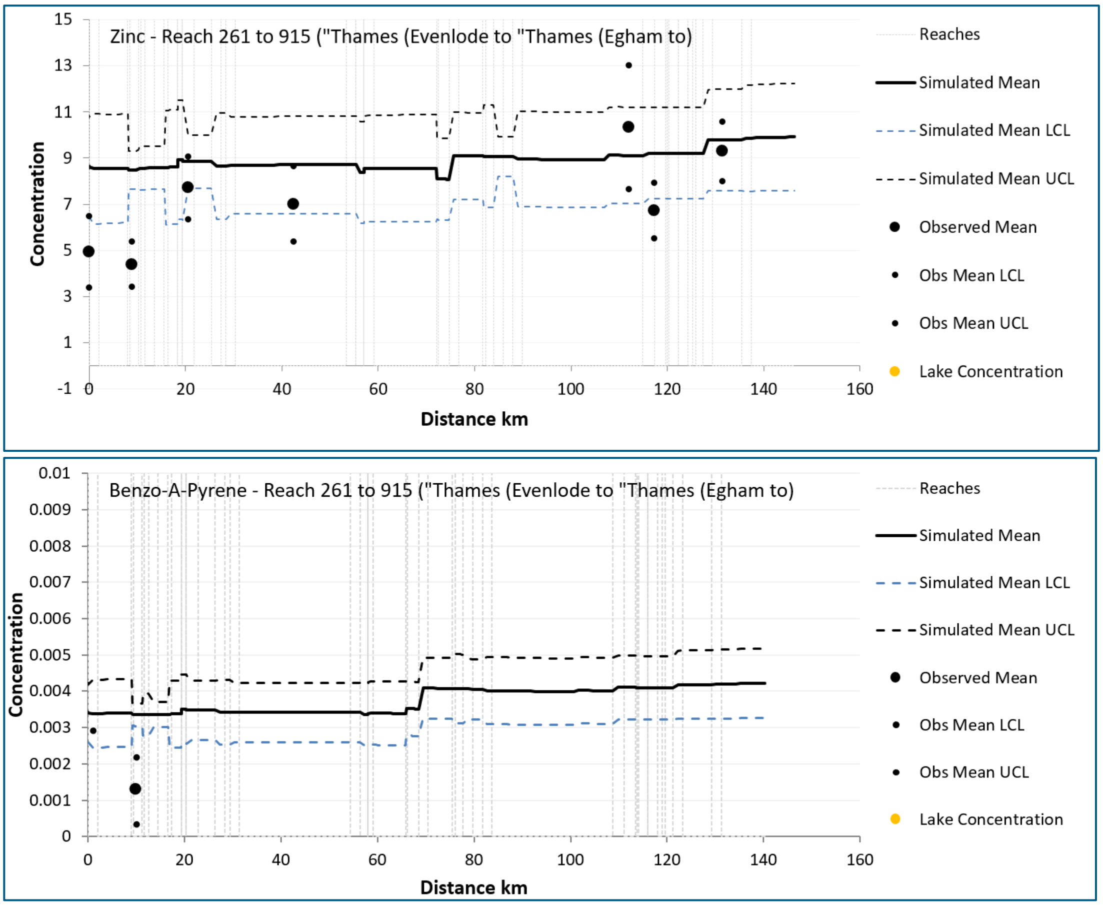


Figure A6.2-3 – Calibrated model results for key chemicals in the river stretch affected by SESRO (LCL & UCL – upper and lower confidence limits)



(LCL & UCL – upper and lower confidence limits)

Figure A6.2-4 – Calibrated model results for further key chemicals in the river stretch affected by SESRO

A6.2.3.2. Source apportionment

Source apportionment outputs from SAGIS-SIMCAT for key chemicals along the river stretch affected by SESRO are shown in Figure A6.2-5 and Figure A6.2-6 (before SESRO). For orthophosphate, Thames Water Sewage Treatment Works (STWs) make up the largest proportion of the concentrations, whereas for nitrate, BOD and benzo-a-pyrene diffuse sources predominate. For ammonia, intermittent discharges provide a significant contribution to concentrations although it should be born in mind that the underlying data for this sector is based on relatively simplistic assumptions, so is less reliable than for STWs. Likewise, the SAGIS source apportionment data for background inputs of zinc and benzo-[a]-pyrene is based on limited data (data for soil chemistry and atmospheric deposition).

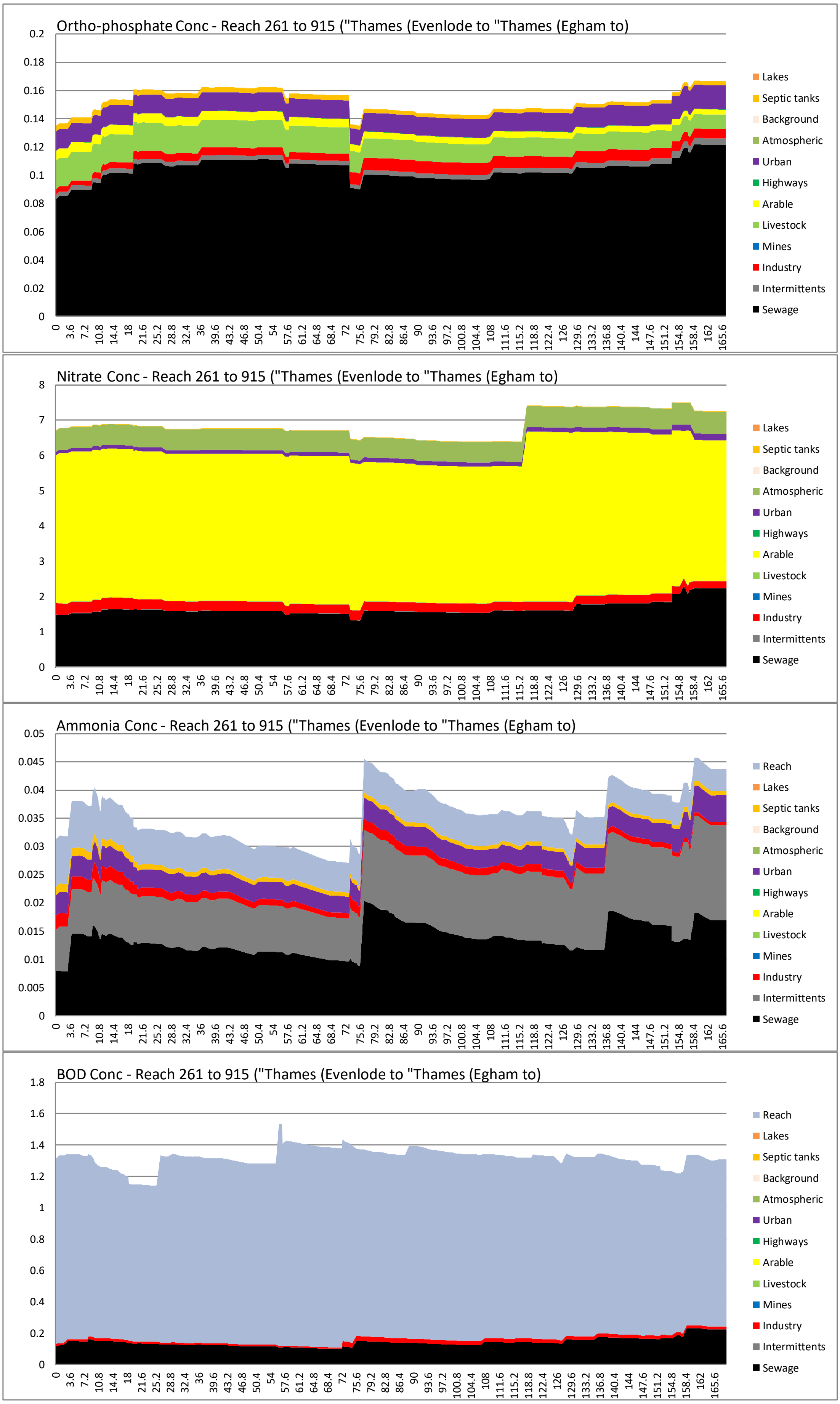


Figure A6.2-5 – Source apportionment of key chemicals downstream of SESRO.

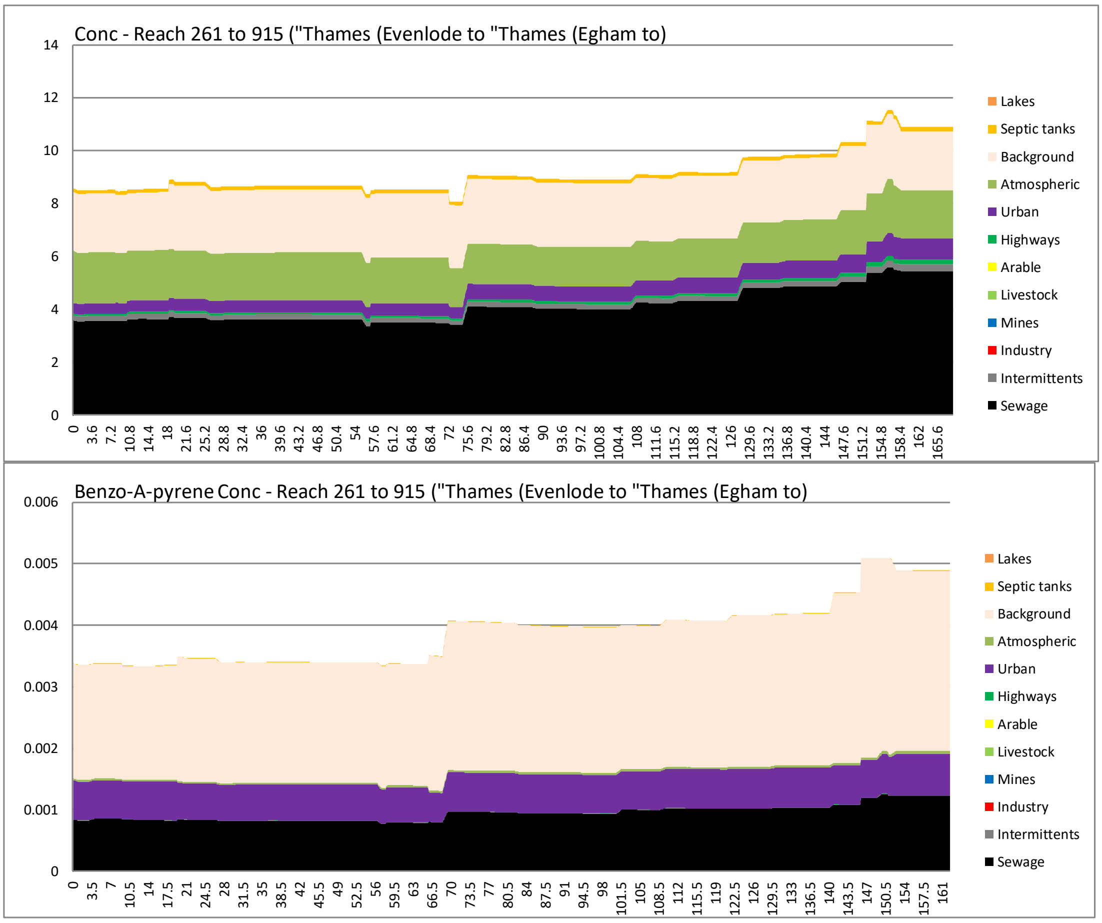


Figure A6.2-6 – Source apportionment of further key chemicals downstream of SESRO.

A6.2.3.3. Modelling of SESRO

The SAGIS lake model is a tank model with settling rates and exchanges with the sediment. For this initial modelling, it was assumed that a steady state is reached and there are no net exchanges with the sediment. All metals and organics were assumed to have no losses in storage whilst a 'normal' range of settling rates were applied to Total P, orthophosphate and nitrate (0.01 to 0.2 m/day; the model applies a range of settling rates over this range). BOD and ammonia can be generated by biological processes as well as lost, so zero decay rates were applied (in reality, losses and gains occur at different times of year).

An example of simulated reservoir concentration is shown in Figure A6.2-7 and Figure A6.2-8 for Total P, a key metric for reservoir classification. Monthly concentrations are stable and range between 0.03 and 0.085 mg/l depending on the settling rate). This would place the reservoir in the eutrophic range following the OECD classification. None of the chemicals have concentrations of concern in relation to Drinking Water Standards.

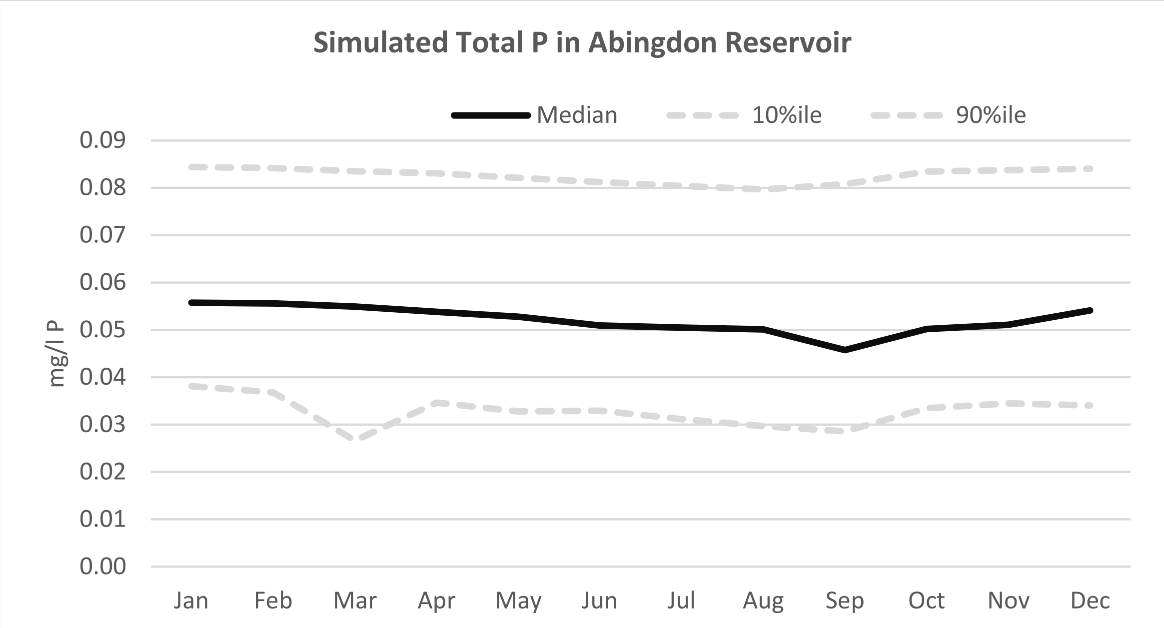


Figure A6.2-7 – Modelled reservoir concentrations from the SAGIS lake model showing envelope of results from Monte Carlo simulation

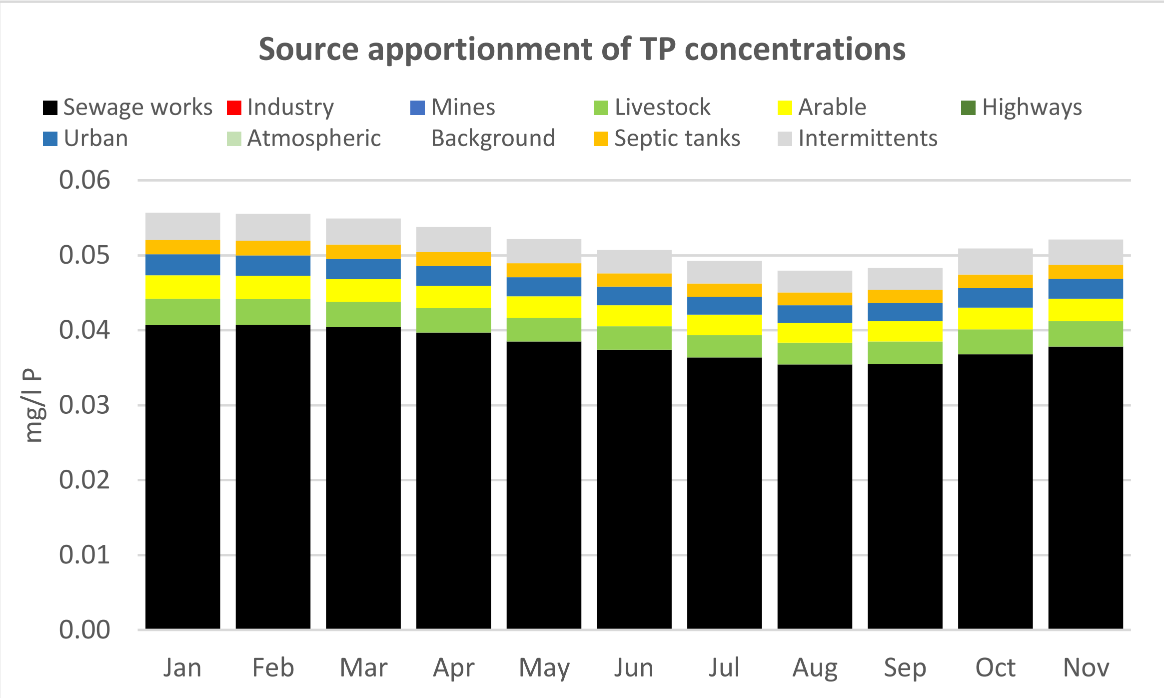


Figure A6.2-8 – Source apportionment of simulated total P concentration in SESRO.

Modelled annual average simulations concentrations for all the chemicals of interest are shown in Table A6.2-3. Observed data (2011–2020) for Farmoor Reservoir and Wraysbury Reservoir, existing reservoirs that receive similar water from the River Thames, are shown for comparison. Although the reservoirs are not directly comparable in terms of size, retention time and operation, the comparison is useful to ground truth the results.

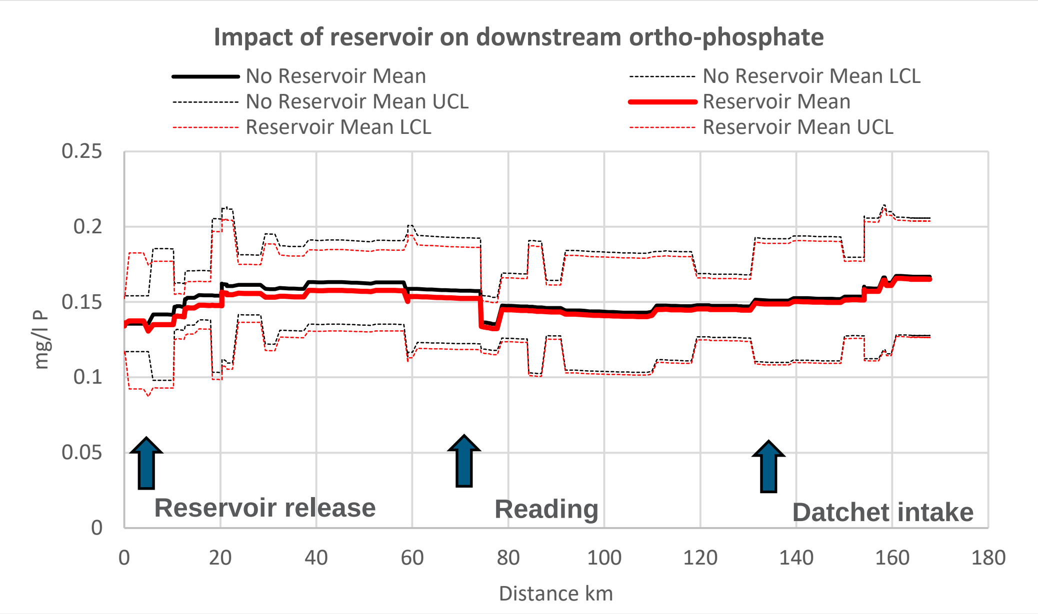
Table A6.2-3 – Simulated concentrations of chemicals of interest in SESRO

Chemical	SESRO Mean	SESRO 90%ile	SESRO 10%ile	Wraysbury (Mean)	Farmoor (Mean)
Total P (mg/l)	0.052	0.086	0.030	0.208	nd
Orthophosphate (mg/l)	0.039	0.062	0.022	0.157	0.077
Nitrate (mg/l)	2.019	3.764	1.020	5.95	3.77
Ammonia (mg/l)	0.046	0.048	0.044	0.132	0.06
BOD (mg/l)	1.65	1.695	1.615	nd	nd
Zinc (µg/l)	7.168	8.000	6.406	2.9	2.67
Mercury (µg/l)	0.003	0.003	0.002	nd	<0.1
Nickel (µg/l)	1.361	1.523	1.219	nd	<1.3
Cadmium (µg/l)	0.016	0.018	0.015	nd	<0.1
Lead (µg/l)	0.364	0.405	0.325	nd	<0.2
Copper (µg/l)	1.670	1.857	1.500	nd	3.95
Di-(2-Ethylhexyl)phthalate (µg/l)	0.0844	0.0921	0.0761	nd	nd
Nonylephenol (µg/l)	0.0027	0.0031	0.0023	nd	nd
Naphthalene (µg/l)	0.0028	0.0032	0.0025	nd	nd
Indeno-[1,2,3-cd]-Pyrene (µg/l)	0.0039	0.0043	0.0034	nd	<0.001
Fluoranthene (µg/l)	0.0027	0.0030	0.0024	nd	0.003
Benzo-[ghi]-Perylene (µg/l)	0.0025	0.0028	0.0022	nd	<0.001
Benzo-[k]-Fluoranthene (µg/l)	0.0049	0.0055	0.0044	nd	<0.001
Benzo-[b]-Fluoranthene (µg/l)	0.0025	0.0028	0.0022	nd	<0.001
Benzo-[a]-Pyrene (µg/l)	0.0599	0.0657	0.0536	nd	<0.001
Anthracene (µg/l)	0.0212	0.0232	0.0190	nd	nd

(nd = no data). Mean concentrations provided for Wraysbury Reservoir and Farmoor Reservoir for comparison.

A6.2.3.4. Downstream impacts on River Thames

The impact of the releases of water from the reservoir on downstream water quality in the River Thames at 1km intervals was modelled in SAGIS-SIMCAT by returning monthly outputs from the reservoir model using the monthly transfers shown in Table A6.2-3. The results in this section refer to model runs using observed effluent quality and flow (At Permit model runs are presented in Section A6.2.3.5). An example of the simulated change in river quality (orthophosphate) is provided in Figure A6.2-9. This shows a reduction in downstream concentration as a result of the reservoir storage and release. The change is greatest immediately downstream of the outfall, after which it diminishes, with only a small change at the Datchet Intake. Further abstraction locations may be developed as part of the SRO schemes, including an offtake to Southern Water near Reading and a further abstraction to Affinity Water between Henley-on-Thames and Datchet.



(LCL and UCL = upper and lower confidence limits)

Figure A6.2-9 – Chainage plot of mean ortho-phosphate concentration with and without operation of the reservoir

Figure A6.2-10 shows changes to simulated monthly river flow statistics and monthly average ortho-phosphate concentrations at sample point PTHR0105 (Culham Bridge) a few miles downstream of the reservoir intake and outfall (i.e. selected as the first Environment Agency monitoring point below the intake). In the winter, river flows are reduced by a small amount as a result of the abstraction to the reservoir, whereas in the summer river flows are increased substantially because of releases, particularly for very low flows (at Q_{95} flows[2]). This results in a decreased concentration of orthophosphate in the river in summer because concentrations in the reservoir water are lower than in the river at this time of year.

[2] Q_{95} or the 95th centile is a river flow which is exceeded for 95% of the time in the flow record.

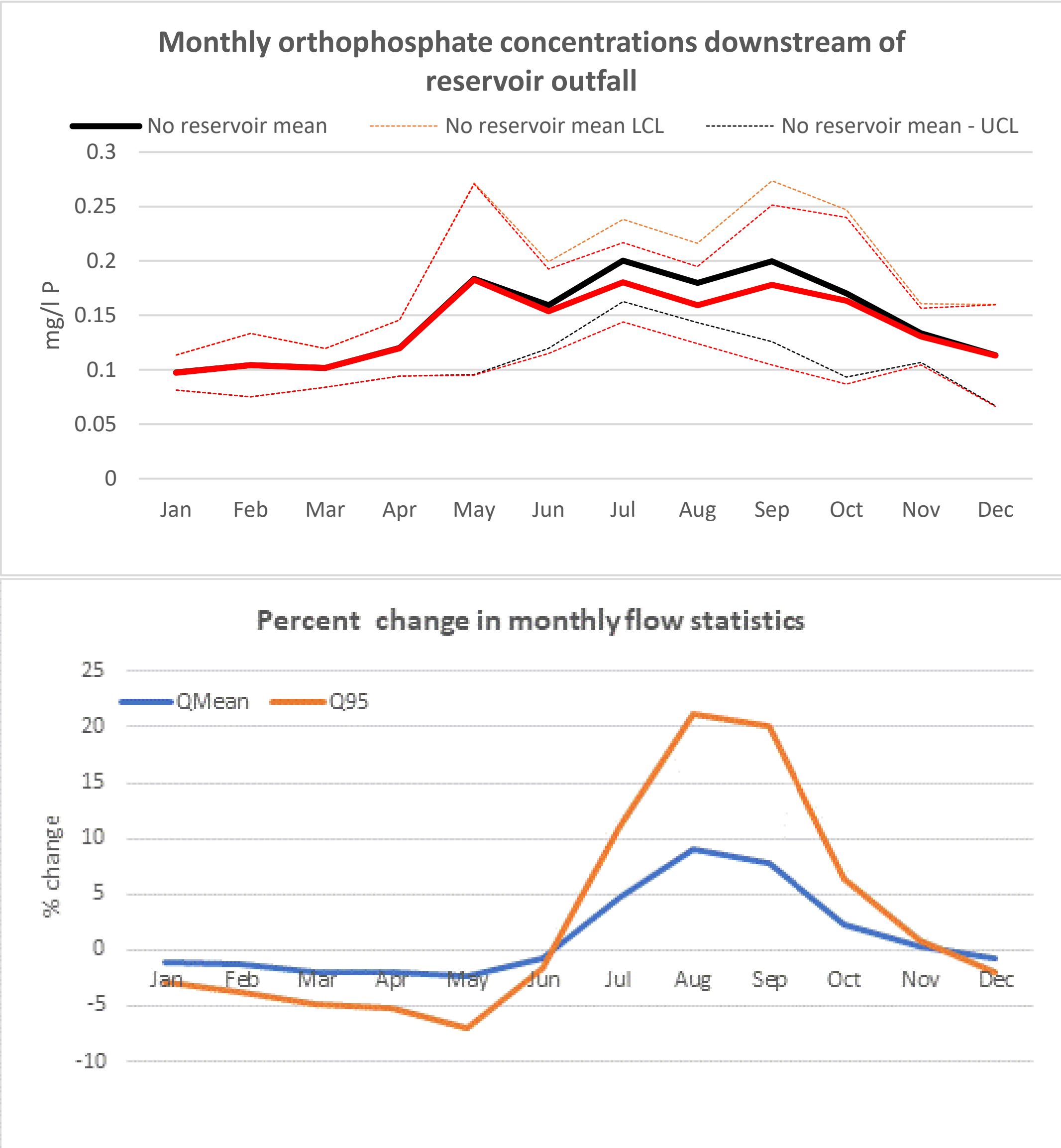


Figure A6.2-10 – Comparison of monthly concentrations of orthophosphate and river flow statistics downstream of the reservoir outfall at Culham Bridge with and without operation of the reservoir

Table A6.2-4 and Table A6.2-5 shows simulated concentration statistics for all chemicals of interest, at Culham Bridge (sample point PTHR0105) and at the Datchet intake.

Table A6.2-4 – Modelled water quality statistics in the River Thames at sample point PTHR0105 (Culham Bridge) and % change (post SESRO compared to pre SESRO).

Negative values suggest an improvement due to lower concentrations (yellow and green), positive values (red) a potential deterioration due to higher concentrations.

	Without Reservoir			With Reservoir			%change		
Chemical	Mean	90%ile	99%ile	Mean	90%ile	99%ile	Mean	90%ile	99%ile
Total Phosphate (mg/l)	0.198	0.301	0.698	0.188	0.276	0.677	-5.395	-8.340	-2.956
Ammonia (mg/l)	0.040	0.045	0.216	0.042	0.045	0.234	4.216	0.606	8.565
Phosphate (mg/l)	0.147	0.223	0.506	0.141	0.211	0.506	-4.382	-5.682	-0.034
Nitrate (mg/l)	6.895	10.639	15.797	6.527	9.836	15.107	-5.346	-7.549	-4.368
BOD (mg/l)	1.335	2.132	2.709	1.336	2.164	2.708	0.127	1.534	-0.022
Zinc (ug/l)	8.492	14.551	21.106	8.160	13.298	18.240	-3.915	-8.611	-13.579
Mercury (ug/l)	0.003	0.006	0.009	0.003	0.005	0.008	-3.511	-7.710	-12.153
Nickel (ug/l)	1.627	2.769	5.704	1.572	2.617	5.333	-3.435	-5.478	-6.520
Cadmium (ug/l)	0.019	0.032	0.049	0.019	0.030	0.049	-3.031	-6.054	0.555
Lead (ug/l)	0.438	0.750	1.248	0.425	0.673	1.391	-2.927	-10.288	11.486
Copper (ug/l)	2.029	3.431	5.924	1.852	2.973	4.897	-8.705	-13.361	-17.341
Di-(2-Ethylhexyl)phthalate (ug/l)	0.099	0.166	0.246	0.097	0.154	0.221	-2.539	-6.966	-10.214
Anthracene (ug/l)	0.003	0.005	0.009	0.003	0.005	0.008	-3.317	-5.575	-13.882
Benzo-[A]-Pyrene (ug/l)	0.003	0.006	0.008	0.003	0.005	0.008	-2.849	-8.187	-9.477
Benzo-[B]-Fluoranthene (ug/l)	0.005	0.007	0.012	0.004	0.007	0.012	-2.911	-2.559	-5.798
Benzo-[K]-Fluoranthene (ug/l)	0.003	0.006	0.011	0.003	0.006	0.011	-2.069	0.573	-1.519
Benzo-[GHI]-Perylene (ug/l)	0.003	0.005	0.009	0.003	0.005	0.008	-2.509	-2.938	-1.839
Fluoranthene (ug/l)	0.006	0.010	0.013	0.006	0.009	0.012	-3.513	-6.805	-9.385
Indeno-[1,2,3-CD]-Pyrene (ug/l)	0.003	0.005	0.009	0.003	0.005	0.009	-2.124	-1.396	-3.057
Naphthalene (ug/l)	0.072	0.118	0.174	0.070	0.112	0.153	-3.178	-5.445	-12.023
Nonylephenol (ug/l)	0.026	0.043	0.066	0.025	0.042	0.061	-2.503	-3.031	-8.645

Table A6.2-5 – Modelled water quality statistics in the River Thames at the Datchet intake and % change (post SESRO compared to pre SESRO).

Negative values suggest an improvement due to lower concentrations (yellow and green), positive values (red) a potential deterioration due to higher concentrations.

	Without Reservoir			With Reservoir			%change		
Chemical	Mean	90%ile	99%ile	Mean	90%ile	99%ile	Mean	90%ile	99%ile
Total Phosphate (mg/l)	0.224	0.315	0.622	0.208	0.287	0.782	-7.325	-9.053	25.787
Ammonia (mg/l)	0.036	0.035	0.318	0.035	0.032	0.321	-2.971	-8.019	0.817
Phosphate (mg/l)	0.162	0.228	0.367	0.149	0.212	0.436	-8.094	-6.874	18.857
Nitrate (mg/l)	7.366	11.946	21.293	7.284	11.407	22.184	-1.111	-4.512	4.184
BOD (mg/l)	1.335	2.104	2.768	1.343	2.053	2.784	0.644	-2.410	0.556
Zinc (ug/l)	9.791	15.300	19.306	9.689	14.682	18.816	-1.039	-4.039	-2.538
Mercury (ug/l)	0.005	0.007	0.009	0.005	0.007	0.009	-0.571	-1.348	-2.525
Nickel (ug/l)	2.038	3.217	4.567	2.021	3.135	4.529	-0.849	-2.524	-0.841
Cadmium (ug/l)	0.023	0.036	0.050	0.023	0.035	0.048	-0.979	-2.455	-4.544
Lead (ug/l)	0.525	0.833	1.350	0.522	0.804	1.361	-0.585	-3.559	0.852
Copper (ug/l)	2.519	3.882	6.109	2.461	3.712	5.522	-2.306	-4.381	-9.599
Di-(2-Ethylhexyl)phthalate (ug/l)	0.136	0.205	0.284	0.136	0.200	0.281	-0.337	-2.434	-1.035
Anthracene (ug/l)	0.004	0.006	0.008	0.004	0.006	0.008	-0.776	-1.787	-4.318
Benzo-[A]-Pyrene (ug/l)	0.004	0.006	0.009	0.004	0.006	0.009	-0.450	-3.524	-2.681
Benzo-[B]-Fluoranthene (ug/l)	0.006	0.010	0.016	0.006	0.009	0.016	-0.682	-2.021	-1.817
Benzo-[K]-Fluoranthene (ug/l)	0.004	0.008	0.013	0.004	0.008	0.013	-0.137	-0.599	-2.036
Benzo-[GHI]-Perylene (ug/l)	0.004	0.007	0.010	0.004	0.007	0.011	-0.572	-0.986	6.789
Fluoranthene (ug/l)	0.008	0.012	0.014	0.008	0.012	0.014	-0.781	-2.592	-2.259
Indeno-[1,2,3-CD]-Pyrene (ug/l)	0.004	0.007	0.011	0.004	0.007	0.011	-0.365	3.182	2.536
Naphthalene (ug/l)	0.101	0.156	0.213	0.101	0.154	0.208	-0.020	-1.003	-2.302
Nonylephenol (ug/l)	0.036	0.054	0.080	0.036	0.053	0.075	-0.240	-0.612	-6.571

For most chemicals and metrics, apart from ammonia, the model outputs indicate that downstream concentrations in the River Thames would reduce as a result of SESRO. For chemicals for which there is a loss in the reservoir (Total P. orthophosphate and nitrate – Section A6.2.2.5), overall loads of chemicals in the river are reduced because some of the mass is retained by the reservoir, in sediment or lost due to transformation to other chemicals. For chemicals for which no loss was simulated in the reservoir, reductions will still tend to occur in the river because of dilution in the summer by the release of reservoir water. For many chemicals, the period when releases from the reservoir occur coincides with the highest concentrations in the river because of reduced dilution of inputs from upstream point sources in the summer .Reservoir concentrations tend to be more stable and 'evened out' because of storage while concentrations in the river tend to be lower in the autumn and winter when the reservoir is filled because of high dilution of inputs from upstream point sources. The net effect of this is to 'dampen' the summer peak in concentrations in the river.

Another effect of the reservoir release is to increase summer flows in the River Thames which reduces the travel time of the water. This in turn may reduce losses of chemical in the river (represented in SIMCAT by a first order decay rate), a process that becomes more important for chemicals with a high loss rate. Total P, and ortho-phosphate, for example, have SIMCAT decay rates of 0.2 day^{-1} which equates to an approximate loss of 50% of the load over a travel time of 3 days, whereas ammonia with a decay rate of 2 day^{-1} equates to a 96% loss over the same period. This may explain why ammonia was found to increase downstream of the intake as concentrations are more influenced by decay than dilution. Intermittent discharges are also important for ammonia (Figure A6.2-5) and spills will tend to occur at higher river flows when water is being transferred to the reservoir rather than being released. At these times, SESRO will reduce river flows and therefore, reduce dilution in the river. It is also important to note that 99%ile results from SIMCAT are less reliable than the lower percentiles, because spills occur for only a small number of the Monte Carlo shots so an element of 'randomness' becomes more of an influence on the results.

The impacts of these changes on compliance with WFD targets (Table A6.2-6) can be seen to be largely beneficial because concentrations would decline as indicated in Table A6.2-4 and Table A6.2-5. For metals, assessment of compliance with WFD is based on bio-availability standards so not been considered here (further analysis using the Environment Agency's MPER model would be required).

Table A6.2-6 – Modelled WFD status for key chemicals before and after SESRO

	Below outfall -Culham Bridge		Datchet intake	
Chemical	Without reservoir	With reservoir	Without reservoir	With reservoir
Orthophosphate	Good	Good	Good	Good
Ammonia	High	High	High	High
BOD	High	High	High	High

A6.2.3.5. At permit model

Environment Agency modelling is normally based on 'At Permit' conditions, i.e., all wastewater discharges with permits set to their permitted flow and effluent concentrations (only orthophosphate was modelled as this is a key chemical for WFD status). To model the impact of SESRO on the 'At Permit' model, effluent quality and flow were set to their permit values following Agency guidance and the model carried out without and with SESRO, as before. Figure A6.2-11 shows the modelled changes on ortho-phosphate concentrations in the River Thames before and after SESRO. Similar changes can be seen to the observed data model run (Figure A6.2.9) but in this case the WFD status is unchanged by SESRO at Moderate for much of the length of the river. This is because greater phosphorus loads will be input to the River Thames from sewage works as headroom in effluent quality and flow is lost.

Phosphorus inputs to SESRO will also increase with average predicted concentrations in the reservoir increasing from 52 to 71 µg/l.

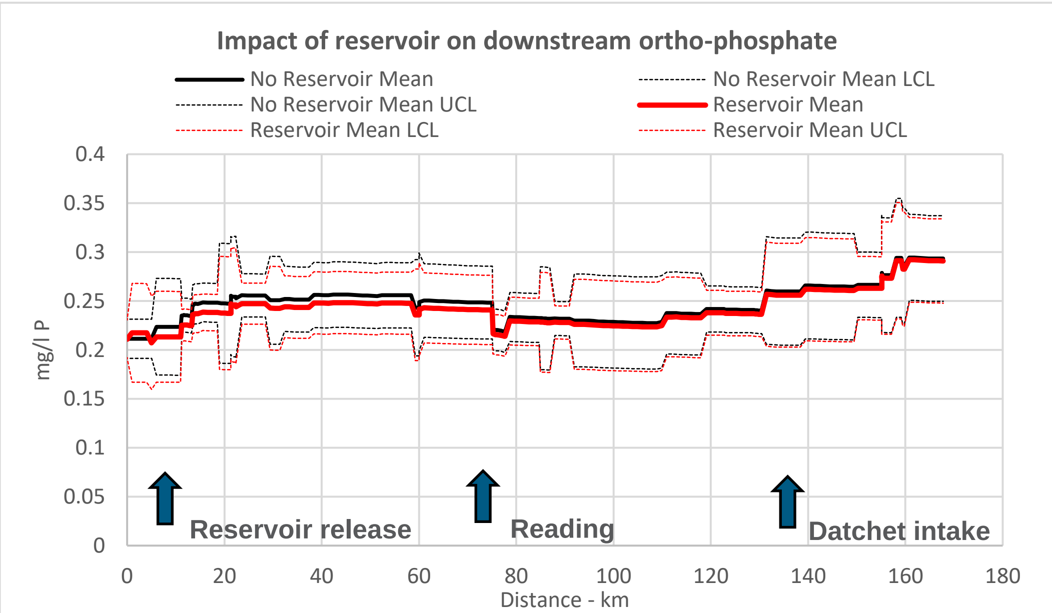


Figure A6.2-11 – Chainage plot of mean orthophosphate concentration with and without operation of the reservoir under 'At Permit' conditions

A6.2.3.6. River Ock

Figure A6.2-12 and Figure A6.2-13 shows the modelled impact on water quality of the River Ock for key WFD chemicals. The primary impact is to reduce flows in the Cow Common Brook by 35% because of the reduced drainage area. Since the width of the channel will remain the same, the travel time will increase, which reduces the concentrations because the modelled decay will increase. The exception to this is ammonia because there are two CSOs (combined sewer overflows) in the catchment and the reduced river flow reduces dilution of their inputs (the 90th percentile is not effected in this way because the impact of the spills is at a higher percentile). Above the confluence between the River Ock and River Thames, the impact is much reduced (in this case the reduced flow will also affect dilution of inputs to other streams in the River Ock catchment).

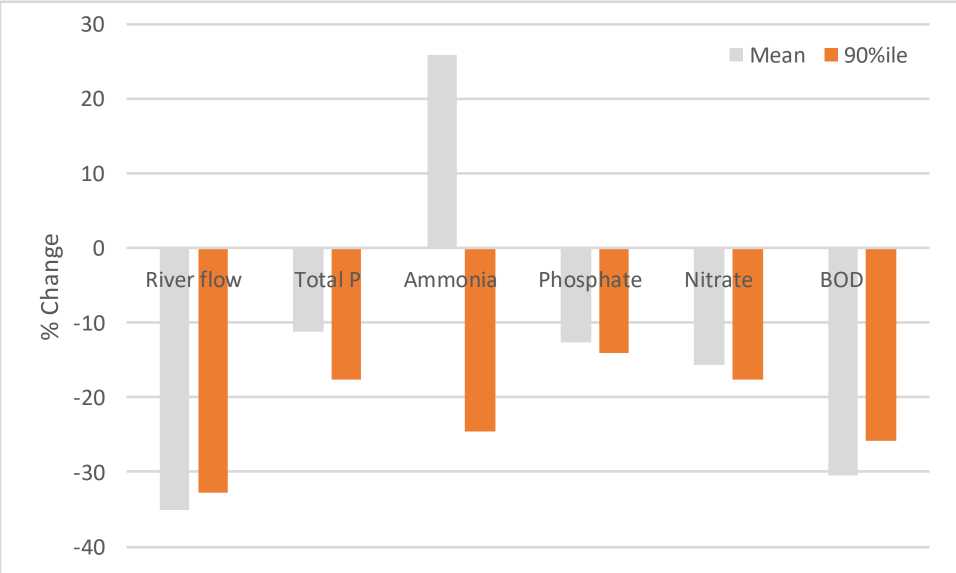


Figure A6.2-12 – Percentage change in Mean and 90th percentile concentrations at the end of the Cow Common Brook as a result of SESRO

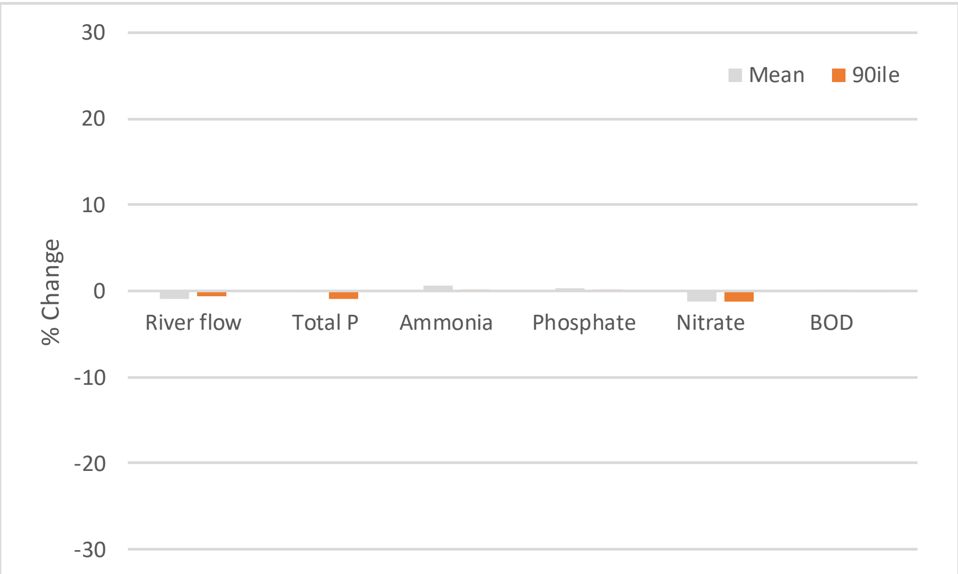


Figure A6.2-13 – Percentage change in Mean and 90th percentile at the confluence between the River Ock and River Thames

A6.2.3.7. Pesticides

The possibility was identified that high pesticide concentrations may occur in the River Thames during high flow periods when the reservoir is being filled which may, in turn, result in high pesticide concentrations in the reservoir. This situation may persist until the water is released to the river in the summer which might then increase pesticide concentrations in the River Thames (normally summer river concentrations tend to be low).

Although pesticides are not routinely modelled using SAGIS-SIMCAT, an initial investigation was undertaken to scope the importance of this issue.

Observed data on pesticides concentrations (2015–2020) in the River Thames at the Farmoor intake provided by Thames Water (Figure A6.2-14) were first reviewed to identify key chemicals with the largest concentrations and with sufficient data to be modelled (many pesticides have concentrations below detection limit for most samples). On this basis, the following top five pesticides, with the highest observed concentrations, were selected to input to SIMCAT: glyphosate, propyzamide, metaldehyde, clopyralid and mecoprop.

The pesticides were added to the existing SAGIS-SIMCAT suite of chemicals and, in the absence of existing model data, monthly loads were input to the river immediately upstream of the intake to SESRO by adding a discharge to input pesticide loads, equivalent to those observed in the River Thames. These were based on observed pesticides data at the intake to Farmoor Reservoir, approximately 20 km upstream, and observed river flows at Sutton Courtenay Flow Gauge (NRFA reference 39046), a short distance downstream of the outfall. The resulting simulated monthly concentrations were then compared to the observed data to check that the loads were applied correctly, and adjustments made to ensure the resulting concentrations upstream of the intake matched the observed values.

Once in the river, the model assumes that pesticides were transferred to the reservoir, stored, and released in the same way as for other chemicals. Pesticide losses in the reservoir were assumed to be zero apart from glyphosate for which a moderately high settling rate was specified because this pesticide is known to decay relatively rapidly in environmental waters (a settling rate of 0.3–1.5 m/day).

Simulated pesticide concentrations in the reservoir are summarised in Table A6.2-7.

Table A6.2-7 – Simulated pesticide concentrations in SESRO

	Mean	90th Percentile
Metaldehyde	0.0296	0.0317
Clopyralid	0.0107	0.0109
Mecoprop	0.0101	0.0104
Popyzamide	0.0636	0.0675
Glyphosphate	0.0069	0.0136

Simulated monthly concentrations immediately downstream of the River Thames outfall with and without operation of the reservoir are compared in Figure A6.2.15 (simulated concentrations further downstream were not assessed). For most of the pesticides, river concentrations show a small reduction with the operation of SESRO; apart from propyzamide and metaldehyde that show increases in summer when stored pesticides in the reservoir are returned to the river when river concentrations are low. This reflects the stronger seasonal pattern displayed by these pesticides. Although the percentage increase in the concentrations of propyzamide and metaldehyde is high, this is from a low baseline, so river concentrations remain low compared to the drinking water standard of 0.1 µg/l.

These results indicate that SESRO will have little impact in terms of water treatment risks from pesticides. Although summer concentrations are increased, in some cases, initial concentrations are low so the levels following the reservoir operation remain low.

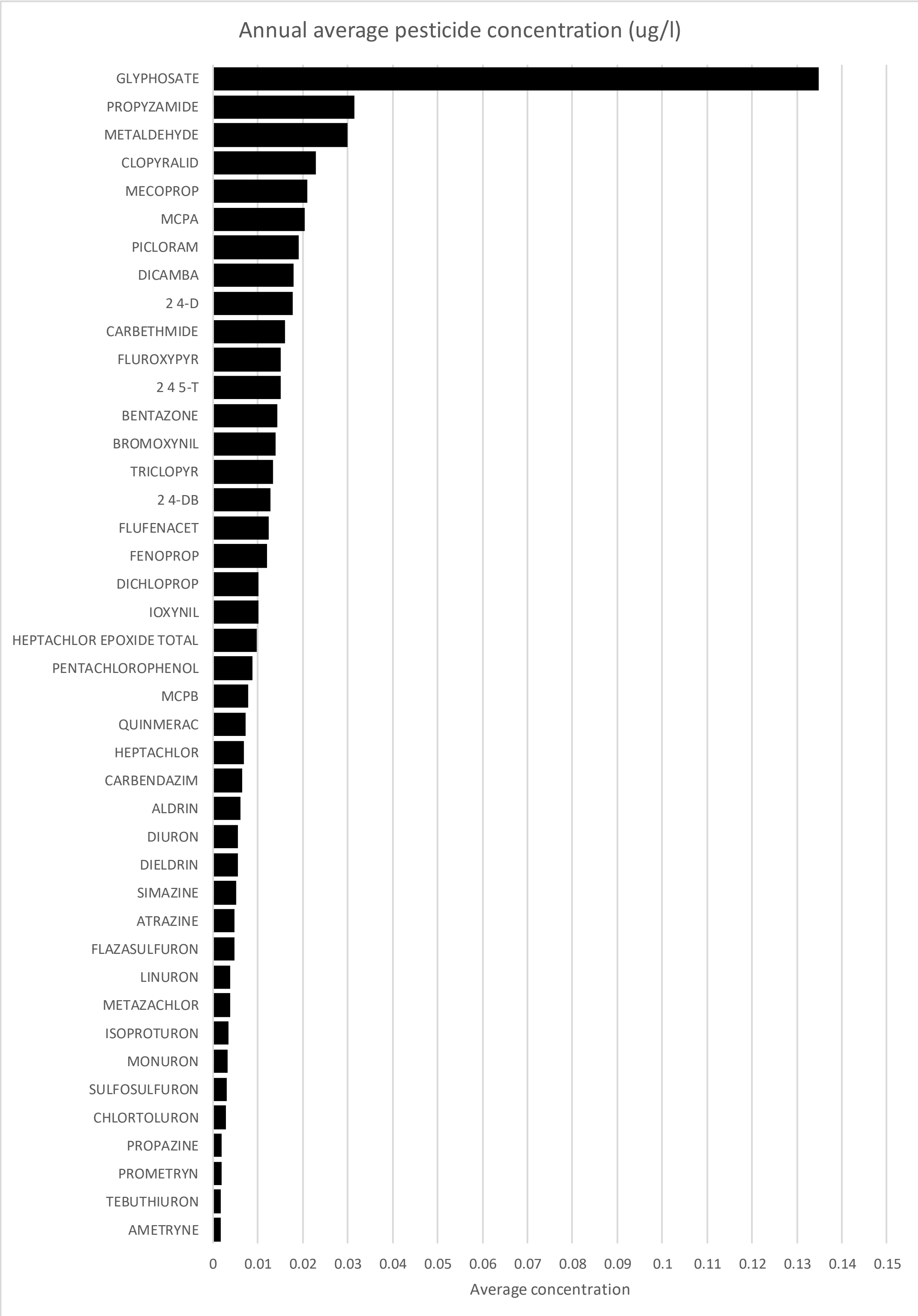


Figure A6.2-14 – Observed pesticide concentrations at the intake to Farmoor Reservoir.

Figure A6.2-15 – Simulated impact of SESRO on pesticide concentrations downstream of the reservoir outfall.

A6.2.4. Uncertainty analysis and mitigation

Key uncertainties that need to be considered when making use of the outputs of the SAGIS-SIMCAT modelling, presented in this Appendix, are listed in Table A6.2-8, along with actions that might reduce these uncertainties going ahead into the Gate 2 work. These uncertainties are partly the result of the short time-scale available for this work, which required the use of existing models that have not been updated for a long time (using 2010–2012 data).

Table A6.2-8 – Key modelling uncertainties and potential mitigation.

Comments	Mitigation
The SAGIS-SIMCAT modelling is based on a combination of 2010 data and more recent CIP updates. Within the available timescale it was not possible to update the models with more recent observed water quality data. This is particularly an issue for the organic chemicals for which very little observed data was available.	More recent data is available from the Environment Agency monitoring, the CIP and Thames Water (e.g., raw water monitoring). Inclusion of this data in further modelling would increase confidence the work.
Assumptions were made on decay rates, settling and release rates, for example zero losses in the reservoir for most chemicals, including most pesticides. No sediment release was included in the reservoir modelling.	Further modelling and sensitivity testing of decay and settling rates including seasonal profiles for rates in the reservoir would improve how the model represents these processes.
Calibration of ammonia showed a relatively poor fit with observed data. Intermittent discharges are identified as a potential issue for ammonia. Representation of intermittent discharges in SAGIS-SIMCAT are relatively simplistic.	Improved data on intermittent discharges would improve confidence, for example, making use of Event Duration Monitoring and sewer network modelling data.
The SIMCAT analysis was based on modelling quality using a 40-year data set for river flows. Although this shows long-term risk, impacts on water quality may be more extreme during shorter periods for example during droughts.	SIMCAT is not well suited to assess event-based impacts on water quality although a sensitivity analysis could be carried out by repeating the simulations for shorter periods using different flow statistics. Alternatively, this could be addressed by using a time series model.
The pesticide analysis was a screening exercise to explore this issue and information on inputs of pesticides across the catchment was not incorporated.	Further data could be added to the SAGIS-SIMCAT model to improve representation of pesticide including inputs downstream of SESRO.

A6.2.5. Discussion and conclusions

The analysis presented in this Appendix provides an initial assessment of some of the key water quality risks associated with SESRO in advance of more detailed water quality work in Gate 2. This detailed work might include refined work with SAGIS-SIMCAT as well as a combination of a 3D hydrodynamic reservoir model, PROTECH-D for reservoir algae and Infowork for the river modelling.

Positive aspects of the impact of SESRO on water quality in the River Thames based on the outputs from the SAGIS-SIMCAT work are likely to be:

1. For chemicals that are likely to show significant losses during storage in SESRO, the reservoir will reduce overall loads passing down the River Thames.
2. When abstraction from the River Thames to SESRO occurs in the autumn and winter, chemicals associated with point sources such as sewage works will have relatively high dilution because of high river flows. River concentrations will, therefore, tend to be lower when compared to the summer when water is released back to the river. This again, will tend to reduce river concentrations.
3. Because of the long storage time in the reservoir, the variability water quality seen in the river will be dampened. Water returned to the river will therefore have more stable water quality than when abstracted to the reservoir.
4. Release of water to the river in summer will increase downstream river flows and, therefore, increase dilution of discharges from downstream point sources which will improve water quality.

Negative aspects are likely to be:

1. The reservoir has the potential to store chemicals that have high concentrations when transfers to the reservoir occur (e.g. associated with runoff or storm discharges). These ‘stored’ chemicals might then be returned to the river at times when river concentrations tend to be low in summer. The initial assessment of this process on pesticides, however, indicated that this impact is likely to be small.
2. River flows will be reduced when water is being transferred to the reservoir during periods of high flow. This reduction might coincide with times when storm overflows occur which will make them subject to less dilution. This effect is likely to be small, however, as SESRO would take a very small proportion of the river flow under these conditions.
3. Increased summer river flows that result from SESRO will reduce travel times and, therefore, reduce within river losses by chemical degradation and sedimentation.

Overall, the modelling results indicate that SESRO would have a beneficial impact on water quality because the positive influences greatly ‘outweigh’ the negative ones. Compliance with WFD standards is predicted to be unchanged.

The primary risk from storage in the reservoir comes from phytoplankton growth and the effects of this on water quality through the release of algal metabolites and toxins and disinfection biproducts. These processes have not been assessed in this study, as SIMCAT-SAGIS is not a suitable modelling platform so that they will need to be addressed separately.