Executive summary

This report presents the findings of investigations commissioned by Thames Water to meet its obligations under the Environment Agency's National Environment Programme (NEP) to determine what scope exists for reducing the adverse water quality impacts of the Kennet and Avon Canal on the River Kennet SSSI by targeting investment at those Thames Water's sewage treatment works (STWs) which discharge into the Kennet and Avon Canal. The primary focus is to determine whether reducing phosphorus inputs from Thames Water's STWs would significantly reduce the algal blooms in the canal and, if or where appropriate, to identify those works where measures would be most cost-effective.

As a result of nutrient inputs, the Kennet and Avon Canal has become hyper-eutrophic; the canal exhibits annual algal blooms, turning from a milky green to orange through algal succession. Fisheries investigations on the Canal indicate a thriving population of coarse fish (Environment Agency. Pers. Comm.); however, where the canal discharges / overflows into the River Kennet SSSI there appear to be a number of impacts including: changes in water clarity (impacting on amenity and fishery) and consequent impacts on macrophyte growth and clogging of spawning beds. The impacts are perceived to be immediately apparent downstream of Copse Lock, through Craven Fishery and the Benham Estate which border the Kennet SSSI as far as the western outskirts of Newbury.

The Kennet & Avon Canal is supported by pumping from Wilton Water, a shallow reservoir at the canal summit near Crofton. The reservoir is largely baseflow (groundwater) fed but also receives input from the discharge of treated effluent from Wilton and East Grafton sewage treatment works (STWs). Downstream from Wilton there are a number of other STW discharges including: Great Bedwyn, Shalbourne and Kintbury which discharge directly or indirectly into the canal. In addition to STW inputs, the baseflow to Wilton Water is already nutrient rich, as a result of diffuse source inputs. This investigation focuses on the potential impacts of discharges from Wilton, East Grafton, Great Bedwyn and Kintbury STWs.

Shalbourne STW discharges to the Shalbourne Stream which in turn is a tributary of the R. Dun. A new bypass channel constructed in 1999 diverted Shalbourne Stream away from the canal and into the river. Consequently, Shalbourne STW is not directly considered as part this investigation. Similarly, although the Froxfield STW flows into the Froxfield Stream within the canal catchment, most of this stream (two thirds) flows to the River Dun rather than the canal and this STW was therefore outside the investigation scope although it is considered indirectly in as much as it will be a factor influencing water quality in the reach from Froxfield to Copse Lock.

The overriding aim of this investigation is to determine the scope that may exist by targeted investment at Thames Water's smaller STWs to reduce the adverse water quality impacts of the Kennet and Avon Canal on the River Kennet SSSI. The primary focus is to determine whether reducing phosphorus inputs from Thames Water's STWs would significantly reduce the algal blooms in the canal and if so, to identify those works where measures would be most cost-effective.

The NEP scope for this investigation sets out the following objectives:

- To determine whether reducing phosphorus inputs to the Kennet and Avon Canal from Thames Water's STWs would significantly reduce the incidence of algal blooms in the canal, particularly where the canal merges with the River Kennet at Copse Lock (NGR SU 41711 67038).

- Depending upon the answer to (1) above, to identify those STWs where actions would be most cost-effectively targeted. Where the effectiveness of such actions also requires reduction of diffuse phosphorus inputs, to quantify the reductions required.

- To comment on the likely benefits of identified actions to the River Kennet SSSI.

- To make recommendations for the future management of phosphorus inputs to the Kennet and Avon Canal (Crofton Top Lock to Copse Lock).

The investigation relies primarily on existing monitoring data and data from published literature, reflecting the extent of previous investigations on the Canal and River Kennet and the significant volume of data collated prior to this study. However, where gaps in data have been identified, further monitoring has been undertaken where feasible to do so. This is largely confined to intensive monitoring of water quality of the canal and River Kennet at / downstream of Copse Lock.

Initial conceptual understanding

An initial baseline review of the published evidence in relation to the water quality impacts of the Kennet and Avon Canal on the River Kennet SSSI was undertaken as Phase 1 of this investigation (Appendix A). It provides a summary review of:

- Scientific literature relevant to catchment phosphorus issues.
- Key evidence / data gaps based on an initial conceptual understanding of the issues in the Canal / SSSI system.
- Recommendations for further monitoring and investigation and the implications for delivery of the proposed programme for this investigation.

Published literature together with data from Environment Agency and CEH monitoring have been reviewed to provide an initial assessment of the potential source contribution by STWs and conceptualisation of linkages between nutrient sources, water quality and algal dynamics within the Kennet and Avon Canal (Figure E1). Key features of the conceptual understanding are described further below.

STW effluent is a key source of high Soluble Reactive Phosphorus (SRP) to Wilton Water, the main source of water supply to the Kennet and Avon Canal. Whilst a step reduction in SRP in effluent discharging into the River Kennet has been observed since the mid 2000s (Neal et al., 2010), over halving of SRP concentrations in the river, phosphate stripping at those works discharging to the canal has been limited to Kintbury STW.

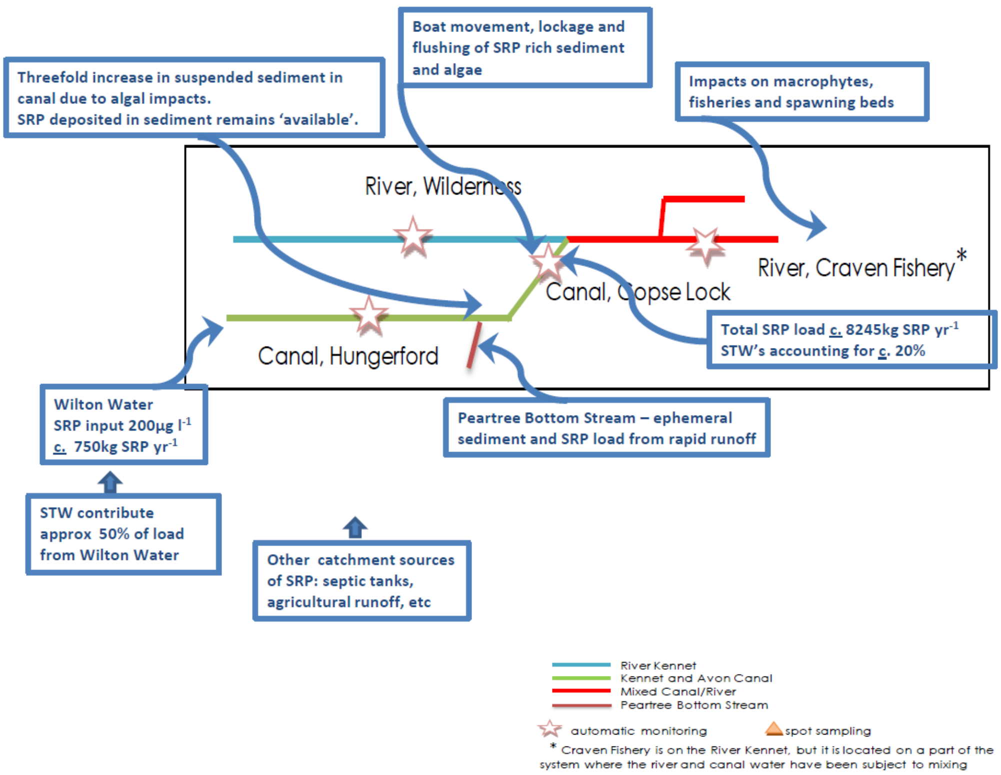

Figure E.1. Conceptual framework summarising SRP / algal issues at the end of Phase 1

Typically, SRP in the canal is higher in the autumn/winter compared to the spring/summer, reflecting the higher algal growth and nutrient uptake rates during the spring/summer. Chlorophyll concentrations in the canal are an order of magnitude higher than in the river due to the long residence times and the higher temperatures in the canal, which promote algal growth (Neal et al., 2010).

The canal acts as a point source of sediment, algae and total phosphorus to the river, especially during the summer months. This coincides with peak boat traffic and lockage which has been linked to the disturbance of bottom sediment in the canal. However, patterns in suspended solids (SS), SRP and chlorophyll concentrations in the canal are 'erratic' and not always linked to boat movements, which suggests some variation in source contributions.

Suspended sediment concentrations show good correlation with chlorophyll, suggesting that elevated sediment levels are due to the presence of algal material rather than inorganic sediment (Halcrow, 2007). However, no clear pattern was apparent in turbidity due to boat movements, suggesting a complex interplay of factors including catchment management. Flashy, ephemeral catchment inputs such as Peartree Bottom Stream, upstream of Copse, can have a significant localised impact on both flow and sediment load.

Neal et al. (opp. cit.) using analysis of Sodium and Boron concentrations as markers of effluent sources, suggest that effluent inputs to the canal remain largely constant downstream of Wilton, with the exception of a small increase at Kintbury STW. In-stream variations in SRP are mainly due to biological processes. Assessment of data available for this report indicates that STW discharges account for approximately 50% of the load from Wilton Water to the canal and approximately 20% of the total SRP load at its confluence with the River Kennet.

However, within the canal, the low flow, long residence times and generally warm water temperatures results in high biological activity and uptake of SRP; periods of high uptake of SRP corresponding with highest algal growth. SRP within the water column of the canal is effectively stripped or removed from solution by the algae, although it is still present in the canal but in a different chemical state. In simple terms, SRP within the water column will be determined by the balance of algal uptake (from solution) and algal die off (becoming sediment), with a volume left undigested in the water column. Neal et al (opp.cit.) suggests that the volume of algal generated sediment in the canal increases downstream from Wilton Water to Copse by a factor of three times the current suspended sediment load. Sediment load in the canal is gradually transferred downstream as a result of physical mixing associated with boat passage and lockage and natural flushing of water through the canal. As a result, progressive translocation and boat movement / lockage result in the canal acting as a point source well in excess of the observed suspended sediment levels in the canal.

By contrast, Zeckoski (2010) and Halcrow (2007) note more significant natural catchment inputs of sediment, Zeckoski suggests that the algal contribution may be limited to 15% of the total sediment load at Copse. There are significant ephemeral sediment (and SRP) source contributions from catchments such as the Peartree Bottom Stream which respond to rapid runoff events and typically exhibit plumes of bed sediment where they discharge into the canal (Halcrow, 2007). These appear to be important, not only as sources, but also in setting up the sediment load; the canal then acts as a series of sources and temporary sinks of sediment, creating pulses of sediment in response to flow, lockage and re-suspension by the passage of narrowboats.

In contrast to the commonly held conceptual model of the canal – river impact pathway, there would appear to be two distinct processes (although the effects of each may vary temporally and spatially):

- The generation of sediment (suspended and bed load) by natural catchment processes and its periodic re-suspension and transport in response to flow events, lockage and passage of narrowboats; and,
- The clearly visual impact of algal growth in response to the combination of high nutrient status and long residence time within the canal.

The interactions downstream of Copse are not particularly well understood; no empirical / field analysis has been undertaken to confirm the perceived impact pathways in relation to the question of whether the algae inoculate the River Kennet or die off as a result of changing flow conditions. However, changes in water clarity (impacting on amenity and fishery), impacts on macrophyte growth and clogging of spawning beds have been observed immediately downstream of Copse, through Craven Fishery and the Benham Estate which border the Kennet SSSI as far as the western outskirts of Newbury.

This assessment

Taking forward key gaps identified in the conceptual understanding of the water quality impacts arising as a result of the interactions between the canal and the River Kennet, this report provides an assessment of the:

- Hydrology and water balance of the Kennet and Avon Canal and its interactions with the River Kennet.

- Water quality processes in the Kennet and Avon Canal considering the available water quality data and improved understanding of the hydrological processes affecting the canal.

- Relative contribution of all potential sources of phosphorus to the canal, reflecting the interplay of the canal and catchment hydrological processes affecting the canal system through the development and application of phosphorus source apportionment modelling to the Kennet and Avon Canal.

- Sediment sources, source apportionment and the total sediment load to the canal (and delivered into the River Kennet downstream of Copse Lock).

- Phosphorus and algal dynamics, drawing on the combined assessment of the hydrology and water balance of the canal, updated understanding of water quality and source apportionment of phosphorus and sediment and the relative impacts of land use and potential scenarios for phosphorus stripping at sewage treatment works.

Revised conceptual framework

The conceptual framework developed from the review of published literature (Section 2) is based on the assumption that the canal operates as a single, continuous, linear system which, due to the combination of low flow, long residence times, high phosphorus load and seasonally high temperature, acts as a simple linear 'biological reactor'. As a result, algal generated sediment load increases by a factor of three compared to the natural load (Neal et al., 2010).

This assessment, coupled with the work undertaken by Zeckoski (2010) and subsequently updated in this assessment suggests that the canal processes are more complex and that the system might be better considered as three distinct components based on the hydrological processes influencing each reach (dee Figure E2):

1. **<u>The Wilton Water component</u>**

The Wilton Water catchment contributes approximately 24% of the phosphorus load to the canal, the majority of which is derived from diffuse agricultural sources (43%); STWs contribute approximately 13% of the annual load, although at times of low catchment flows this can increase to 25%. Phosphorus release from lake sediment is also an important source (and store or temporary sink from catchment sources), accounting for up to 32% of the annual load.

Following on from the above, Wilton and East Grafton STWs provide a minor contribution of the total phosphorus load to the canal on an annual basis, contributing less than 4% (on average).

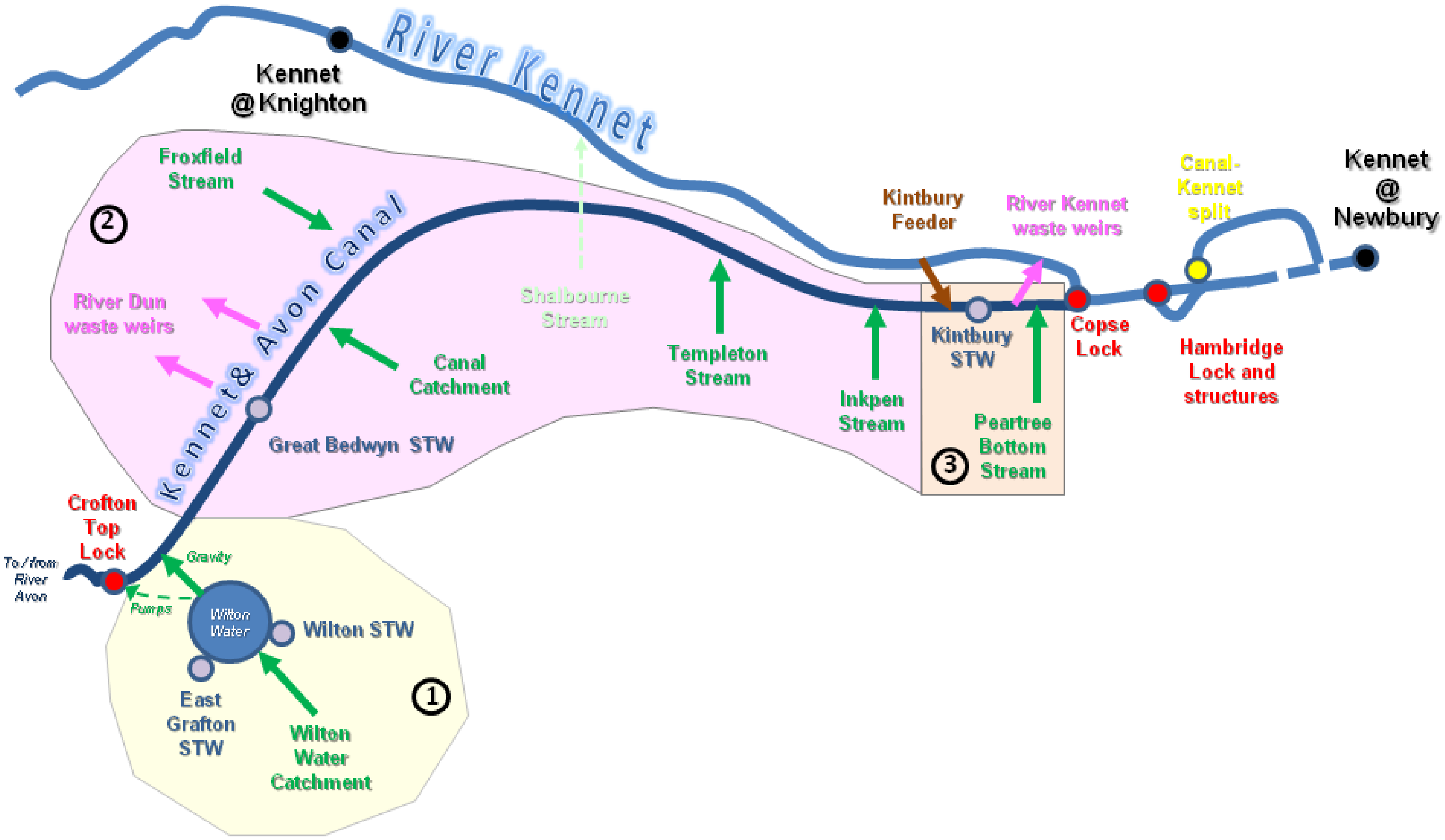

Figure E.2. Revised conceptual understanding of the canal showing the three main components

2. The Canal downstream of Wilton to Kintbury

This part of the canal receives upstream inputs from Wilton Water and discharge from Great Bedwyn STW, which currently accounts for 10% of the average annual phosphorus load to the canal.

This reach also receives hydrological and diffuse inputs from most of the sub-catchments flowing into the canal (in downstream order the Wilton Water, Canal, Froxfield, Templeton and Inkpen Stream sub-catchments).

This is the largest component of the canal in terms of its aerial extent. As a result, it has the greatest potential to react in the manner conceptualised in Section 2 given the combination of sub-catchment diffuse inputs, inputs from Great Bedwyn STW andthe potential for long residence times (given the number of canal reaches).

Chlorophyll concentrations indicate a continuous algal bloom throughout the summer in this part of the canal.

3. The Canal from Kintbury to Copse Lock and the confluence with the River Kennet

The River Kennet input to the canal via the Kintbury Feeder provides a distinct hydrological change downstream of Kintbury, providing a significant fluvial influence on the lower reaches of the canal. During high flow periods, up to 30% of the flow in the River Kennet can be diverted into the canal via the Kintbury Feeder at Barton Court. This can account for more than 90% of the annual hydrological budget of the canal; equating to replacement of the entire canal storage volume in one day. It also represents a phosphorus source of more than 50% of the total annual loads of P to the canal on an annual basis. Based on available data, the inflows appear to coincide with:

- An earlier onset of algal blooms at Copse Lock compared to upstream reaches of the canal.
- Re-priming of algal growth following apparent boom-bust cycles of growth and exhaustion of available phosphorus.

Issues and linkages

The previous conceptual framework suggested that the canal acts as a point source of sediment, algae and phosphorus to the River Kennet. However, much of the current conceptual understanding directly links suspended sediment load with algal load. As a result, conclusions have been drawn directly linking phosphorus, STW inputs and algal growth with observed suspended load discharged into the River Kennet. This assessment indicates that there is no simple relationship; that there are three separate processes to consider:

A. Interaction between phosphorus and algal growth

Algal blooms are an annual feature of the canal environment, although the magnitude varies in response to prevailing hydrological conditions; chlorophyll concentrations are typically reduced in drought periods. During an algal bloom, soluble reactive phosphorus (SRP) in the canal is decreased markedly as a result of its transformation to Particulate Phosphorus (PP). This is evident at all canal locations downstream of Forebridge (SU2956466559).

The onset of the algal bloom differs between the middle and lower sections of the canal (components 2 and 3 above); there is an earlier onset of the algal bloom in component 3 (Kintbury to Copse / River Kennet) which appears to be in response to significant inflows from the River Kennet via the Knitbury Feeder. Whilst there is a continuous summer algal bloom in component 2 of the canal, component 3 exhibits ‘boom-bust’ cycles, with re-growth apparently stimulated by hydrological events and additional inflows, possibly from the River Kennet.

The interaction of algal growth with available phosphorus is complex, reflecting source inputs and hydrological functioning of the canal. STW inputs account for 17% of the total phosphorus load in the canal. Diffuse agricultural sources (particularly arable land use) account for 73% of the load.

Of the total diffuse agricultural sources inflowing to the canal, the most significant sub-catchments are the Templeton (22%), Wilton (22%), Froxield (21%) and canal (20%). The Inkpen and Peartree sub-catchments provide much smaller contributions. Inflows from the River Kennet are considered separately. When these are included, they represent 51% of the total load to the canal.

From the foregoing, the dominant contributing sources causing spring algal blooms would appear to be diffuse catchment / agricultural sources. Whilst STW inputs may become quantitatively more significant at low flows, their impact is likely to be limited because algal blooms start earlier in the year (March) when diffuse catchment sources to the canal are still dominant and application of phosphorus-based fertiliser on arable land is at its peak.

B. Natural catchment sediment dynamics

Neal et al (2010) referred to contribution of algae to the overall suspended sediment load at Copse and the progressive translocation of sediment as a result of lockage and narrowboat passage through the canal. The sediment source apportionment undertaken here has identified the Shalbourne and Wilton Water catchments as of potentially highest risk in terms of sediment generation and contribution to the canal catchment. Areas of medium risk, where the rate of sediment transfer from fields to watercourses to canal may be rapid, are those typically along the river valleys, adjacent to watercourses (e.g. Froxfield Stream).

Published estimates of agricultural sediment erosion rates indicate a potential total annual sediment load to the canal of 16,000 tonnes/yr (Defra, 2008; Morgan, 1980). This represents a sedimentation rate of approximately 0.05m/year, which is also consistent with estimates from Halcrow (2007).

By comparison, the estimated average algal contribution delivered into the River Kennet downstream of Copse Lock is 500 tonnes/yr; two orders of magnitude smaller than that associated with (largely inorganic) catchment sources. This suggests that the net contribution of the algal load at Copse Lock to the total suspended load discharged to the River Kennet is small (ca. 3%).

This is confirmed by chemical analysis of sediment samples; Organic Matter% in dredged samples from the Kennet and Avon Canal were within the range commonly reported for UK rivers and lower than those reported for other local rivers, such as the Enbourne and Lambourn. This would appear to indicate that sediment in the Kennet and Avon canal may not contain large amounts of algal material and is likely to be largely (inorganic) catchment-sourced.

The catchment sediment inputs to the canal are ephemeral and typically result in visible plumes where they discharge into the canal (e.g. Peartree Bottom Stream, Templeton Stream) or accumulations (as bars) of sediment where they discharge into the river (e.g. downstream of Copse Lock).

C. The effects of operation and use of the canal

Following on from the above, the canal acts as a temporary store of sediment received during the winter. This is the period of maximum sediment input and corresponds with the the more limited use of the canal during winter. As use of the canal increases in spring and summer the canal is likely to act as a source of sediment, creating pulses of sediment in response to flow, lockage and re-suspension of sediment by the passage of narrowboats. Whilst lockage and the passage of narrowboats creates a clearly visual impact, the effect in terms of total load is temporary; monitoring data shows that turbidity reduces after each lockage and generally at the end of every day and does not appear to be permanently sustained as a result of these activities.

Overall, there is no clear, consistent relationship between elevated turbidity at Copse Lock and the Benham and Craven Fisheries downstream. Whilst under certain conditions elevated turbidity at Copse Lock are evident at the fisheries, for most of the time there would appear to be other factors that also have a significant influence on the River Kennet beyond simply lockage and boat passage. In particular, the impact of bottom-opening weir structures on the accumulation and release of sediment is likely to be important; anecdotal evidence has been provided in relation to significant deposition immediately downstream of the Kintbury Feeder and Copse Lock. In addition, the operation of the number of large, bottom-opening structures between Copse Lock and the fisheries (e.g. Hamstead Lock and other structures close to Copse Lock) may well play a significant role in mobilising accumulated sediment upstream of the weir.

Whilst there is no empirical evidence / direct field analysis to confirm impact pathways resulting from the interaction between the canal and the River Kennet, this conceptual framework would suggest that there are three separate processes operating independently and in-combination. Source apportionment assessment indicates that the primary impacts are more likely due to catchment derived suspended sediment load and the effects of canal structures in containing or releasing sediment downstream.

Assessment of potential for impact

The export coefficient / source apportionment modelling provides an assessment of source contributions of phosphorus <u>to</u> Wilton Water and <u>to</u> the canal. In this context, 'the canal' refers to the total geographic extent from the Crofton Top Lock to Copse Lock where the canal joins the River Kennet. The outputs from the export coefficient modelling are described in terms of % annual contribution of total load to the canal. These outputs are passed to the Zeckoski algal model which provides a more geographically discrete assessment of impact on algal growth in each canal reach / pound between Crofton and Copse Lock. The outputs from the Zeckoski model are described in terms of total wet algal load at Copse Lock.

Assessment of the relative impact of STW discharges to the canal on phosphorus and algal dynamics:

a) <u>What are the key catchment characteristics determining water quality condition?</u>

- Source apportionment assessment indicates that diffuse agricultural sources typically accounts for close to three quarters of the annual phosphorus loads to the canal.
- Implementation of phosphorus stripping at Kintbury STW has already resulted in a significant reduction in annual STW contributions to the canal from a historic annual mean of 37% to 17%. Further planned implementation at Great Bedwyn (by 2015) will reduce annual STW contributions to the canal to 10% of total phosphorus load.
- Inflows from the River Kennet via the Kintbury Feeder are a key feature influencing both the water quality and algal dynamics of the canal in its lower reaches[1].

<u>What are the key catchment characteristics determining ecological condition?</u>

- Algal blooms are an annual feature of the river and the canal environment reflecting the high phosphorus status, although the magnitude varies in response to prevailing hydrological conditions. Algal growth has an immediate benefit to water quality in the canal by reducing soluble reactive phosphorus; although this is generally in transformation to particulate phosphorus (total phosphorus remains consistent). Chlorophyll concentrations in the canal are typically an order of magnitude greater than in the River, and the canal typically exhibits significantly less seasonal variation. Macroinvertebrate communities in the canal are typically less diverse than compared to the River Kennet, reflecting the heavily modified habitat conditions. The heavily modified environment of the

[1] Hydrological assessment of the Kintbury Feeder stream was undertaken by the Environment Agency in 2008.

canal also has a significant effect on sediment dynamics; the catchment provides a significant input of sediment, the majority of which moves slowly and sporadically through the canal system in response to high flow events, lockage and resuspension by narrowboat passage. Fisheries investigations on the Canal indicate a thriving population of coarse fish (Environment Agency, pers comm.).

- There are a number of perceived impacts where the canal discharges / overflows into the river SSSI, which supports a salmonid fishery. The Natural England condition assessment (2008)[2] refers to impacts of suspended solids, exceedence of phosphorus targets and morphological impacts. The impacts of changes in water clarity (impacting on amenity and fishery), on macrophyte growth and clogging of spawning beds are perceived to be immediately apparent downstream of Copse, through Craven Fishery and the Benham Estate which border the Kennet SSSI as far as the western outskirts of Newbury.

b) What are the current water quality issues in the canal catchment and to what extent does phosphorus contribute to these issues?

- Three distinct issues can be identified within the canal and the River all of which have the potential to influence condition: phosphorus, sediment and algal dynamics are all expressed in different ways and have different impacts on the condition of the River Kennet SSSI.
- There is a gradual downstream decline in phosphorus concentrations in the Canal and a clear seasonal separation between high autumn-winter Soluble Reactive Phosphorus (SRP) and Total Phosphorus (TP) concentrations and lower spring-summer concentrations. Peaks in phosphorus concentrations occur in winter / spring. As a result, water quality in the canal ranges from Good to Moderate, with occasional winter / spring peaks causing Poor status.
- Chlorophyll concentrations in the Canal are typically an order of magnitude greater than in the River Kennet upstream. The seasonal increase in concentrations in the canal typically starts earlier than in the River; at Copse Lock, however, there is a distinct 'boom and bust' cycle; algal populations (and TP concentrations) can fall to zero during the summer months. Whilst there has been a historic focus on the links between phosphorus and algal growth in the canal, the results from this investigation suggest that the algal load in suspension to the River Kennet SSSI is small and that a more dominant influence is exerted by catchment-derived sediment load. Diatomaceous mats and / or benthic algae may still exist and are visible throughout the River Kennet.

What are the current water quality issues in the river catchment and to what extent does phosphorus contribute to these issues?

- The Environment Agency has identified elevated turbidity at in the River Kennet at Newbury as the main reason for the adverse condition of the SSSI (Natural England, opp.cit.). Elevated turbidity has been historically ascribed to inflows of algal-rich material from Copse Lock.
- Analysis of the long term suspended solids (and turbidity) data for Hambridge Road (River Kennet downstream of Newbury, SU 490672) indicates an increase in baseline concentrations following a large peak in 1999/2000. This appears to coincide with the restoration of the connection between the River Shalbourne and River Kennet. Following which there appears to have been a significant change in the sediment dynamics of the River Kennet (at Hambridge Road, Newbury). Whilst there is still a strong seasonal trend, the data indicates an underlying increase in summer baseline turbidity.
- There is a clear seasonal pattern of turbidity throughout most of the catchment that shows peak suspended solids concentrations (a surrogate of turbidity) corresponding with the highest flows, potentially indicative of contributions largely from catchment sources.
- The estimated algal contribution delivered into the River Kennet downstream of Copse Lock is 500 tonnes/yr (on average), two orders of magnitude smaller than that associated with (largely

[2] http://www.sssi.naturalengland.org.uk/special/sssi/unit_details.cfm?situnt_id=1027151

inorganic) catchment sources. This suggests that the net contribution of the algal load at Copse Lock to the total suspended load discharged to the River Kennet is small (ca. 3%).

c) <u>What effect does the current level of phosphorus have on water quality (algal development)?</u>

- Within the canal, algal dynamics and phosphorus concentrations are closely interrelated; algal growth is in part a response to available phosphorus and during the development of the seasonal algal bloom, SRP is significantly reduced in the water column.
- As part of the investigation, the canal algal model of Zeckoski (2010) has been updated and interfaced with the range of model approaches developed.
- Model results show that planned phosphorus stripping at Great Bedwyn STW in addition to that already implemented at Kintbury STW will reduce algal concentrations in the canal. However, the dominant influence on the algal dynamics of the canal is the timing and magnitude of diffuse phosphorus source inputs.

d) <u>What is the scale of the impact on the Kennet SSSI priority waterbody?</u>

- The perceived impact pathway between the canal and the River Kennet SSSI has historically been related to the increases in turbidity in the River Kennet downstream of Copse Lock. The turbid plume that enters the river at this location has historically been assumed to consist primarily of diatomaceous algae.
- Comparison of algal and inorganic sediment loads generated within the canal indicate that the algal component of the turbidity load discharged at Copse Lock is likely to be at least two orders of magnitude less than catchment-derived sources.
- The results of this assessment suggest that there is a larger sediment issue that needs to be investigated, including quantitative sediment studies downstream of Copse Lock to further confirm the impact pathways on the River Kennet SSSI priority waterbody. There is no consistent transmission of turbidity impacts downstream of river structures into the Kennet Fisheries.

e) <u>What is the scale of the impact on the River Dun priority waterbody?</u>

- Based on modelling work undertaken by the Canal and Rivers Trust (CRT), there are two potential ‘impact pathways’ between the canal and the river. These are spillways located at Bedwyn Mill and Great Bedwyn.
- These spillways operate infrequently during the wettest months of the wettest years; however, when they do operate, they convey significant volumes of water into the River Dun, equivalent to ca. 30% of flows in that watercourse.
- These events tend to occur during the winter months when algal concentrations are minimal and there is significant dilution within the Dun catchment as a whole. As a result, the potential for impact of the canal on the River Dun priority waterbody is expected to be small.

f) <u>From the available data, is it possible to identify / quantify the main sources of phosphorus?</u>

- Application of an export coefficient approach has shown that overall, diffuse agricultural sources account for 73% of the annual phosphorus sources to the canal.
- The most significant source contributing sub-catchments of the total diffuse load to the canal are the Templeton (22%), Wilton (22%), Froxfield (21%) and canal (20%) sub-catchments.
- Sewage treatment works currently account for 17% of the total annual phosphorus load to the canal.

g) <u>To what extent are STWs a major / dominant contributor?</u>

- Historically (pre-2007), discharges from the four STWs in the canal catchment accounted for 37% of the annual phosphorus budget.
- Following phosphorus-stripping at Kintbury STW in 2007, this STW proportion reduced to 17%; the largest contribution coming from Great Bedwyn STW (10% of the annual load) followed by Kintbury (3%), East Grafton (3%) and Wilton (1%).

- Phosphorus-stripping at Great Bedwyn (2015) is assessed to reduce the STW contribution of phosphorus to the canal to approximately 10% of the annual load. This will also reduce the maximum monthly contributions from STWs to the canal to <25%.

h) Does the available data indicate any significance (or potential significance) of Phosphorus within the canal bed sediment?

- Total phosphorus concentrations in canal sediment compare with those at average to high for published data for 6 English rivers, and are similar to concentrations observed in the River Kennet (House and Denison, 2005).
- The key sediment impact relates to the quantities of sediment conveyed into, and from, the canal rather than the quality of canal bed sediment.
- Further investigations should focus on the mechanisms of transfer of sediment load and the relationship to, and potential for impact on, bed sediment quality in the River Kennet.

i) Does the discharge of treated effluent to Wilton Water have a disproportionately high influence on water quality in the canal owing to its discharge at the top of the system?

- Two STWs discharge into Wilton Water; East Grafton and Wilton STWs. Source apportionment modelling of Wilton Water show that a range of processes contribute to the Wilton Water phosphorus balance including (in order of importance) arable agriculture (43%), sediment phosphorus release (33%), STWs (13%) and other (11%). The Wilton Water catchment contributes approximately 20% of the phosphorus load to the canal, the majority of which is agriculturally or internally (sediment) derived.
- Algal scenario modelling has shown that phosphorus stripping at East Grafton and Wilton STWs would deliver limited benefits, reducing algal loads in the canal by 2.5% and 1% respectively.
- Phosphorus stripping at East Grafton and Wilton STWs could deliver some improvement at Wilton Water, although the dominant inputs are from diffuse catchment sources (agricultural) and release of phosphorus from sediment in storage (expected to be largely agriculturally derived). The temporary package plant at East Grafton STW appears to have significantly reduced the total STW contributions to Wilton Water. Scenario modelling of Wilton Water indicates that maintaining current temporary discharge quality would result in the overall STW phosphorus contribution to Wilton Water reducing from 13% to 4% of the total load. However, modelling algal response to this scenario shows limited benefit at Copse Lock, although there could be more localised benefit.

Assessment of the extent to which targeted improvements at STWs (or in relation to dealing with the impacts of those discharges) would provide improvement in water quality and ecological condition in the River Kennet SSSI and River Dun priority water body.

a) What options already exist for improving water quality in the canal?

- The introduction of phosphorus stripping at Kintbury STW has already reduced the overall STW derived phosphorus load to the canal from 37% to 17%.
- Algal modelling undertaken as part of the investigation has shown that phosphorus-stripping at Kintbury STW has been associated with a 5% reduction in the total algal load in the canal at Copse lock.
- Phosphorus stripping at Great Bedwyn STW will reduce loads further, the overall contribution of STW to the canal falling to 10%. This is estimated to lead to a 10% reduction in algal loads relative to current levels at Copse Lock.
- Implementation of phosphorus-stripping at those works discharging to Wilton Water is only likely to reduce algal loads in the canal by 3.5% in total (East Grafton 2.5% and Wilton Water 1%). Although not specifically designed to deliver phosphorus reduction, the installation of a temporary

(SAF) package plant at East Grafton has had an indirect benefit, delivering significantly reduced phosphorus concentrations from the STW outflow.

- Measures to manage sediment loads are likely to be more important than further measures for phosphorus and algae. A series of physical measures to control sediment at source, or along transfer pathways, would be most appropriate in terms of the magnitude of likely benefit accrued. A number of measures are already being implemented as part of Catchment Sensitive Farming (CSF) initiatives. However, in addition, opportunities for targeted sediment management including dredging, trapping and / or strategic 'flushing' of the lower canal using River Kennet inflows should be investigated under the Water Framework Directive Programme of Measures (Environment Agency).

b) Will targeted measures at STWs discharging to Wilton provide a significant benefit to the Canal as a whole?

- The STWs discharging to Wilton are small when considered relative to other phosphorus sources in the Wilton Water catchment, the Great Bedwyn and Kintbury STWs or diffuse phosphorus sources in the canal catchment as a whole. Further targeted phosphorus stripping at the East Grafton and Wilton STW will provide limited additional benefit, reducing annual algal loads in the canal at Copse Lock by 2.5% and 1% respectively.
- At East Grafton, the installation of a temporary package plant is already delivering reduced phosphorus concentrations from the STW outflow. Recent water quality monitoring during this period shows a clear benefit to water quality with a ten-fold reduction in historic phosphorus concentrations at the STW outflow to Wilton Water.

c) To what extent will potential reductions in phosphorus from STWs lead to desorption of phosphorus into the water column from canal bed sediment?

- From data available, there are no unusually high concentrations of phosphorus in the sediment of the Kennet and Avon canal; concentrations of TP are similar to those recorded in the River Kennet and other rivers in England or the Thames Valley.
- Sediment quality is related to catchment processes rather than sewage treatment works discharge quality. Given the dominant contribution by diffuse agricultural sources, any further reduction in STW loads is unlikely to result in potential for desorption from the canal bed sediment.

d) Would a change in the canal to a macrophyte dominated ecology aid water quality recovery?

- Macrophytes may aid water quality recovery by direct uptake of phosphorus from the water column, providing a more diverse ecosystem that competes with algal dominance and by making the canal less favourable for algal photosynthesis through shading. However, the potential extent of macrophyte coverage along the canal is likely to be small and limited largely to the canal margins; where water depths are shallow enough to support emergent macrophytes and where marginal vegetation growth will not affect boat traffic on the canal.
- An additional feature influencing the establishment of macrophyte cover is likely to be the presence of shading along the length of the canal. Bowes et al (2012) shows that shading can dramatically reduce algal growth; although this will have a consequent impact on SRP.
- In combination, these factors suggest that whilst there may be benefits of a macrophyte-dominated ecology within the canal, they are likely to be limited. A more likely benefit may arise from increased shading along the length of the canal; Bowes et al. (2012) have shown that riparian planting of trees can have dramatic effects on algal growth.
- Benefits might also accrue from filtering of canal water through an offline macrophyte-dominated system such as a reedbed, although this is constrained locally by land availability, the need to maintain boat passage at all times of year and the likely requirement of a costly pumped system to be effective.

To identify those works and measures at STWs which could provide a cost-effective response to the water quality issues in the River Kennet SSSI and River Dun priority water body.

- Following on from the above, phosphorus stripping is already in place at Kintbury STW and is being implemented at Great Bedwyn STW. These measures will reduce STW phosphorus concentrations being discharged to the canal, resulting in a reduction of the overall STW contribution to the total phosphorus load contribution to the canal to 10%.
- Further targeted measures to reduce phosphorus load from STWs have been shown to have limited benefit in terms of the net reduction of algal growth in the canal; phosphorus stripping at East Grafton and Wilton STWs are estimated to lead to a reduction in algal load of 2.5% and 1% respectively. In other words, further targeted improvements at the STWs are unlikely to provide a significant benefit to ecological condition of the canal or the river.
- Whilst the overriding impact on Wilton Water is a result of diffuse agricultural inputs (43%) and internal sediment loading (33%), STW discharges to Wilton Water can at times of low flow account for up to 25% of the total phosphorus source contribution based on historic data. The assessment of potential benefit on phosphorus and algal loads reported here indicates that whilst this does not appear to significantly influence the condition of the canal, there may be implications for the management of water quality and algal growth within Wilton Water. Recent monitoring data for East Grafton indicates significant improvement in discharge quality related to the operation of temporary treatment facilities at the works. Maintaining performance at the level provided by the temporary treatment works will provide a significant reduction in the STW load to Wilton Water.
- Further targeted measures at STWs beyond those currently in place do not appear to be justified based on the assessment of evidence within this investigation.
- The study has emphasised the importance of sediment contribution to the canal environment and potential measures to manage sediment source delivery and its intermittent transmission through the highly modified environment of the canal and to the River Kennet. Some physical measures to control sediment at source or along transfer pathways are already being considered as part of Catchment Sensitive Farming (CSF) initiatives. In addition to ongoing dredging activities, targeted sediment management measures might also include trapping, strategic 'flushing' of the lower canal using River Kennet inflows and review of the impact of the management and operation of weir structures in relation to the potential storage and mobilisation of sediment. These measures fall beyond the responsibility of Thames Water.
- The study has also identified a number of measures which may potentially help to manage the extent and magnitude of algal blooms within the canal. These include planting of marginal macrophytes and the potential for riparian tree planting to provide shading of the canal, which recent studies (Bowes et al, 2012) have indicated to be effective in reducing algal populations within the Thames catchment. These measures also fall beyond the responsibility of Thames Water.

Recommendations

Although this study has concluded that the main source contribution of phosphorus is diffuse catchment inputs arising from agricultural land use and the overall impact of discharges from sewage treatment works in the catchment is limited (and will decrease further following implementation of phosphorus stripping at Great Bedwyn STW), the following recommendations are made in relation to targeted actions by Thames Water:

1. **A weir for flow measurement should be installed at Wilton STW**. This STW is currently the only STW in the whole catchment where continuous flow measurement is not undertaken. Although this is not a condition of the licence, the particularly high profile of the discharge historically and the fact that it discharges into a lentic system suggest a permanent weir should be installed to confirm the findings presented in this study.

2. **Review of the operation of temporary water treatment plant at East Grafton and benefit to water quality**. Recent data from East Grafton STW shows a clear benefit to water quality from the influence of the temporary package plant at the works, with a ten-fold reduction in historic phosphorus concentrations. Whilst the discharges from East Grafton and Wilton STW are small, the combined load contribution to Wilton Water can at times reach 25% which is likely to contribute (but not cause) to sustained algal growth in the reservoir. Consideration should be given to whether the enhanced performance of the package plant at East Grafton can be sustained by permanent, unmanned works over the longer term.

In addition, although a large amount of data has already been collected in the Kennet, it is recommended that a number of additional items are considered to provide a robust evidence-base for decision making in the catchment. All of the items identified could be incorporated within the WFD monitoring network currently being reviewed by the Environment Agency.

3. A **water level recorder should be installed on the Kintbury Feeder Stream**. This monitoring location will serve to confirm the relative importance of this source of water to the lower part of the canal and will further confirm the influence of this water source on algal dynamics at Copse Lock, and its potential knock-on effects on the water quality of the River Kennet.

4. The historic water quality monitoring location at Hambridge Road represents the longest water quality record (since 1980) in the catchment of the River Kennet. This monitoring location has not been monitored between 2009 and 2011. It is recommended that **the Hambridge Road monitoring location be reactivated to become the main 'benchmark'; monitoring location for the upper Kennet catchment.** In addition, it is recommended that the parameters monitored are extended, at least for the next three-year WFD period. **The monitoring suite should include total phosphorus and chlorophyll** (as well as the current routine suite that includes orthophosphate and turbidity) to provide a robust data set with which to characterise the impacts of Copse Lock on the River Kennet.

5. Currently the main uncertainty regarding the impacts of Copse Lock on the River Kennet and the potential mitigation activities that may be used to improve the physical and ecological condition of the river relate to the composition of the turbid plume entering the river at Copse Lock. It has been historically perceived that the plume consists of algal material but some work has identified the broadly inorganic (catchment sediment) component of the plume. **The precise nature of the turbidity problem on the River Kennet needs to be fully confirmed**; different mitigation actions will be required to deal with inorganic sediment relative to algae-derived increases to address the changes in river turbidity that are currently driving river condition failures.

The study has also identified a number of measures which may potentially help to manage the extent and magnitude of algal blooms within the canal. These include planting of marginal macrophytes and the potential for riparian tree planting to provide shading of the canal, which recent studies (Bowes et al, 2012) have indicated to be effective in reducing algal populations within the Thames catchment.

The study has emphasised the importance of sediment contribution to the canal environment and potential measures to manage sediment source delivery and its intermittent transmission through the highly modified environment of the canal and to the River Kennet. Some physical measures to control sediment at source or along transfer pathways are already being considered as part of Catchment Sensitive Farming (CSF) initiatives. In addition to ongoing dredging activities, targeted sediment management measures might also include trapping, strategic 'flushing' of the lower canal using River Kennet inflows and review of the impact of the management and operation of weir structures in relation to the potential storage and mobilisation of sediment.