

Havant Thicket Reservoir Project

Environmental Statement Volume 4 – Appendices

Appendix A15

A15.3 Water Quality Modelling Report

Portsmouth Water Ltd.

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Executive Summary

This report presents a data analysis and literature review of treatment risk associated with the development of Havant Thicket Storage Reservoir (HTWSR) and impacts on downstream water quality. Information on revisions made to the HTWSR water quality model spreadsheet tool, originally developed by RM Walls in 2011, are also presented. Changes made by Atkins to the water quality model have been agreed with the Environment Agency, who have confirmed that the model is a suitable basis for modelling water quality impacts of the new reservoir to support the Environmental Impact Assessment of the HTWSR scheme (28 February 2019). Model outputs from the revised water quality model to assess the key influences on total phosphorus and nitrate concentrations in the reservoir are presented, including for drought scenarios.

This report presents three key elements:

1. a data analysis and literature review of reservoir water quality to inform the assessment of water treatment risks (covered in a separate report - (Atkins, Havant Thicket Early Start Studies: Study 4 Water Quality Report, 2019)
2. details of the revised reservoir water quality spreadsheet model and outputs from the associated modelling work and;
3. an assessment of impacts on downstream water quality.

Changes made by Atkins to the water quality model were first discussed and agreed with the Environment Agency (Paul Davison – 28th February 2019). Key changes to the modelling have included the development of a time series approach, using outputs from the Atkins Pywr water resources model for the new reservoir, and improvements to the representation of reservoir processes including updated inputs from birds and interactions with the sediment. Sensitivity analysis was also carried out to test the key controls on the outputs for the modelling work. Outputs from the revised reservoir modelling approach were then fed into the assessment of the downstream impact.

Overall, the results of the modelling and analysis show the water quality in the reservoir will be good compared to most reservoirs in southern England but there will still be a low to moderate risk to water treatment from algal growth. Impacts on the downstream watercourses are positive with a clear improvement in water quality predicted.

Key conclusions of the report are as follows:

Reservoir Water Quality

1. Overall, the assessment indicates that the trophic status of the reservoir is likely to be between oligotrophic to mesotrophic which represents a low to moderate risk from algae. Compared to other surface water reservoirs in southern England, the trophic status will be low.
2. The model output shows the importance of reservoir drawdown and refill on water quality. Concentrations of nutrients and algal risk increase substantially during drought periods and shortly afterwards, when the reservoir is drawn down and then refilled. This is important because it is during these periods when the reservoir is most likely to be used because other water resources in the area would be less available.
3. Input of phosphorus from birds is estimated to make up a large proportion of all inputs, at least comparable to inputs from the Bedhampton Springs. The sensitivity indicates that this is a potential risk because future bird numbers are difficult to estimate and may therefore be higher than the assumed baseline numbers. Bird numbers in the upper range of those recorded in other lowland reservoirs that are close to the sea in Southern England would result in a significant increase in trophic state and risk from algae.
4. If large numbers of gulls used the reservoir as a roost this would result in a substantial increase in nutrient inputs and risk from algae.
5. In contrast, inputs of nitrogen are dominated by inputs from the Bedhampton and Havant Springs. Predicted concentrations will be well below the Drinking Water standard even during and after drought events when concentrations are predicted to increase.

6. Another key area of uncertainty is the exchange of phosphorus from the sediment. High rates of release in the summer would offset the losses of phosphorus in the reservoir and increase the trophic state. It is difficult to predict these interactions as they vary greatly between reservoirs. However, the average depth of the Havant Thicket Reservoir is 10m which should mean that sediment exchange is less likely than in more typical shallow reservoirs.
7. Possible short-term increases in total phosphorus concentrations in the Bedhampton and Havant Springs that may have occurred historically are of less significance in terms of treatment risk.
8. The reservoir spreadsheet model will allow future sensitivity testing during the outline design of the new reservoir.
9. The implications for water treatment are addressed in detail in a separate report (Atkins, 2019). This includes mitigation options to reduce treatment risks associated with the reservoir water.

Downstream Water impacts of the Reservoir

1. In general, the development of the reservoir will improve water quality downstream because the quality of the Havant and Bedhampton Spring water is better than the existing water quality in the Hermitage Stream.
2. The water from the Bedhampton springs is generally of very good quality and the majority of water stored in the reservoir will be derived from the spring source. The large body of water (approx. 8,700 MI) will provide a buffering effect, helping to smooth out peaks for example in iron, manganese and magnesium which currently arise from the three small streams. Water discharged from the reservoir into the Riders Lane Stream will therefore be of a more consistent quality.
3. Parameters associated with anions and hardness would increase downstream of the reservoir as a result of greater hardness concentrations within the spring water, compared to stream flow concentrations but these changes diminish downstream and would only be small in the Hermitage Stream. An increase in calcium concentrations downstream could have a positive benefit in relation to biodiversity.
4. Downstream nitrate concentrations within the streams would increase, reflecting the greater concentrations of nitrate in the Bedhampton and Havant Springs compared to the surface waters but again these changes would diminish downstream and only be small in the Hermitage Stream.
5. Some nitrate is lost in the reservoir after spring water has been transferred as a result of natural denitrification processes and transfer to supply. Consequently, the average annual nitrogen loads to Langstone Harbour are predicted to reduce by up to 7.1 kg N/day during normal operation when the reservoir is not being used for public water supply, and up to 16 kg N/day over the longer term taking into account reservoir operation. During the initial reservoir fill period from 2026 to 2029 these benefits would be substantially greater at around 50 kg N/day due to the large quantities of spring water used to fill the reservoir. The construction of the new reservoir will, therefore, help protect the condition of the Special Area of Conservation (SAC) and Special Protected Area (SPA) site.
6. Phosphorus concentrations downstream of the reservoir would be reduced after the reservoir is built, due to low phosphorous concentrations within the reservoir compared to the existing stream flows.
7. Ammonium, suspended solids and most metal concentrations will also be reduced in the Riders Lane Stream.
8. Biological Oxygen Demand (BOD) should be reduced downstream once the reservoir is in place due to the greater opportunity for oxidation of organic matter whilst water is stored in the reservoir.
9. None of the above changes are of concern with regards to water quality in the rivers and Water Framework Directive (WFD) classification.
10. Changes in temperature downstream of the reservoir were also assessed; this indicates that the mixing of the compensation water with the Riders Lane stream is extremely unlikely to result in

a change of temperature immediately below the confluence of the streams greater than 3°C; the WFD threshold. Changes further downstream will be less because of increased dilution.

11. The output of the mass balance calculations is that water quality downstream of the reservoir will improve. Consequently, there is no risk of a deterioration in WFD Status. The only chemicals that show a substantive increase in concentrations are calcium, nitrate, nitrite, alkalinity, electrical conductivity and total dissolved solids. None of these determinands affect WFD classification or are specific pollutants or priority hazardous substance so have no implications for WFD status.

Overall conclusions

1. Overall, therefore, the development of Havant Thicket Reservoir is predicted to result in an improvement in water quality and no change in WFD chemical status in the downstream receiving water courses will result.
2. The large volume of water in the reservoir will ensure greater stability in water quality and any changes will occur slowly. This will buffer the effects of the short-term changes in water quality which currently occur.
3. Having established through the high level screening model exercise that the reservoir is not likely to have any significant adverse impact on water quality in the Hermitage Stream catchment, and that it is more likely to provide benefits to water quality, it is considered that this modelling report should meet the information requirements necessary to support the proposed outline / hybrid planning application.

1. Introduction

- 1.1.1. This report builds on previous analysis of water quality risk associated with Havant Thicket Winter Storage Reservoir (HTWSR) regarding the risk to water treatment, downstream water quality in the Hermitage Stream and nutrient inputs to Langstone Harbour. including a previous study and report by R.M.Walls (2011). In particular, it presents results from a revised water quality modelling methodology, that takes into account feedback from the Environment Agency. This revised approach also seeks to align the water quality modelling methodology with recent water resources modelling, undertaken by Atkins for Portsmouth Water, using stochastic weather data to create 1000 years of hydrological inputs and demand (Atkins, Havant Thicket Reservoir - Deployable Output Assessment and Review of Scheme Costs: Phase 2, 2018).
- 1.1.2. Section 2 presents the Phase 1 work – data analysis and literature review on the key influences and environmental controls on water quality in the proposed reservoir in relation to risks to water treatment and impacts on downstream watercourses. Section 3 presents the Phase 2 work – the revised water quality model and associated model outputs. Section 4 presents an analysis of downstream impacts.
- 1.1.3. This report has informed the development of the water quality treatment strategy for the new reservoir, which is detailed within a separate Atkins report, (Atkins, 2019).

1.2. Study Background

- 1.2.1. Portsmouth Water are leading a joint project with their neighbours Southern Water to develop proposals for a new winter storage reservoir at Havant Thicket, for completion by 2029. The current outline design of the reservoir was developed by Arup Consultants in 2009 on behalf of Portsmouth Water, but the project was not taken forward to planning stage at that time due to changes made to the Company's Water Resources Management Plan. There is however now a strong need to build the reservoir to support the transfer of an additional 21 Ml/d of water to Southern Water by 2029. The project will also increase the resilience of water supplies to Portsmouth water's customers and provide recreational and amenity benefits. A substantial area of new wetland will also be created along the northern shore of the reservoir providing new habitat for birds and other wildlife.
- 1.2.2. The proposed site of the new reservoir is located to the north of Havant in Hampshire, adjacent to Warren Park, Rowlands Castle and Staunton Country Park (Appendix A). The reservoir will be approximately 1.6 km long × 0.8 km wide, with an area of 1.18 km² and capacity of approximately 8,700 million litres (Ml). The reservoir site was chosen because it lies within a shallow valley underlain by good quality clay, suitable for construction of the reservoir embankments, and its proximity to Portsmouth Water's spring water source at Havant and Bedhampton, which is located approximately 3.5 km to the south of the reservoir site.
- 1.2.3. The surface geology of the reservoir site is London Clay Formations and more recent Quaternary deposits. The London Clay is underlain by the Harwich Formation (formerly known as the London Clay Basement Beds), which outcrops over the north-eastern part of the site and comprises sand and silty loam with abundant flint pebbles and cobbles. This is in turn is underlain by the Palaeogene Reading Formation, which comprises mainly stiff red and grey mottled clay; fine-grained clayey sand and, locally, ferruginous sandstone at its base. The Reading Formation extends across the whole site and is underlain by the Upper Chalk. The latter outcrops in the South Downs and supplies water to the Havant and Bedhampton Springs. The catchment geology results in flashy runoff with flows declining to very low levels in the summer.
- 1.2.4. The reservoir site lies within a shallow valley, and includes approximately 160 hectares of predominantly open grassland, with some woodland, hedgerows and ditches. Three small unnamed ephemeral watercourses flow from north to south across the proposed reservoir site that converge before forming the Riders Lane Stream. The Riders Lane Stream continues to flow south for approximately one mile before joining the Hermitage Stream. The Hermitage Stream flows south through Bedhampton and into Langstone

- Harbour (Appendix A). Langstone Harbour is an internationally important wildlife site with Special Area of Conservation (SAC) and Special Protection Area (SPA) status.
- 1.2.5. Most of the land on the reservoir site has been agriculture land since the late 1960's and is used for grazing. The reservoir surface water catchment is mainly on land used for forestry by Forestry England.
 - 1.2.6. Proposed amenity features include a new visitor centre, footpaths, cycle tracks, bridle ways and bird watching facilities, with the potential for provision of fishing platforms and educational water sports activities.
 - 1.2.7. The outline design of the reservoir is planned to be completed by the end of 2020 together with an Environmental Impact Assessment to support the planning application for the scheme. Following completion of detailed design, construction of the reservoir embankment is planned to commence in 2023, with final commissioning of the reservoir by March 2029.
 - 1.2.8. HTWSR will operate as a pumped storage reservoir utilising surplus water from the Havant and Bedhampton Spring source, within the annual licenced quantity of 98 MI/d. The current outline design assumes that surplus water will be pumped from Bedhampton to the reservoir through a new combined inlet/outlet pipeline laid between Bedhampton and HTWSR. Outflows from the reservoir will be by gravity through the inlet/outlet pipeline to Bedhampton prior to re-pumping to Farlington WTW, located 2.5 km to the west of Bedhampton.
 - 1.2.9. Maximum inflows to HTWSR from Bedhampton are expected to not exceed 40 MI/d, based on updated water resource modelling of the reservoir carried out by Atkins in 2017/18.

1.3. Previous Water Quality Studies

- 1.3.1. A water quality study for HTWSR was previously carried out from 2008 to 2011, which comprised water quality modelling of stored water within the reservoir and an assessment of downstream water quality impacts of the scheme on the Hermitage Stream, Riders Lane Stream and Langstone Harbour. A mass balance water quality blending model was developed using Excel software to assess the blending of water from the Bedhampton Springs source and the three ephemeral streams under different operating scenarios.
- 1.3.2. The key conclusions from the R.M. Walls water quality report are as follows:
 - The water from the Bedhampton springs is of very good quality. The majority of water stored in the reservoir will be derived from the springs source. The large body of water (approx. 8,700 MI) will provide a buffering effect, helping to smooth out peaks in iron and manganese which currently arise from the three small streams, as well as helping to reduce magnesium concentrations. Water discharged from the reservoir into the Riders Lane Stream will be of a more consistent quality.
 - Phosphate, ammonium, suspended solids and most metal concentrations will be reduced in the Riders Lane Stream.
 - BOD should be reduced downstream once the reservoir is in place due to the greater opportunity for oxidation of organic matter whilst water is stored in the reservoir.
 - The modelling indicates that the probability of the reservoir being eutrophic is minimal, and that the risk of algal bloom is low.
 - The water from the springs is very clear and the reservoir will act as a stilling basin for sediment washed in from the upper catchment. The construction of a retained wetland area along the northern edge of the reservoir will also reduce suspended solids.
 - As a consequence of the reservoir development, the nitrogen load entering Langstone Harbour will be reduced by up to 61 kg/d.

- The risk of thermal stratification within the reservoir is reduced by the adoption of multiple draw off points (three levels) incorporated within the outline design and provision for aeration plant has been provided within the Control House.
- The flow regime into Riders Lane Stream will be entirely controlled by compensation releases from the reservoir. It has been assumed that flows will be maintained at a similar level to the present condition. There is an opportunity to provide higher flows in the summer months if considered to be beneficial to the stream environment.

1.4. Consultation with the Environment Agency

1.4.1. Atkins reviewed previous work and updated the mass balance water quality model, developed by RM Walls in 2011, with recent data. During the current study, a number of meetings have been held with the Environment Agency to discuss this updated water quality model. This included a meeting, held with the EA National Modelling team in February 2019, at which the EA agreed the existing model was a suitable tool for modelling the water quality impacts of the new reservoir and to support the Environmental Impact Assessment for the scheme, provided that agreed modifications were implemented (confirmed by e-mail: Paul Davison – 28 February 2019). These changes have now been fully implemented, the details of which are presented in Sections 3 and 4.

Table 1.1 - Sampling Locations, Frequency and Data Period

Sample Points	Data Period	Number of Samples (Typical per parameter)
Havant Thicket 1 (Western)	2008–2010 2018–2019	18 4
Havant Thicket 2 (Middle)	2008–2010 2018–2019	29 10
Havant Thicket 3 (Eastern)	2008–2010 2018–2019	26 7
Havant Thicket 4 (Winterslow Drive)	2008–2010 2018–2019	28 14
Havant Thicket 5 (Staunton Country Park Stream)	2008–2010 2018–2019	11 7
Havant Thicket 6 (Hermitage Stream Purbrook Way)	2008–2010 2018–2019	13 16
Havant Thicket 7 (Corhampton Crescent Footbridge)	2008–2010 2018–2019	12 15
Havant Thicket 8 (Priorsdean Crescent – post confluence)	2008–2010 2018–2019	23 13
Havant Thicket 9 (Bittern Close– Pre-confluence)	2008–2010 2018–2019	12
Havant Thicket 21 (Post- confluence –EA)	2008–2010 2018–2019	12 15
Havant Thicket 22 (New Road Hermitage Stream – EA)	2008–2010 2018–2019	12 15

Sample Points	Data Period	Number of Samples (Typical per parameter)
Havant and Bedhampton Springs (Bedhampton No1 Collection Chamber RWBH1)	2008–2019	Varies between parameters
Farlington unfiltered	2008–2019	Varies between parameters

1.5. Water Quality Monitoring

- 1.5.1. Portsmouth Water has undertaken water quality sampling from eleven surface water sample points within the Hermitage Stream and Riders Lane catchment during years 2008 to 2010 to inform the previous water quality modelling work. Regular water quality sampling re-commenced in May 2018 and continues to be carried out on a monthly basis in order that the water quality model can be updated to inform the EIA and Water Framework Directive Assessment which will be completed during 2020 (additional data for the period May 2018 to October 2019 is used in this report). Often, during the summer, these ephemeral streams dry up, so no sampling is possible.
- 1.5.2. A catchment map is included in Appendix A showing the reservoir site in relation to the Hermitage Stream and Riders Lane Stream catchments, the water sampling locations and the spring source location at Bedhampton.

2. Phase 1 – Data analysis and literature review

2.1. Methodology

2.1.1. The raw water quality of the reservoir has been assessed using the methods outlined below:

Review of raw water quality data

2.1.2. Chemical inputs to the reservoir will be sourced primarily from the transfer of Bedhampton Springs water and the ephemeral streams that flow in from the local catchment (inputs from rainfall and direct runoff from the area immediately around the reservoir will only form a minor component of the chemical inputs). Observed water quality data is available for both the Bedhampton Springs and the local streams. A review of this data provided a first basis for assessing the possible range of chemical concentrations in the proposed reservoir.

Mass balance mixing of source waters

2.1.3. A simple method for determining the average concentration of chemicals based on mixing the average concentrations in the source waters was developed during previous work on the reservoir in 2011 in the form of a spreadsheet model. This combined the estimated loads of each chemical from different sources and applied the combined flow to calculate the mixed input concentration. It was conservatively assumed that this is the same as the average reservoir concentration with no losses occurring during storage. The model was updated with recent water quality sampling data.

Estimation of trophic conditions using OECD equations

2.1.4. A methodology was developed for Portsmouth Water in 2011 to assess the nutrient inputs to the reservoir (R.M. Walls, 2011). The nutrient inputs were calculated as follows:

- Annual average inputs to the reservoir from Bedhampton Springs were calculated by multiplying the average nutrient concentration by the average transfer flow.
- Annual average inputs to the reservoir from local streams were calculated by multiplying the average nutrient concentration (for all three streams) by the average estimated inflow. The estimated flow was derived on an area basis from measured flow downstream in the Hermitage Stream.
- For nitrate, inputs from rainfall were estimated from observed rainfall and typical concentrations in rainwater.
- Inputs of nutrients from the area immediately around the reservoir were based on published export coefficient values (P.J. Johnes, 1996).

2.1.5. The estimated nutrient inputs to the reservoir were combined with the residence time to estimate the within-reservoir nutrient concentrations as well as chlorophyll-a concentrations based on the OECD lake classification equations (OECD, 1982). On this basis the reservoir was classified with regards to its trophic status (oligotrophic, mesotrophic, eutrophic, hyper-eutrophic). This was expressed as the probability of the reservoir being in each trophic class based on the confidence limits associated with the OECD equations.

2.1.6. This analysis forms the basis of the outputs presented in this Section, prior to the development of the revised modelling approach presented in Section 3.

Comparative data on water quality in other reservoirs

- 2.1.7. For chemical parameters for which mass balance cannot be applied, such as pH and turbidity, expert judgement was applied based on knowledge of other lowland surface water reservoirs.

Review of potential pollution sources in the catchment and reservoir

- 2.1.8. In addition to those chemicals measured in the water quality sampling programme, there is potential for episodic inputs from the catchment, for example those associated with the application of pesticides and chemical spills. The natural catchment area to the reservoir will, however, be small, and will largely comprise of Forestry England land. The Forestry England were contacted by Portsmouth Water and asked about their historic and planned use of pesticides.
- 2.1.9. This local catchment will form part of a jointly owned reservoir management area and Portsmouth Water will, thereby, be able to influence catchment management and mitigate pollution risks.
- 2.1.10. Other potential sources of chemicals are from wildfowl that feed and roost on the reservoir and the adjacent wetland area and from anglers through their use of ground bait. These were quantified on the basis of export coefficients from scientific literature that estimate quantities of phosphorus and nitrogen excreted by different species of birds per day and the typical nutrient content of ground bait along with typical quantities used per angler. These values were combined with estimates of numbers of wildfowl that are likely to be supported by the reservoir and number of anglers likely to fish there, to estimate chemical loads.

2.2. Review of raw water quality

- 2.2.1. Chemical inputs to the reservoir will be sourced primarily from the transfer of Havant and Bedhampton Springs water and the ephemeral streams that flow in from the local catchment (inputs from rainfall and direct runoff from the area immediately around the reservoir will only form a minor component of the chemical inputs). Observed water quality data is available for both the Bedhampton Springs and the local streams, which provides a first basis for assessing the possible range of chemical concentrations in the proposed reservoir.
- 2.2.2. The variability in the concentrations in the source waters will, however, be attenuated by storage in the reservoir. During normal years when the reservoir is not used for public water supply the reservoir will have an average retention time of 5 - 10 years (based on the volume of 8700 ML and assuming evaporation losses only), and under these conditions water quality in the reservoir will tend toward the mean value of the mixed waters. Variability in concentrations in the reservoir will be more influenced by changing patterns of drawdown and refill when the reservoir is used for public water supply (during periods of drought) and longer-term changes in the concentrations in the source water than short term variability in influent concentrations.
- 2.2.3. A method for determining the average concentration of chemicals based on mixing the average concentrations in the source waters was developed during previous work on the reservoir in 2011 in the form of a spreadsheet model. This combines the estimated loads of each chemical from the different sources and applies the combined flow to calculate the mixed input concentration. Table 2.1 provides a summary of observed mean and percentile influent concentrations for key chemicals along with estimated mixed concentrations within the reservoir.

2.3. Phosphorus and algae

- 2.3.1. Phosphorus is a key chemical in relation to environmental and treatment risk for the proposed reservoir. Although it does not have a direct impact through toxicity, it constitutes a key control on algal and macrophyte growth in freshwaters (OECD, 1982).

Inputs from Bedhampton springs and local streams

- 2.3.2. The average influent concentration of total phosphorus to the reservoir from the Bedhampton and Havant Springs and the local streams over the period 2011 to 2019 was 13 µg/l which is similar to the value used in the previous reservoir spreadsheet model, developed by RM Walls in 2011.
- 2.3.3. Analysis of the observed phosphorus data in the Bedhampton Springs (Farlington unfiltered and Chamber No 1 data sets), however, indicates that some variations in concentrations occur, which may be related to hydrological conditions and the movement of groundwater (Figure 2.1). There have been periods when concentrations have been markedly larger than the long-term average. For example, average phosphate concentrations in 2015 were 41 µg/l. The observed variability in phosphorus concentrations in the Springs, therefore, suggests there may be years when phosphorus inputs might increase the risk from algae.
- 2.3.4. Some caution is required when drawing this conclusion because comparison of ortho-phosphate and total phosphorus in Figure 2.1 indicates ortho-phosphate concentrations are higher than total phosphorus which should not be the case (analysis between these two forms of phosphorus was carried out on different samples and different days so a direct comparison cannot be made).
- 2.3.5. The detection limit prior to 2012 for ortho-phosphate was too high to allow clear conclusions to be drawn on the variability of concentrations before this year, although the limited total phosphorus data shows little indication of periods with increased concentrations.
- 2.3.6. No relationship is evident between observed phosphorus concentrations and turbidity (also shown in Figure 2.1). Turbidity is highest in the winter, presumably during recharge of the aquifers with surface water during this period.

Table 2.1 - Observed water quality data and predicted reservoir concentration after mixing (2011-2019)

		Modelled*	Observed							
		HTSR	Springs (data from 2011–2019)		Feeder streams (2018–2019 – see section 1.4)					
			Bedhampton		HT 1		HT 2		HT 3	
Determinand	Unit	Avg*	Avg	95%	Avg	95%	Avg	95%	Avg	95%
Aluminium (total) as Al	µg/l	311	35.2	164	1288	3069	1250	3206	990	3540
Colour	mg/l Pt/Co	9	1.30	4.13	55.3	98.6	43.8	94.4	48.0	83.1
Iron (total) as Fe	µg/l	1133	37.1	145	4663	2539	3463	9941	8325	36027
Manganese (total) as Mn	µg/l	234	0.47	1.40	706	1182	345	942	670	2540
Turbidity	NTU	7.5**	0.60	2.11	376	90.2	87.7	437	67.6	413.2
Total Organic Carbon	mg/l	ND ⁴	0.99	2.09	13.22	21.70	10.69	21.48	12.63	31.25
Total Dissolved Solids (TDS)	mg/l	247	250	353	116	119	95	117.4	110	124
Temperature	degC	10	11.1	12.1	8.54	13.67	9.96	16.0	10.6	19.1
pH	-	8.4**	7.22	7.38	5.52	6.49	5.63	7.24	5.56	6.49

		Modelled*	Observed							
		HTSR	Springs (data from 2011–2019)		Feeder streams (2018–2019 – see section 1.4)					
			Bedhampton		HT 1		HT 2		HT 3	
Determinand	Unit	Avg*	Avg	95%	Avg	95%	Avg	95%	Avg	95%
Alkalinity, as CaCO ₃	mg/l	179	239	251	13.8	14.7	21.1	48.2	15.0	30.8
Calcium hardness, as CaCO ₃	mg/l	ND ⁴	112	117	52.8	87.7	83.3	261	53.3	149
Chloride	mg/l	27.2	21.7	24.3	46.5	77.9	35.3	49.7	36.7	42.4
Sulphate SO ₄	mg/l	18	16.9	22.7	35.4	70.6	39.6	104	37.1	106
Total P ⁵	ug/l	13	21.5	31.0	19.8	50.5	29.4	80.3	21.7	57.7
Nitrate N		6.4	33.3	38.6	0.95	3.43	0.78	1.90	1.02	2.41
Calcium Ca	mg/l	89	112	117	13.6	25.4	21.5	83.5	9.9	25.1
Conductivity	µS/cm	438	525	576	316	370	266	493	242	432

* Mixed concentration calculated by annual spreadsheet model unless stated otherwise

** Cannot be calculated by the mixing model so expert judgement applied

3 Derived from trophic status model, chlorophyll data for source waters not available

4 Not included in spreadsheet model

5 Modelled TP using reservoir model (median values)

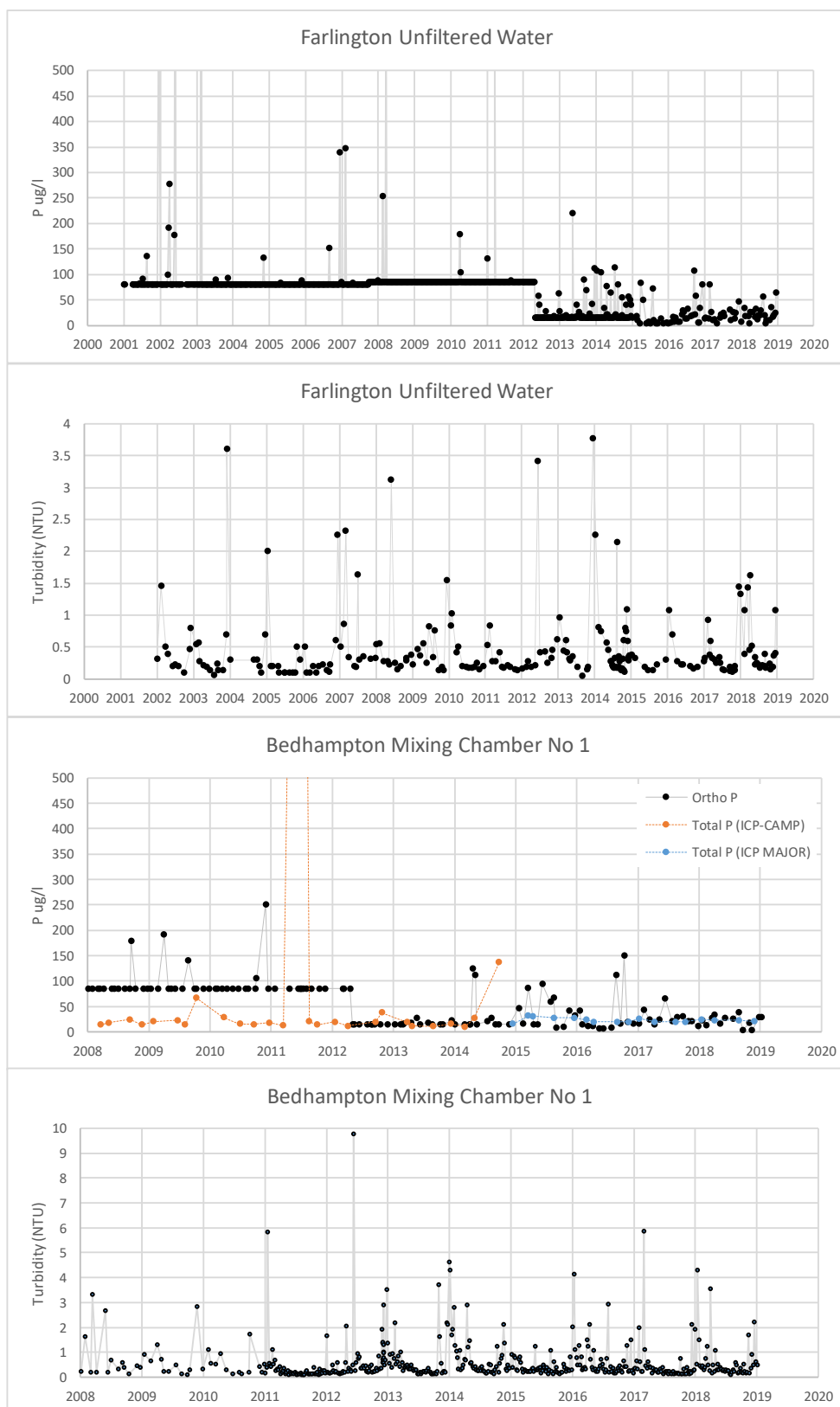


Figure 2.1 Time series data for turbidity, ortho-phosphate and total phosphorus in the Bedhampton Springs (only ortho-phosphate was measured in Farlington unfiltered)

Inputs from birds

2.3.7. Input of phosphorus from wildfowl is a recognised cause of eutrophication of lakes and reservoirs. In general, wildfowl populations that feed on lakes are a limited source of nutrients as a whole because much of their food and associated phosphorus comes

from the lake. There are circumstances, however, in which inputs of phosphorus from wildfowl become more significant. This is the case where birds feed elsewhere and, therefore, transfer the phosphorus from other locations to the lake. This occurs when birds roost beside lakes; for example, gull roosts typically on islands, while starling roosts on reedbeds beside lakes can also be significant. Geese can also provide significant inputs of phosphorus when large flocks move from place to place to feed. Even for species for which the phosphorus is sourced from the lake, the phosphorus will be transferred to a form more available to algae (i.e. biomass to dissolved or suspended material).

2.3.8. Some studies have been undertaken on the impact of wildfowl on lake chemistry.

- Water birds were found to cause decreasing water quality and intensive eutrophication in Lake Hilversumse Wasmeer in the Netherlands (Leentvaar 1967) and Lake Wintergreen in Michigan, USA (Manny, Johnson, & Wetzel, 1994).
- Considerable amounts of nutrients were introduced by cormorants to Kis-Balaton Reservoir in Hungary (Gere & Andrikovics, 1992).
- (Dobrowolski, Halba, & Nowicki, 1976) found that the total phosphorus concentrations attributed to bird droppings for the following lakes were: Lake Luknajno 30 kg ha⁻¹ yr⁻¹, Lake Warniak 11 kg ha⁻¹ yr⁻¹, and Lake Mikolajskie 20 kg ha⁻¹ yr⁻¹.
- Dense aggregations of migrating or wintering geese contributed large amounts of nutrients to the Bosquedel Apache National Wildlife Refuge, New Mexico, USA (Post, et al., 1998) and to Lake Arendsee, Germany (Rönicke, et al., 2008).
- Gulls were associated with increased P and N concentrations in Gull Pond, Wellfleet, Canada (Portnoy, 1990)), introducing 104 kg yr⁻¹ to the lake (44 ha).
- Canada goose and mallard were found to input significant loads of phosphorus in Lake Wintergreen, Michigan, USA (Manny, Johnson, & Wetzel, 1994).
- (Marion, Clergeau, Brient, & Bertru, 1994) estimated that starlings deposited 41% of a total of 2530 kg yr⁻¹ phosphorus input from birds to Grand-Lieu lake in France. (6292 ha).
- In the UK, a very large roost of black headed gulls (250,000 birds) was implicated in the eutrophication of Hickling Broad and improvements in the lake followed the elimination of the roost (Moss & Leah, 1982).
- (Meinikmann, Hupfera, & Lewandowskia, 2015) estimated inputs from wildfowl to Lake Arendsee (514 ha) in Germany of 200 kg yr⁻¹.

2.3.9. The surface area of Havant Thicket Reservoir will be 118 ha, which provides a comparison with the cited loading values above (i.e. Gull Pond, Grand-Lieu Lake and Lake Arendsee for which comparative areas are provided).

2.3.10. To place these literature values into context, the total phosphorus loads to Havant Thicket associated with different types and number of birds are shown in Table 2.2 which compares to estimated combined inputs to Havant Thicket Reservoir from Bedhampton and Havant Springs and the natural streams of 65 kg yr⁻¹. A particular concern is potential input from black headed gulls that have large populations in the area and from cormorants (this species often occurs in moderate numbers on reservoirs). Mediterranean Gulls are increasing markedly in South Hampshire (a local colony has increased to 1,700 pairs but historical data is insufficient to include in the analysis at present). Clearly, the inputs may increase if several of these species are present along with inputs from less common species.

- 2.3.11. For comparison, the numbers of these bird species in seven reservoirs in Southern England that are close to the sea are shown in Table 2.3. This indicates that the number of birds required to significantly increase algal risk at Havant Thicket Reservoir would be relatively high but not unrealistically so, compared to the other reservoirs, particularly with regards to cormorants.

Table 2.2 - Phosphorus export from wildfowl

Species	P Export kg yr ⁻¹	Langstone Harbour 16/17 Annual Peak Count	Number of birds present required to input 50 kg yr ⁻¹ of P [†]
Black headed gull	0.088*	4384	570
Herring gull	0.12	326	420
Brent geese	0.05	5552	1000
Canada geese	0.037	270	1350
Cormorant	0.95	27	53
Lapwing	0.04	1147	1250

* Data taken from SAGIS database (UKWIR)

† Required numbers if present throughout – greater numbers required for migratory species

Table 2.3 - Wildfowl numbers (annual peak count) from WeBs survey 2016/17 for selected reservoirs in Southern England that are within 10 km of the sea

Species	Barcombe Mills	Chew Valley	Cheddar Reservoir	Alton Water	Trinity Broads	Testwood Lakes	Blashford Lakes
Black headed gull	189	8	533 (2700 in 2012)	387 (637 in 2012)	259	0	6000
Herring gull	68	0	12 (250 in 2012)	15 (Common gull = 163)	15	0	unknown
Lesser black backed gull	4	0	43	23	6	0	8000
Brent geese	0	0	0	0	0	0	0
Canada geese	241	326	12 (217 in 2013)	52	0	511	113
Greylag geese	77	0	0	892	211	3	0
Cormorant	56	320	39	171	119	24	158
Lapwing	83	222	10	38	10	66 (268 in 2017)	142
Area km ²	0.13	4.5	0.9	1.64	1.59	0.55	0.7

Area of HTWSR = 1.18 km². Blashford Lakes numbers provided by site manager

- 2.3.12. Bearing in mind the proximity of the proposed reservoir to the sea (and, therefore, populations of gulls), the proposed development of a wetland at the reservoir to create habitat for wildfowl and the existence of urban feeding areas for gulls nearby, the risk of significant inputs of nutrient from wildfowl cannot be discounted (more detailed analysis of bird numbers to input to the revised water quality modelling is provided in Section 3).

- 2.3.13. A consideration raised by Portsmouth Water is that the wetland area to the north-west of the proposed reservoir, where birds are likely to mainly congregate, will be separated from the main reservoir when summer water levels are low by a retaining structure (Figure 2.2). This raises the possibility that nutrients may, to some extent, be retained in this area rather than pass into the main reservoir from which water will be abstracted to the treatment works. Although this might be the case in normal circumstances, phosphorus will still accumulate in this wetland area along with elevated algal populations and be subject to later release. Although this release may occur in the winter when water levels are high, this phosphorus will be retained in the reservoir until the spring, unless there is a high degree of flushing during this period which is not planned. Another possibility is that summer storms might flush out the water in the wetland area, along with large populations of algae into the main reservoir, which could fuel increases in algae; summer storms of this nature are expected to increase with climate change. Simple rainfall-runoff modelling would provide a means to assess the degree of flushing of the wetland area that might occur in the summer which is planned as part of the wetland design.

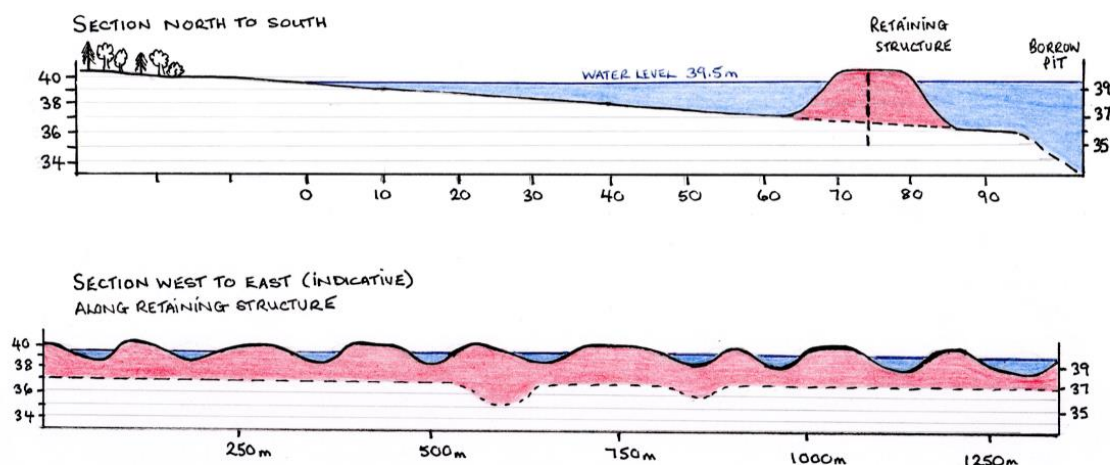


Figure 2.2 Wetland area in the proposed reservoir (diagram provided by Portsmouth Water)

Angling and ground bait

- 2.3.14. The use of ground bait can in some circumstances provide significant inputs of phosphorus to lakes if a popular coarse fishery becomes established (Brown A. , 2012). In general, these sources are of greater importance in small lakes where the length of the shoreline is large compared to the area and volume.
- 2.3.15. From the literature, a typical annual P loading value from ground bait is 0.58 kg/angler/year (range of literature sources, Amaral, Brito, Ferriera & Neves 2013; Arlinghaus and Mehner, 2003; Brown, 2012, Nieser, Arlinghaus, Renner and Mehner, 2004, Radford, Reddington, Anderson and Gibson, 2004).
- 2.3.16. Not all anglers use ground bait; some use dead bait that has a lower phosphorus input and some do not use live bait. Overall, however, angling could provide significant inputs of phosphorus, depending on the number of coarse anglers fishing on the reservoir (e.g. 10 fishermen would provide an input of approximately 5 kg per year). Portsmouth Water indicated that if angling is permitted there would be only a small number of fishing platforms, so the risk should be low, as long as the fishing is controlled effectively.

Recycling and accumulation of phosphorus

- 2.3.17. Under some circumstances, accumulation of phosphorus in the sediment and its subsequent release can increase the trophic state of a lake or reservoir. The exchange of phosphorus between water and sediment is complex and influenced by many factors,

including biological processes (e.g. bacterial activity, mineralisation, and bioturbation), migration of algae between the sediment surface and water column as well as chemical (e.g. redox conditions, pH, iron:P ratio, nitrate availability), and physical factors (e.g. resuspension and sediment mixing – Sondegaard et al. 2001; Figure 2.3). Thermal stratification can play an important role in influencing phosphorus exchange, particularly in deeper lakes where a stable thermocline develops, and oxygen concentrations decline on the hypolimnion. In shallow lakes other processes tend to be more important.

- 2.3.18. Normally steady state conditions develop if phosphorus inputs are stable with no net annual exchange between the water column and sediment. However, in shallow lakes (<10 m), a process can occur in which net release of phosphorus from the sediment can be caused by biological activity in the summer for a relatively short period (e.g. July to September) whereas during the rest of the year there is a net loss (Sondegaard, 2007). This has the effect of increasing the size of phytoplankton populations in the summer. Even if no net release of phosphorus from the sediment occurs over the entire year, the size of the summer peak can tend to increase as phosphorus accumulates. Typically, summer release of phosphorus is evident when total phosphorus concentrations show a marked increase during the summer; a pattern shown by many reservoirs in England (including those with moderate depth of up to 10 m). Although Havant Thicket reservoir will be relatively deep (average depth = 10 m), substantial shallow areas will be present outside the deep borrow pit.
- 2.3.19. These sediment processes are dependent on an accumulation of phosphorus that can take many years to develop which can result in a deterioration in water quality over time. This tends to be particularly important if there is a low flushing rate during the summer and early autumn so that phytoplankton biomass can die and settle onto the bed and, thereby, retain phosphorus within the lake.
- 2.3.20. Typically, reservoirs have low algal populations after construction, when they are first filled, because fish populations are low and grazing pressures from zooplankton high. An increase in fish populations over time is another reason why reservoirs tend to show a long-term deterioration with regards to algae over the first 10 to 15 years.

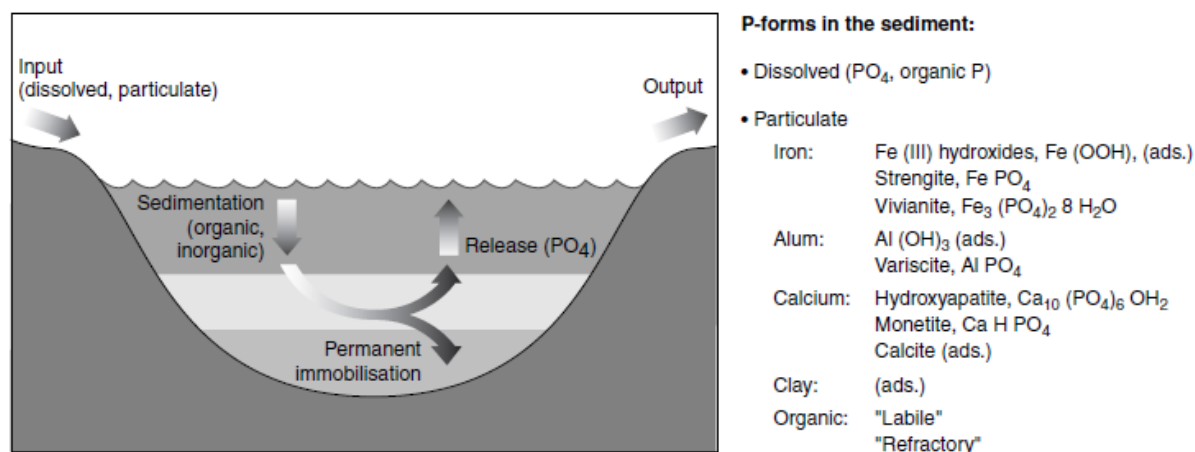


Figure 2.3 Schematic of key sediment phosphorus exchange processes (from Sondegarrrd 2001)

- 2.3.21. Fluctuating dissolved oxygen conditions above the sediment, related in part to stratification, can result in 'pulses' of release that can temporarily increase phytoplankton growth if the phosphorus becomes mixed into the epilimnion (the shallow layer) during the summer growing season (Reynolds, 1984). The effect of this is to increase the potential variability in phytoplankton growth and the likelihood that blooms will occur even if long-term average sediment phosphorus concentrations remain stable. Stratification can occur in relatively shallow reservoirs during periods of calm, stable weather conditions (analysis by Wessex Water has shown that significant stratification can occur in relatively shallow lakes (UKWIR, 2015) but stable stratification with a sharp thermocline is far more likely within deeper reservoirs
- 2.3.22. Previous analysis has indicated that the likelihood of stratification in Havant Thicket Reservoir is considered low (RM Walls, 2011) although this did not take into account the presence of a deep borrow pit. Installation of a mixing system such as compressed air would reduce the risk of transient stratification in the proposed reservoir. The engineering of alternative draw-off points (depth and location) would allow use of the water with the best quality if this is heterogeneous within the reservoir. It is unlikely however that different positioning of draw-off points can fully mitigate the risks associated with stratification. The preventative measure of reservoir mixing is considered to be best practice.
- 2.3.23. There is also some potential of phosphorus inputs from soil phosphorus after the reservoir is filled. Bearing in mind the fact that land use in this area has been low intensity grazing and, before this, woodland, this risk is likely to be low but cannot be discounted until soil chemistry analysis is carried out during outline design.

Trophic status and algal growth

- 2.3.24. The average influent concentration of total phosphorus to the reservoir from the Bedhampton and Havant Springs and local streams over the period 2011 to 2019 was 19.3 µg/l (see Section 2.3.1). Using the OECD equations (OECD, 1982), this translates to a within-reservoir total phosphorus concentration of 8.1 µg/l and an average chlorophyll-a concentration of 1.7 µg/l (2.4 µg/l when the reservoir is drawn down) and a probability of 86% of oligotrophic conditions prevailing under normal conditions and 70% when the reservoir is drawn down (14% and 30% probability of mesotrophic conditions, respectively). In general terms, an oligotrophic categorisation indicates low risk whereas a mesotrophic categorisation indicates a medium risk.
- 2.3.25. As indicated in the previous sections there are further potential inputs from other sources, particularly from birds and a degree of uncertainty regarding interactions with the sediment, which might increase the risk of a higher trophic status and problems with algae. In contrast to direct inputs from the springs and streams, these risks are difficult to assess and have consequently been addressed in more detail in Section 3 of this report.

Comparison with other sites

- 2.3.26. Very few surface water reservoirs in the U.K. are groundwater fed so there are few similar examples with which Havant Thicket Reservoir can be directly compared. One example, however, that has been identified is Leigh Reservoir (operated by Wessex Water), which is spring fed and has low phosphorus concentrations. Significant problems with algal blooms (and associated by-products such as taste and odour) developed to the degree that Wessex Water applied Phoslock¹ to the reservoir to strip phosphorus from the water column and control release from the sediment (Phoslock is believed to have been beneficial but no published data is available). Another example is Ormesby Broad in Norfolk, which is a drinking water source operated by Northumbrian Water. This lake is predominantly fed by groundwater and spring inputs (80%) with few significant potential catchment sources of phosphorus. The lake, however, supports large phytoplankton populations which are believed to be driven by a marked summer

¹ Phoslock is the commercial name for a [bentonite](#) clay in which the sodium and/or calcium ions are exchanged for [lanthanum](#). The addition of this element allows it to bind with phosphates. It can be used to bind phosphate in freshwater natural aquatic systems

release of phosphorus from the sediment. Lake Arendsee (Rönicke, et al., 2008) is a groundwater fed reservoir in Germany that suffers from eutrophication issues, although in this case there is an urban area in the catchment, which might contribute inputs of phosphorus.

- 2.3.27. Although these examples are limited, they indicate that there is the potential for significant algal risk where the dominant source of water is groundwater. None of the examples located are fed by chalk groundwater springs.

Climate change

- 2.3.28. Climate change has the potential to modify the risk outlined in this note. The likelihood of the reservoir being drawn down in future is likely to increase. A reduction in the mean depth in the summer will tend to increase algal risk because the algae will become more exposed to light. Light would also increase on the sediment surface increasing the growth of benthic algae that can later migrate into the water column. Stirring of the bed by wind would also become more likely under these circumstances. Summer storms are additionally likely to increase in magnitude because of climate change, increasing the likelihood of flushing out of nutrients from the wetland area. Bird populations and resident species will change, although it is difficult to predict the implications of this for nutrient inputs. The effect of these climate related changes is likely to be to modify risk in terms of the frequency of perturbation events rather than fundamentally changing the scale of the risk.

Conclusions and summary

- 2.3.29. The information provided in this section indicates a categorisation of the reservoir as low to medium risk with regards to algae, and for creation of associated disinfection by-products at this stage. The additional factors, discussed above, were not considered in the previous analysis of risk in 2011 (i.e. the variability in phosphorus concentrations in the Bedhampton Spring water, potential inputs from wildfowl and the role of the sediment in supporting summer release of phosphorus).
- 2.3.30. We believe these processes have the potential to be of sufficient magnitude to result in a moderate risk categorisation for water treatment purposes. Because the processes are complex and highly uncertain, it is difficult to quantify this risk with any certainty but on the basis that the precautionary principle is applied to the development of water treatment strategies, it is difficult for them to be discounted at this stage. Our experience of working on many reservoirs and lakes in the UK and elsewhere is that there is a significant degree of uncertainty and unpredictability in how algal risk changes over time; sometimes long-term deterioration (or improvement) in algal populations can occur despite no clear change in nutrient inputs (associated with the processes outlined above and perhaps unknown factors) and such uncertainty needs to be factored in when estimating risk.
- 2.3.31. Table 2-4 places a semi-quantitative summary of the risk outlined above based on this initial analysis (prior to the more detailed analysis presented in Section 3).

Table 2.4 - Algal risk from issues identified

Risk	Likelihood	Severity	Mitigation
Variable groundwater quality	Low to Moderate	Moderate	Difficult to control but further analysis may provide better quantification
Inputs from wildfowl	Moderate	Moderate	Can influence by how wetland is designed
Inputs from angling	Low	Low	
Sediment	Moderate	Moderate	Modification of the flushing regime. Design of wetland. Artificial aeration

2.4. Pathogens

2.4.1. Potential sources of microbial contaminants and pathogens that might be associated with surface water storage are inputs of faecal coliforms from wildfowl (e.g. gulls) and animals. Risk from *Cryptosporidium* would be low because there will be no livestock or sewage sources in the small woodland catchment (although some inputs will occur from wild animals such as deer). Storage of water in the reservoir will increase risk from pathogens compared to the existing spring source although this will remain low compared to other surface water reservoirs in Southern England.

2.5. Taste & Odour

- 2.5.1. Taste and odour problems can be generated by algae in the reservoir (e.g. Geosmin and MIB). The risk associated with algal bloom, can therefore be translated to taste and odour.
- 2.5.2. Macrophyte beds are a common feature of many reservoirs and generally do not result in significant water treatment issues. Some species, notably stoneworts such as *Chara* and *Nitella*, however, are well known to cause a bitter, garlic taste in the water (Kawczynski, 1995). Although the abundance of these species is normally insufficient to result in significant problems, macrophyte biomass can increase rapidly if conditions are favourable. Sporadic events of massive, often single species dominated beds of macrophytes are not an uncommon event in reservoirs. An example of this occurred in Pitsford Reservoir in Northamptonshire in the 1990s in which a proliferation of *Chara* caused severe taste and odour problems, which required emergency dosing of Powdered Activated Carbon and compensation to customers.
- 2.5.3. *Chara* and *Nitella* are associated with calcareous water with low nutrient concentrations such as occurs in several of the Norfolk Broads. Since Havant Thicket is characterised in this way, with stored water predominantly supplied from the spring water at Havant and Bedhampton, it is likely that they will become a feature within HTWSR, albeit normally with low abundance. It is, however, a distinct possibility that, under some circumstances, abundance might increase rapidly (e.g. if nutrients increase because of variability in influent concentrations or associated with the presence of wildfowl). The reason that this is not a common problem is that nutrient concentrations in most surface water reservoirs are sufficiently high that other species of macrophytes tend to dominate.
- 2.5.4. Taste and odour are therefore risks that the treatment strategy will need to address for drinking water.

2.6. Suspended Solids/Turbidity

2.6.1. Turbidity in the Havant & Bedhampton Springs is much lower than in the existing streams which enter the reservoir site from the north. The reservoir will act as a stilling basin for sediment washed in from the upper catchment, allowing sediments to settle out and by buffering transient events. The outline reservoir design acknowledges the high suspended solid load in the feeder streams at times and has ensured the water flows

through a wetland before entering the main water body. It is anticipated this will trap the silt. Thus, even during a summer storm event the risk of reduced water quality due to mobilisation of silt will be less.

- 2.6.2. As a result, the discharges from the reservoir are expected to carry a reduced load of suspended solids compared to present loads in the stream. Furthermore, if the compensation water is maintained at a steady rate, bed material will not be re-suspended and downstream suspended solids will remain low.
- 2.6.3. Turbidity in the reservoir will primarily be associated with algal growth and resuspension of material from the bed and exposed mud when the reservoir is drawn down. Resuspension of particles from the bed is dependent on the exposure to wind along with the depth and physical structure of the sediment. Since all these processes are hard to quantify, the estimated values for reservoir turbidity presented in Table 2.1 are derived conservatively from typical values observed at other surface water reservoirs.

2.7. Disinfection By-Product (DBP) Formation Potential

- 2.7.1. The potential for disinfection by-products (DBPs) is closely linked to risk from algal growth within the reservoir because they are a result on chemical reactions between disinfection treatment with chlorine and algal cells and organic chemicals released by them. These chemicals are only an issue for water supply post treatment and disinfection and are not relevant for environmental water quality within the reservoir and downstream.

2.8. Pesticides

- 2.8.1. Observed concentrations of pesticides in the Bedhampton and Havant Springs are low with very few exceedances of the drinking water standard in the raw water (see Table 2.1). No significant sources of pesticides have been identified in the small natural catchment which is predominantly Forestry England land. A request for information from the Forestry England on their use of pesticides in the local catchment indicated that chemicals have not been applied in the last three years and in the future the only chemicals that are likely to be used are glyphosate treatment of the gravel car park surfaces and Asulox/Asulam as a treatment to control bracken.
- 2.8.2. Future use of pesticides in the catchment can be controlled by the future site management team for the new reservoir so any risk that arises through changes in land use can be mitigated.

2.9. Soluble Metals

- 2.9.1. Soluble metal concentrations in the source waters are insufficient to result in a risk to treatment. Relatively high concentrations of total iron and manganese are present in the local streams (Table 2.1) and it is possible that these could be solubilised during periods of low oxygen concentrations in the reservoir during periods of stratification. The latter is, however, unlikely to occur if an artificial destratification system is installed.

2.10. Hydrocarbons

- 2.10.1. Observed concentrations of hydrocarbons in the Bedhampton and Havant Springs are very low, and no significant sources have been identified in the natural catchment. The greatest risk is from fly tipping and accidental spills, but this can be mitigated by how the area is managed; for example, using barriers to reduce access by vehicles. Risk from hydrocarbon use can be further reduced by banning petrol engines from boats on the reservoir as has often been imposed by other water companies on their surface water reservoirs.

2.11. Nitrates

- 2.11.1. Figure 2.4 shows that observed average nitrate concentrations (as mg/l NO₃) in the Bedhampton and Havant Springs are well below the drinking water standard of 50 mg/l.

Average concentrations in local streams are very low with average concentrations below 2 mg/l. Risk of exceedance of the nitrate drinking water standard is, therefore, low at present. The only circumstance that would change this is a long-term increase in nitrate concentrations in the springs. Natural denitrification processes taking place in the reservoir will further reduce the risk of nitrate exceedance although the degree of denitrification is difficult to predict as it varies markedly between reservoirs.

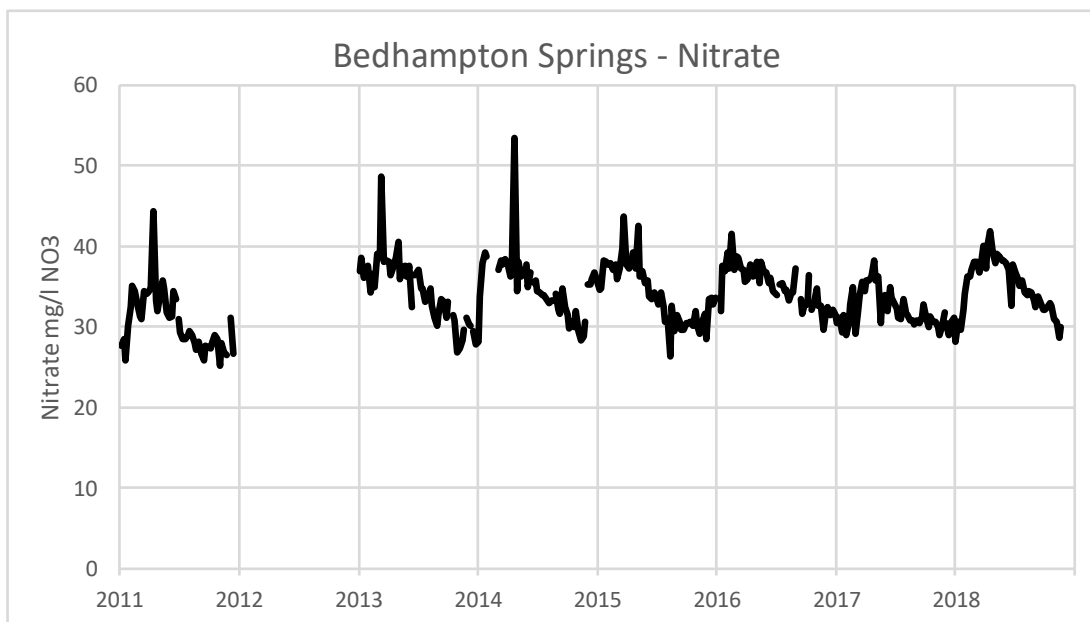


Figure 2.4 Nitrate concentrations in the Bedhampton Springs

2.12. Ammonia

2.12.1. The predicted concentration of ammonia in the reservoir based on mixing of the source waters is low (0.04 mg/l). Ammonia in surface water reservoirs is, however, more dependent on within-reservoir processes. For example, concentrations can rise sharply when algal and macrophyte populations die. Ammonia can also increase if oxygen concentrations decline in the deeper layers of the reservoir as a result of stratification which can be mixed into the reservoir as a whole when the reservoir overturns. As mentioned, earlier stratification risks can be mitigated if a destratification system is installed. Bearing in mind the low to moderate risk from algae (Section 2.3.28), ammonia concentrations are unlikely to be high compared to other surface water reservoirs in southern England.

2.13. pH

2.13.1. The reservoir's pH will primarily be influenced by the hardness of the water and algal and macrophyte photosynthesis, which will tend to increase pH (typically a diurnal pattern is observed with increasing pH during the day and decreasing pH during the night). The magnitude of this diurnal flux is determined by the biomass of macrophytes and algae. pH values in the reservoir are expected to be in the range 8.2–8.6 depending on these factors although higher values might occur toward the end of a summer day with high light levels if algal populations are high. Bearing in mind the low to moderate risk from algae (Section 2.3.8), pH values are unlikely to be high compared to other surface water reservoirs in southern England.

2.14. Total Organic Carbon (TOC)

2.14.1. Organic carbon in the Bedhampton and Havant Springs groundwater is low and although concentrations in the local streams may occasionally be high (e.g. in the autumn when plant material in the catchment is decomposing) inputs of organic carbon

from the influent water will tend to be low. The primary source of organic carbon will, therefore, be from algae and macrophytes growing in the reservoir. However, bearing in mind the low to moderate risk from algae (Section 2.3.8), TOC values are unlikely to be high compared to other surface water reservoirs in southern England. TOC values may increase significantly during periods of die-off of macrophytes and algae, primarily in late summer and autumn, although this is difficult to quantify.

2.15. Colour

- 2.15.1. Risk of colour is similar to that from TOC outlined above, with relatively low risk at most times.

2.16. Micropollutants

- 2.16.1. Micropollutants (e.g. priority hazardous substances and endocrine disruptors) are unlikely to be a risk as there are no significant potential sources, such as wastewater or legacy of industrial usage in the catchment.

2.17. Hardness

- 2.17.1. As the Bedhampton and Havant Springs water is sourced from a chalk aquifer, the water is hard which will also be the case in the proposed reservoir (similar to that of the current raw water before storage).

2.18. Summary of risks

- 2.18.1. A summary of water quality risks primarily related to an assessment of the need for treatment for drinking water quality is presented in Table 2.5 below. The only substantive change in the level of risk compared to the current raw spring water without surface water storage is the potential for algal growth in the reservoir and secondary consequences such as microbiological risk, taste and odour, soluble metals and production of disinfection by-products.

Table 2.5 - Summary of water quality risks

WQ Risk	Assessment approach & quantification e.g. quantitative or qualitative	Commentary (noting where further work is planned / recommended to be done)	Likelihood baselined against current risk	Severity baselined against current risk	Risk Rating e.g. Red Amber Green	Mitigation before treatment
Microbiological	Qualitative	No livestock or wastewater expected in catchment – some risk from wild animals Faecal coliforms / virus / coliform risk only likely to be significant if a gull roost develops. Water will be classified as surface water (classification E).	Moderate	High	Red	
Algae (total and sub-groups)	Qualitative / Quantitative (updated spreadsheet model)	On the basis of phosphorous inputs & retention time low to moderate risk, to which potential local inputs from birds and accumulation of phosphorous added = moderate risk. Diatoms, dinoflagellates and colonial green algae likely to dominate based on retention time mixing & nutrient levels. Retention time of cyanobacterial blooms suggest low risk of cyanobacterial toxins.	Moderate	Moderate	Amber	Consider reservoir management techniques – mixing, bio-manipulation etc.
Taste & odour (including Geosmin & MIB)	Qualitative / Quantitative	Mainly caused by algal activity but also potential for macrophyte growth in shallow reservoir	Moderate	Moderate	Amber	

WQ Risk	Assessment approach & quantification e.g. quantitative or qualitative	Commentary (noting where further work is planned / recommended to be done)	Likelihood baselined against current risk	Severity baselined against current risk	Risk Rating e.g. Red Amber Green	Mitigation before treatment
DBP formation potential	Qualitative / Quantitative (derived from algae type)	Risk of increased DBP precursors related directly to surface run-off (organic compounds) & algal risk	Moderate	Moderate	Amber	
Soluble metals	Qualitative	Manganese and iron are rarely an issue in shallow hardwater lowland reservoirs. Short-term risk during hot static periods may occur.	Moderate	Moderate	Amber	Consider artificial mixing to reduce risk of stratification
Pesticides	Quantitative – based on influent water data	Pesticide concentrations in springs low, no significant sources expected in the natural catchment. It is noted that there has been one instance of 2,4-D exceeding the PCV in the treated water from Farlington WTW – this was not identified in the raw water and as such the source is unknown.	Low	Moderate (persistence in reservoir if enters)	Green/ Amber	Consider land management to ensure future risk remains low.
Suspended solids / turbidity	Qualitative	Primary source likely to be from algal growth in reservoir due to low input from spring source & settlement time for catchment inputs (unless short-circuiting occurs).	Low	Moderate (during algal blooms)	Green/ Amber	

WQ Risk	Assessment approach & quantification e.g. quantitative or qualitative	Commentary (noting where further work is planned / recommended to be done)	Likelihood baselined against current risk	Severity baselined against current risk	Risk Rating e.g. Red Amber Green	Mitigation before treatment
Hydrocarbons	Qualitative / Quantitative	Risk of fly-tipping / boat spills is principal risk.	Low	Moderate	Green/ Amber	Consider physical security & monitoring with abstraction control
						Consider limitations on petrol-powered boats for recreational uses
Nitrates	Quantitative (updated spreadsheet model)	Some indication of underlying upward trend during peak season in historic Bedhampton Springs data. Expect some benefit from dilution from other streams & denitrification during reservoir storage.	Low	High	Green/ Amber	Consider monitoring with abstraction control
Ammonia	Qualitative / Quantitative (updated spreadsheet model)	Low levels (0.045 mg/L vs PCV 0.5 mg/l) indicated by mass balance of influent waters, most expected to be generated by algal and plant growth within reservoir – unlikely to be particular issue.	Low	Moderate	Green/ Amber	Artificial mixing

WQ Risk	Assessment approach & quantification e.g. quantitative or qualitative	Commentary (noting where further work is planned / recommended to be done)	Likelihood baselined against current risk	Severity baselined against current risk	Risk Rating e.g. Red Amber Green	Mitigation before treatment
pH	Qualitative	Diurnal increase due to algal growth may occur but expected to benefit from buffering capacity of hard spring inflow and relatively low pH	Low	Low	Green	
Total Organic Carbon (TOC)	Qualitative / Quantitative (updated spreadsheet model)	Most of the TOC is likely to be generated by biological activity (algal and macrophyte) in the reservoir. Smaller inputs will come from the woodland catchment. The spring inputs would be low in TOC (average value = 1 mg/l).	Low	Low	Green	
Colour	Qualitative	In a hardwater reservoir like this, most colour will be generated by algal activity rather than inputs from the catchment.	Low	Low	Green	
Micropollutants e.g. pharmaceuticals	Qualitative	No data available – risk should be low compared to urban catchments.	Low	High	Green	
Hardness	Qualitative	Hard water expected as result of spring hardness – as current.	Low	Low	Green	

WQ Risk	Assessment approach & quantification e.g. quantitative or qualitative	Commentary (noting where further work is planned / recommended to be done)	Likelihood baselined against current risk	Severity baselined against current risk	Risk Rating e.g. Red Amber Green	Mitigation before treatment
Bromide	Qualitative	Unknown influent concentrations from Bedhampton Springs / feeder streams (reservoir storage not expected to significantly influent bromide concentrations).	Unknown	Unknown	Unknown	Only an issue if ozone treatment were proposed. Start monitoring to quantify risk if proposed

3. Phase 2 – Revised reservoir water quality model

3.1. Revisions to reservoir model

- 3.1.1. The existing annual reservoir model, developed by RM Walls in 2011, estimates the retention time and annual average nutrient input loads to the reservoir. The OECD equations (OECD 1982) are then used to predict within lake nutrient and chlorophyll-a concentrations and assign the trophic status, accordingly. Within the equations, losses of nutrients within the reservoir are taken into account. The model assigns a probability that the reservoir is within different trophic conditions (oligotrophic, mesotrophic, eutrophic etc.). Outputs of this model are presented and discussed in Section 2.3.24.
- 3.1.2. The input data for this existing reservoir model were first updated for the period 2011–2019 along with other elements of the water quality spreadsheet. The model was then reviewed by Atkins and the Environment Agency and a number of revisions were suggested and implemented which are listed below. The EA National Modelling team confirmed that the amended water quality model would be appropriate for modelling water quality impacts of the reservoir to support the EIA for the reservoir scheme, provided these amendments were correctly applied (28th February 2019, see Section 1.4).
- Improving data inputs
 - PSYCHIC & NEAP – N instead of export coefficients
 - Create inputs for birds
 - Use Lowflows data to estimate natural flow reservoir inputs
 - Seasonality/time series
 - Re-arrange the spreadsheet so that input time series/monthly data for flow and water quality are applied to tie in with previous water resources modelling
 - Add loss and sediment interaction functions to reservoir model
 - Sensitivity testing
 - Improve scope to carry out sensitivity testing
- 3.1.3. Implementation of these changes is described below. Further details of how the revised reservoir model works are provided in Section 3.2. Only phosphorus and nitrogen are considered because these are the key chemicals influencing the trophic state and treatment risk from algae (other chemicals are considered using the existing mixing model as reported in Sections 2.4 to 2.17; Table 2.1 and 2.5).

Modifications to the model

- 3.1.4. The modifications to the reservoir model involve a change from an empirical approach, described above, to a time series approach in which the change in the mass of chemicals in the reservoir is estimated from the inputs and outputs of water and nutrients during each time step (i.e. per week). The approach also takes into account within reservoir losses and exchange with the sediment but, in contrast, the previous methodology, this applies a decay rate or settling rate that calculates loss per day, with similar rates to determine exchange with the sediment. These calculations are repeated for each time step to create an output time series. Further details of these changes are detailed below:
- **Seasonality and time series** – The new reservoir spreadsheet model was created to run on a variable time step to align with the data period of time series data inputs. The objective was to allow assessment of reservoir water quality under different hydrological conditions (e.g. droughts) and to align the modelling with the Pywr water resource modelling that produces time series outputs for input and output flows to and from the reservoir (Atkins, 2018). It allows assessment of the changes in water quality during a range of hydrological conditions (e.g. periods of drought and refill – e.g. Figure 3.4).

- **Alignment with water resources model** – The modelling spreadsheet was developed so it can directly take outputs from the Pywr water resources model to drive the water quality simulation (using the theoretical thousand years of modelled output). This allows it to test the impact of drought scenarios without pre-processing of data (see Section 3.6).
- **Inputs from birds** – The existing water quality model does not include inputs from birds but, as indicated in Section 2.3.7 to 2.3.13 of this report, these may be significant. These inputs have, therefore, been added into the model. Sensitivity testing in relation to a range of possible bird populations was also carried out (see Section 3).
- **Stream flows** – The existing estimates of stream flows from the ephemeral streams to the reservoir have been replaced by values derived from the LowFlows hydrological model that provides national estimates of naturalised flows based on rainfall, geology, observed flow data and artificial influence (e.g. abstractions and discharges) and is the basis of the river flows in the SAGIS model and Environment Agency water resources GIS. It improves the existing methodology because it provides naturalised flows.
- **Local inputs of nutrients** – The export coefficients used to estimate local inputs of nutrients (in the area immediately around the reservoir that do not drain into the streams) have been replaced by outputs from the PSYCHIC and NEAP N models that were developed by ADAS to estimate phosphorus and nitrogen export from catchments, based on agricultural census and management data as well as hydrological data. These models are widely used by the Environment Agency and the water industry.
- **Processes and rates** – The new time series reservoir model takes into account loss rates of nutrients within the reservoir (applying a range of typical rates from the scientific literature). Exchanges of nutrients with the sediment are also modelled explicitly.
- **Sensitivity analysis** – The spreadsheet model has been set up to allow sensitivity testing. This allows outputs from different model set ups (up to 3 scenarios) to be compared in the spreadsheet graphs.
- **Annual reservoir model** – The existing annual reservoir model developed by RM Walls has been retained for comparison. This, however, has been modified to receive the same data as the new reservoir model in the form of long-term average values (e.g. average flows from the springs derived from Pywr model and for the streams. The outputs of this model are presented in Sections 2.1 to 2.3).

3.2. Model build

Water balance

- 3.2.1. The reservoir water quality modelling is based on the deployable output analysis in the Pywr water resource modelling. The methodology is, therefore, based on the best current understanding of how the reservoir will be operated and can be easily modified in the future if planned inflows and outflows change.

Inputs from Bedhampton Springs

- 3.2.2. Flow inputs to the reservoir from the Bedhampton Springs are based on the modelled long-term weekly transfer volume taken from the Pywr water resource model.

Inputs from streams

- 3.2.3. Flow inputs to the reservoir from the three influent streams are based on their estimated monthly flows which are derived from the SAGIS model of the area, provided by the Environment Agency (Q_{mean} and Q_{95} per km^2 multiplied by the catchment area of the streams).

Outputs to treatment works

- 3.2.4. The time series output to the treatment works is based on the weekly flow output of the Pywr water resources model; the load released from the reservoir is calculated from the simulated concentration in the reservoir.

Outputs via compensation water

- 3.2.5. As a baseline scenario for discussion with the Environment Agency, it is proposed that the compensation flow from the reservoir water quality model is based on the Q_{50} long term average for the Riders Lane Stream catchment area, upstream of the embankment. By proportioning the Q_{50} flows from the Hermitage gauging station to the Riders Lane catchment upstream of the embankment the following monthly stepped profile was derived, representing a natural run-off profile for the upper catchment, as shown in Table 3.1. This was applied to the reservoir water quality model.
- 3.2.6. Further modelling and consultation will be required with the Environment Agency to agree the final compensation profile to be adopted as part of the HTWSR scheme. Whilst the Q_{50} profile would appear to be an appropriate starting point, further refinement will be required to consider the flow profile during drought events, where a reduced annual rate compared to the long-term Q_{50} average is likely to be appropriate. This would then provide a reasonable balance between mirroring the natural ecology, so in extreme years there is no flow from the site, but a biodiversity benefit is provided in more typical years. Having some flow of water provides a source of drinking water for wildlife using the streams including animals, birds and insects.

Table 3.1 - Compensation flow

Month	m ³ /s	l/s
January	0.028	27.9
February	0.025	25.2
March	0.022	22.3
April	0.018	18.2
May	0.017	17.1
June	0.013	13.0
July	0.009	9.2
August	0.008	8.2
September	0.007	6.8
October	0.011	11.4
November	0.018	18.4
December	0.018	18.3

Linking to model to the Pywr water resources model

- 3.2.7. The water quality model has been set up to be consistent with outputs from the Pywr water resources model for HTWSR for reservoir inflows and outflows for different drought return periods. The reservoir volume generated by Pywr is used, rather than calculating a new water balance. For other model inputs and outputs (e.g. from the streams, birds etc.), monthly average values are used (i.e. inputs and outputs of water and chemical loads). The model is based on a weekly timestep, reflecting the outputs from the Pywr model.

Nutrient inputs

- 3.2.8. Representation of inputs of total phosphorus and nitrogen to the reservoir are described below.

Inputs from Bedhampton Springs

- 3.2.9. Inputs to the reservoir from the Bedhampton Springs are based on the modelled weekly transfer volume taken from the Pywr water resource model and monthly average observed total phosphorus concentrations in the Bedhampton Springs (Table 3.2 below).

Inputs from streams

- 3.2.10. Inputs to the reservoir from the three influent streams are based on the estimated monthly flows in the streams and monthly average total phosphorus concentrations in the streams (Table 3.2).

Table 3.2 - Monthly total phosphorus influent concentrations (µg/l)

Month	Bedhampton Springs	Stream 1	Stream 2	Stream 3
January	23.67	5.00	23.69	14.41
February	22.92	10.78	5.33	8.89
March	18.60	8.53	7.36	13.78
April	17.36	15.70	5.00	7.70
May	22.92	153.90	33.65	26.44
June	22.92	92.80	65.28	94.90
July	22.92	92.80	38.70	43.08
August	18.83	31.70	122.85	18.90
September	20.00	30.40	30.00	23.00
October	20.67	5.00	16.47	16.68
November	10.00	19.22	15.09	12.31
December	20.00	9.50	9.50	9.50

Inputs from local catchment

- 3.2.11. Inputs from the local catchment are based on total phosphorus outputs from the monthly PSYCHIC (loads per km²) model taken from the SAGIS for the grid cells closest to the reservoir (grid cells 110471 and 109472). This is multiplied by the local area around the reservoir (0.29 km² taken from the previous modelling work).

Inputs from birds

- 3.2.12. Inputs from birds are calculated from predicted bird numbers and export rates per bird taken from the scientific literature (derived during the development of the SAGIS tool).
- 3.2.13. Predicted bird numbers are estimated from existing bird counts (British Trust for Ornithology WEBS data) for eleven reservoirs and lakes in southern England, located close to the sea (less than 10 km). The five-year rolling average of the peak monthly bird count for each of the key species was taken from the WeBS website. The exception was Blashford Lakes for which data was provided by the reserve site manager (for Ibsley Water). The wetland bird count data for Blashford Lakes did not include gulls so the numbers for the key species (lesser black backed gulls and black headed gulls) were taken from the 2017–2018 annual site report². The statistics were then divided by the surface area of the reservoir/lake to derive numbers per km² (Table 3.3 below).
- 3.2.14. The median value per km² of these eleven counts was then used to estimate numbers of each species in Havant Thicket reservoir (by multiplying this statistic by the planned area of the reservoir). This approach does not take into account regional differences in bird abundance but the broad makeup of types of birds (ducks, geese, waders etc.) is likely to be reasonable. For certain species the methodology was modified as follows:
- Cormorant numbers were considered to be higher in 'put and take' fisheries (i.e. where fish are stocked to be caught). Since Havant Thicket Reservoir will not have

² Blashford Lakes - Annual Report - September 2017–August 2018. HIWWT.

this type of fishery, the put take fisheries were excluded from the calculation (Abberton, Arlington, Barcombe, Chew and Blagdon are put and take fisheries)

- Mediterranean Gulls are rapidly increasing in numbers, possibly related to climate change. The historical data does not, therefore, provide a good guide to future numbers in the reservoir. Numbers were, instead, estimated using expert judgement taking into account local knowledge from Portsmouth Water (considering current trends and the significant fluctuating population in Langstone Harbour nearby).

3.2.15. An overall estimate was made for roosting small to medium passerines (e.g. including herondines and wagtails) following discussion with Portsmouth Water. These numbers are assumed to be present during the period September to November. Winter roosting starlings are considered separately as part of the sensitivity testing as indicated below).

Table 3.3 - Bird counts in reservoirs in southern England less than 10 km from the sea and derived numbers for Havant Thicket Reservoir

	Count per km2																Havant Thicket Reservoir				
Bird Species	Hickling	Trinity	Alton	Abberton	Arlington	Testwood	Blashford L	Barcombe	Chew	Cheddar	Blagdon	Mean	Median	20%ile	80%ile	Average	Medium	Low	High	Comments	
Mute Swan	66.9	92.5	10.4	77.2	8.3	10.9	32.0	30.0	31.7	58.7	37.6	41.5	35.2	12.0	73.6	48.9	41.5	14.2	86.8		
Greylag Goose	394.2	113.8	379.9	221.7	106.3	34.5	161.4	795.0	0.2	0.0	0.0	200.6	125.2	0.2	417.9	236.8	147.8	0.3	493.1		
Canada Goose	16.2	0.0	32.3	312.4	866.7	378.2	123.7	1010.0	82.8	77.2	250.3	286.3	136.1	35.5	416.0	337.9	160.6	41.9	490.9		
Brent Goose	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0		
Shelduck	17.5	1.3	7.9	8.9	0.0	5.5	1.7	0.0	4.5	0.0	1.2	4.4	1.9	0.0	8.7	5.2	2.2	0.0	10.3		
Wigeon	56.5	1.9	20.7	519.4	472.9	138.2	920.0	40.0	69.4	266.3	268.5	252.2	152.0	44.0	520.2	297.6	179.4	51.9	613.8		
Teal	1466.2	22.6	38.4	1110.1	129.2	96.4	169.1	395.0	490.5	463.0	737.0	465.2	434.5	106.0	810.7	549.0	512.7	125.1	956.6		
Gadwall	165.6	20.8	45.7	102.1	6.3	29.1	210.6	215.0	91.2	13.0	156.4	96.0	100.3	22.8	182.1	113.2	118.3	26.9	214.9		
Mallard	180.5	186.2	85.4	287.3	318.8	172.7	71.4	545.0	251.1	259.8	324.2	243.9	276.2	190.0	350.6	287.7	325.9	224.2	413.7		
Pintail	3.9	0.0	0.6	75.3	16.7	0.0	139.1	0.0	11.4	16.3	29.7	26.6	12.6	0.0	32.7	31.4	14.8	0.0	38.5		
Shoveler	92.2	61.6	11.0	352.5	6.3	41.8	317.1	385.0	81.9	10.9	258.8	147.2	90.1	12.1	348.9	173.7	106.3	14.2	411.7		
Pochard	21.4	69.2	78.7	473.4	2.1	23.6	144.6	265.0	146.6	380.4	158.2	160.3	159.0	26.0	291.5	189.1	187.7	30.7	344.0		
Tufted Duck	118.8	371.1	222.6	608.0	6.3	43.6	287.1	465.0	481.5	105.4	633.9	303.9	315.9	116.0	529.6	358.6	372.7	136.9	624.9		
Goosander	0.0	0.0	1.2	11.8	0.0	3.6	66.6	5.0	7.8	1.1	6.7	9.4	4.0	0.0	8.5	11.1	4.7	0.0	10.1		
Little Grebe	5.2	1.3	11.0	7.8	0.0	0.0	40.6	10.0	12.5	1.1	20.0	9.9	8.6	1.2	13.8	11.7	10.1	1.4	16.2		
Great Crested Grebe	9.7	47.8	74.4	216.7	81.3	18.2	61.7	45.0	95.5	42.4	39.4	66.5	52.6	43.3	89.4	78.5	62.0	51.1	105.5		
Cormorant	19.5	76.1	59.1	208.0	64.6	36.4	226.3	285.0	92.7	22.8	75.2	106.0	82.7	40.0	228.8	116.6	90.9	44.0	251.7	Cormorants numbers will be elevated at put and take trout fisheries (these have therefore been excluded from calculation) - see footnote	
Little Egret	0.0	0.6	12.2	11.4	4.2	36.4	6.3	0.0	4.7	1.1	9.1	7.8	5.2	0.7	12.5	9.2	6.2	0.8	14.8		
Grey Heron	1.3	6.9	3.0	9.5	6.3	14.5	34.0	30.0	6.0	2.2	12.7	11.5	7.6	3.4	16.0	13.6	9.0	4.0	18.9		
Moorhen	0.6	3.1	23.8	9.3	10.4	20.0	7.4	5.0	35.8	1.1	76.4	17.5	10.2	3.5	26.2	20.7	12.0	4.1	30.9		
Coot	172.1	556.6	334.8	1487.1	27.1	30.9	703.1	355.0	681.3	1728.3	836.4	628.4	612.3	189.3	920.0	741.5	722.5	223.4	1085.6		
Black-headed Gull	10.4	93.7	253.0	1346.4	2.1	0.0	8571.4	1085.0	1.7	228.3	410.3	1091.1	251.1	2.3	1193.5	1287.5	296.3	2.7	1408.3		
Common Gull	0.0	18.9	41.5	27.4	0.0	0.0	142.9	785.0	0.2	33.7	126.1	106.9	30.2	0.0	138.7	126.1	35.6	0.0	163.6		
Lesser Black-backed Gull	0.0	3.8	14.0	9.3	0.0	0.0	11428.6	20.0	0.0	46.7	40.0	1051.1	10.2	0.0	44.0	1240.3	12.0	0.0	51.9		
Herring Gull	0.0	4.4	7.3	24.1	6.3	0.0	7.1	385.0	0.0	225.0	49.1	64.4	7.9	0.0	54.0	76.0	9.3	0.0	63.7		
Great Black-backed Gull	14.9	2.5	2.4	27.8	2.1	0.0	7.1	35.0	2.8	1.1	5.5	9.2	3.1	2.3	16.4	10.9	3.6	2.7	19.4		
Mediterranean Gull	0.0	1.9	0.0	0.2	0.0	1.8	7.1	5.0	0.0	0.0	0.6	1.5	0.2	0.0	2.1	100.0	100.0	50.0	300.0	Mediterranean gull numbers are currently low but are believed to be increasing due to climate change - increased numbers have therefore been used	
Common Tern	0.0	13.8	45.7	18.4	0.0	5.5	0.0	0.0	6.0	0.0	0.6	8.2	0.7	0.0	15.2	9.7	0.8	0.0	18.0		
Medium sized passerines	0.0					0.0	0.0					0.0				300.0	300.0	100.0	500.0	Suggested numbers from Portsmouth Water to include species such as starling, heronines and wagtails . Does not include larger winter murmuration roosts of starling as these are likely to be short lived	
Lapwing	174.7	6.3	23.2	762.7	27.1	316.4	203.4	415.0	47.8	10.9	66.1	186.7	72.7	25.5	348.0	220.3	85.7	30.1	410.6		
Black tailed godwit	8.4	0.0	100.0	28.3	0.0	7.3	0.0	0.0	1.9	0.0	4.2	13.7	2.1	0.0	9.3	16.1	2.5	0.0	11.0		
Redshank	0.0	0.0	2.4	0.8	0.0	7.3	1.1	0.0	0.2	0.0	0.0	1.1	0.0	0.0	1.3	1.3	0.0	0.0	1.5		
Curlew	1.9	0.0	0.0	3.2	0.0	0.0	12.9	0.0	0.0	0.0	0.0	1.6	0.0	0.0	2.1	1.9	0.0	0.0	2.5		
Golden Plover	0.0	0.0	0.0	320.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.1	0.0	0.0	0.0	34.3	0.0	0.0	0.0		
Ringed Plover	0.6	0.0	0.0	24.3	0.0	0.0	1.4	0.0	2.6	0.0	3.0	2.9	0.0	0.0	2.8	3.4	0.0	0.0	3.4		
Ruff	27.9	0.0	0.6	9.3	0.0	0.0	0.9	0.0	1.3	1.1	0.6	3.8	0.7	0.0	1.4	4.5	0.8	0.0	1.7		

Put and take fisheries – Abberton, Arlington, Barcombe (fishery now closed), Chew and Blagdon

Method of calculation – the numbers given are the five year moving average of the annual peak count for the period 2013 to 2018 as reported on the WeBs website. Numbers are then distributed around the year based on typical seasonal profiles (included in the SAGIS database). The Median, 20%-ile and 80%-ile statistics were calculated from the 11 count values for the listed sites.

These form the basis of the low, medium and high values for the sensitivity testing

For species marked in dark grey, another method was used as described in the comments

Havant Thicket numbers apply an area of 1.18 km² (i.e. 1.18 times the count per km²)

- 3.2.16. The numbers were distributed through the year based on a typical monthly distribution compared to the monthly peak value (for example, for winter migrants, numbers would be zero in the summer). Typical monthly profiles, previously derived in the SAGIS modelling system, were used in this case (originally using data for selected sites).
- 3.2.17. Using these estimated monthly numbers, nutrient inputs to the reservoir from birds were estimated based on export rates for the bird species taken from the scientific literature (Table 3.3). Where no information was available, export rates were based on similar species and body mass. For model sensitivity testing the 20th percentile and 80th percentile of the 11 sites were used. In addition, the following scenarios were considered in the sensitivity testing:
- A gull roost of 10,000 black headed gulls (November to February)
 - A winter starling ('murmuration') roost of 10,000 birds (December and January).

Table 3.4 - Nutrient export rates for key species (g/day)

Bird Species	Weight	P Export g/day	N Export g/day
Herring gull	0.97	0.32	0.978
Lesser Black-backed Gull	0.83	0.3212	0.9782
Great Black-backed Gull	1.56	0.3604	1.3104
Black Headed Gull	0.29	0.174	0.522
Common Gull	0.4	0.15	0.844
Mediterranean Gull	0.26	0.17	0.51
Greylag goose	3.34	0.0803	0.7921
Canada goose	3.96	0.1022	1.0147
Brent goose	1.5	0.01	0.03
Shelduck	1.2	0.04	0.12
Wigeon	0.75	0.0215	0.2082
Teal	0.32	0.01	0.1
Mallard	1.21	0.0151	0.1475
Gadwall	0.75	0.0215	0.2082
Pochard	0.82	0.0235	0.2277
Mute swan	9	0.1037	1.0384
Coot	0.25	0.0058	0.0560
Moorhen	0.15	0.0029	0.5192
Pintail	0.87	0.0215	0.2082
Shoveler	0.63	0.0151	0.1477
Tufted Duck	0.6	0.015	0.045
Cormorant	3	0.95	2.9
Little Grebe	0.17	0.0538	0.1643
Great Crested Grebe	0.73	0.2312	0.7057
Little Egret	0.45	0.1425	0.435
Grey Heron	1.5	0.475	1.45
Common tern	0.12	0.015	0.045

Bird Species	Weight	P Export g/day	N Export g/day
Starling	0.075	0.01	0.03
Medium sized passerine	0.05	0.01	0.03
Lapwing	0.22	0.0293	0.088
Redshank	0.13	0.0173	0.052
Curlew	0.73	0.0973	0.292
Golden Plover	0.21	0.028	0.084
Ringed Plover	0.064	0.0085	0.0256
Ruff	0.2	0.0267	0.08
Others	0.3	0.025	0.075

- 3.2.18. Figures 3.1 and 3.2 summarise the contribution of types of bird and individual species to estimated phosphorus loading. Inputs are estimated to be dominated by cormorants, grebes, and gulls, followed by ducks and geese. Key species contributing to nutrient inputs are predicted to be cormorants and black headed gulls.

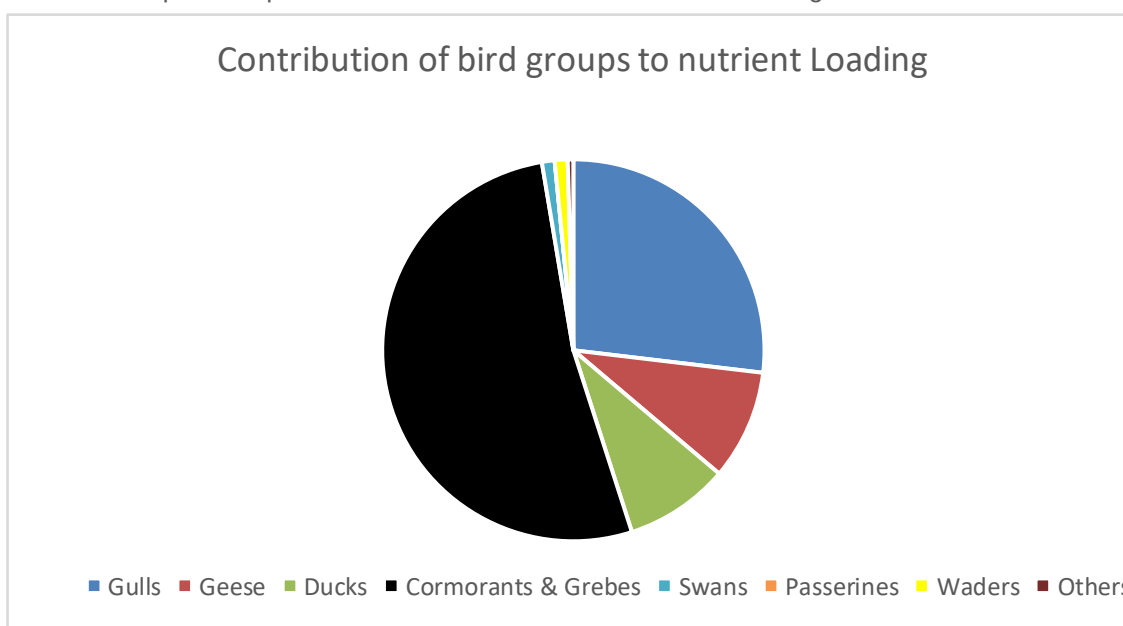


Figure 3.1 Relative nutrient inputs from different bird types to the reservoir water quality model

Inputs from anglers

- 3.2.19. Inputs from anglers were estimated using the existing methodology developed for the SAGIS model. Seasonal patterns of inputs from ground and dead bait per angler were applied. It was estimated that there will be an average of five anglers fishing on the reservoir each day.

Inputs from sediment

- 3.2.20. Interactions of phosphorus in the spreadsheet model are represented in the model as phosphorus pools in the water column and sediment. Transfers between these pools are

based on a simple lake model developed by Chapra 1997³, described by the equations below.

$$V_1 \frac{dp_1}{dt} = W - Qp_{in} - v_s A_s p_1 + v_r A_s p_2$$

$$V_2 \frac{dp_2}{dt} = v_s A_s p_1 - v_r A_s p_2 - v_b A_s p_2$$

Where:

- subscripts 1 and 2 designate the water and the enriched surface sediment layer;
- W = chemical load to the lake from inflows and direct discharge;
- Q = flow out of the lake;
- V_1 = lake volume;
- p = chemical concentration;
- V_2 = active sediment volume;
- v_s = settling velocity (m/day);
- A_s = surface area of the sediment (m²);
- v_r = sediment release velocity (m/day); and
- v_b = the permanent burial velocity (m/day).

³ Chapra S.C. (1997) Surface Water Quality Modelling. McGraw Hill International.

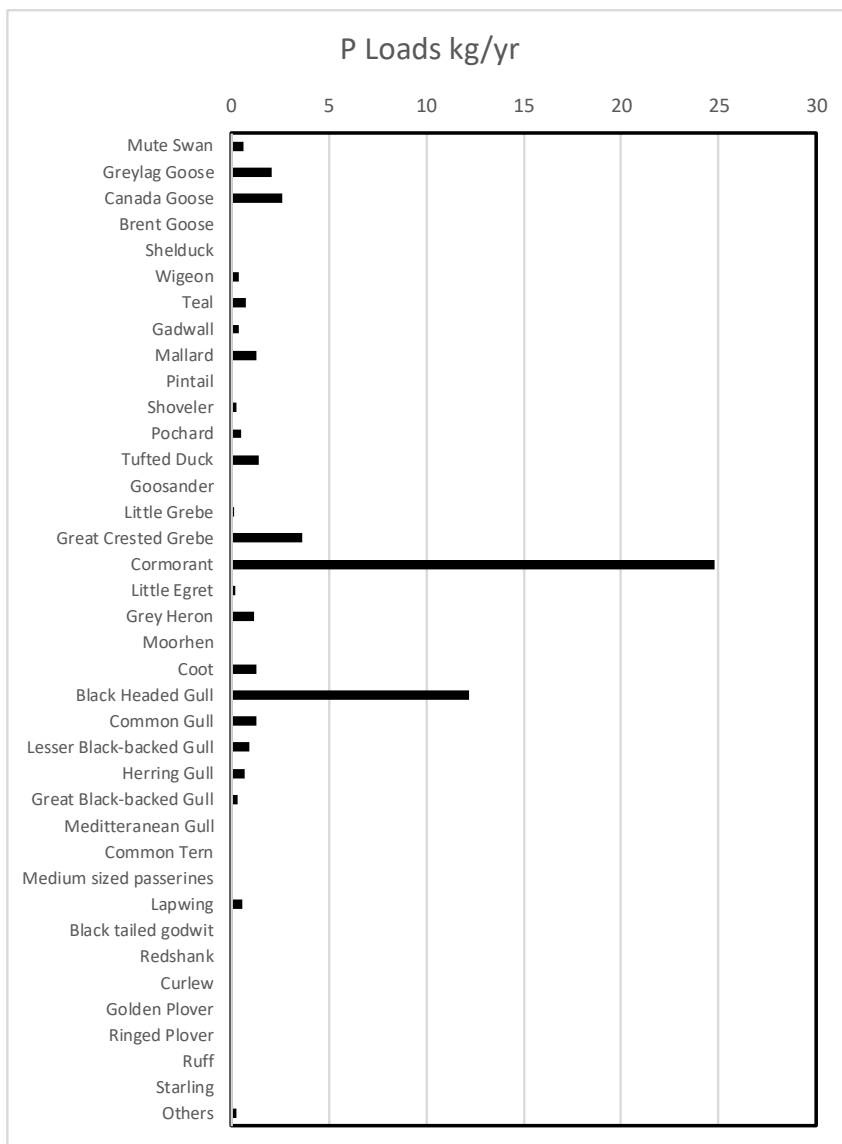


Figure 3.2 Relative nutrient inputs from different bird species to the reservoir water quality model

- 3.2.21. Apparent settling, re-suspension rates and burial rates, are applied to simulate chemical exchanges between the water column and sediment and determine within-lake losses. These can be specified on a monthly basis if required (e.g. to represent widely observed seasonal changes in process rates).
- 3.2.22. The initial set up applied typical rates as specified by Chapra, 1997 and previous modelling work on lakes (SAGIS applies the same equations). The impact of changes to these process rates is explored in the sensitivity testing presented in Section 3.5. The rates were set to achieve a steady state reservoir and sediment concentration over a period of 10–20 years (a typical period for a reservoir or lake to reach a new steady state; Chapra, 1997). Sediment concentrations were then set to this steady state value. Sediment phosphorus exchange was only modelled for phosphorus. Sediment storage and exchange are not regarded as important processes for nitrogen.

Inputs from rainfall

- 3.2.23. Volume inputs from rainfall are based on monthly average values from the nearby rain gauges at Southampton and Eastbourne (1980 to 2018; average of the two sites) along with measured concentrations of nutrients in rainfall (UKEAP: Precip-Net). Rainfall concentrations are insignificant for phosphorus but of greater importance for nitrogen.

Summary information of nutrient inputs

- 3.2.24. Figure 3.3 shows the estimated relative contribution of different sources of phosphorus to Havant Thicket Reservoir. Birds and the Havant and Bedhampton springs contribute the greatest inputs of phosphorus. There is clearly a high degree of uncertainty regarding bird inputs because the numbers of birds that will come to feed and roost on and around the reservoir is unknown. This, however, is explored later in the sensitivity analysis presented in Section 3.5 of this report.

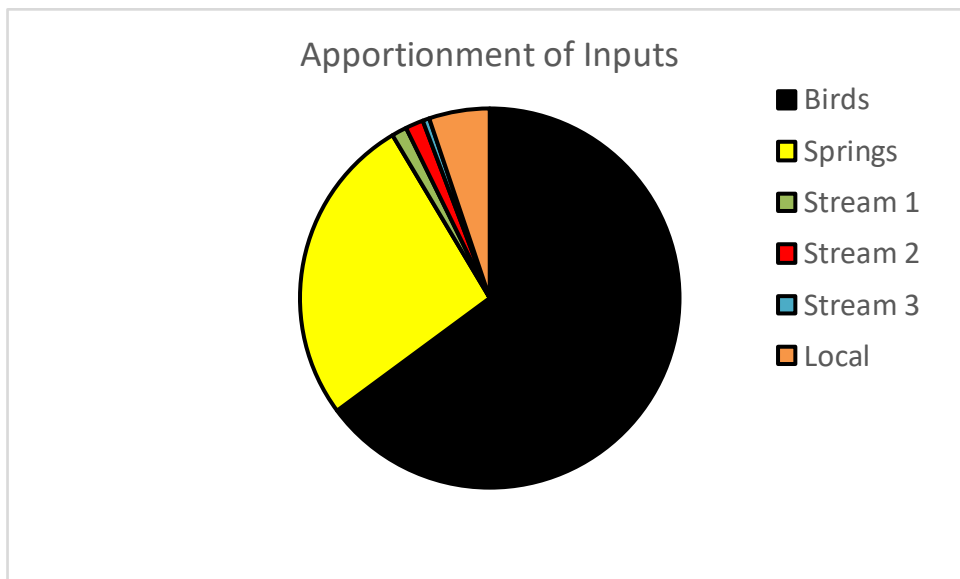


Figure 3.3 Estimate contribution of different sources of phosphorus to Havant Thicket reservoir

3.3. Model output

Total phosphorus

- 3.3.1. Figure 3.4 shows an example of the model output for a 100 years sequence (these are theoretical rather than real years with 1000 years applied in total in the calculations) of flows from the Pywr water resources model for three total phosphorus settling rates (5, 10 and 25 m.yr⁻¹) which are a typical range of values (Chapra, 1997). In this case, no phosphorus exchange with the sediment has been modelled. This analysis shows that increases in concentrations occur during and shortly after dry periods when the reservoir is drawn down during which there is less dilution of the inputs, particularly from birds and shortly afterwards when the reservoir is refilled with spring water.
- 3.3.2. Long term average concentrations for the three settling rate values are 4, 9 and 16 µg/l which compares to 12.3 µg/l from the existing annual reservoir model. This indicates that the two approaches are consistent.
- 3.3.3. Figure 3.5 shows how the trophic status of the reservoir changes over the simulation period for the three settling rates (based on an annual rolling average of the total phosphorus concentration and OECD classification). This indicates that the trophic state of the reservoir is generally between oligotrophic and mesotrophic with oligotrophic conditions prevailing at the greatest loss rates and mesotrophic conditions prevailing at the lowest loss rates.

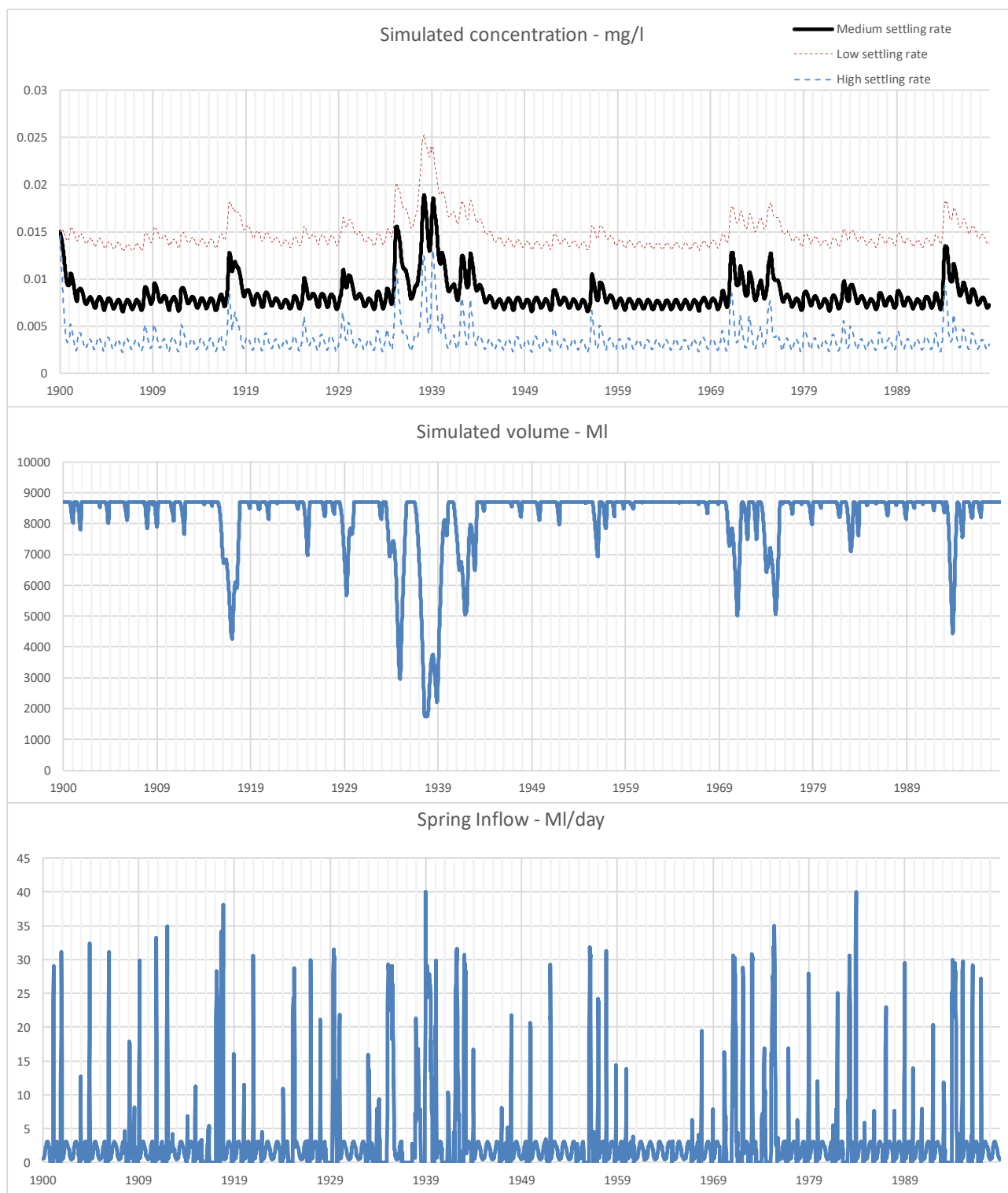


Figure 3.4 Modelled total phosphorus concentrations compared to reservoir inflows and volume (one of 100 hundred year sequence).



Figure 3.5 Estimates trophic state of the reservoir based on a rolling average of the simulated total phosphorus concentration

3.4. Nitrate

- 3.4.1. The reservoir water quality model was also set up for nitrogen, using similar data to total phosphorus. For the inputs from Havant & Bedhampton Springs and the streams, inputs for nitrate and ammonia are combined (it is assumed that ammonia will be converted to nitrate within the reservoir). Inputs from birds and anglers applied the export coefficients for nitrogen rather than phosphorus. It was assumed that no exchanges with the sediment occur as these are generally unimportant for nitrogen. Typical loss rates were applied as before (5, 10 and 25 m/year in this case referenced from Harrison et al. 2009; average values for temperate reservoirs are estimated to be 9.35 m/year).
- 3.4.2. In contrast to total phosphorus, nitrogen inputs are dominated by inputs for Bedhampton springs (Figure 3.6).

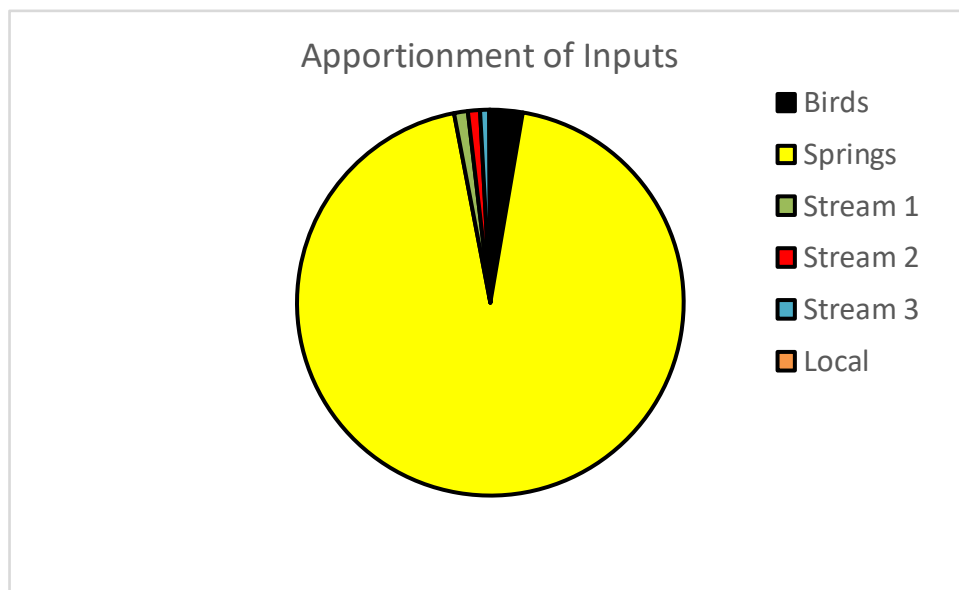


Figure 3.6 Apportionment of nitrogen inputs to the reservoir

- 3.4.3. Simulated concentrations are shown in Figure 3.7 for a 100-year sequence, compared to reservoir volume and input flows from Bedhampton springs. Concentrations are well below the Drinking Water Directive prescribed value of 11.2 mg/l N (50 mg/l NO₃). In relation to algal growth, nitrate concentrations are high such that phosphorus will be limiting for algal growth rather than nitrogen (Reynolds, 1984; nitrate concentrations would need to be well below 1 mg/l N to be limiting). The variations in concentration are primarily related to the reservoir fill and the degree of dilution of inputs to the reservoir with higher concentrations during and shortly after drought periods.
- 3.4.4. Because the treatment risk is low and it is unlikely to limit algal growth, nitrate is not considered further in this section of the report (i.e. in the sensitivity testing and drought periods). The implications for downstream water quality in the Hermitage Stream are considered in Section 4.5.

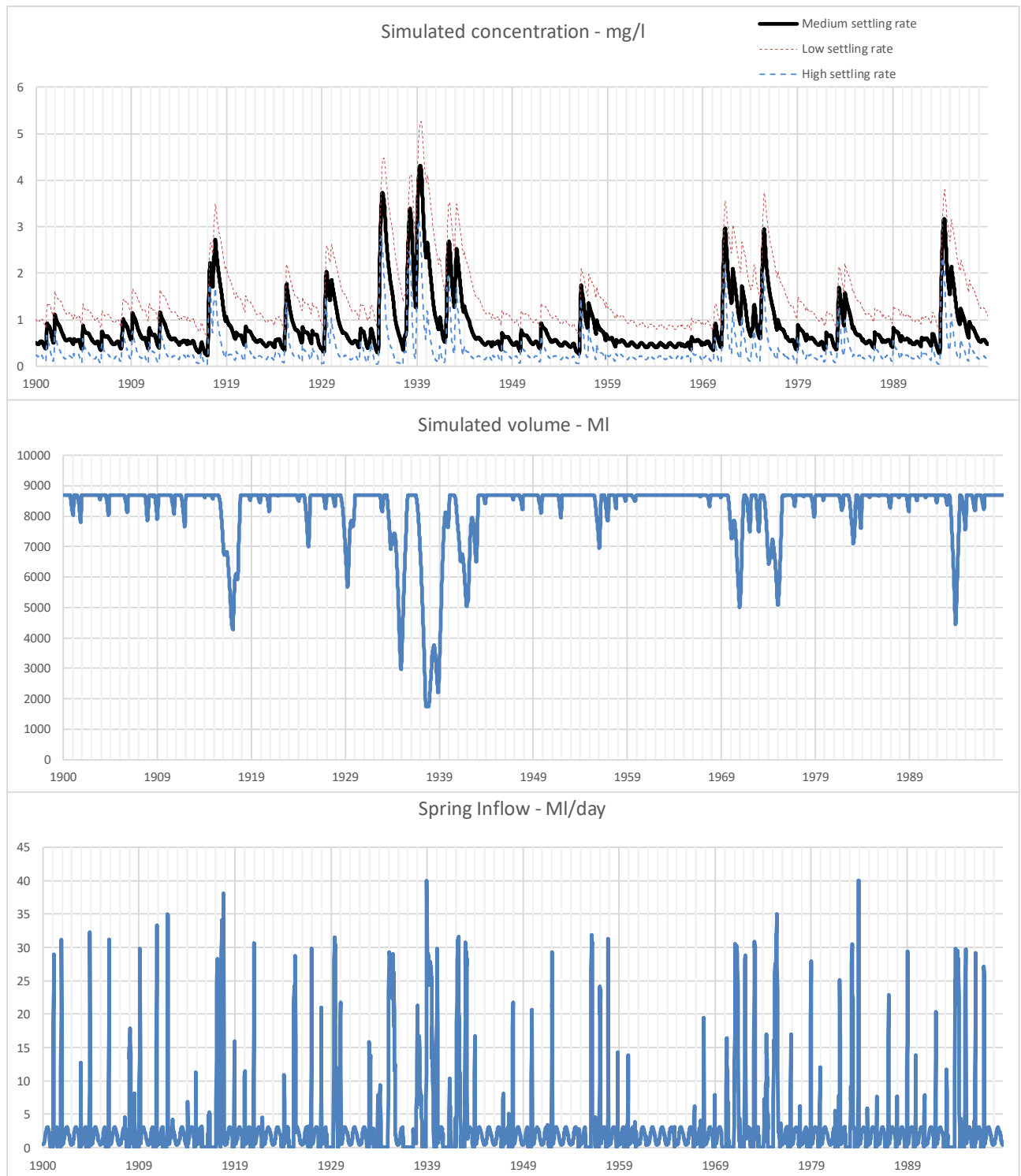


Figure 3.7 Simulated nitrate concentrations in Havant Thicket reservoir.

3.5. Sensitivity analysis

3.5.1. Further sensitivity testing was carried out to determine the effect of modifying the model inputs and parameters in relation to key areas of uncertainty.

Bird inputs

3.5.2. Wildfowl numbers in the reservoir were modified as follows:

- Eightieth percentile value for the numbers of each species per km² from Table 3.3.
- Twentieth percentile value for the numbers of each species per km² from Table 3.3.
- Starling roost in the winter (see Section 3.2.17)
- Gull roost in winter (see Section 3.2.17)

Overall bird numbers

3.5.3. Figure 3.8 (upper graph) shows simulated total P concentrations (using a typical medium settling rate) for high, medium and low bird numbers. This indicates that numbers of birds have a potentially substantial impact on reservoir total P. The bottom graphs show impact on the mean and 95 percentile concentrations with bars showing the range of values for the three settling rate values (low, typical and high). Figure 3.9 shows how this translates to a probability that the reservoir will be at risk of different trophic states. This indicates that the higher 80%ile populations would result in a substantial increase in likelihood that mesotrophic/eutrophic conditions would occur. As before, the peak concentrations occur during and after periods of reservoir drawdown when there is reduced dilution of inputs from birds and during refill when inputs from the springs increase.

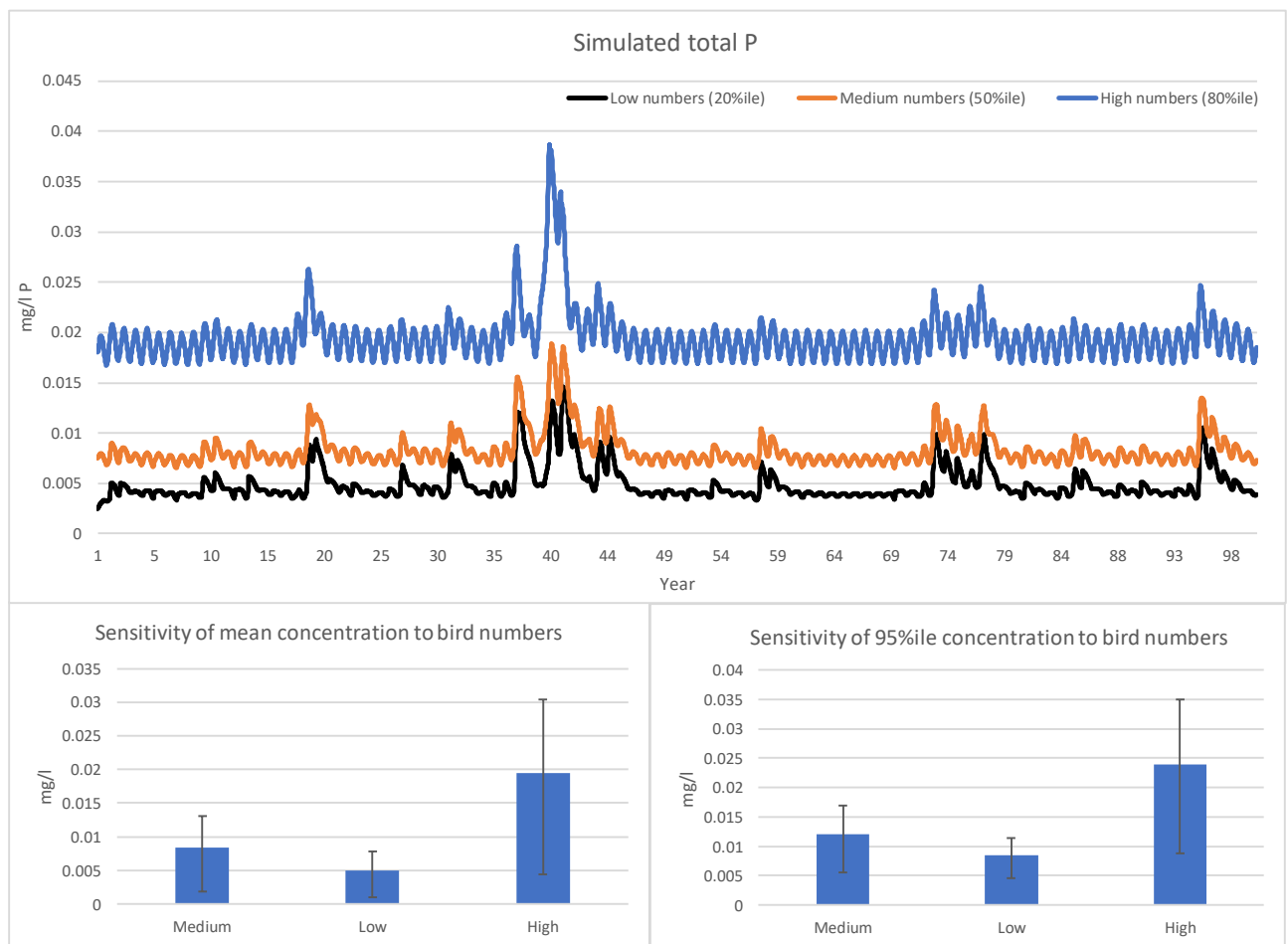


Figure 3.8 Impact of scenarios for birds numbers on simulated reservoir total P concentration.

Upper graph shows time series results (for a medium settling rate). The lower graphs show the range of mean and 95%ile values for the low, medium and high settling rates.

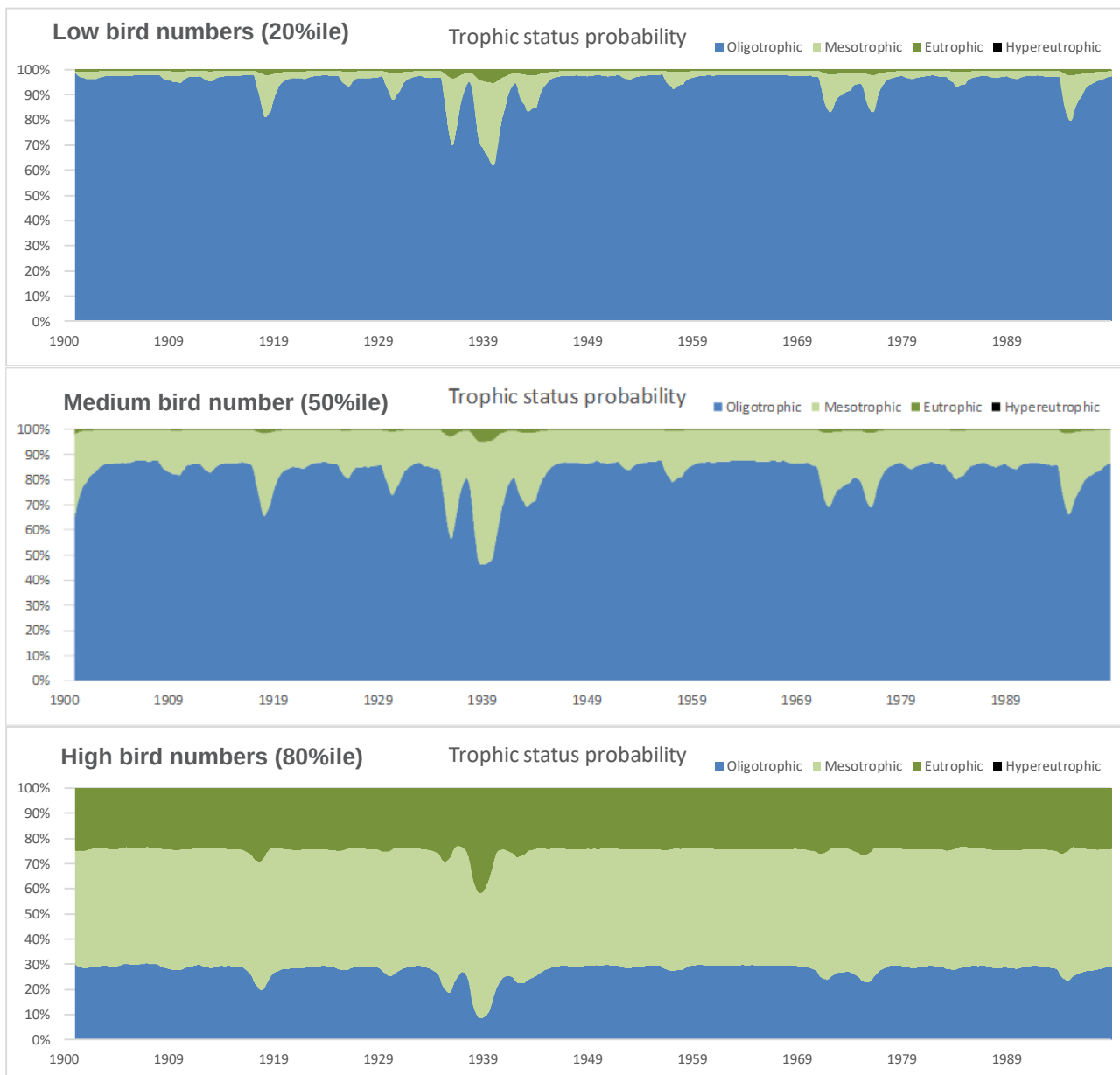


Figure 3.9 Impact of bird numbers on predicted trophic state of the reservoir

Starling and gull roosts

- 3.5.4. Figure 3.10 shows the modelled impact of a 10,000-population winter starling roost in the wetland beside the reservoir on total Phosphorous (total P) concentrations. The change in total P concentrations is small, in relation to the uncertainty associated with the settling rate. A starling roost of this size would, therefore, represent only a small risk to water quality.

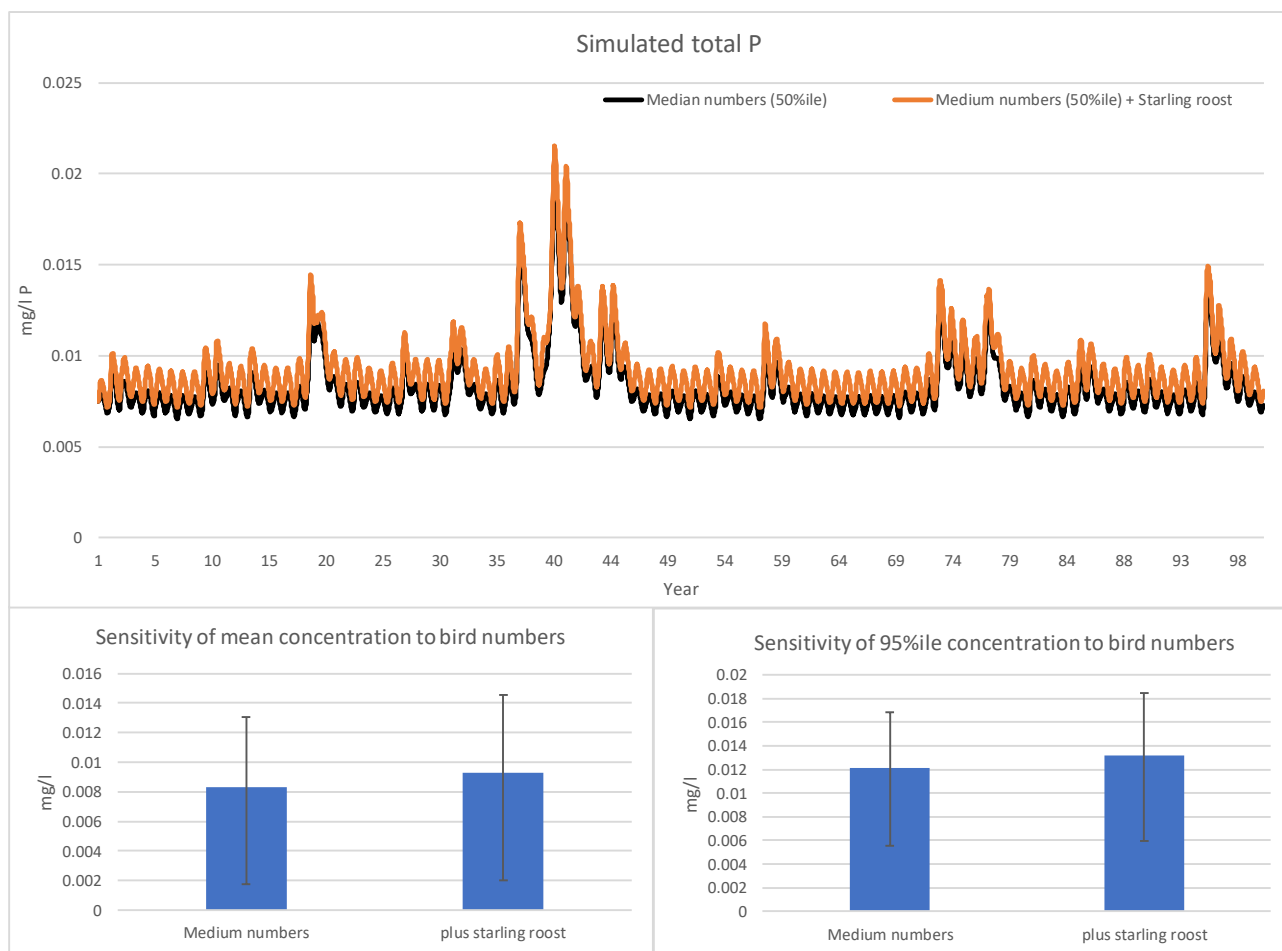


Figure 3.10 Impact of a 10,000 population winter starling roost on simulated reservoir total P concentration.

Upper graph shows time series results (for a medium settling rate). The lower graphs show the range of mean and 95%ile values for the low, medium and high settling rates.

3.5.5. Figure 3.11 shows the modelled impact of a 10,000-population winter black headed gull roost on total P concentrations in the reservoir. The change in total P concentrations is substantial indicating that a large roost of gulls would be a significant risk to water quality, shifting the reservoir toward mesotrophic conditions (Figure 3.12).

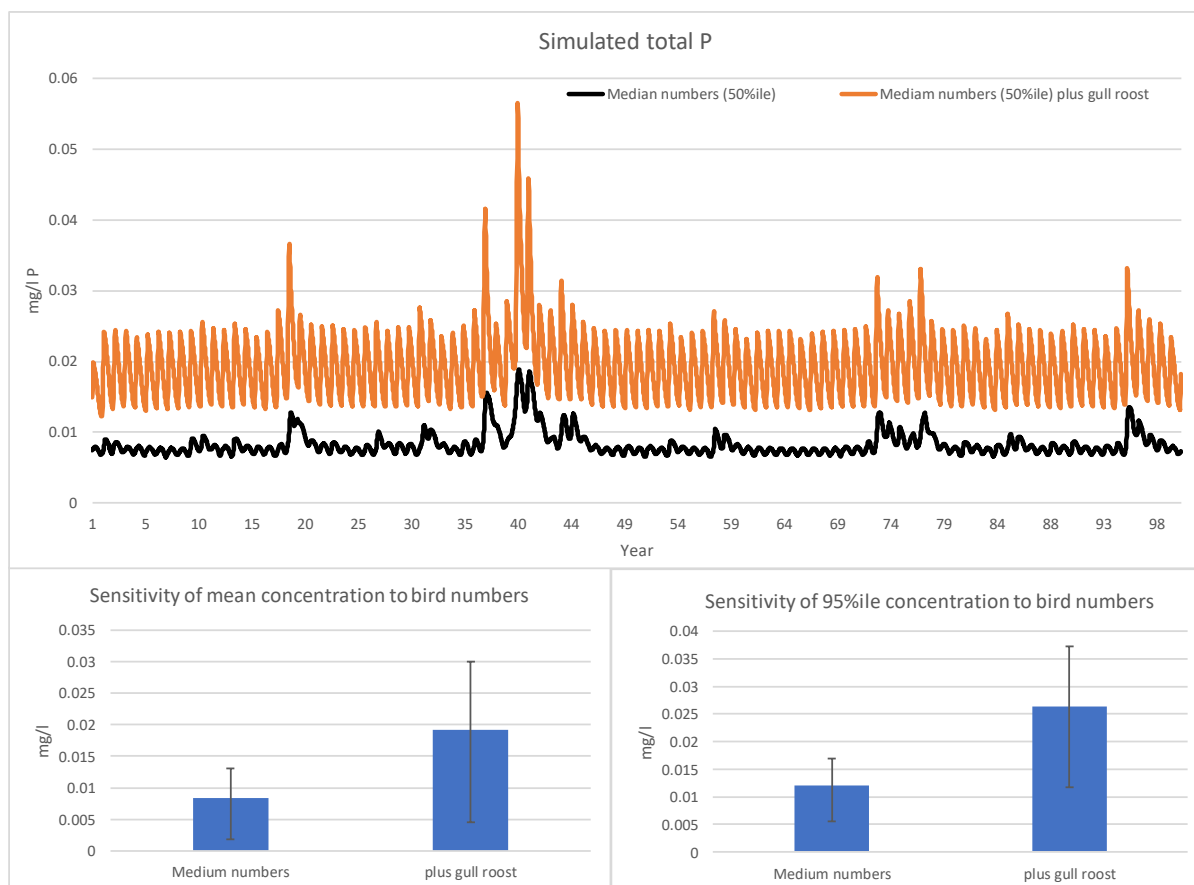


Figure 3.11 Impact of a 10,000 population black headed gull roost on simulated reservoir total P.

Upper graph shows time series results (for a medium settling rate). The lower graphs show the range of mean and 95%ile values for the low, medium and high settling rates.

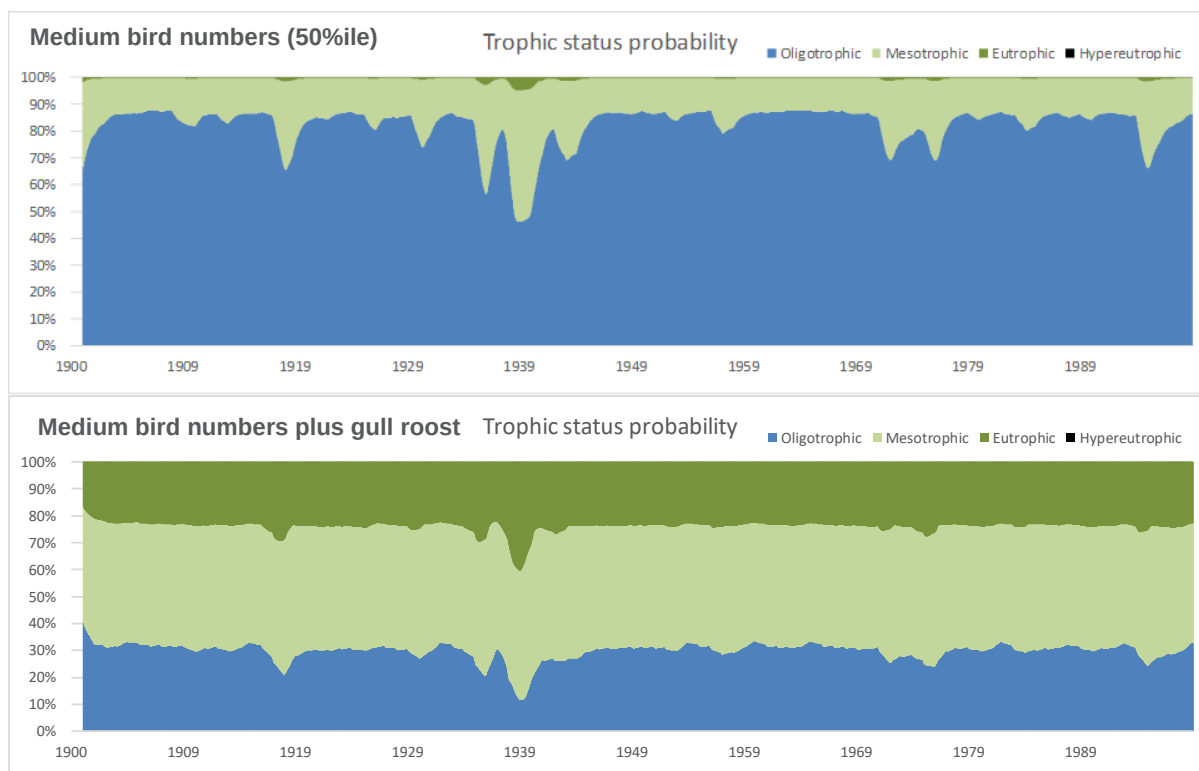


Figure 3.12 Impact of a 10,000 population black headed gull roost on trophic state of reservoir.

Total P concentrations in Bedhampton and Havant springs

3.5.6. Figure 3.13 shows the impact of modifying the total P concentrations in the Bedhampton and Havant springs on reservoir total P concentrations. The high value is a doubling of concentrations (average concentration of 0.0432 mg/l) comparable to the highest annual average observed concentrations (see Section 2.3.1). The lowest values are a halving of the spring concentrations. The results indicate that reservoir concentrations are less sensitive to Bedhampton spring concentrations than to birds, reflecting the lower contribution of the source to loads to the reservoir.

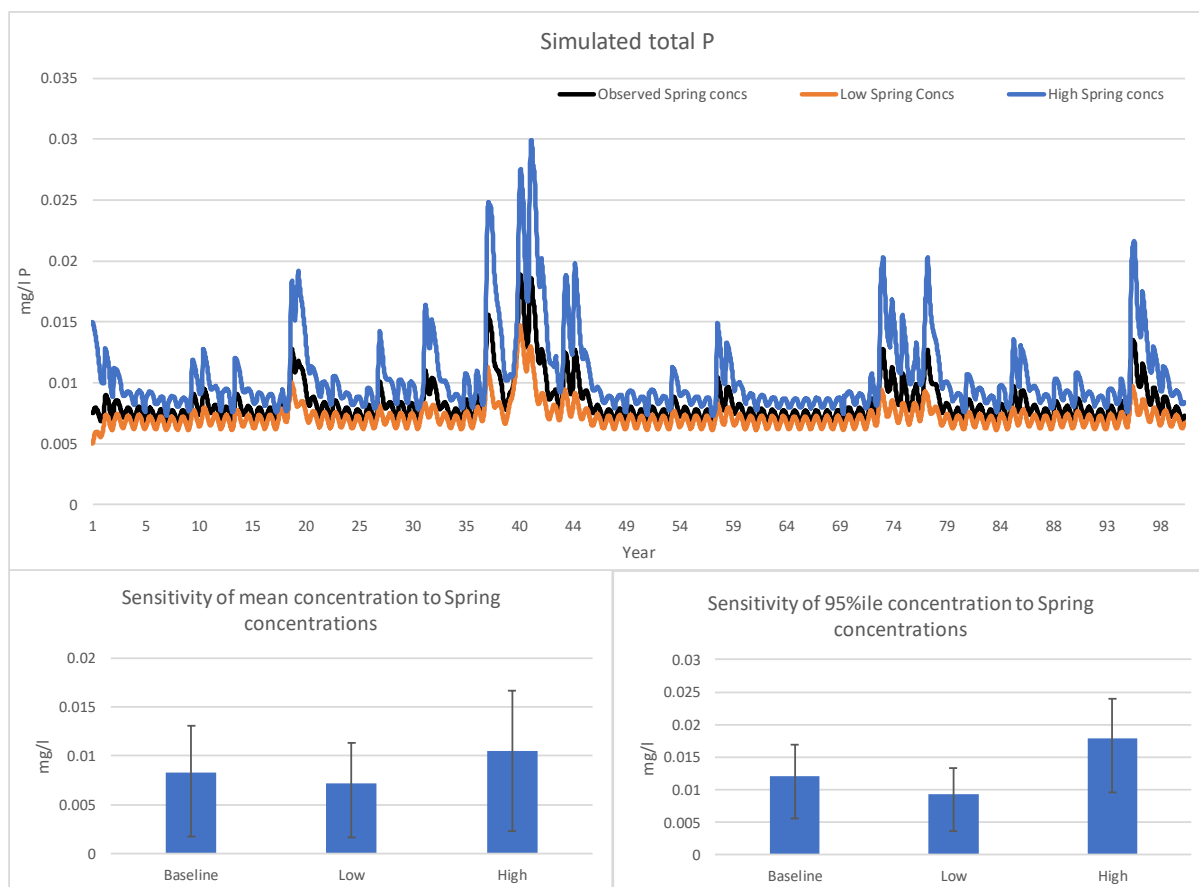


Figure 3.13 Impact of different scenarios for Bedhampton and Havant springs concentrations of total P on simulated reservoir total P concentrations

Upper graph shows time series results (for a medium settling rate). The lower graphs show the range of mean and 95%ile values for the low, medium and high settling rates.

Total P sediment interaction

- 3.5.7. Figure 3.14 shows the impact of simulating a phosphorus exchange with the sediment at a low and high rate. The higher rate returns most of the phosphorus that settles into the sediment back to the water column during the summer whereas for the lower release rate the effect is less marked. These results indicate that sediment release has the potential to substantially increase the total phosphorus concentrations in the reservoir by reducing the losses of phosphorus to the sediment. The modelling is based on a new steady state developing between the water column and the sediment over a period of 10 to 20 years. The high sediment release rate would shift the reservoir into a mesotrophic state (Figure 3.15). Sediment release in this example is based on a steady state of phosphorus concentrations in the sediment developing; legacy issues of historical inputs are not relevant for Havant Thicket Reservoir.
- 3.5.8. The behaviour of Havant Thicket Reservoir with regards to sediment exchange is difficult to predict because its mean depth of 10 m is between shallow and deep such that shallow lake processes associated with biological activity on the sediment surface will occur at a lower rate than a truly shallow lake whilst deep lake process are also unlikely to apply. These results, however, illustrate that sediment exchange is an important area of uncertainty regarding the future trophic state of the reservoir.

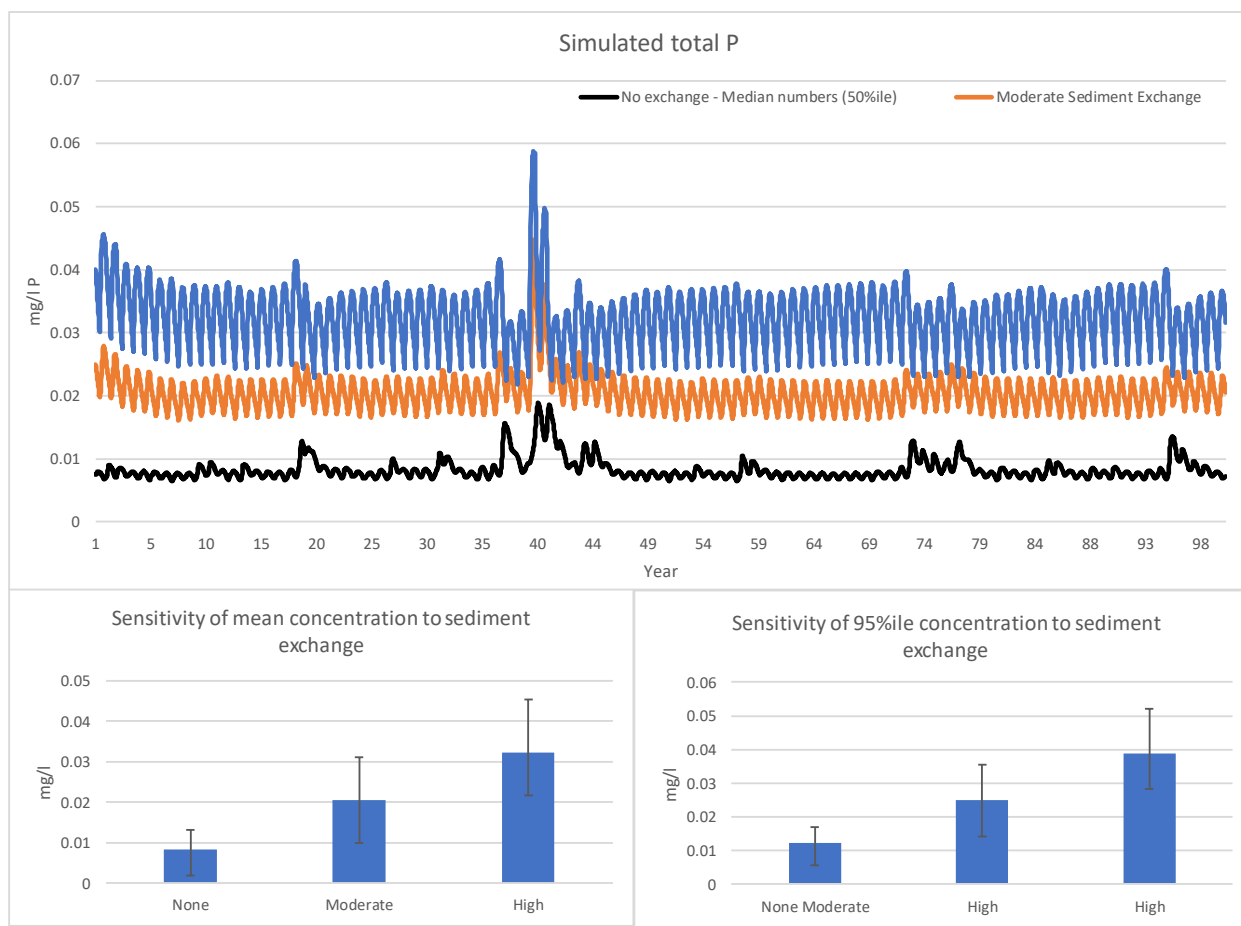


Figure 3.14 Impact of different scenarios for sediment exchange rates on simulated reservoir total P concentration.

Upper graph shows time series results (for a medium settling rate). The lower graphs show the range of mean and 95%ile values for the low, medium and high settling rates.

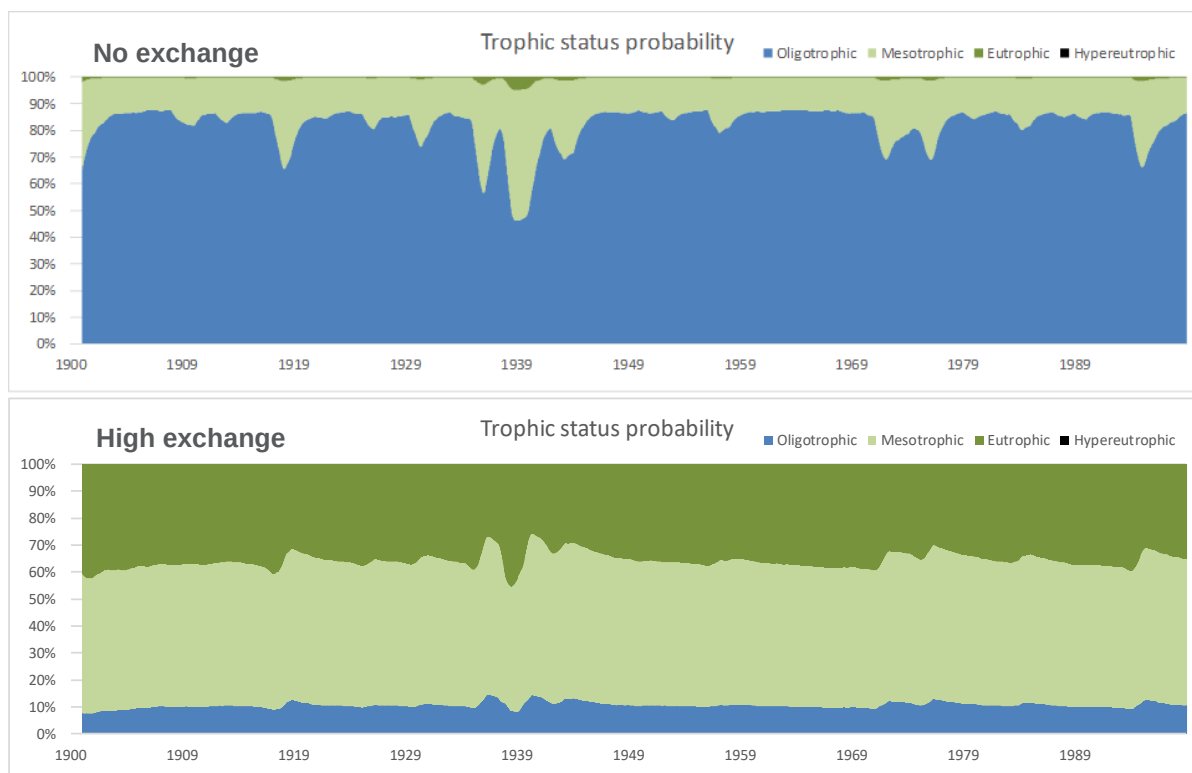


Figure 3.15 Impact of sediment exchange on predicted trophic state of the reservoir

Compensation flows

- 3.5.9. Figure 3.16 shows the impact of changes to the compensation flow from the reservoir on total P in the reservoir. The low compensation flow would match modelled stream inflows with low summer flows (close to zero). The higher compensation flow doubles the flows shown in Table 3.1. These results show that reservoir total P concentrations and trophic state are largely insensitive to the compensation flow.

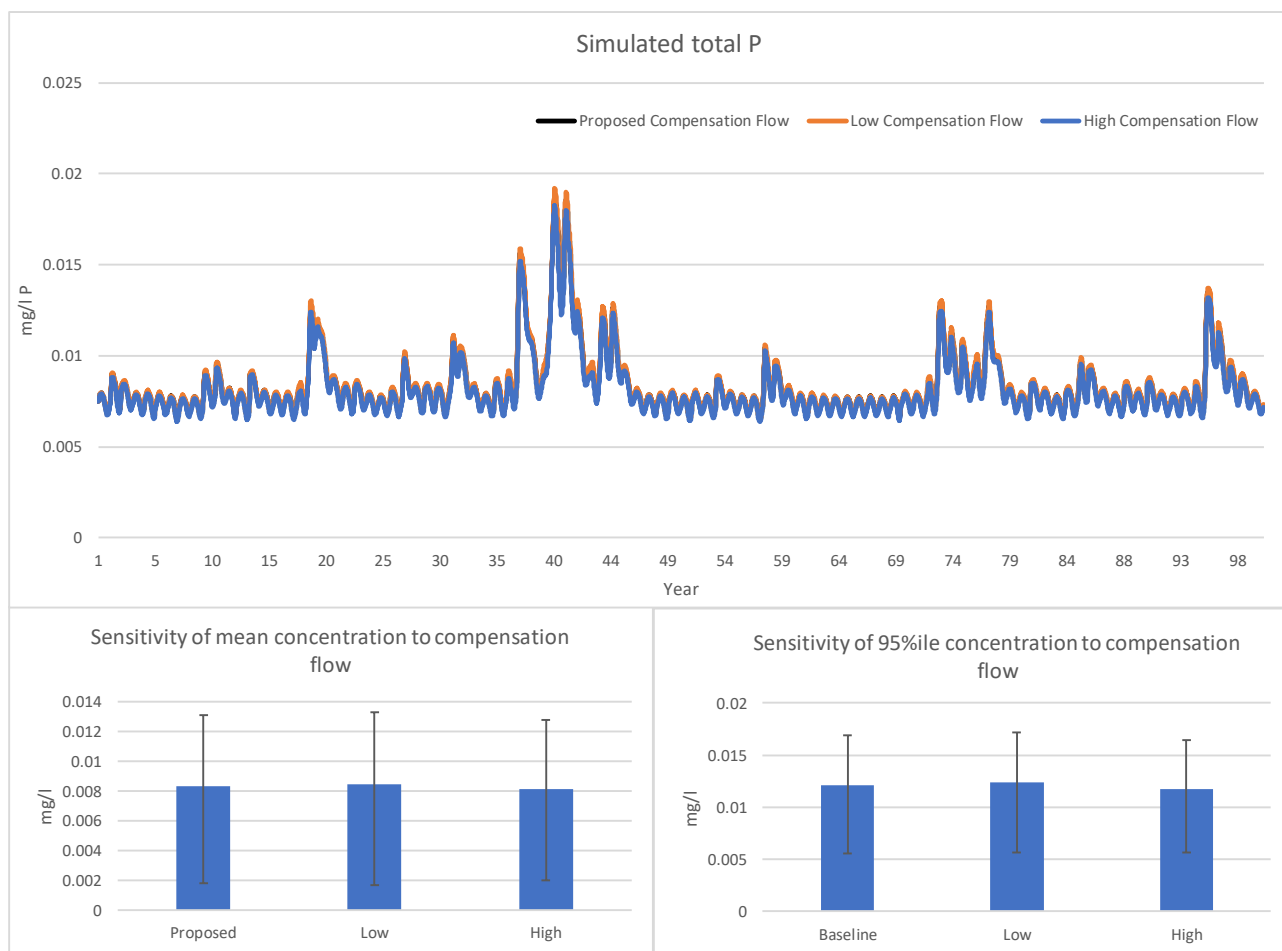


Figure 3-16 Impact of compensation flow on simulated total P in the reservoir.

Upper graph shows time series results (for a medium settling rate). The lower graphs show the range of mean and 95%ile values for the low, medium and high settling rates.

3.6. Drought Scenarios

3.6.1. Previous Pywr water resources modelling assessed the deployable output of the system for different drought return periods as set out in the Company's Drought Plan as follows:

- 1:20
- 1:40
- 1:80
- 1:200

3.6.2. Figures 3.17 to 3.20 show modelled water quality for total phosphorus for these examples of events with the return periods. These illustrates that total phosphorus concentrations increase as water levels are drawn down, representing an enhanced risk of algal bloom, and typically it takes over a year following reservoir refill for concentrations to return to more normal levels.

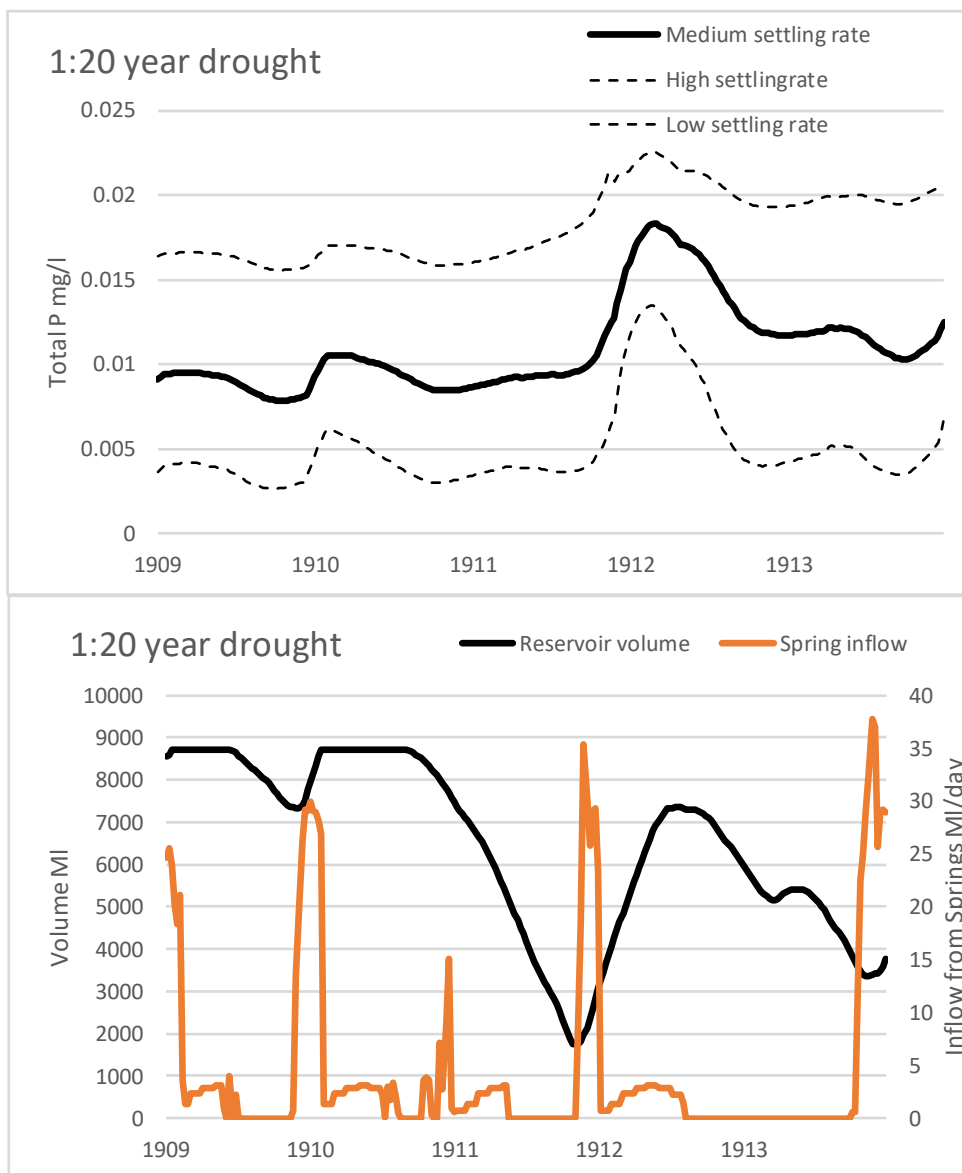


Figure 3.17 Modelled reservoir volume and pumped inputs from Bedhampton and Havant Springs (Pywr model) and total phosphorus concentrations for a 1 in 20 year drought.

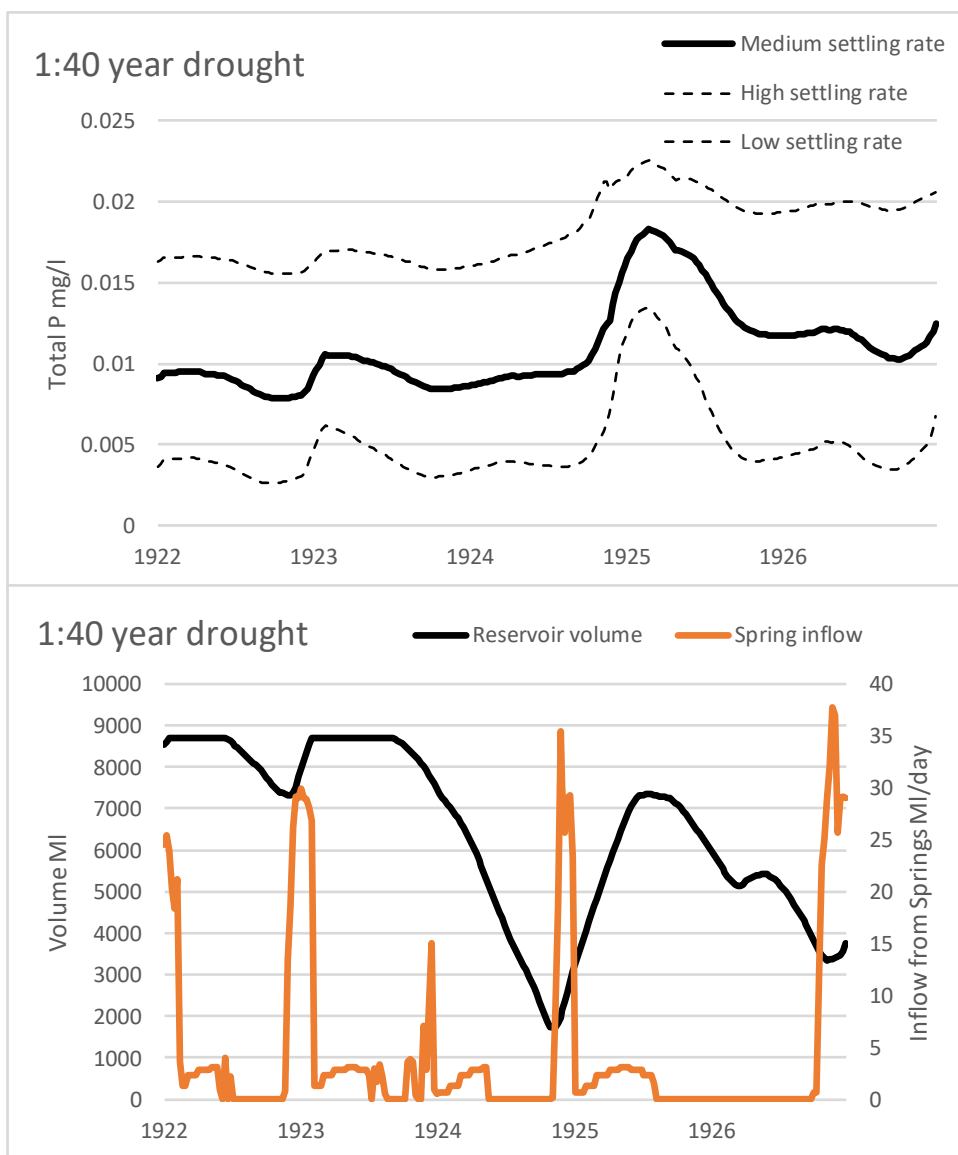


Figure 3.18 Modelled reservoir volume and pumped inputs from Bedhampton and Havant Springs (Pywr model) and total phosphorus concentrations for a 1 in 40 year drought.

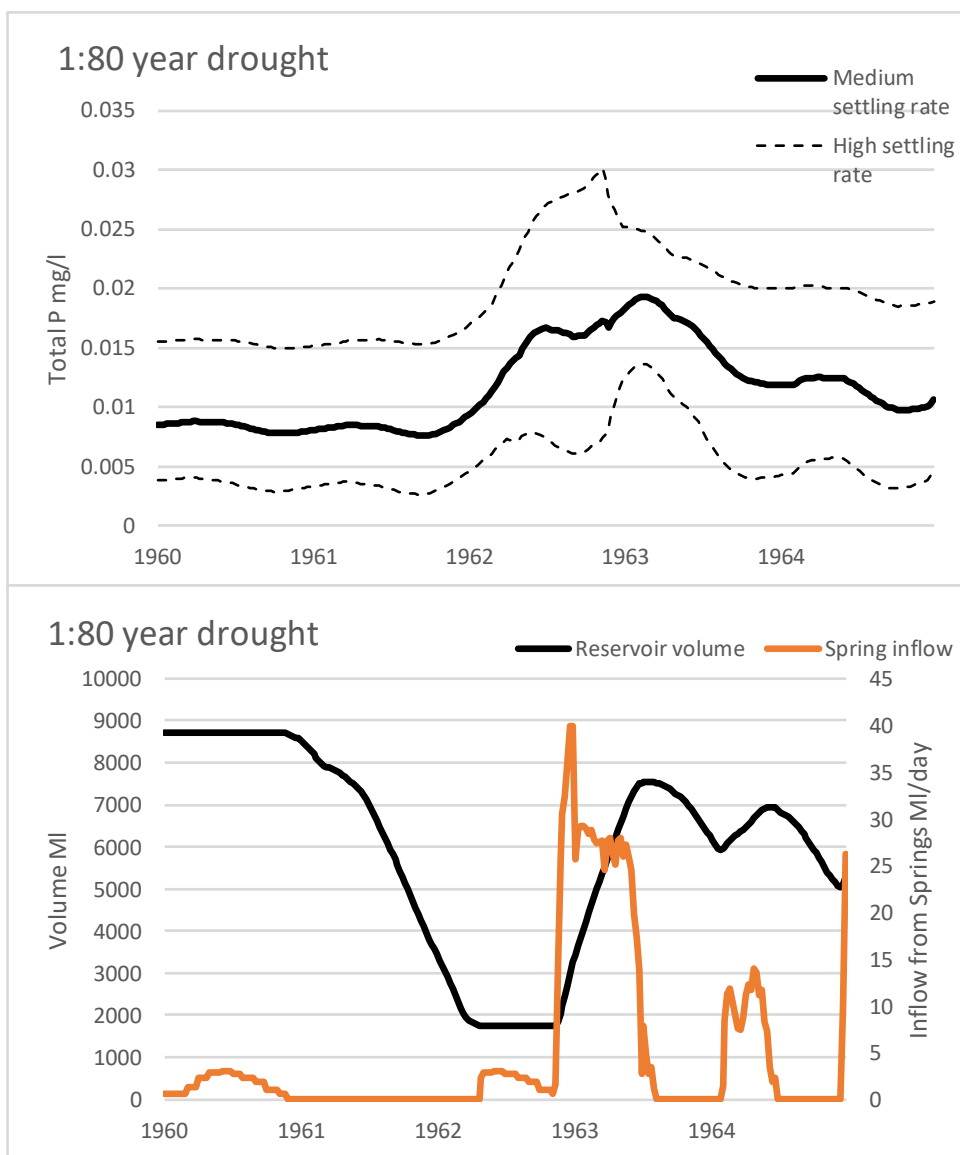


Figure 3.19 Modelled reservoir volume and pumped inputs from Bedhampton Springs (Pywr model) and total phosphorus concentrations for a 1 in 80 year drought.

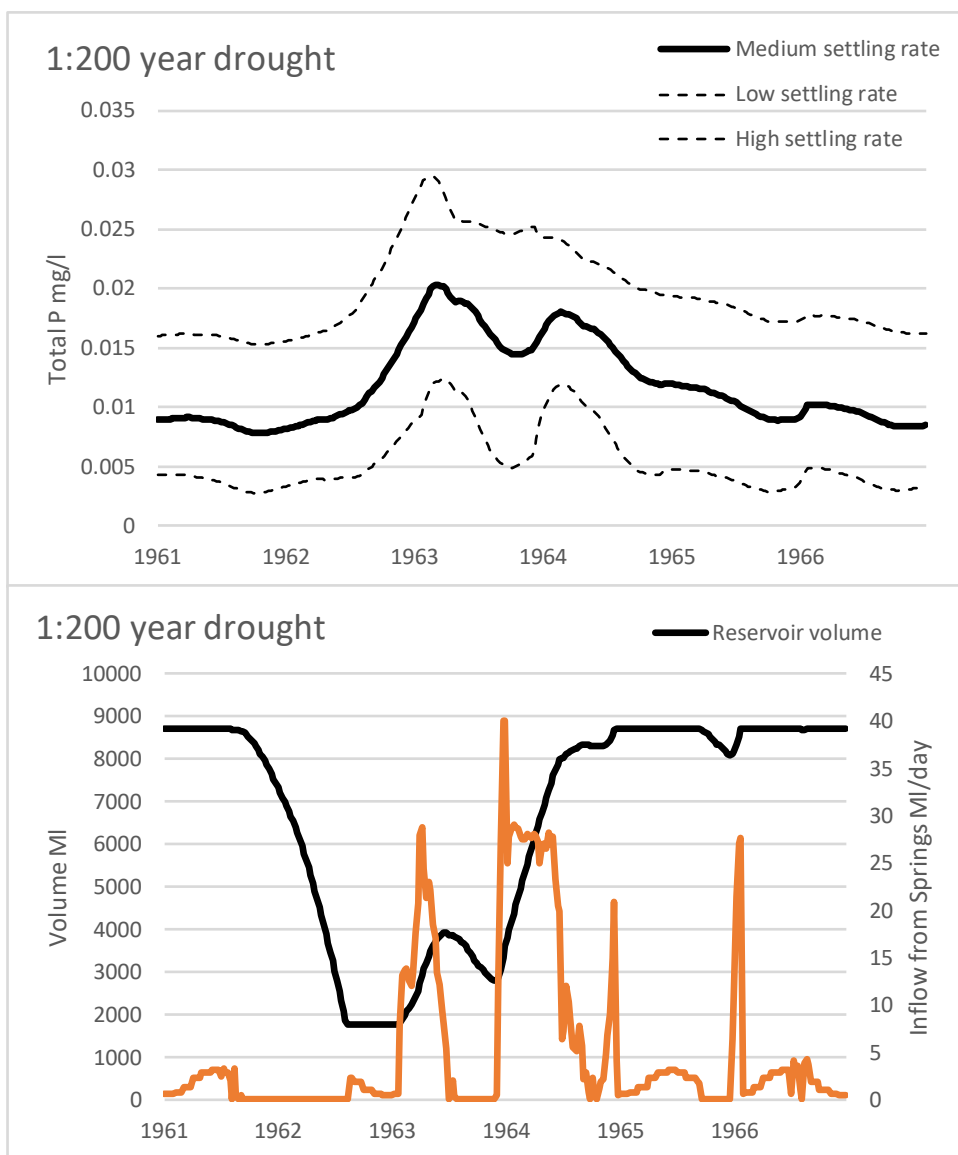


Figure 3.20 Modelled reservoir volume and pumped inputs from Bedhampton Springs (Pywr model) and total phosphorus concentrations for a 1 in 200 year drought.

3.7. Conclusions

3.7.1. Key findings from the detailed reservoir modelling are:

- The model output shows the importance of reservoir drawdown and refill on water quality. Concentrations of nutrients and algal risk increase substantially during drought periods when the reservoir is drawn down and afterwards when the reservoir is refilled. This is important because it is during these periods when the reservoir is most likely to be used when other water resources in the area are less available.
- Inputs of phosphorus from birds are estimated to make up a large proportion of all inputs, at least comparable to inputs from the Havant and Bedhampton Springs. The sensitivity analysis indicates that this is a potential risk because future bird numbers are difficult to estimate and may therefore be higher than the assumed baseline numbers. Bird numbers in the upper range of those recorded in other lowland reservoirs that are close to the sea in Southern England would result in a significant increase in trophic state and risk from algae.
- A large gull roost would result in a substantial increase in nutrient inputs to the reservoir.
- In contrast inputs of nitrogen are dominated by inputs from the Bedhampton and Havant Springs. Concentrations would be well below the drinking water standard.
- Another key area of uncertainty is the exchange of phosphorus from the sediment. High rates of release in the summer would offset the losses of phosphorus in the reservoir and increase the trophic state. It is difficult to predict these interactions with the sediment as they vary greatly between reservoirs. As the average depth of the reservoir is 10m this should mean that sediment exchange is less likely than in more typical shallow reservoirs.
- Possible short term increases in total phosphorus concentrations in the Bedhampton and Havant Springs that may have occurred historically are of less significance in terms of treatment risk.
- The reservoir spreadsheet model will allow future sensitivity testing during the outline design of the new reservoir if required.

4. Assessment of environmental impact of reservoir on receiving waters

4.1. Background

- 4.1.1. Previous analysis of potential impacts of the reservoir on downstream water quality was carried out by R.M. Walls in 2011 using a mass balance spreadsheet. Changes in downstream water quality were estimated using simple mass balance of annual average loads and flows at several locations downstream of the proposed reservoir. Observed water quality data and distributed river flows were used to calculate existing chemical loads (before the reservoir is built). Inputs in areas with no sample data were based on quality for areas with similar land use. The loads were then modified by substituting the component of the existing loads in the Riders Lane Stream with estimated output loads from the reservoir (derived from the reservoir spreadsheet model). Potentially beneficial reactions within the streams were not included because of the short distances between nodes and relatively rapid flow. Thus, components such as ammonium, phosphate and biochemical oxygen demand (BOD) were treated as conservative. Dissolved oxygen (DO) was also treated conservatively and was not considered to fall below a critical level.
- 4.1.2. In addition, further analysis was carried out on impacts on temperature, pH and nitrogen inputs to Langstone Harbour. Estimation of changes in temperature below the mixing point between the Riders Lane and Hermitage Streams were illustrated by calculating the maximum and minimum temperature in the Riders Lane Stream required to achieve the permissible change 3 °C (Standard from WFD and the Freshwater Fish Directive) based on different mixing ratios.
- 4.1.3. Changes in pH were estimated by mixing river water in the Hermitage Stream at a single location (New Road) with water from the Bedhampton Springs (using observed water quality statistics). The revised composition of cations and anions was calculated using mass balance and then revised pH estimated. Similar calculations were carried out on electrical conductivity and alkalinity.
- 4.1.4. Nitrogen loads to Langstone Harbour before and after the construction of the reservoir were assessed the outputs of the mass balance model on revised river quality at the outfall of the Hermitage Stream and the load diverted to the reservoir as a result of the transfer.
- 4.1.5. All of these calculations are contained in a single water quality spreadsheet model along with the model of reservoir water quality outlined in Sections 2.1, 2.2 and 3.1 of this report.
- 4.1.6. The existing calculations, outlined above, were updated with recent observed water quality data (for Bedhampton – data from 2011–2018, local streams – data from May 2018 to May 2019, Hermitage Stream at New Road – data from 2011 – 2018– Section 1.4).
- 4.1.7. The approach was then reviewed by Atkins and the Environment Agency National Modelling Team (Paul Davidson) which recommended minor changes on the pragmatic basis that water quality in the Bedhampton and Havant Springs is generally better than water quality in the Hermitage Stream, so the impacts are more likely to be positive than negative. The agreed changes are listed below which were implemented in the revised modelling spreadsheet (also containing the revised reservoir model):
- Incorporation of revised loads from the reservoir using outputs from the new reservoir model.
 - Incorporation of variable compensation flows into the calculations.

- Transfers of water from the Bedhampton Springs to the reservoir based on the Pywr water resource model outputs.

4.1.8. Following the first issue of this modelling report, further comments from the Environment Agency were provided. They also requested some additional analysis. This analysis is presented in a separate Addendum at the end of this report but also referenced in this Section.

4.2. Temperature

4.2.1. Figure 4.1 reproduces the key analysis by R.M. Walls 2011 which shows the temperature required in the Riders Lane stream to result in a less than a 3°C difference (the Water Framework Directive standard for classification as applied by UKTAG guidance; defined by the 98th percentile value) in the Hermitage Stream downstream of the confluence.

4.2.2. With a mixing ratio of 1:1, a temperature difference up to 6°C will be compliant with the prescribed change. For example, when the Hermitage Stream is 10°C and the Riders Lane Stream is between 4°C and 16°C. However, the flow in the Riders Lane stream is substantially lower than the Hermitage Stream because it has a much smaller catchment (Walls estimates that flows in the Riders lane Stream are generally 36% of those in the Hermitage Stream). The inference is that, although reservoir outputs are not considered thermal discharges, it is very unlikely that the compensation flow discharge will result in a 3°C change after mixing.

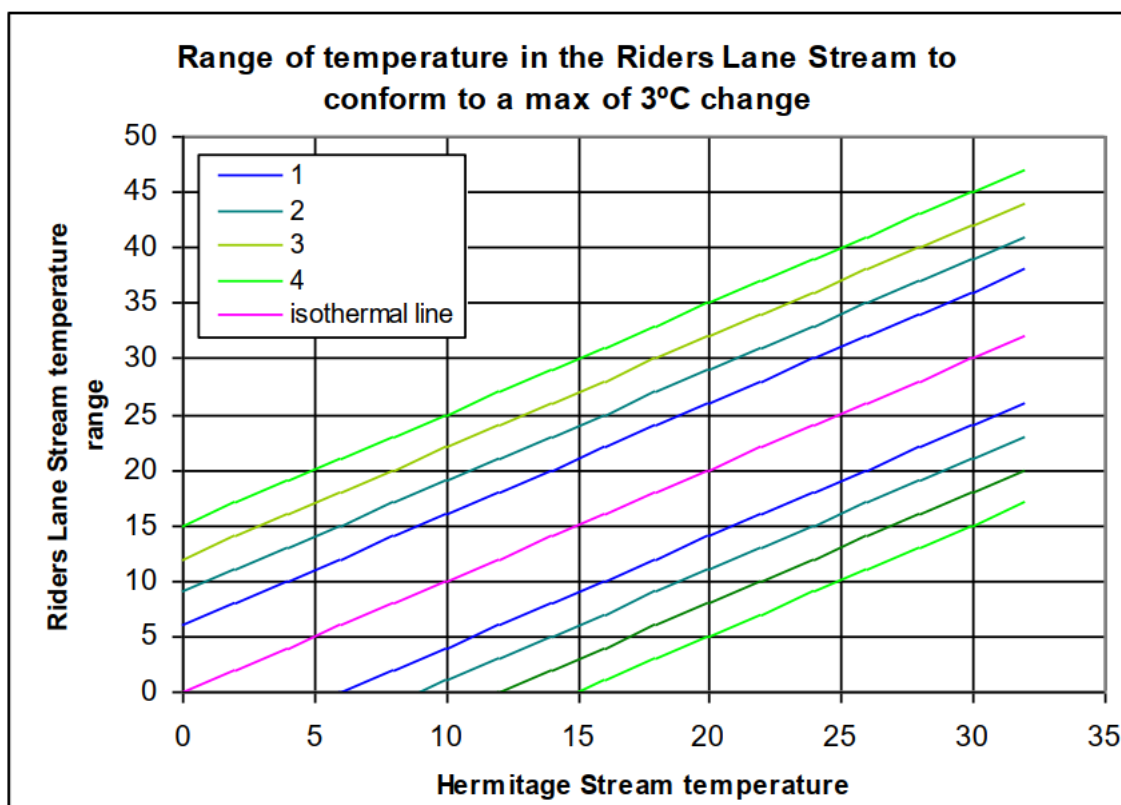


Figure 4.1 Temperature range of the Riders Lane Stream that will not cause the Hermitage Stream temperature to change by more than 3°C at mixing ratios of 1, 2, 3 and 4 (reproduced from Walls 2011)

4.2.3. Whilst the above analysis indicates that the construction of the reservoir is unlikely to result in ecologically significant change in temperature in downstream waterbodies, the Environment Agency requested that the analysis should be modified to estimate the impact on 98th percentile river temperatures, because the WFD impact threshold is a 3°C increase in this metric with an absolute value of 28°C .

- 4.2.4. An analysis to estimate the impact of the building of the reservoir on the 98th percentile water temperature in the rivers downstream is presented in the Addendum at the end of the document. The analysis estimates the impact immediately downstream of the reservoir in the Riders Lake Stream and below its confluence with the Hermitage Stream (see Appendix A; Catchment Map). The results of this analysis support the initial findings, presented above, that the change in temperature in the Hermitage Stream is highly unlikely to exceed 3°C. Although it is possible that a 3°C increase might occur in the Riders Lane Stream, in reality, there is generally no flow in the stream in mid-summer when this might happen. Clearly, the compensation flow regime is of relevance to this; if compensation flows occur in the summer, the comparison is with a situation in which generally there is no flow; if no compensation flows at this time of year, no change will occur compared to the current situation. The absolute 98th percentile threshold of 28°C would not be exceeded in any circumstances.

4.3. Water quality in the Hermitage Stream

Outputs from mass balance calculations

- 4.3.1. Figures 4.2 and 4.3 compare the predicted water quality for key parameters downstream of the reservoir in the Riders Lane Stream, immediately below the confluence between the Riders Lane Stream and in Hermitage Stream, as a percentage change before and after the reservoir is built (Appendix B provides a table showing calculated values). Changes further downstream would be expected to be less because dilution of the reservoir water increases as other inputs of water occur to the stream.
- 4.3.2. Most changes are small and represent an improvement in quality because concentrations are lower in the Bedhampton and Havant Springs water than the ephemeral streams and watercourses downstream of the reservoir.
- Parameters associated with anions and hardness increase downstream of the reservoir as a result of greater hardness concentrations within the spring water compared to stream flow concentrations (i.e. calcium, electrical conductivity, total dissolved solids and alkalinity). These changes diminish downstream and would only be small in the Hermitage Stream. These changes are not considered to be significant. Some ecological benefits might result from the increase in calcium particularly species that require calcium for their exoskeletons (e.g. molluscs and crustaceans).
 - Phosphorus concentrations downstream of the reservoir are reduced after the reservoir is built, due to low predicted concentration in the reservoir compared to the receiving waters
 - Downstream nitrate concentrations in the Riders Lane and Hermitage Streams increase reflecting the greater concentrations of nitrate in the Bedhampton and Havant Springs compared to the surface waters. These changes diminish downstream and would only be small in the Hermitage Stream. These changes are not considered to be significant.
 - Concentrations of manganese and iron which are relatively high in the Riders Lane Stream decline because of dilution with spring water from the Bedhampton Springs
 - For some chemicals such as dissolved oxygen and turbidity, the mass balance approach is problematic because they will be more affected by river flows than input loads. However, as long as the river flow regime remains largely unchanged as planned, they are unlikely to change substantially. The reservoir will tend to decrease turbidity and suspended solids because will act as a stilling basin for sediment washed in from the upper catchment, allowing sediments to settle out and buffering transient events. The construction of the retained wetland area along the northern shore of the reservoir will provide additional benefits in this respect. The growth of algae in the reservoir will, however, tend to increase suspended solids

and turbidity during the summer when they will tend to be low in the rivers of lower flows.

Estimation of changes in pH

- 4.3.3. Further calculations of changes in pH have not been carried out because the Environment Agency did not require further work in this area following the review of the previous calculations by R.M. Walls. This showed, very little change in pH is likely to occur.

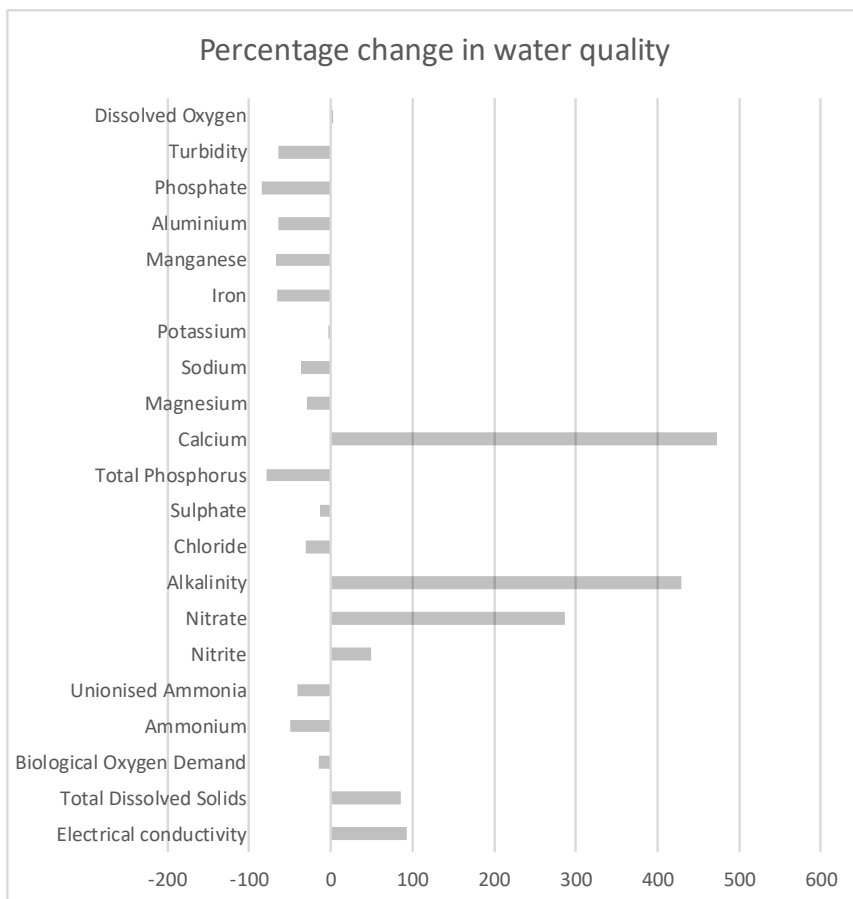


Figure 4.2 Simulated changes to water quality in the Riders Lane stream

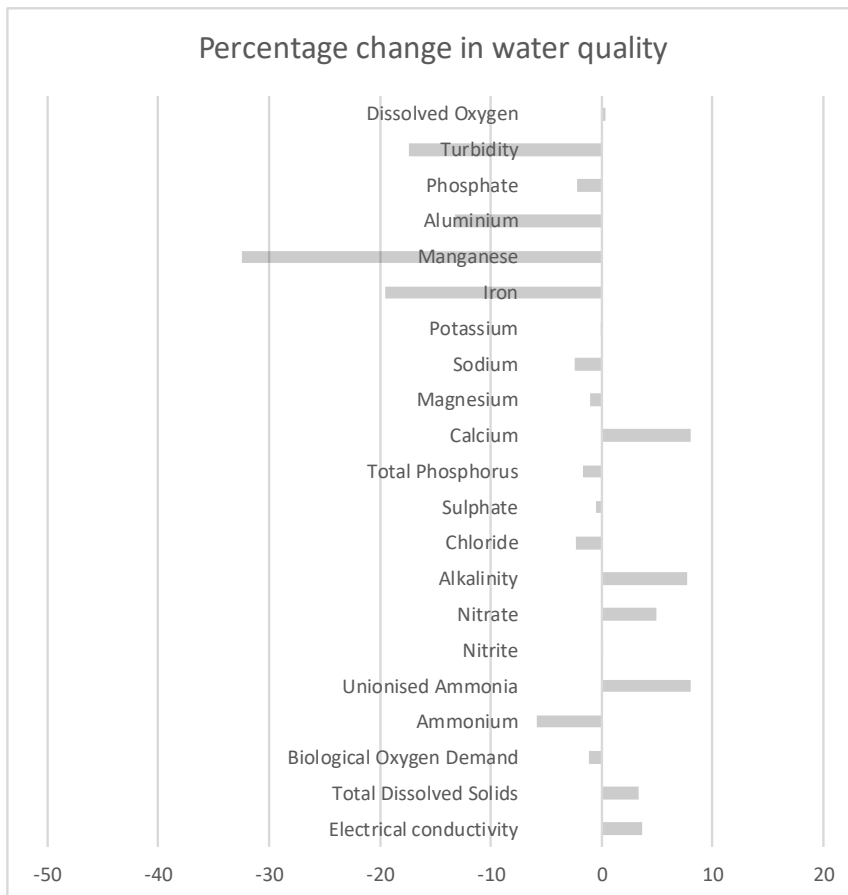


Figure 4.3 Simulated changes to water quality in the Hermitage stream at New Road

4.4. Water Framework Directive Status

- 4.4.1. The overall 2016 classification of Hermitage Stream is Moderate; this is driven by Moderate supporting elements, Biological quality elements and physico-chemical quality elements. The only physico-chemical element to not achieve High/ Good status is Phosphates.
- 4.4.2. The output of the mass balance calculations is that water quality downstream of the reservoir will improve. Consequently, there is no risk of a deterioration in Water Framework Directive Status. The only chemicals that show a substantive increase in concentrations are calcium, nitrate, nitrite, alkalinity, electrical conductivity and total dissolved solids. None of these determinands affect WFD classification or are specific pollutants or priority hazardous substance so have no implications for WFD status.
- 4.4.3. Changes in the key chemicals that affect WFD classification are considered below:

Phosphorus

- 4.4.4. Ortho-phosphate concentrations are predicted to change less than 1% downstream of the reservoir for the baseline reservoir model run (middle losses and bird numbers) and no change in WFD status results. In the Riders Lane Stream the status is High (below 45 µg/l – the High to Good boundary at this location) and in the Hermitage Stream at New Road the status is Moderate (below 200 µg/l – the Moderate to Poor boundary at this location). The classifications would not change as a result of outflows from the reservoir.
- 4.4.5. The changes in ortho-phosphate concentrations that would occur for the other reservoir sensitivity model runs are presented in the Addendum (part 2). For different sensitivity runs, the downstream concentrations vary but would all be less than current concentrations.

- 4.4.6. A 500% increase in alkalinity has been predicted by model outputs. Because phosphate standards are derived from alkalinity and altitude, the increase in alkalinity will make orthophosphate standards less stringent, therefore a change in status may be observed at some points on the river.

Ammonia

- 4.4.7. Ammonia mean concentrations are predicted to decline by 49% immediately downstream of the reservoir in the Riders Lane Stream and 6% in the Hermitage Stream and New Road. The mass balance calculations on water quality do not allow a comparisons of percentile concentrations with the WFD standards for ammonia (a time series or Monte Carlos type model such as SIMCAT would be required for this). However, a reduction in the mean value would almost certainly result in a reduction in the 90th percentile value. The 90th percentile values for ammonia in the Ryders Stream and New Road over the period 2008–2019 were 0.06 mg/l N and 0.08 mg/l N, respectively (Portsmouth Water data) compared to the WFD High status standard of 0.3 mg/l. Bearing in mind that concentrations are predicted to reduce, downstream impacts of the reservoir are unlikely to be of concern.
- 4.4.8. Changes in unionised ammonia concentration are also predicted to be small at New Road with a small increase (8%) in the mean concentration that would result from a small increase in pH. Downstream of the reservoir, a greater increase is likely because of elevated pH in the reservoir associated with biological activity (200% increase based on an upper estimate of reservoir pH of 8.4).
- 4.4.9. As discussed above, the mass balance analysis presented in this report does not provide a measure of the 90th percentile value for unionised ammonia. However, applying the existing observed 90th %ile ammonia value, the pH would need to be increased to over 9 to produce an unionised ammonia value greater than the 21 µg/l Freshwater Fishery standard. At Ryders Lane the equivalent pH value is also greater than 9. Since such high pH values are highly unlikely to occur and ammonia concentrations are predicted to decrease, exceedance of the unionised ammonia standard must also be highly unlikely.
- 4.4.10. A further complication is that the concrete banks of the Hermitage Stream in Havant are believed to increase pH which is likely to be of greater significance than outflows from the reservoir that only accounts for a small proportion of the flows at this location.

Dissolved oxygen and BOD

- 4.4.11. The mass balance approach followed is not well suited to estimate changes in dissolved oxygen concentration because this is dependent on a range of other influences including re-aeration, sediment oxygen demand and macrophyte growth which are not taken into account. However, BOD is predicted to decline by 15% downstream of the reservoir and 1% at New Road so any change is likely to be an improvement. The WFD status for dissolved oxygen at both locations is predicted to be High before and after the development of the reservoir.
- 4.4.12. A caveat, however, needs to be raised that this assumes that the oxygen concentration released by the reservoir will be high, close to 100% saturation. This assumption is reasonable unless the reservoir stratifies and low oxygen in deeper water moves to the point where the compensation water is taken; an unlikely scenario. This risk will be mitigated by having different draw off levels and can be mitigated further by installation of an artificial aeration system into the reservoir.
- 4.4.13. Oxygen levels and BOD have been predicted without attempting to estimate self-purification and thus indicate the worst case. In reality it is likely that BOD should be reduced downstream once the reservoir is in place due to the greater opportunity for oxidation of organic matter whilst water is resident in the reservoir.

Specific pollutants

- 4.4.14. Model outputs are available for two Specific Pollutants iron and manganese. For both of these chemicals, a substantial decline of these chemicals is predicted immediately downstream of the reservoir and at New Road (iron 66% and 20% reduction, manganese 68 and 32% reduction at the two locations).

- 4.4.15. The prescribed concentration for Iron is for the dissolved fraction (existing data is for total) whereas for manganese it is for the bio-available fraction. Further information and analysis would, therefore, be required to assess current compliance. The changes are, however, an improvement so the only possible outcome would be no change or an improvement in compliance.

Summary

- 4.4.16. Overall, therefore, the development of Havant Thicket Reservoir is predicted to result in an improvement in water quality and no change in WFD chemical status in the receiving water courses will result.
- 4.4.17. The large volume of water in the reservoir will ensure greater stability in water quality and any changes will occur slowly. This will buffer the effects of the short-term changes in water quality which currently occur.
- 4.4.18. Having established through the high level screening model exercise that the reservoir is not likely to have any significant adverse impact on water quality in the Hermitage Stream catchment, and that it is more likely to provide benefits to water quality, it is considered that this modelling report should meet the information requirements necessary to support the proposed outline / hybrid planning application.

4.5. Nitrogen inputs to Langstone Harbour

- 4.5.1. Following the construction of the reservoir, the transfer of nutrients from the surface water catchment to Langstone Harbour will remain largely unchanged apart from nutrients released from the small natural catchment of the reservoir that will be intercepted by the reservoir. Of greater significance, part of the current flow from the Bedhampton and Havant Springs to the harbour (along with nutrients) will be transferred to Havant Thicket Reservoir. Once in the reservoir, part of the nutrients will be transferred to the water treatment works and part will be released back to the catchment via compensation releases. Losses of nutrients will also occur within the reservoir by denitrification. Overall, therefore, inputs of nutrients from the Springs to Langstone Harbour will be reduced because only some of these redirected loads will return to the harbour. The existing nitrate concentration in the spring water is relatively high (average 7.6 N mg/l) so nitrogen loads from this source are significant in terms of overall N loads to the harbour.
- 4.5.2. A detailed analysis of the impact of the reservoir on nutrient (N and P) to Langstone Harbour is presented in the Addendum to this report (Part 3). This detailed analysis was prompted by the planning requirement from Havant Borough Council to undertake a nutrient budget of the scheme and replaces previous analysis that used updated spreadsheet calculations, initially developed by R.M. Walls.
- 4.5.3. This analysis shows how nitrogen inputs to the harbour from the Hermitage Stream catchment⁴ would change during the 3-year period of reservoir fill with an average daily reduction of 50 kg N/day. Under baseline conditions when the reservoir is kept full each year to offset evaporation losses, but not used for public water supply, an average daily reduction of 7.1 kg N/day to the harbour is estimated. Over the long term, including periods when the reservoir is drawn down during drought periods and refilled, an average daily reduction of 16 kg N/day to the harbour is estimated. This operational reduction would vary substantially from year to year, depending on how much water is pumped to the reservoir. In all cases, however, the construction of the new reservoir which will help protect the condition of the SAC and SPA sites.

⁴ Nitrogen inputs to the harbour related to drainage of water from the catchment directly to the harbour and from the Hermitage Stream catchment below New Road are not included in the calculations.

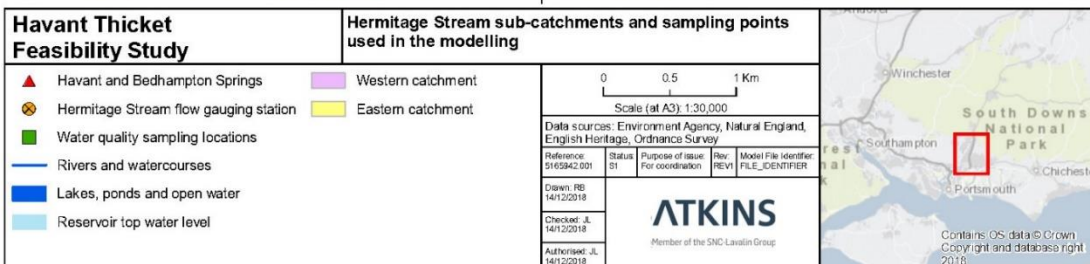
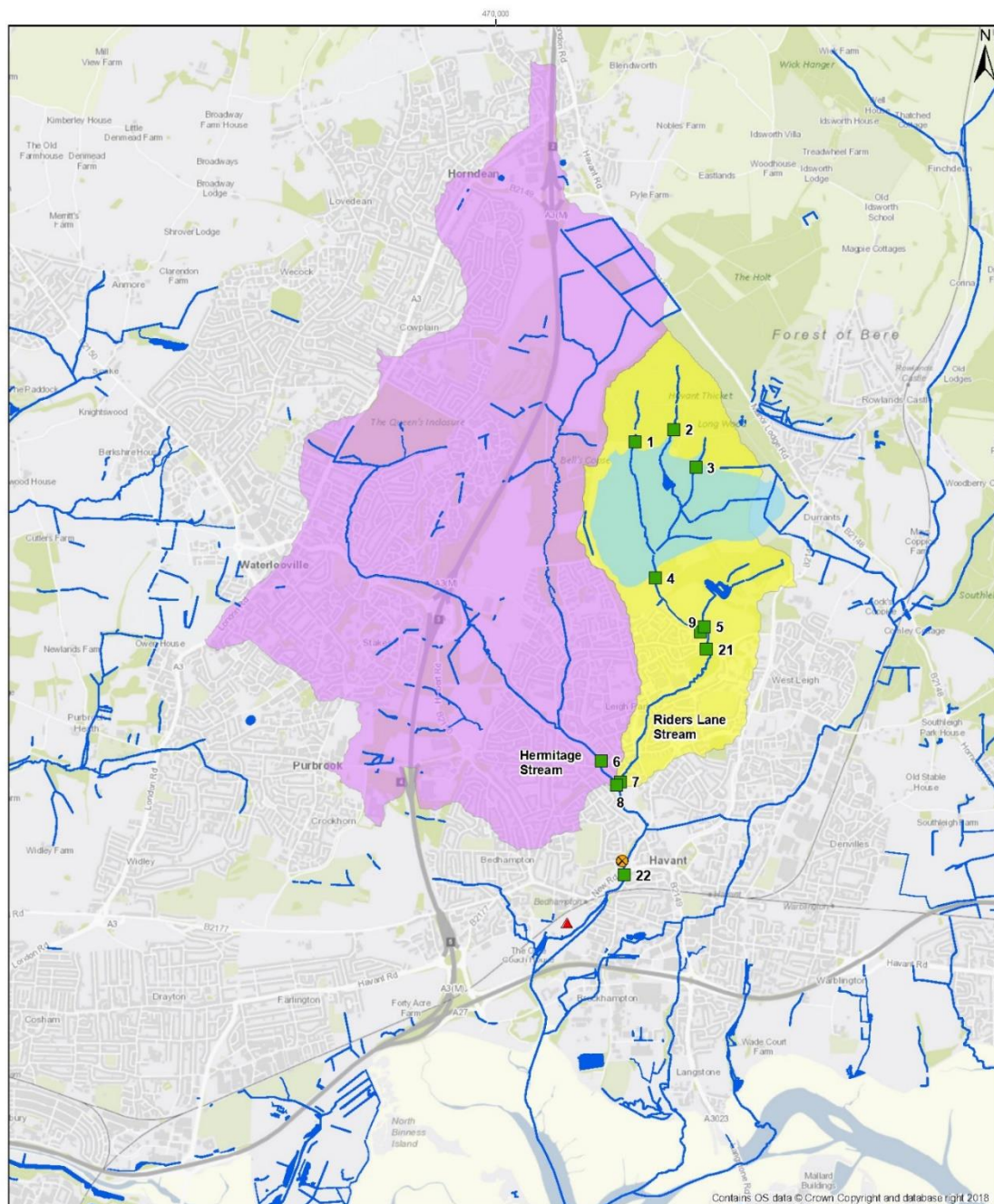
5. Bibliography

- Amaral, S. D., Brito, D., Ferreira, M. T., & Neves, R. (2013). Modeling water quality in reservoirs used for angling competition: Can groundbait contribute to eutrophication? *Lake and Reservoir Management*, 29(4), 257-269.
- Arlinghaus, R., & Mehner, T. (2003). Socio-economic characterisation of specialised common carp (*Cyprinus carpio* L.) anglers in Germany, and implications for inland fisheries management and eutrophication control. *Fisheries Research*, 61(1-3), 19-33.
- Arlinghaus, R., & Niesar, M. (2005). Nutrient digestibility of angling baits for carp, *Cyprinus carpio*, with implications for groundbait formulation and eutrophication control. *Fisheries Management and Ecology*, 12(2), 91-97.
- Atkins. (2017). 5160304-F-DOC-018 - Farlington Solution Report Rev 1.0 (supported by 5160304-F-CAL-013 Farlington Process Calculations).
- Atkins. (2018). *Havant Thicket Reservoir - Deployable Output Assessment and Review of Scheme Costs: Phase 2*. Atkins.
- Atkins. (2019). *Havant Thicket Early Start Studies: Study 4 Water Quality Report*. Atkins - for Portsmouth Water.
- Atkins. (2019). *WRc CT Toolbox for Direct Filtration, UV 40mJ/cm² + CT5*.
- Brown, A. (2012). The national angling survey 2012 – survey report. *The national angling survey 2012 – survey report*. Available at: http://www.resources.anglingresearch.org.uk/sites/resources.anglingresearch.org.uk/files/National_Angling_Survey_Report_2012.pdf.
- Brown, M. (2018). Email: RE: S.818 - Disinfection CT Review Project - site power supplies - original email sent 11-09-18, rec from G Jones 21-9-18.
- Deschesne, M., & Soyeux, E. (2007). Assessment of source water pathogen contamination. *Journal of Water and Health*, 05(1), 39-50.
- Dobrowolski, K. A., Halba, R., & Nowicki, J. (1976). The role of birds in eutrophication by import and export of trophic substances of various waters. *Limnologica*, 279(1), 133-147.
- Drinking Water Inspectorate. (2010, 02 05). *Water safety plans*. (Drinking Water Inspectorate) Retrieved 03 07, 2019, from <http://www.dwi.gov.uk/stakeholders/water-safety-plans/index.htm>
- Environment Agency. (2019, 05 2018). *Guidance: Reservoir discharges: consents, permits and risk assessments*. (UK Government) Retrieved 03 07, 2019, from <https://www.gov.uk/guidance/reservoir-discharges-consents-permits-and-risk-assessments>
- Gere, G., & Andrikovics, S. (1992). Effects of waterfowl on water quality. *Hydrobiologia*, 243(1), 445-448.
- Kawczynski, E. (1995). *Elizabeth Kawczynski, Advances in Taste-and-odor Treatment and Control, edited by I. H. Suffet, Joël Mallevialle*. Denver CO: American Water Works Association Research Foundation, [1995].
- Keates, R. (2017). File: On site power generation.xlsx - rec through PR19 support project summer 2017.
- Leentvar. (1967). Observations in guantrophic environments. *Hydrobiologia*, 29(3-4), 441-489.
- M, S., PJ, J., & E, J. (2001). Retention and internal loading of phosphorus in shallow, eutrophic lakes. *Scientific World Journal*, 1, 427-42.
- Manny, B. A., Johnson, W. C., & Wetzel, R. G. (1994). *Nutrient additions by waterfowl to lakes and reservoirs: predicting their effects on productivity and water quality Aquatic Birds in the Trophic Web of Lakes*. Springer.
- Marion, L., Clergeau, P., Brient, L., & Bertru, G. (1994). *The importance of avian-contributed nitrogen (N) and phosphorus (P) to Lake Grand-Lieu, France*. Aquatic Birds in the Trophic Web of Lakes pp 133-147. Part of the Developments in Hydrobiology book series (DIHY, volume 96).
- Medema, G., & et al. (2006). *Quantitative Microbial Risk Assessment in the in the Water Safety Plan, MicroRisk project*. European Commission. Retrieved 12 13, 2018
- Meinikmann, K., Hupfera, M., & Lewandowskia, J. (2015). Phosphorus in groundwater discharge – A potential source for lake eutrophication. 524, 214-226.
- Mills, M. (2019). Email: Farlington washwater plant - rec 31-1-19.
- Moss, B., & Leah, R. T. (1982). Changes in the ecosystem of a guantrophic and brackish shallow lake in eastern England: potential problems in its restoration. *Internationale Revue der Gesamten Hydrobiologie*, 7(5), 625-659.

- Niesar, M., Arlinghaus, R., Rennert, B., & Mehner, T. (2004). Coupling insights from a carp, *Cyprinus carpio*, angler survey with feeding experiments to evaluate composition, quality and phosphorus input of groundbait in coarse fishing. *Fisheries Management and Ecology*, 11(3-4), 225-235.
- OECD. (1982). *Eutrophication of Waters: Monitoring, Assessment and Control*. Paris.
- OECD. (1982). *Eutrophication of Waters: Monitoring, Assessment and Control*. Paris.
- P.J.Johnes, B. G. (1996). The determination of total nitrogen and total phosphorus concentrations in freshwaters from land use, stock headage and population data: testing of a model for use in conservation and water quality management. *Freshwater Biology*, 36, 451-473.
- Portnoy, J. (1990). Gull contributions of phosphorus and nitrogen to a Cape Cod kettle pond. *Hydrobiologia, Hydrobiologia*(1-2), 61–69.
- Portsmouth City Council. (2015). *Candidate Local Wildlife Sites 2015 update - Report supporting meeting with Cabinet Member for Planning, Regeneration and Economic Development on 10 March 2015*.
- Portsmouth Water. (2014). Drawing: 58-06E Bedhampton No.2 WTW - Site Plan Rev E dated 02-12-14.
- Portsmouth Water. (2018). *Draft Water Resource Management Plan 2018*.
- Portsmouth Water. (2018). HTWSR Water Quality Study_(Study 4) Scope of Work_v4.
- Portsmouth Water. (2019). WQ110301 Disinfection Policy.
- Post, D. M., Taylor, J. P., Kitchell, J., Olson, M. H., Schindler, D. E., & Herwig, B. R. (1998). The Role of Migratory Waterfowl as Nutrient Vectors in a Managed Wetland. *Conservation Biology*, 12(4), 910-920.
- R.M.Walls. (n.d.).
- R.M.Walls. (2011). *Havant Thicket Winter Storage Reservoir: Assessment of the Impact on Water Quality of the Proposed Reservoir*.
- Radford, A., Riddington, G., Anderson, J., & Gibson, H. (2004). *The economic impact of game and coarse angling in Scotland*. Scottish Executive: Edinburgh.
- Reynolds, C. S. (1984). *The ecology of freshwater phytoplankton*. Cambridge University Press.
- Rönicke, H., Doerffer, R., Siewers, H., Büttner, O., Lindenschmidt, K.-E., Herzsprung, P., & Beyer, M. &. (2008). Phosphorus input by nordic geese to the eutrophic Lake Arendsee, Germany. *Fundamental and Applied Limnology / Archiv für Hydrobiologie*, 172(2), 111-119.
- UKWIR. (n.d.). *INTEGRATING RESERVOIR AND WATER TREATMENT MANAGEMENT FOR CONTROL OF ALGAL PROBLEMS*.
- Viney, T. (2019). Email: FW: East and West of Gilman Road site - SINC boundary rec from T Viney 22-02-19.

Appendices

Appendix A. Catchment Monitoring Map



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Project: tasatkins.com/project/060XA/Water/Water/WE/VP/Projects/TEMP (RBY)Havant Thicket Feasibility Study/Project/Havant_Thicket.mxd

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www.atkinsglobal.com

Appendix B. Water quality spreadsheet model – modelled change of water quality downstream of proposed reservoir (mean concentration)

		Riders Lane Stream			Hermitage Stream at New Road		
Chemical	Units	Before	After	Difference %	Before	After	Difference %
Electrical conductivity	uS/cm	220.42	425.67	93.12	577.35	598.56	3.67
Total Dissolved Solids	mg/l	135.09	250.16	85.18	358.26	370.15	3.32
Biological Oxygen Demand	mg/l	2.46	2.1	-14.73	3.33	3.29	-1.12
Ammonium	mg/l	0.14	0.07	-49.14	0.12	0.11	-5.85
Unionised Ammonia	mg/l	0.000466	0.000276	-40.68	0.000399	0.000431	8.05
Nitrite	mg/l	0	0.01	48.73	0.13	0.13	0.15
Nitrate	mg/l	1.63	6.3	286.50	11.43	11.99	4.90
Alkalinity	mg/l	32.15	170.28	429.68	185.19	199.45	7.70
Chloride	mg/l	40.85	28.07	-31.28	56.15	55.2	-2.32
Sulphate	mg/l	21.21	18.42	-13.15	53.77	53.49	-0.53
Total Phosphorus	ug/l	39.36	8.3	-78.91	150.12	147.56	-1.70
Calcium	mg/l	13.76	78.85	473.04	83.62	90.34	8.03
Magnesium	mg/l	4.57	3.2	-29.87	12.93	12.79	-1.08
Sodium	mg/l	22.79	14.46	-36.55	35.57	34.71	-2.41
Potassium	mg/l	1.25	1.22	-2.82	3.55	3.55	-0.10
Iron	ug/l	3754.82	1278.9	-65.94	1302.45	1047.5	-19.57
Manganese	ug/l	867.42	279.93	-67.73	186.67	126.17	-32.41
Aluminium	ug/l	993.96	349.33	-64.86	502.65	436.27	-13.21
Phosphate	ug/l	33.07	5	-84.88	120.21	117.5	-2.25
Turbidity	FTU	24.2	8.49	-64.93	9.28	7.66	-17.44
Dissolved Oxygen	mg/l	9.74	9.98	2.51	9.97	10	0.35

Appendix C. Addendum – Additional analysis, temperature and phosphorous (July 2020)

Following review of version 4.0 of this report as issued to the Environment Agency in January 2020, the EA requested some further analysis of the downstream impacts of the reservoir scheme concerning temperature and phosphorous. The results of this further analysis are presented within this addendum to the main report.

C.1. Part 1 – Analysis of changes of temperature downstream of the reservoir

C.1.1. Introduction

C.1.1.1. Construction of the Havant Thicket Reservoir will modify temperature in the Riders Lane Stream and Hermitage Stream because water outflowing the reservoir will substitute flows from the catchment, and temperature is likely to differ between these source waters. The large volume of water in the reservoir will tend to 'store' temperature and, therefore, reduce its variability and range. If thermal stratification develops this will be made more complicated. However, this is considered unlikely to occur because of the shallow nature of the waterbody and the intention to introduce artificial reservoir mixing to protect water quality (see Section 2.3.4).

C.1.2. Analysis

C.1.2.1. An empirical approach was adopted to estimate the impact of the reservoir on the WFD standards of the 98th percentile temperature value; either an absolute 98th percentile value of <28°C or <3°C difference compared to ambient values. Ambient values, in this case, are taken to be the observed temperatures before the creation of the reservoir.

C.1.2.2. The following steps were taken:

- Current temperatures in the Riders Lake Stream and Hermitage stream were derived from observed data from Portsmouth Water (Site 4; Appendix A) and the Environment Agency (New Road) for the period 2008 to 2020.
- Estimated temperature values for the reservoir outflow were based on recorded temperatures (from the Environment Agencies WIMS data⁵) at other reservoirs in Southern England (less than 10 km from the sea). Data was gathered for the period 2010–2020 for Abberton Reservoir, Blagdon Lake, Cheddar Reservoir and Hickling Broad. The following statistics were calculated: 98th percentile of all values, monthly maximum, monthly minimum and monthly mean.
- Flows in the Riders Stream were based on Catch Mod hydrological modelling of the reservoir catchment, developed by Atkins to support the determination of compensation flows.

⁵ <https://environment.data.gov.uk/water-quality/view/landing>

- River flows in the Hermitage Stream at the confluence with the Riders Lake stream were estimated from observed river flows at the Hermitage Stream river flow gauge a few kilometres downstream based on catchment area.
- It was assumed that the compensation release either follows: 1) the existing flows as estimated by the Catch Mod catchment modelling or 2) the previous estimates used for the reservoir modelling (derived using an area comparison with observed flows in the Hermitage Stream).
- It was assumed that the water temperature does not change in the distance travelled from the reservoir outflow to the confluence with the Hermitage Stream. Any changes in temperature will tend to be toward the ambient temperature of the Hermitage Stream so this approach is conservative.
- Derived temperatures below the confluence were calculated by 'mass balance'.

C.1.3. Results

- C.1.3.1. Figure C.1 compares the percentile values for water temperature measured at Site 4 immediately downstream of the proposed reservoir outflow (see Appendix A) and the percentile values for the reservoir temperature (derived from other reservoirs). The 98th percentile for temperature in the Riders Lake stream is 16.4°C whereas the comparable value for the reservoirs is 22.1°C. It is important, however, to note that the Riders Lane Stream often dries up in the summer so it is often not possible to measure water temperature under these mid-summer conditions when reservoir temperatures would be highest. This has the effect of lowering the upper stream percentiles (the 98th percentile for the Hermitage Stream is 20.6°C). In these circumstances, the absence of flow is clearly more important than temperature and if, ultimately, the compensation flow reflects this seasonal drying up of the stream, the issue of temperature will be irrelevant because there will be no flows in the stream. The Environment Agency confirmed that the Riders Lane Stream is not assessed for WFD compliance due to its ephemeral nature so the potential changes in temperature in this stream are not of concern.

C.1.3.2. The 98th percentile value does not exceed the WFD maximum value of 28°C for cyprinid waters in the streams or the reservoir outflow.

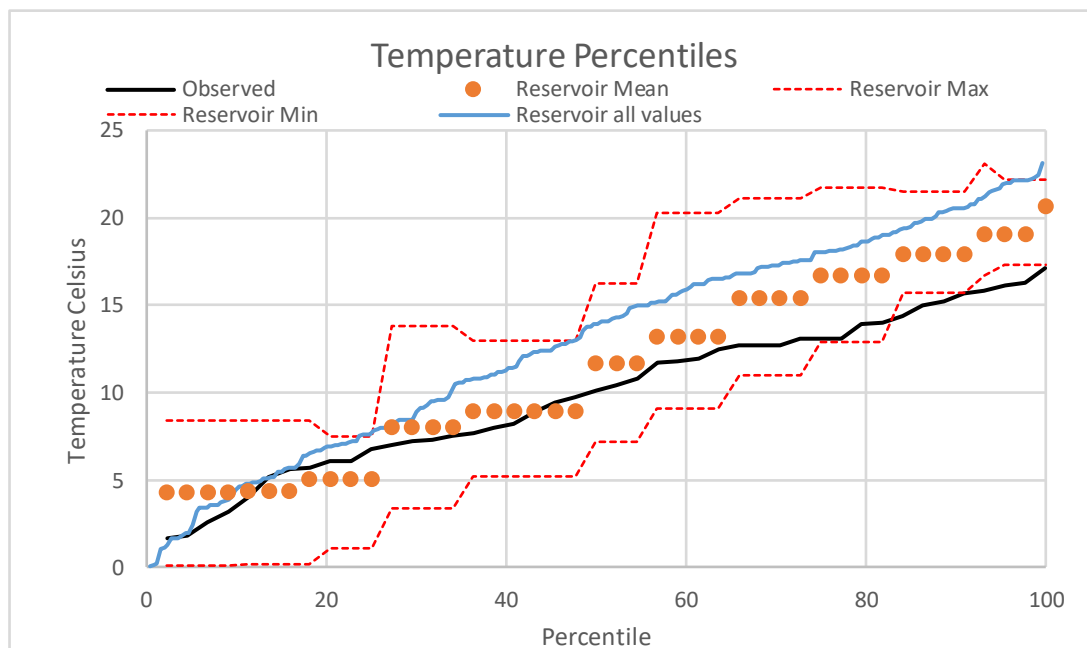


Figure C.1 Percentile values for water temperature in the Hermitage Stream and data for other reservoirs. The monthly reservoir temperature envelope used for the mixing calculations is also shown

C.1.3.3. Figure C.2 shows the estimated change in temperature downstream of the confluence between the Riders Lane Stream and Hermitage Stream based on simple mass balance of the two waters. The upper graph shows the estimated change in temperature for each of the occasions when temperature was measured in the Hermitage Stream based estimated river flows at that time. The calculation uses the monthly average for the estimated reservoir temperature as well as the monthly maximum and minimum reservoir temperature value. For example, for the reservoir monthly maximum, this applies the highest monthly values recorded at any of the reference reservoirs which is clearly conservative. The lower graph shows the percentile values in Hermitage Stream compared to values after mixing with the reservoir water (mean, minimum and maximum values). These results show that even for the conservative case of mixing the highest recorded monthly reservoir temperature with the Hermitage Stream the temperature change would be less than 1°C. It is highly unlikely, therefore, that temperature changes in the Hermitage Stream would exceed the WFD threshold on 3°C.

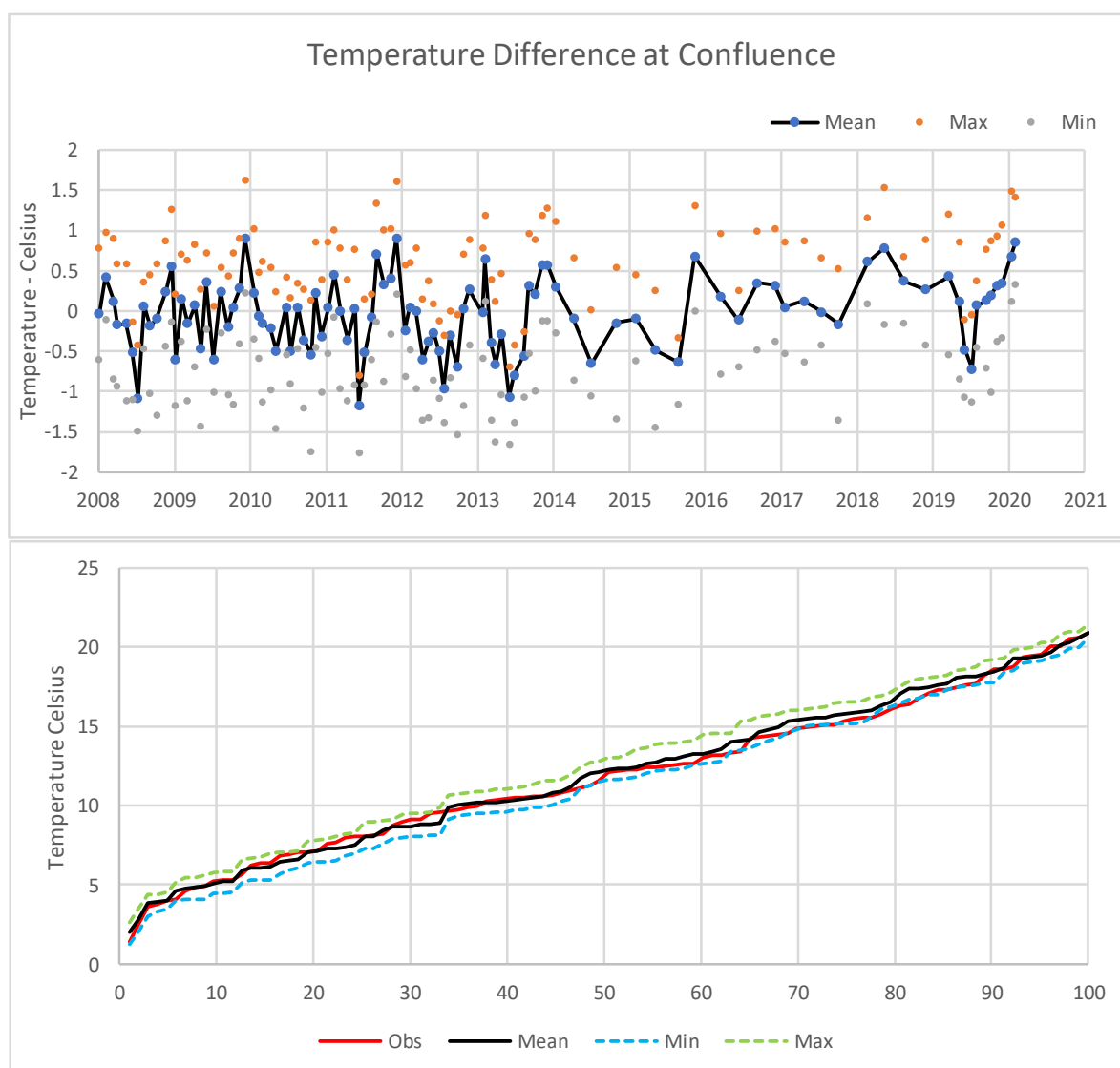
C.1.3.4. The 98th percentile value does not exceed the WFD maximum value of 28°C for cyprinid waters in the Hermitage Stream.

C.1.3.5. Table C.1 compares the change in the 98th percentile temperature downstream of the confluence, applying compensation flows based on the CatchMod modelling and the higher fixed monthly values that were used in the reservoir modelling. This shows that even with the greater compensation flows the changes in temperature would be less than 1%.

Table C.1 - Change in 98%ile temperature below confluence between the Riders Stream and Hermitage Stream

Model	Reservoir Temperature		
	Mean monthly	Min Monthly	Max Monthly
CatchMod flows	-0.23	-0.6	0.47
Reservoir Model Compensation Flows	-0.4	-0.87	0.6

Figure C.2 Estimated changes in temperature downstream of the confluence between the Riders Lane Stream and Hermitage as a result of releases of water from the reservoir.



C.2. Part 2 – Sensitivity of reservoir phosphorus and downstream concentrations in the Hermitage Stream

C.2.1.1. Figure C.3 shows the predicted concentrations in the Riders Lane Stream and below the confluence with the Hermitage Stream for the reservoir sensitivity scenarios presented in Section 3 of this report, compared values before the reservoir is built. This shows that although there are marked differences in the Riders Lake Stream, these differences become far less below the confluence. In all cases, however, concentrations are less than before the reservoir is built reflecting the relatively good quality of the water pumped up from the Bedhampton and Havant Springs and losses in the reservoir which apply in different degrees to all scenarios.

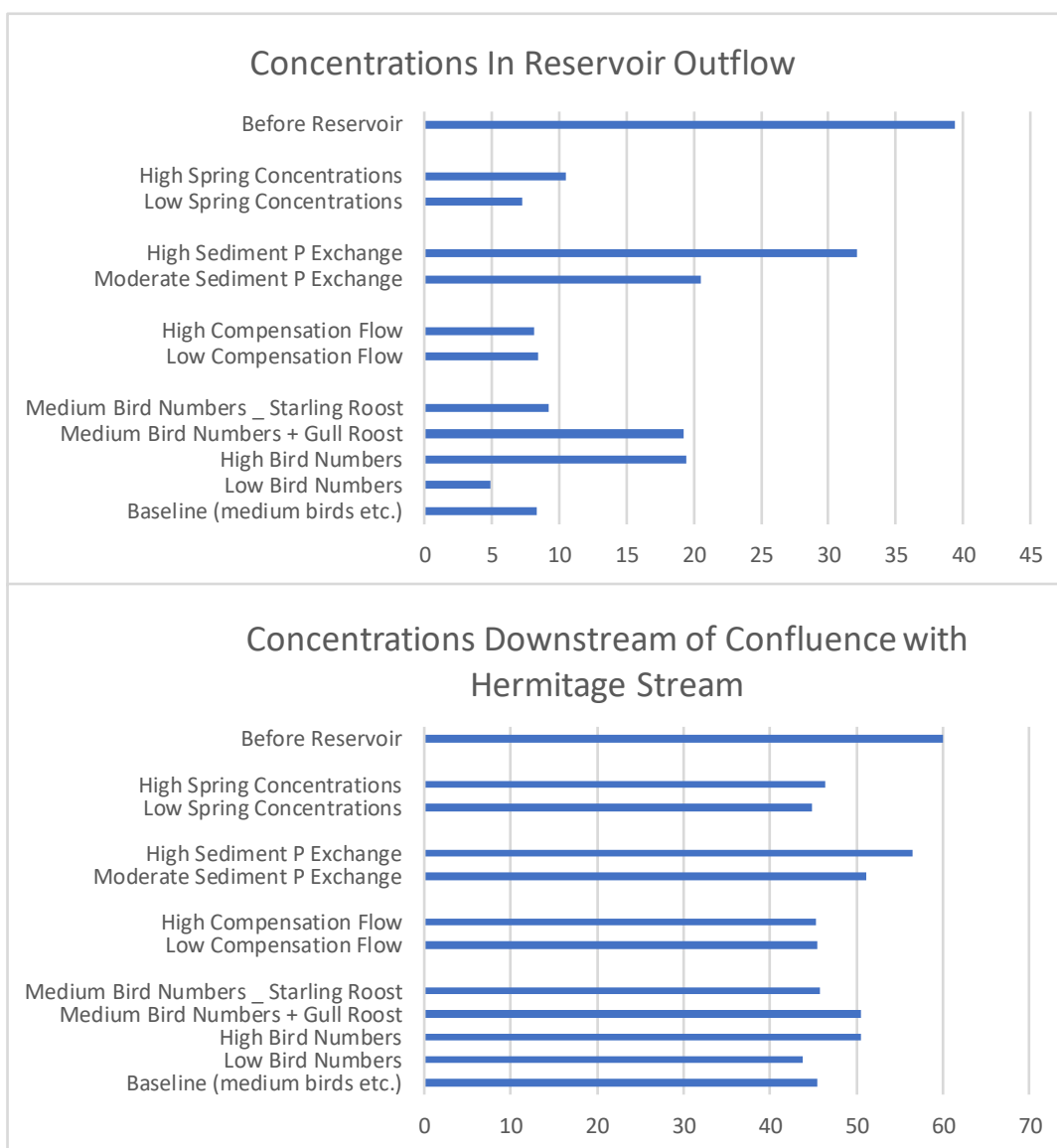


Figure C.3 Comparison of simulated Total Phosphorus downstream of the reservoir for the different reservoir sensitivity scenarios

C.3. Part 3 – Analysis of changes in nitrogen loads to Langstone Harbour

- C.3.1.1. Havant Borough Council is committed to development taking place only if it is sustainable and includes relevant environmental protections. Part of this consideration is whether there would be a detrimental impact on the water quality on any European Designated Nature Conservation Sites, notably Langstone and Chichester Harbours which are Special Protection Areas (SPAs) and RAMSAR sites. An issue of particular concern in respect to these sites is the input of nutrients and eutrophication that results from these inputs. Nitrogen has been shown to be of particular concern as it is believed to have a strong influence on the ecology of the harbours.
- C.3.1.2. Consequently, Havant Borough Council requires a nutrient budget to be undertaken for any development or change of land-use that may modify inputs of nutrients into the harbour and mitigation applied with the aim of achieving nutrient neutrality (i.e. avoiding an increase in nutrient inputs). A calculation procedure has been developed to estimate the change in nutrient inputs that result from a new development that takes into account changes in wastewater flows to treatment works and the release of diffuse nutrients from the land.
- C.3.1.3. Although this approach is not designed to address the specific case of Havant Thicket Reservoir, a nutrient budget has been calculated to assess whether it achieves nutrient neutrality and to provide evidence of its impact on the overall nutrient budget of Havant Borough.
- C.3.1.4. The methodology builds on existing water quality modelling work carried out for the Environmental Assessment of the Havant Thicket Reservoir Scheme.

C.3.2. Background

- C.3.2.1. Figure C.4 compares the movement of water and nutrients to Langstone Harbour before and after construction of Havant Thicket Reservoir. Following the construction of the reservoir, the transfer of nutrients from the surface water catchment to Langstone Harbour will remain largely unchanged apart from nutrients released from the small natural catchment of the reservoir that will be intercepted by the reservoir. Of greater significance, part of the flow from the Bedhampton and Havant Springs to the harbour (along with nutrients) will be transferred to Havant Thicket Reservoir.
- C.3.2.2. Once in the reservoir, part of the nutrients will be transferred to the water treatment works and part will be released back to the catchment via compensation flow releases. Losses of nutrients will also occur within the reservoir due to denitrification. Overall, therefore, inputs of nutrients from the Springs to Langstone Harbour will be reduced following construction of the new reservoir because only some of these redirected loads will return to the harbour.

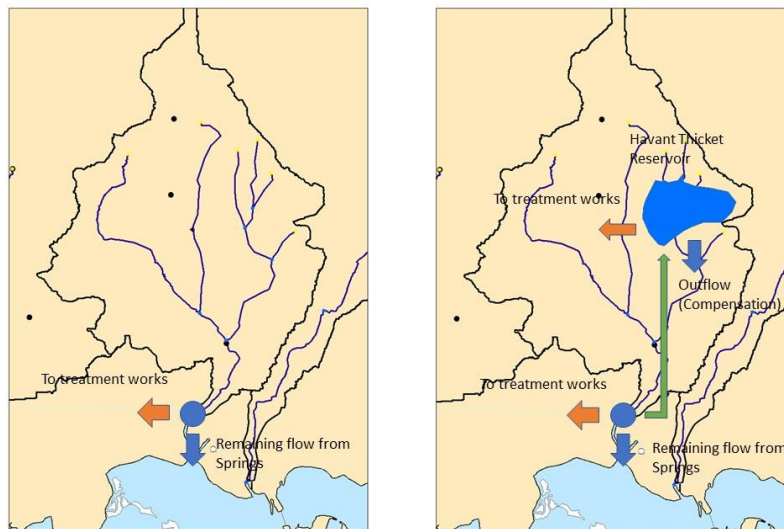


Figure C.4 Changes in transfer of nutrient following the construction of Havant Thicket Reservoir

C.3.3. Methodology

C.3.3.1. Three conditions have been considered with regards to inputs of nitrogen (N) to the harbour:

Period of reservoir fill – After construction of the embankment the reservoir will be filled by pumping water from the Bedhampton and Havant Springs over a 3 year period from 2026 to 2029. During this period up to 40 MI/d of water will be transferred to the reservoir from the Springs during the winter months from November to April in each year over the 3 year filling period. The reservoir will have a total storage capacity of around 8,700 MI, and hence around 2,900 MI of spring water will be pumped into the reservoir each year from Bedhampton during the filling period.

Baseline – Havant Thicket reservoir will act as a drought resilience scheme where water from the springs at Bedhampton is stored for public water supply during droughts. Hence in normal years outside of drought periods no water will be abstracted from the reservoir for water supply. During these 'normal' baseline years, only water required to keep the reservoir full to offset evaporation losses will be pumped from the Springs (estimated to be around 600 MI/year).

Operational – During periods of drought where availability of water from Portsmouth Water's groundwater sources will be constrained, there will be a requirement to draw on the stored water within the reservoir to maintain public water supply. The operational use of the reservoir during drought periods has been modelled using a Pywr water resources model that simulates a range of drought conditions and reservoir use.

- C.3.3.2. The basis of the nutrient assessment before and after construction of the reservoir is given below:

C.3.4. Before construction of the reservoir

- C.3.4.1. Inputs of nutrients from the Hermitage Stream catchment to the harbour were assessed by calculating daily N loads using observed water quality data at New Road (upstream of the Springs) and flow data from the Hermitage Stream flow gauge for the same day. Nitrogen inputs related to drainage of water from the catchment directly to the harbour and in the Hermitage Stream catchment below New Road are not included in these calculations.
- C.3.4.2. Flow inputs from the Springs to the harbour were calculated from the modelled flows from the Springs minus the amount of water transferred to the water treatment works for public water supply. This is the existing supply system before construction of the reservoir where Portsmouth Water abstract a proportion of available water from the Springs at Bedhampton and treat the water at Farlington WTW. The nutrient loads to the harbour were then based on monthly average concentrations of nutrients in the Spring water from Portsmouth Water's water quality monitoring data.

C.3.5. During fill and operation of the reservoir

- Inputs from the Hermitage Stream catchment were modified by subtracting the estimated load to the reservoir from its local catchment since this no longer passes directly to the harbour but, instead, is intercepted by the reservoir.
- Concentrations in the reservoir were based on mixing stream water from the reservoir catchment and Spring Water from Bedhampton.
- A conservative assumption is made that no loss of nitrogen occurs in this reservoir during the three-year fill period. The behaviour of denitrification during the early fill phase is difficult to predict because sediment chemistry and microbial activity will be in a state of flux after the soils are initially inundated.
- During operation of the reservoir, losses of nitrogen from denitrification are conservatively assumed to be 45% based on literature and other lowland reservoirs in Southern England (see information box below).
- It was assumed that there are no losses of nutrients from compensation flows between the reservoir and the harbour which is reasonable since it is only a short distance of approximately 4 km.
- The analysis assumes that any transfers to the water treatment works from the reservoir for public water supply are not returned to the harbour. The return of water is dependent on wastewater flows and effluent permits that are not directly influenced by the operation of the reservoir.
- During the fill period it is assumed that an average of 2,900 Ml each year is pumped to fill the reservoir over a period of 3 years.
- Potential longer-term operation was based on outputs of the Pywr water resources model which was used for the reservoir water quality modelling. The Pywr model simulates transfers of water to and from the reservoir for a modelled period of 1000 years for different sequences of wet and dry periods, based on historic water level data and forecast water demand.

Denitrification in reservoirs

Denitrification is an important process in reservoirs and lakes by which microbial activity at the sediment/water interface results in a reduction of the nitrate molecule under low oxygen concentrations to form N_2 which is lost to the atmosphere. The process depends on the development of the correct microbial flora, chemical conditions in the sediment and transport of nitrate for the water column into the sediment and because of these complexities, rates of nitrogen loss in reservoirs are variable. Loss rates are expected to increase with the reservoir retention time because there is a greater period of time for these losses to occur. A review of N loss rates in reservoirs and lakes is provided by Harrison et al. 2009 upon which the N loss rates applied in this analysis are based. Information was compared to data for other reservoirs in Southern England.

During the three-year fill period for Havant Thicket Reservoir the N loss rates are conservatively assumed to be zero for the purposes of the nutrient assessment. During operation (baseline and operational scenarios) the loss rate is conservatively assumed to be 45%.

C.3.6. Results

Reservoir fill conditions

- C.3.6.1. During reservoir fill, the amount of water pumped to reservoir will be greater than the water released back to the harbour via compensation to enable the reservoir to fill.
- C.3.6.2. The transfer of nitrogen to the reservoir from the harbour under these conditions was calculated from the average N concentrations in the Springs and the amount of water transferred, as shown below in Table C.2. N concentrations in the reservoir were calculated by blending of the Spring water with the inflows from the three streams to the north of the reservoir (modelled flows in the streams and observed water quality data, collected by Portsmouth Water are available). The estimated net gain of N to the reservoir and loss to the harbour is 54,317 kg which is equivalent to an average of 49 kg/day during the three-year fill period.
- C.3.6.3. The loss to the harbour would increase if a proportion of the reservoir were also lost by denitrification during the fill period (not included in Table C2). For example, a 40% loss in the mass of N each year the benefit would increase the loss to 60,800 kg or 55.5 kg/day. The sensitivity of the estimated reduction in N load to the harbour to N loss in the reservoir is low. This is because the reduction in loads to the harbour are primarily caused by the inflows being greater than the outflows.

Table C.1 - Inputs and outputs of water and N to Havant Thicket reservoir during reservoir fill conditions (over 3 years)

Inflow from Springs MI	N Load from Springs kg	Compensation flows MI	Compensation N loads kg	Net loss to harbour kg
9,300	70,680	3,972	16,360	54,317

1. The blending of water between the springs and streams results in a reservoir concentration of 5.7 to 6.3 mg/l N which was used to calculate the Compensation N loads
2. Evaporation loss is assumed to increase each year as the open area of the reservoir increases and included in the inflow volume
3. None of the input from the streams is lost because N loss in the reservoir is zero. The new change is therefore zero.

Baseline conditions

- C.3.6.4. The baseline condition, as outline above, is for periods when no pumping takes place to the reservoir apart from a transfer of water to offset losses to evaporation to keep the reservoir full. The compensation flow from the reservoir will be designed to match natural inflows so this does not result in any loss or gain of water stored within the reservoir.
- C.3.6.5. The reduction of N inputs to the harbour under this condition is illustrated in Table C.3 below. The estimated quantity of water transferred to the reservoir is estimated to be 600 MI each year to offset evaporation loss from the 1.1 km² surface area of the reservoir at top water level.
- C.3.6.6. The steady state N concentration in the reservoir is assumed to be 55% of the blended inflow concentration from the springs and streams, assuming a 45% loss due to denitrification, which results in an average estimated steady state N concentration of 1 mg/l N. This results in a reduction of N inputs to the harbour of 2,588 kg N/year or an average daily reduction of 7.1 kg N/day.
- C.3.6.7. In contrast to the reservoir fill period, reductions in N inputs to the harbour under baseline conditions will be more strongly influenced by N loss in the reservoir. If the N loss were to increase to 70% this increases the reduction of inputs to the harbour to 11 kg N/day. Figure C.5 shows the relationship between reduction in N in the reservoir and the reduction in N input to the harbour.

Table C.1 - Inputs and outputs of water and N to Havant Thicket reservoir during baseline conditions

Inflow from Springs MI/year	Inflow from Streams MI/year	N Load from Springs kg/year	N Load from Streams kg/year	Compensation flow MI/year	Compensation N Loads kg/year	Net loss to harbour kg/year
600	1,324	4,560	1191	1,324	3,163	2,588

1. Assumes 45% is lost of the N input from the Springs and Streams
2. The blended N concentration in the reservoir is calculated to be 2.39 N mg/l after applying the loss which was used to calculate the Compensation N loads
3. The net change is the input from the springs plus streams minus the output via the compensation water

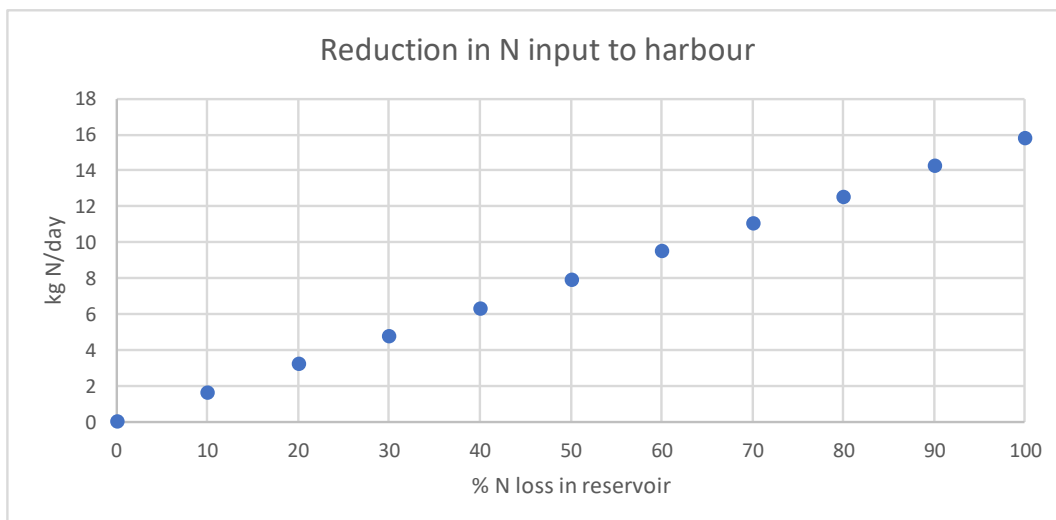


Figure C.1 Comparison of reduction in N to Langstone Harbour and estimated N loss in reservoir

Operational conditions

- C.3.6.8. Reductions in N loads to the harbour under operational conditions during drought periods were estimated using the 1000-year time series from the Pywr water resources model for transfers of water to the reservoir from the Springs and transfers from the reservoir to public water supply.
- C.3.6.9. As before the loads from the Springs were calculated from the quantity of water transferred and the observed water quality data in the Springs. Inputs from the streams to the north of the reservoir were calculated from monthly estimated flows and monthly observed water quality data. Output N loads to treatment used the estimated transfer to the treatment works from the Pywr model along with estimated N concentrations in the reservoir. Likewise, outputs via the compensation flows were calculated from monthly compensation flows and estimated N concentrations in the reservoir.
- C.3.6.10. Overall this analysis shows that there would be a long term average reduction in nitrogen loads to the Langstone Harbour of 16 kg N/day under these operational conditions for the new reservoir when the reservoir is drawn down during droughts and then refilled. In some years, however, the annual average reductions could be substantially higher or lower depending on how much water is transferred to the reservoir, (Figure C.6).

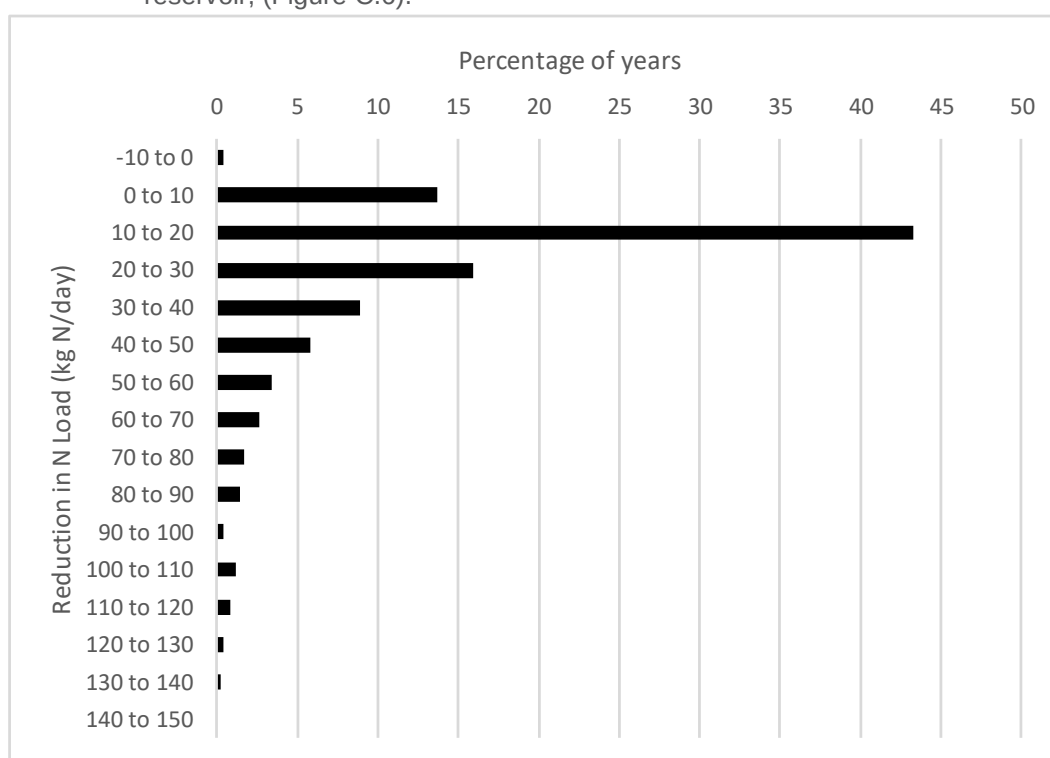


Figure C.1 Distribution of annual changes in N loads to Langstone Harbour (proportion of years)

- C.3.6.11. The analysis for the operational condition was repeated as outlined above for Total P inputs to Langstone Harbour which was estimated to be reduced by 2% as a result of the construction of the reservoir (equivalent to a reduction of 0.05 kg/day). This reduction is much lower than would occur for nitrogen because the Total P concentrations in the Spring water are low. Consequently, a much greater proportion of the phosphorus inputs to the harbour come from the catchment rather than the reservoir/Springs.

C.3.7. Discussion and Conclusions

- C.3.7.1. During the reservoir fill period which is planned over a three year period from 2026 to 2029, there will be a substantial reduction in the N input to Langstone Harbour due to the large volume of water transferred to fill the reservoir from the spring source at Bedhampton. The average daily reduction over this filling period is estimated at approximately 50 kg/day.
- C.3.7.2. Once the reservoir comes into operation in 2029 the reductions will be much less, close to a baseline average daily reduction of approximately 7 kg/day. This baseline value is particularly significant because it represents the lower bound reduction in N inputs to the harbour that will occur each year during normal operation where the reservoir is topped up each year to replace evaporation losses.
- C.3.7.3. When the reservoir is operated during drought periods to meet public water supply, reductions in N inputs will increase substantially above baseline levels when the reservoir is being refilled.
- C.3.7.4. The primary uncertainty in this analysis is the amount of N that will be lost from the reservoir as a result of denitrification. Reflecting this uncertainty, a conservative value of 45% reduction has been applied in this analysis but if greater reductions in N occur in practice once the reservoir is built, the benefits in terms of reductions of N to Langstone Harbour will increase accordingly.



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