Copse Lock Feasibility Study

Final Report

Environment Agency

23 September 2011

Plan Design Enable

Notice

This document and its contents have been prepared and are intended solely for the Environment Agency's information and use in relation to a feasibility study for Copse Lock.

Atkins Limited assumes no responsibility to any other party in respect of or arising out of or in connection with this document and/or its contents.

Document History

Job number: 5100642			Document ref: Copse Lock Feasibility Final			
Revision	Purpose Description	Originated	Checked	Reviewed	Authorised	Date
Rev 1.0	First draft	PS/VJ/IM/EW	BC	BA	PS	23/03/11
Rev 2.0	Revision following comment	PS/VJ/EW	BC	BA	PS	23/5/11
Rev 3.0	Revision following comment	PS/VJ/MI/EW	BC	PS	PS	19/9/11

Table of contents

Tables

Figures

Executive summary

At the point where the River Kennet and Kennet and Avon Canal join just downstream of Copse Lock it has been shown that poor quality canal water is mixed with better quality river water. A full options appraisal has been undertaken to identify options for improving water quality where the canal and river mix (Halcrow 2007). One of the options considered was to separate the river and canal. A subsequent report by HR Wallingford (2008) proposed six potential options for separation. The purpose of this report is a consideration of the feasibility of these options.

A feasibility study is required to explore the options put forward by Halcrow and HR Wallingford so that further detailed work can focus on a smaller number of options. This feasibility report considers the six options based on:

- Engineering aspects
- Water quality impact
- Ecological and fisheries impact
- Overall costs and benefit assessment

Engineering Aspects:

Work by Halcrow and HRW separately identified the engineering and planning requirements for a number of options. The engineering requirements of each of the proposed options have been considered further here to establish whether there was a viable route for a new separated channel (river or canal). For all of the options proposed, the river and canal will need to cross either by the river going under the canal or the canal crossing over the river. A key consideration in this is the extent to which local topographic conditions will facilitate or act as a constraint to separation.

Of the six options, three separated the river to follow a route to the south of the current joint river-canal. Topographic survey of the area shows that each route would need to cut into valley slopes with rises of approximately 5m. As a result, any new channel would require the removal of least 35,000 m^3 of earth, leading to substantial local landscape and environmental impacts to achieve the required river and channel height. The environmental impact of works on this scale is likely to be significant and prohibitive. The increase in slope does not allow an alternative route to be considered at the proposed location. As a result, in our opinion, options based on a southerly route are unlikely to be cost effective given the engineering requirements, and these three options can be dismissed.

Options for diversion of the river using the floodplain to the north of the current joint river-canal are based on the river crossing under the canal to rejoin the existing river channel at Craven Fishery. Following a site visit in March 2011, in our opinion the most feasible location for the crossing is just upstream of Hamstead Lock because of the relative elevations either side of the canal. Two options were proposed for the crossing; a culvert or a siphon. Comparing levels on the upstream and downstream side of the crossing point showed that a culvert is feasible but requires dropping the downstream river bed level by approximately 2.5m. This will have a significant impact on the current operation of the downstream Craven Fishery but a re-profiled channel could be designed subject to a further feasibility study of geophysical constraints.

The alternative crossing method is to use a siphon to pass the river under the canal. It is possible to engineer a crossing if the newly created (northerly) river channel is embanked so that the water level on the upstream side of the crossing point (which is currently lower than the downstream level) matches the downstream level. This engineering approach is feasible. The siphon channel will require a significant commitment to maintenance to keep it operational

The sixth option proposed is to separate the canal by crossing it over the river and following a route to the north of the existing joint river and canal. So the canal can cross the river, Copse Lock would be moved downstream. To ensure the levels are sufficient for the crossing the canal would need to be banked approximately 4m above the current floodplain level. Downstream of the new Copse Lock the canal will need to be perched approximately 2.5m above the floodplain level.

The engineering considerations above dismissed three of the six options. The three remaining options followed routes to the north of the existing joined river and canal, downstream of Copse Lock. Routing the river following a new route to the north will need the river to cross under the canal using a siphon or culvert. Routing the canal following a new route to the north will require relocation of Copse Lock and the new canal section to be elevated above the floodplain to a height of between 2.5m to 4m.

All six options consider a second separation of the river and canal at Marsh Benham weir, just downstream of the Craven Fishery. It is at this point that the river and canal cross each other. An assessment of the levels associated with putting a culvert under the canal to pass the river water without interaction with the canal suggest that this is not possible if the downstream water level of the river is to be maintained and there is not a significant change to the River Kennet downstream of the weir. A flow survey of the current joining of the canal and river at Marsh Benham weir indicates that the faster flowing river water creates turbulence where it meets the slow flowing canal water which creates a flow wall that holds back the canal water. As such it appears there is little mixing of canal and river water at this point.

The implication is that a culvert may not be necessary. It is recommended that any works at the location are not undertaken until the river and canal have been separated and there is further investigation of flow interaction between the newly cleaner river water and the newly poorer quality canal water.

Water Quality Considerations

The key intention of separating the river and canal is to prevent poor quality water from the canal mixing with better quality water from the River Kennet. A review of previous studies and analysis of spot sampling and automatic monitoring data sets indicated that the water quality of the canal is significantly different to that of the river, with respect to a number of important water quality indicators, such as suspended solids, chlorophyll and dissolved oxygen saturation (DO%) levels. Differences in water quality between the canal and the river are more pronounced in the spring and summer, due to increased photosynthetic activity in the water column. Poor water quality in the canal appears to be linked to high photosynthetic activity rates, while some previous studies have also indicated that boat movements and lock operations are additional important factors controlling the algal/nutrient dynamics in the system.

Based on this information, a number of preliminary conclusions were outlined with regard to changes to the water quality of the area just downstream of Copse Lock arising from separation of the canal and the river.

- A decrease in chlorophyll and suspended solids concentrations is anticipated, leading to an increase in water clarity.
- Soluble reactive phosphorus (SRP) levels may increase, while ammonia levels may decrease (further investigation will need to look at potential changes to the amount of un-ionised ammonia, the form of ammonia most toxic to fish). However, separation of the canal and the river may also lead to changes in the ecological balance of the system, potentially leading to a higher or lower nutrient uptake rate than currently observed. Such changes will need to be considered during further investigations, including water quality modelling. Changes relating to nutrient status are also likely to vary between seasons.
- DO% levels are likely to decrease; however, as levels are currently very high in the canal and the river (10th percentile >83%[1]), this is unlikely to result in an overall negative effect on water quality.

These conclusions need to be confirmed by further investigation and modelling, which will also examine impacts downstream of Copse Lock. The most appropriate models for this application are thought to be a canal model developed by Zeckoski (2010; applied to the Kennet and Avon canal) and an INCA-P model (developed by the University of Reading; applied to the River Kennet [WRA, 2007]). We propose to run the canal model first, using its outputs as an additional ‘discharge’ or boundary to the River Kennet INCA-P model, allowing simulation of a number of scenarios relating to separation of the canal and the river under different environmental conditions. Any water quality modelling results will be analysed in the context of available information in the system and in discussion with the ecology and other specialist teams.

Ecology and Fisheries Impact

The impact on ecology and fisheries as a result of separating the river and canal will be closely linked to the water quality changes. From an ecological perspective all of the options are likely to result in an improved

[1] Based on automatic monitoring at Hungerford (canal), Wilderness (river), Copse Lock (canal) and at Craven Fishery (river) during 2005-2008.

macroinvertebrate, macrophyte and fish community in the river section that flows through the Craven Fishery and downstream of the Marsh Benham Weir junction (noting that the culvert option at Hamstead Lock which will require water levels to be lowered and a new channel created).

Within the Kennet and Avon canal there is a potential for deterioration in the macroinvertebrate community and fish assemblage due to the removal of the influence of freshwater flow from the River Kennet i.e. the canal section will no longer be mixed with river water which is of high quality.

The new river channel sections can be designed to maximise ecological benefit. Habitat quality is unlikely to change where the existing river channel forms part of the option.

In terms of fish passage it is considered that culverting provides the best engineering option to facilitate appropriate design management to mitigate for any affects of the requirement to divert flows within the existing system. This stated, hydraulic modelling will be required to determine flow velocities through the individual structures to provide a more robust assessment of impacts on individual fish species passage in relation to their swimming ability.

Overall Costs and Benefits Assessment

Following topographic survey and review of the engineering considerations, three of the six options proposed are no longer considered justifiable. Of the three remaining options an initial assessment suggests all will achieve the same benefit to water quality by reducing the algal input to the river from the canal but the option that passes the river under the canal at Hamstead Lock by siphon will be at the expense of lost upstream fish passage and will not be acceptable. The loss of fish passage will be counter to Water Framework Directive objectives. The option to culvert the river under the canal will require the bed of the river to be lowered through the Craven Fishery stretch of the river. The development of a new section of canal will require considerable engineering and will create a large landscape impact. The engineering costs associated with both options are £1.2M and £5.5M respectively (based on the scoping costs in HR Wallingford 2008); lowering the river channel through Craven Fishery for the culvert option could add an addition £0.5m to the cost for that option and would require a culvert at Marsh Benham weir (£1.2M).

It is recommended that a second phase of detailed design feasibility is undertaken for the two options that have been identified as initially feasible.

1. Introduction and Background

1.1. Context

The Kennet and Avon Canal joins with the River Kennet at several places along its route. Where the canal and the river join for the first time just downstream of Copse Lock, deterioration in water quality in the river can result from the mixing with canal water of a lower quality. To attempt to address the problem, an option is being considered to separate the river from the canal by either diverting the river or diverting the canal. An investigation has been commissioned to assess the feasibility of seven potential routes for separation that have been put forward.

1.2. Previous Reports

A full options appraisal has been undertaken by Halcrow (2007) and is documented in the report “Kennet River-Canal Interaction Scoping Study Final Report_issue1_rev2”. The report considers a range of options in addition to the separation option and recommends that a feasibility assessment is made to further test the costs and benefits of the option. An initial feasibility report was produced by HR Wallingford (2008) which identified six potential ways in which the river and canal could be separated. The report considered costs and constraints for the implementation of each option but no consideration was made of the water quality or ecological benefits to be gained from a separation. The requirements for a full feasibility assessment were subsequently identified by Windrush AEC (2009). It is the requirements noted in the Windrush AEC (2009) report that is the basis for the current feasibility study.

1.3. Proposed Options

The original option put forward by Halcrow (2007) separated the river from the canal just upstream of the confluence with the canal at Copse Lock. The river would then be re-routed to the north of the canal and re-joins the existing river by passing under the canal just before Hamstead Lock. HR Wallingford considered this route in more detail along with five other options for routes to divert either the river or the canal or engineering solutions for crossings. In total seven options form part of the current detailed feasibility study, although in reality the Halcrow Option is the same as the HR Wallingford option 1.

1.4. Approach

The approach for the current feasibility study is based on the criteria put forward by Windrush AEC. It considers the engineering constraints, the potential environmental benefits (mainly effect on water quality, ecology and fisheries) and the factors required to implement the separation.

A two phased approach to the feasibility has been used. This report is phase 1 which provides an initial screening of options. Each of the options is considered separately for engineering constraints, but at this stage the benefits and implementation factors are assumed to be the same for all options. A multi criteria analysis will be used to differentiate between each of the options and will incorporate an element of cost. The aim of phase 1 is to reduce the number of options being considered.

The second phase will consider in more detail the preferred options identified in phase 1.

2. Engineering considerations

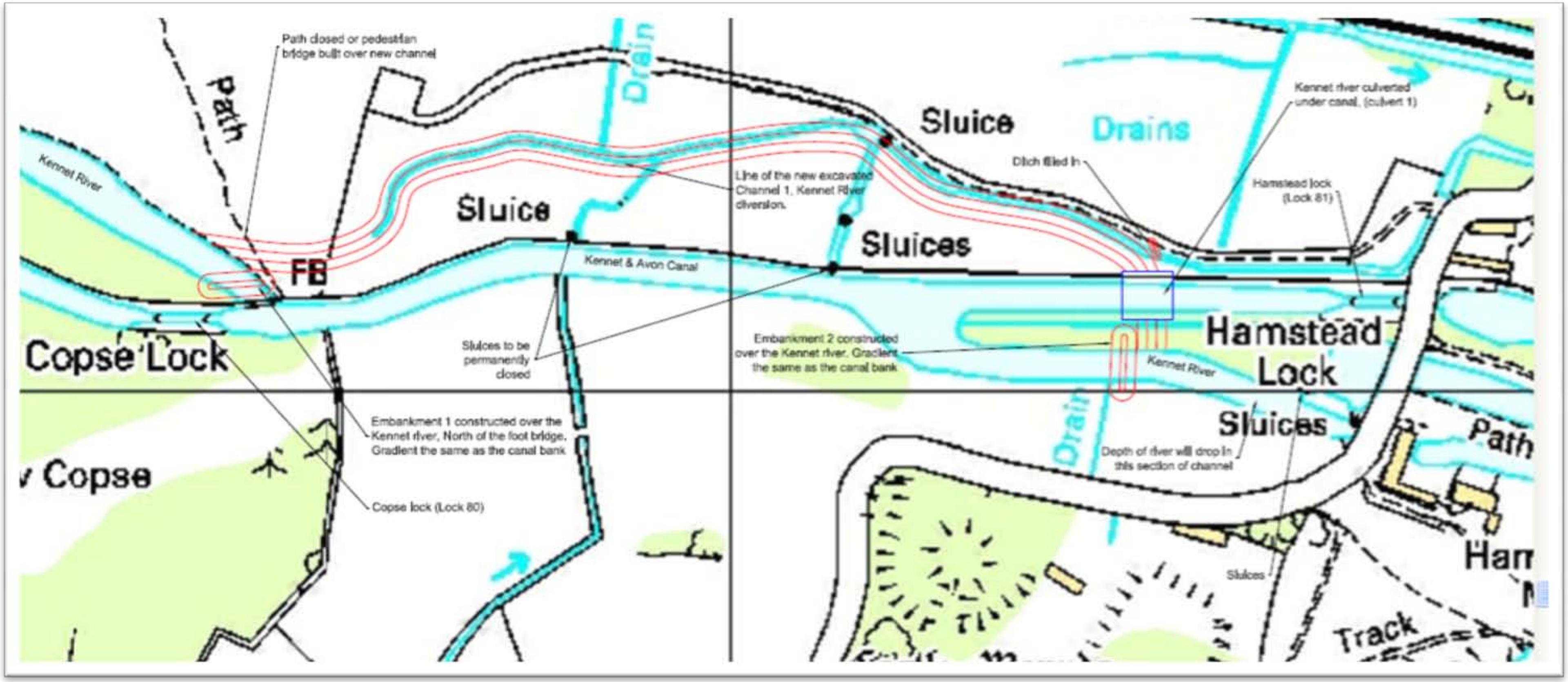
2.1. Approach

To initially assess each of the six options for separation, a site visit on 1st March was used to look at each route and to consider topographical constraints. The site visit was also used to scope out the requirements for an additional survey to ground truth existing LiDAR data and provide the detailed cross sectional data required to model the proposed routes.

Modelling of the routes used an existing flood risk model which was adapted to include the options. The model was used to estimate the impact on flow and level in the river and the canal. The model predicted how much flow will go down the river whilst maintaining current levels in the canal. The survey of levels and LiDAR survey allowed an estimation of whether it is possible to route the river under the canal (or the canal over the river), whilst the modelling indicates what flow any structure should be designed to need to convey. The potential impact on flooding was also considered.

2.2. Option 1 Divert the river to the north of the canal and then culvert under the canal

Option 1 separates the river from the canal just upstream of the point where they currently join after Copse Lock. The new channel would be routed through the floodplain and then pass underneath the canal close to Hamstead Lock to rejoin the river (Figure 1). The design proposed by HR Wallingford rejoins the river upstream of the sluices on the river adjacent to Hamstead Lock but we consider it will be possible to join to the pool downstream of the sluices, avoiding the necessity to decommission the sluices.



100 0 100 200 300 400 500 (m)

Figure 1. The route of option 1 – taken from HR Wallingford (2007)

Topographically there is space to route the river along the chosen path. At the point where the river will be separated the existing floodplain is 1.7m below the current river level (surveyed on 15th March 2011). The levels associated with option 1 are shown in Figure 2. In order for the river to pass under the canal, taking into account the canal depth required for navigation, the new channel will need to have a level similar to the current level of the small channel to the north of the canal. The canal at Hamstead Lock is deeper than the minimum required for navigation, so some infilling can be used to limit the depth required for the culvert. Modelling has identified that to pass the required flow for the 1% annual event, a culvert under the canal is required that is 3.6m wide by 2.1m high.

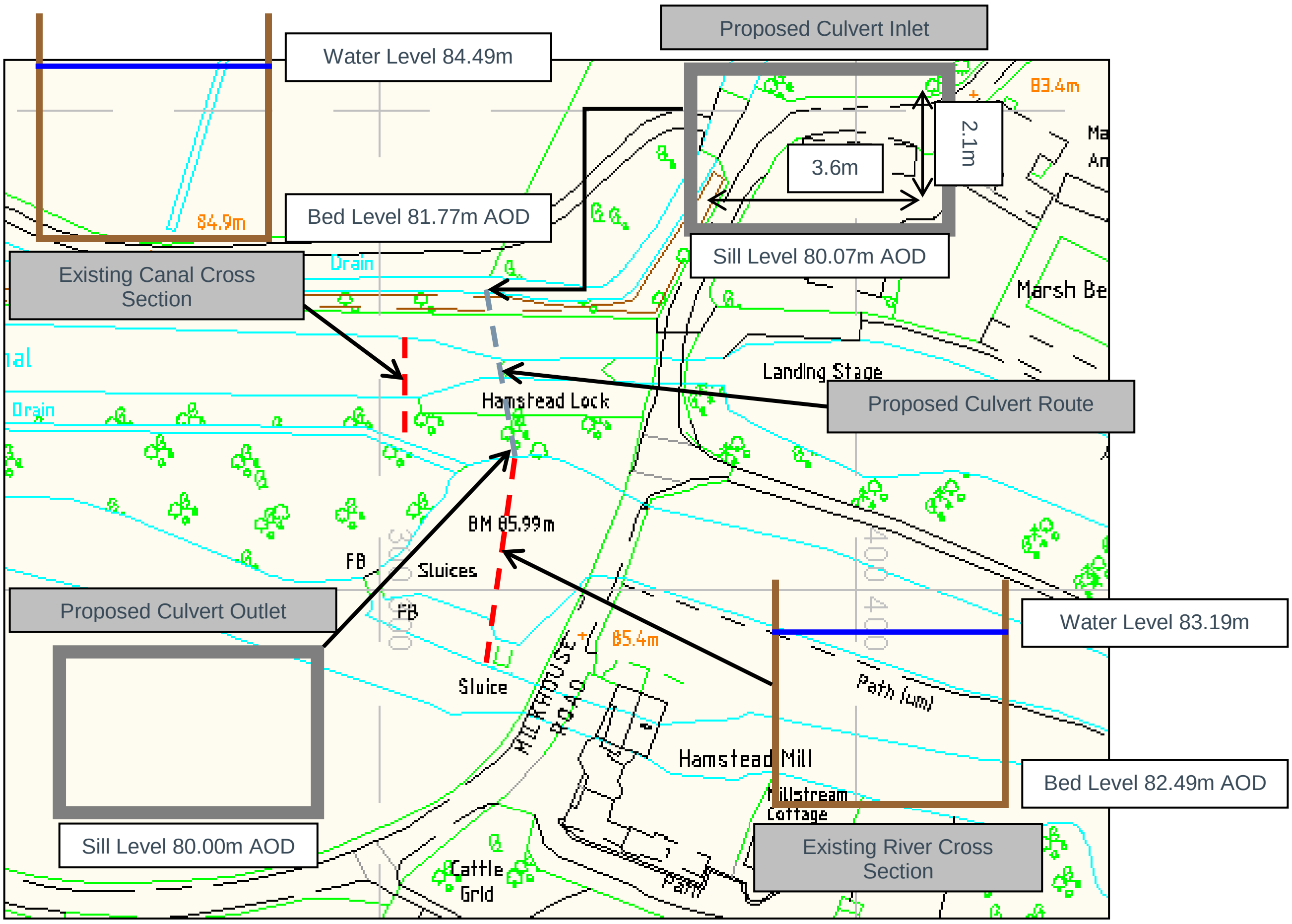


Figure 2. Relative elevations associated with option 1.

The river on the south side of the canal adjacent to Hamstead Lock is currently 1.3m below the water level in the canal (83.19 mAOD). This water level is significantly above the top level of the culvert designed to go under the canal. If a culvert routes the river under the canal, then water level in the river at the downstream side will need to drop by approximately 1m to match the top of the culvert exit. Dropping the water level by 1m will dry out the existing channel as illustrated in Figure 4. To match the level and capacity of the culvert the bed of the river will need to be lowered from the current 82.49 mAOD to 80.00 mAOD.The lowered bed level will need to be continued downstream through the Craven Fishery. The point at which the existing channel bed level matches the lowered bed level is roughly at the Marsh Benham Weir junction 800m downstream. If bed lowering occurs the existing flow and level control structures in the Craven Fishery will need to be removed or modified.

A geophysical survey of the bed of the river will be required as part of a further feasibility assessment of lowering the river bed to determine whether the underlying geology is a constraint on channel bed lowering. The impact of Option 1 on flow and bed levels is shown in Figure 3.

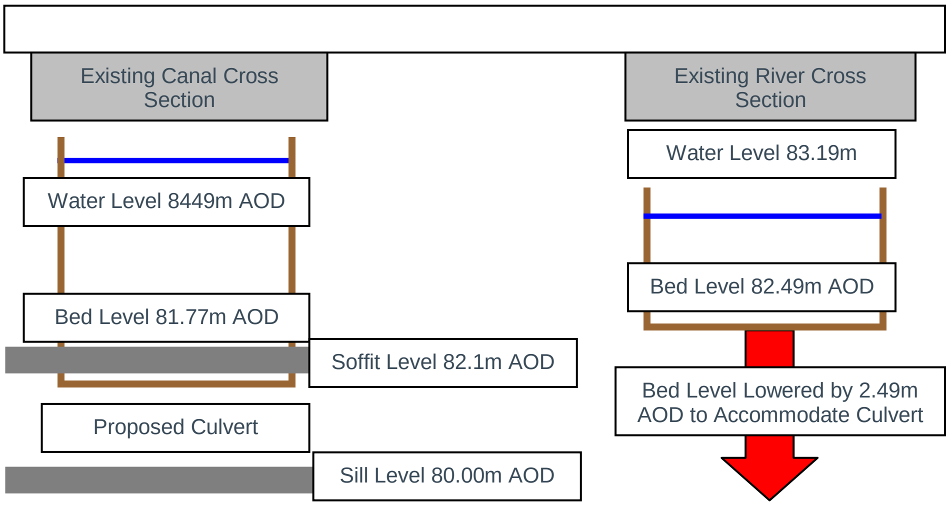
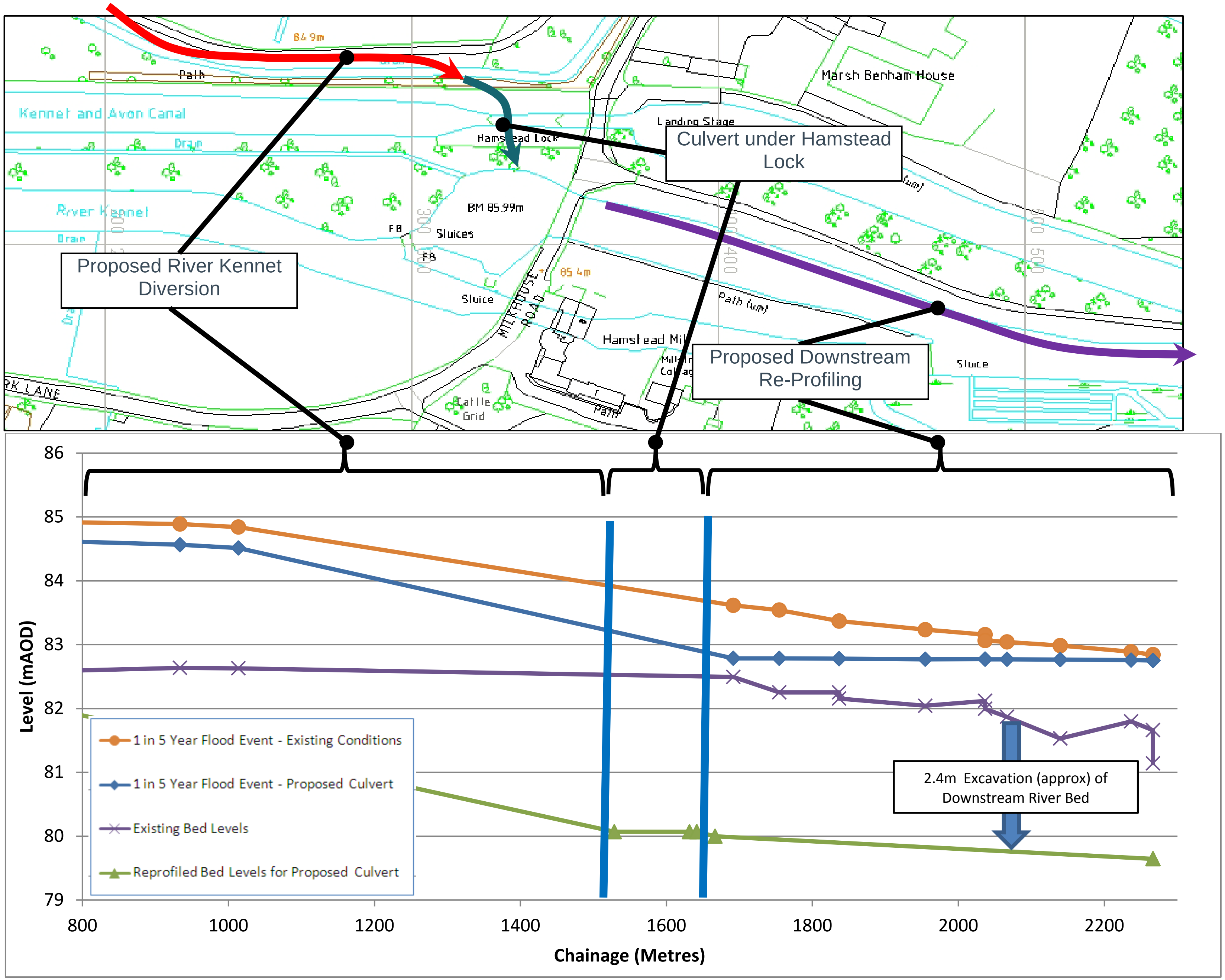


Figure 3. Reduction in bed levels downstream required at culvert outlet.

Figure 4 - Relative elevation and water level associated with option 1.



The assessment of the relative levels shows two key aspects of Option 1:

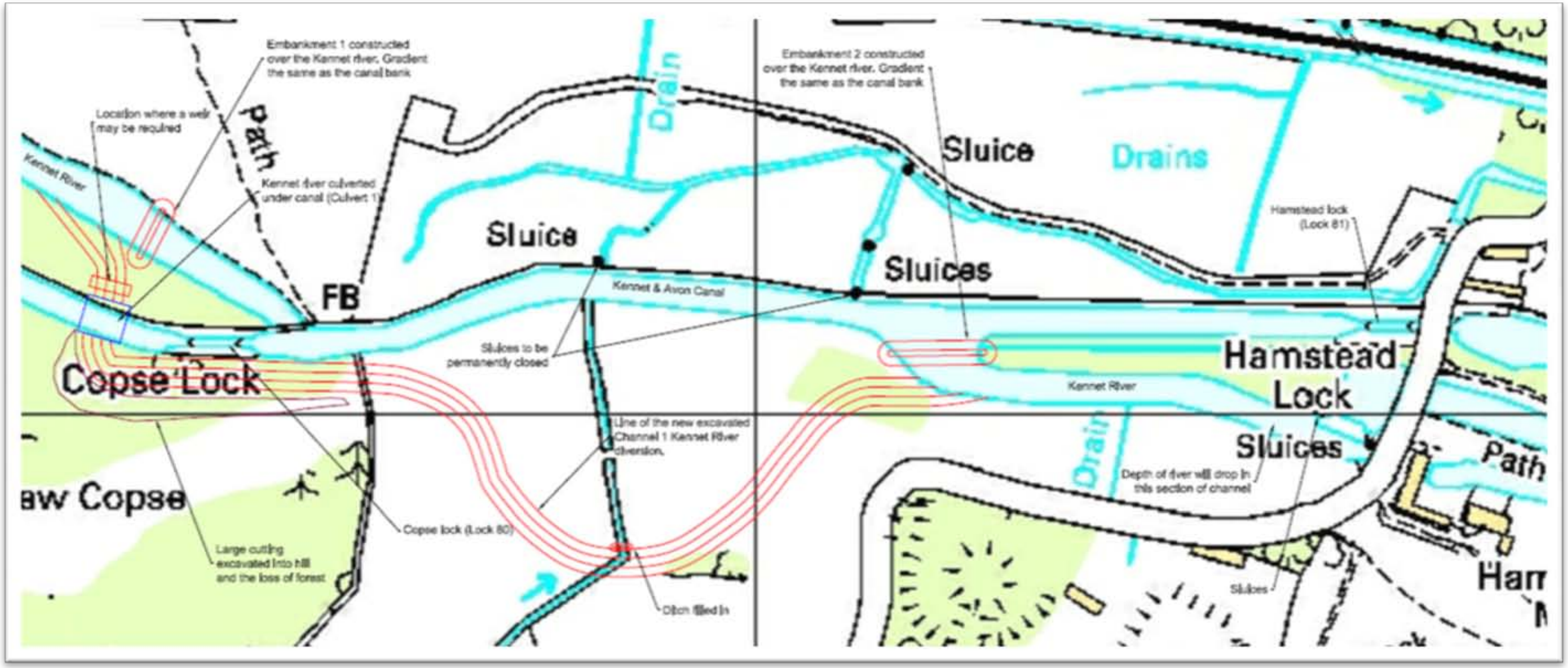
1. Routing the river along the existing floodplain to go under the canal at Hamstead Lock requires a drop in current river level of 1.7m over the 520m length of new river channel; a gradient of 0.003.

2. Where the proposed new river channel is culverted under the canal, the bed level of the channel on the downstream side will need to be 2.5m lower than the current level on the downstream side. Such a bed level is roughly equivalent to the bed level of the river channel at Marsh Benham Weir.

2.3. Option 2 Divert the river to the south of the canal by culvert under the canal

Option 2 also separates the river from the canal at a point upstream of the current join between the river and the canal at Copse Lock. In this case the river is diverted under the canal at a point upstream of Copse Lock where the canal is perched above the river level. The new river route runs alongside the canal and then meanders inland, rejoining the current river course upstream of Hamstead Lock (Figure 5).

Considering firstly the river levels associated with this option, the route is feasible to pass the river in a culvert under the canal. However, the topography that the route will need to pass through after passing under the canal will require considerable engineering and earth removal. At the point where the new river course runs parallel to the canal, the current floodplain/valley floor is relatively narrow and considerable earth removal will be required to create a channel which is at a level that can pass under the canal. The 1m contours derived from the LiDAR survey suggests that adjacent to Copse Lock up to 10m depth of earth will need to be excavated to match the river level (see Figure 6 and Figure 7).



100 0 100 200 300 400 500 (m)

Figure 5. The route of option 2 – taken from HR Wallingford (2007)

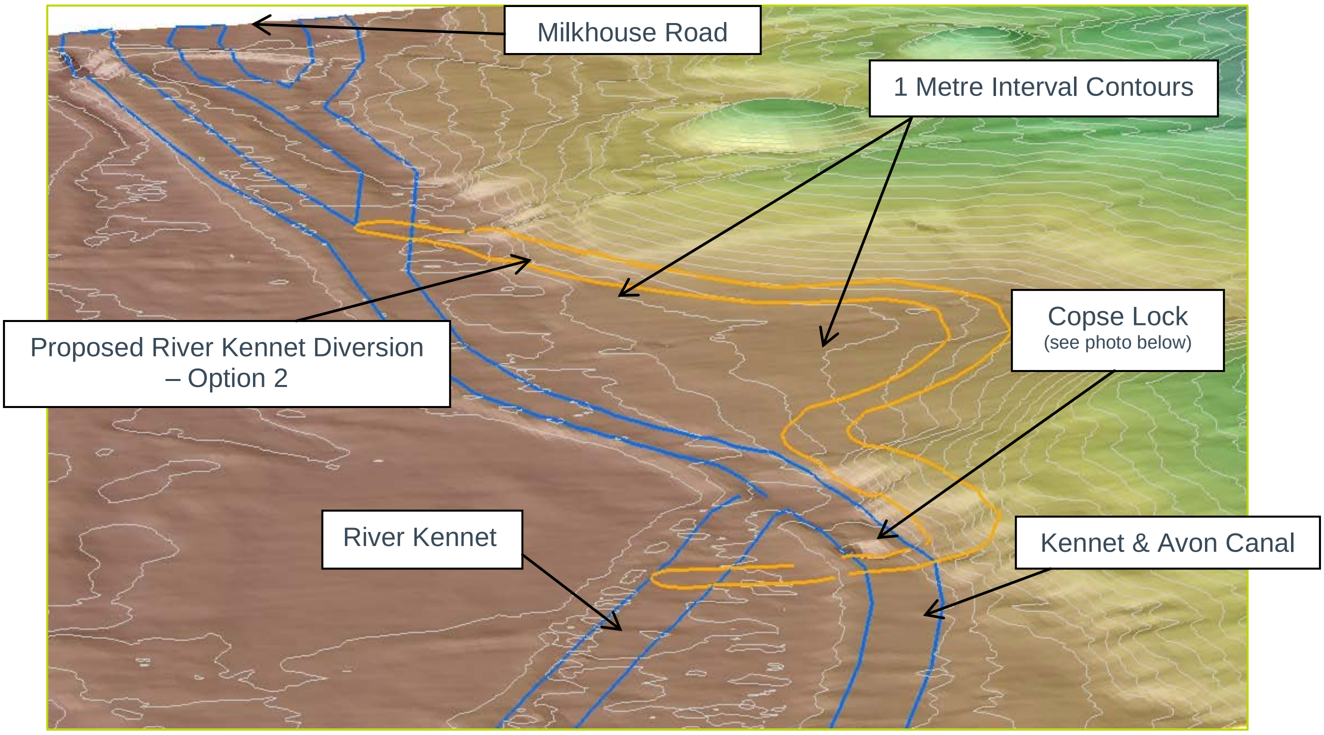


Figure 6. LiDAR projection of topography around Copse Lock and the route of option 2.

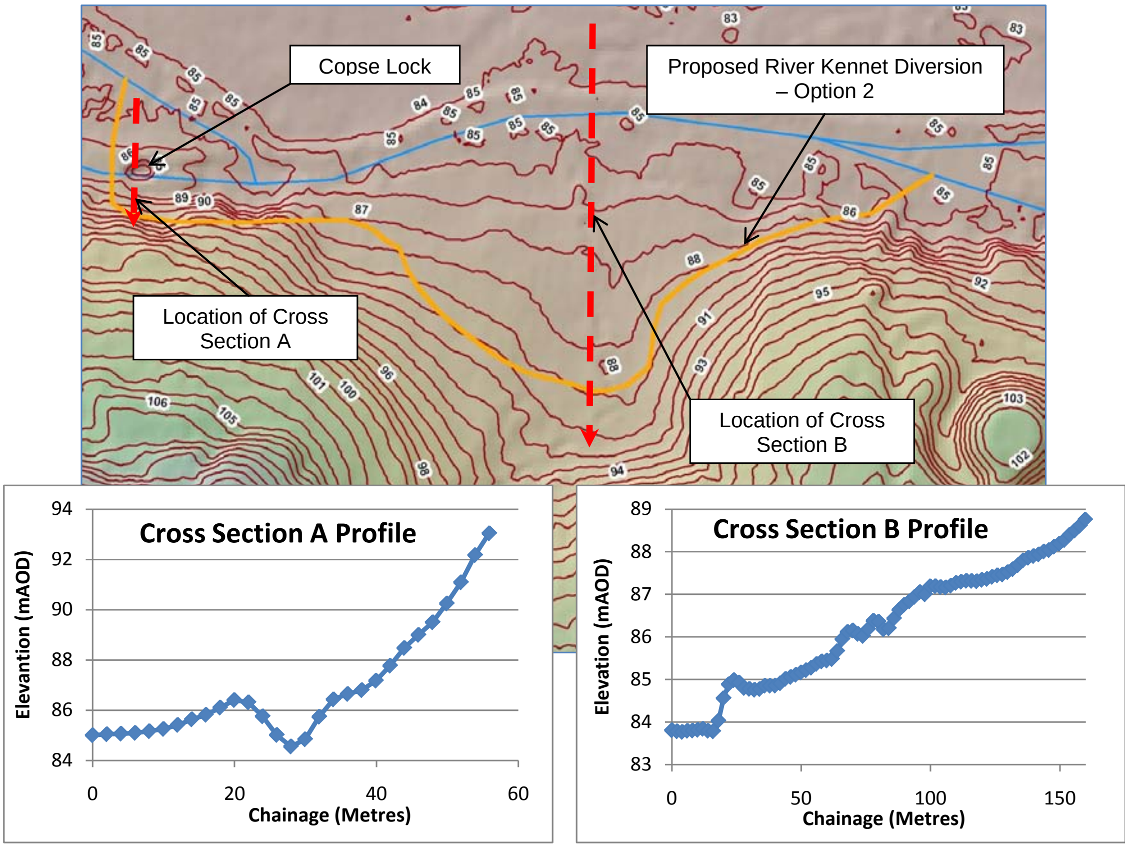


Figure 7. Cross-sectional profiles for two sections of the proposed route.

The current topography for the route of the river before it re-joins the river will also need to be considerably excavated to achieve the required channel height. Figure 7 suggests that up to 7m depth will need to be excavated. The excavation associated with the route has been calculated using the depths from the LiDAR image of the valley side. It is anticipated that 35,000m^3 of material will need to be excavated to create the channel itself. The estimate of excavated material does not include profiling of banks and creation of access paths along the route.

On the basis of the volume of excavation that will be required, it is not considered that Option 2 is justifiable. Excavating this amount will be significant in terms of cost (considered in section 5.1) and environmental impact which we believe may make this option infeasible

2.4. Option 3 Divert the river to the north of the canal and then siphon under the canal

Option 3 follows exactly the same route as Option 1 except at the point where the river passes under the canal immediately upstream of Hamstead Lock a siphon is required rather than a culvert. The option to use a culvert was assessed for option 1 (Section 2.2) and whilst the current levels do allow sufficient space for a culvert, the downstream water level would need to drop by 1.18m which will significantly impact on Craven Fishery without channel adjustment.

To engineer a siphon, the new river channel upstream of the crossing point will need to be embanked to raise the water level by (in the order of) 1.18m. There is some advantage to this at the point where the new channel is created from the existing river at the upstream end; the current difference of 1.7m between water level and floodplain level will be reduced to approximately 0.5m. The new channel would therefore have an effect on gradient by spread a 0.5m drop over 520m (rather current 1.7m drop). The gradient of a channel with a 0.5m drop will require less engineering barriers to achieve the drop.

The siphon bore area needs to be sufficient to convey a 1 in 100 year (1% annual probability) plus climate change event in theory, assuming no blockages, or siltation. The size of siphon derived from flows generated by the modelling was 7.56m^2 which is based on an opening of 3.6m x 2.1m, the same dimensions as the culvert opening. The invert level of the siphon is 79.38 mAOD, which is based fitting the siphon under the canal and filling the canal to the minimum navigable depth of 1.3m and then tunnelling underneath. To ensure that the siphon operates as designed, there will need to be an ongoing maintenance programme to ensure that capacity is maintained.

By using a siphon the water level of the river on the downstream side of the canal at the crossing can be maintained at the current level so there is no fall in water level through the Craven Fishery.

However, because the diversion can only be achieved by a siphon, this will result in a significant barrier to the passage of fish. A barrier to fish passage will mean that Water Framework Directive targets are not met.

2.5. Option 4 Divert the river to the south of the canal by siphon under the canal

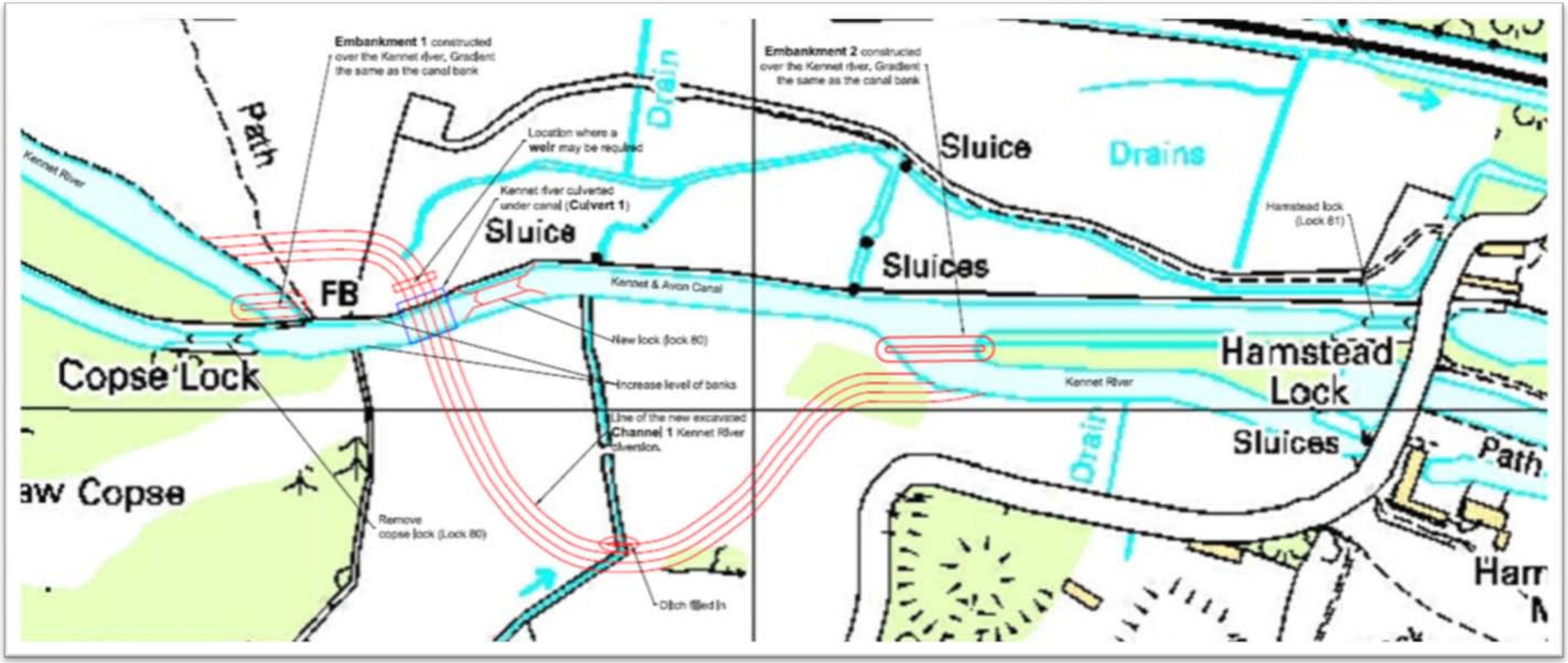
Option 4 follows exactly the same route as Option 2 except that the river passes under the canal just upstream of Copse Lock using a siphon rather than a culvert.

This option was not considered further due to the topographical limitations that were identified for Option 2.

2.6. Option 5 Divert the river to the south of the canal and relocate Copse Lock

Option 5 is similar to Option 2 except that to avoid the topographical space limitation of routing the new river course adjacent to Copse Lock, the lock is relocated further downstream and the river initially routed to the north of a new elevated section of canal before being culverted under the canal (Figure 8). Once culverted under the new section of elevated canal, the river follows the meandering southerly route proposed for Option 2.

This option was not considered further due to the topographical limitations of the southerly route that were identified for Option 2.



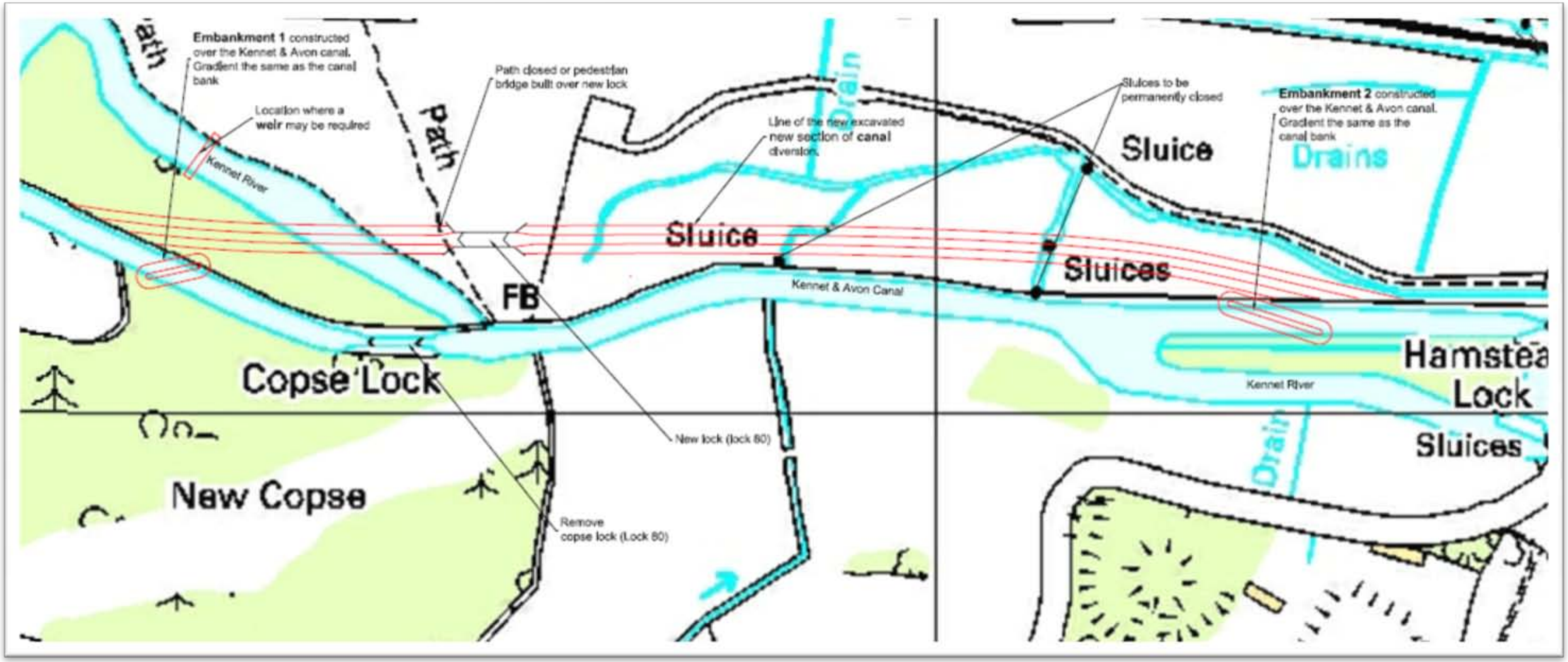
100 0 100 200 300 400 500 (m)

Figure 8. **The route of option 5 – taken from HR Wallingford (2007)**

2.7. Option 6 Divert the canal to the north of the river

Option 6 diverts the canal to the north upstream of Copse Lock. The canal crosses over the river and follows a route to the north of the existing joint river – canal section (see Figure 9). To allow the canal to cross over the river, the current water level of the canal upstream of Copse Lock will be maintained by relocating the lock after the canal has crossed the river. The water level will be dropped at the relocated Copse Lock to match the current level of the river.

Looking at the levels associated with this option, it is possible to engineer a new canal to follow the proposed route. At the point where the canal crosses over the river, levels are 84.65m in the river (from survey on 15th March 2011) and the canal water level is approximately 86.75m (LiDAR level). On the assumption that the lined canal will have a depth of 2m there will be sufficient height to cross the river but there may be a need to drop the river level for flood risk management purposes to allow all flows to be conveyed through the culvert under the new canal. The levels associated with the new canal route crossing over the River Kennet are shown in Figure 10 and the impact on water level in the river is shown in Figure 11.



100 0 100 200 300 400 500 (m)

Figure 9. **The route of option 6 – taken from HR Wallingford (2007)**

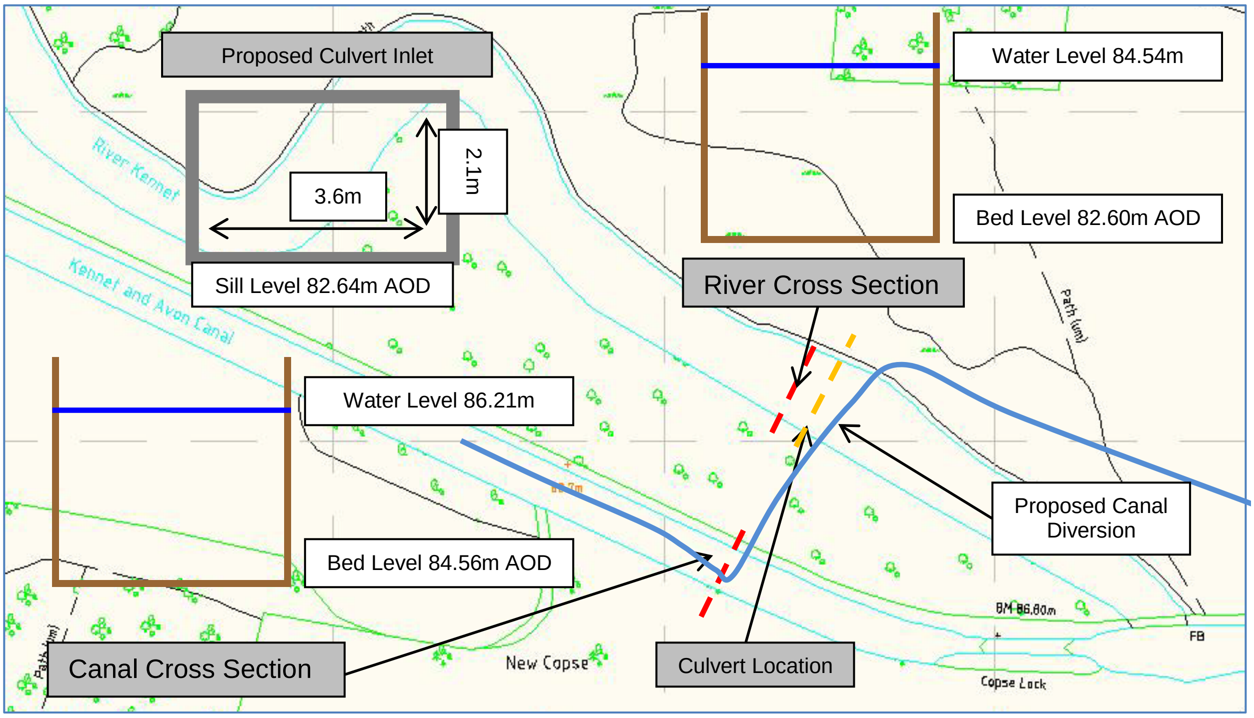


Figure 10. Comparison of canal bed level and river water level at proposed crossing point

From an engineering perspective Option 6 is feasible. Where the canal is routed before the new location of Copse Lock the embankments will need to be at least 4m above the current floodplain level. Once the water level has been dropped to the current river level at the new Copse Lock, embankments will be needed which are at least 2.5m. The difference between canal levels and the current floodplain level for the new route of the canal will mean that significant earthworks will be required to create a new stretch of canal, which will have significant landscape impact.

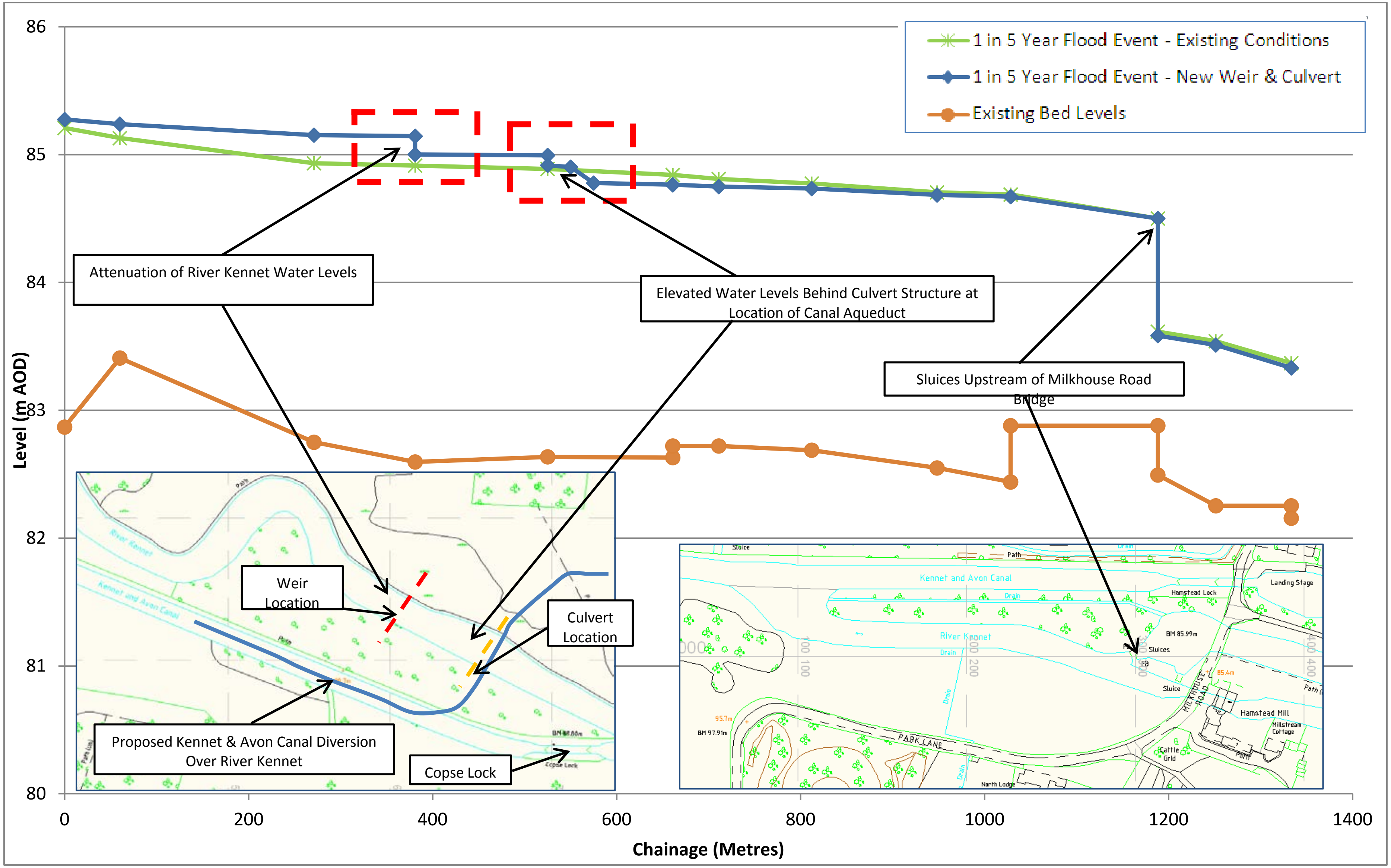


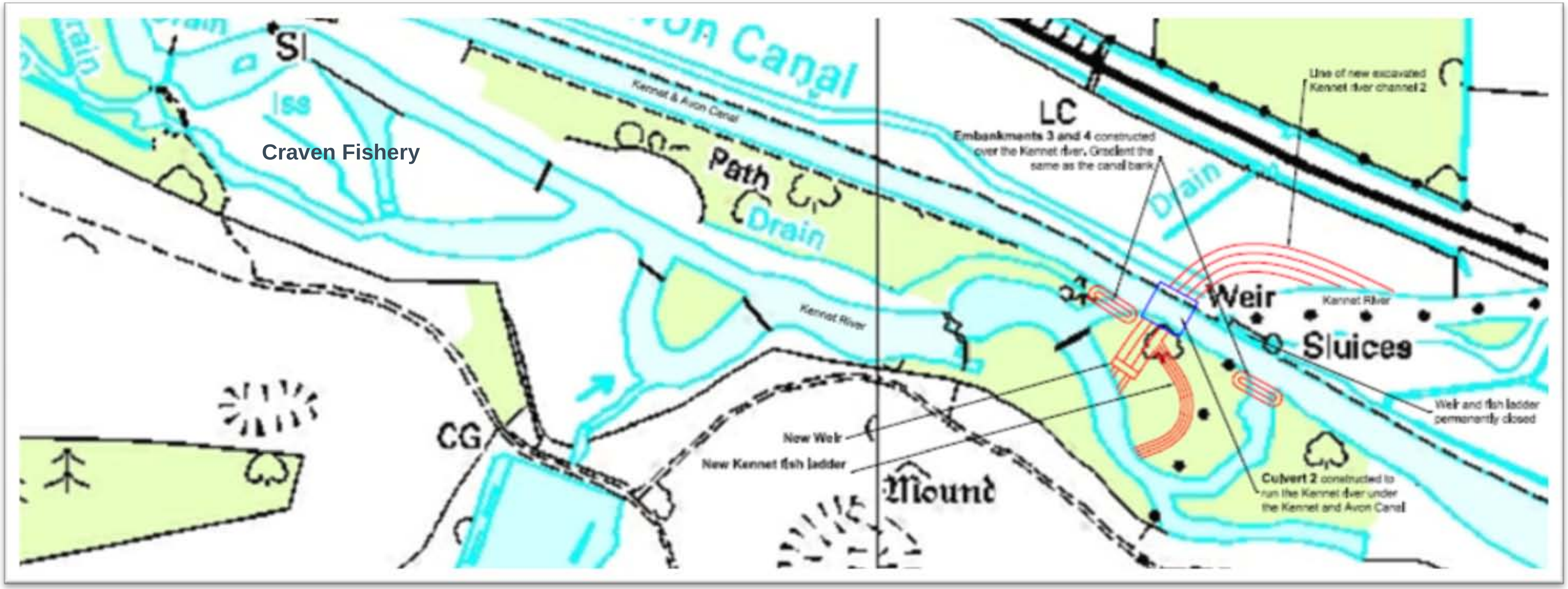
Figure 11. Impact on 20% annual probability flood event in the river from routing the canal over the river

2.8. Marsh Benham Weir junction

For all of the options discussed above, the same works are proposed at the next downstream point where the river and canal rejoin. The river currently joins the canal at the same level and immediately downstream of the join there is a sluice that drops the river level by 2m. The option proposes to continue to separate the river from the canal using a culvert to take the river under the canal (Figure 12). A sluice would be constructed to drop the river level to the current downstream river level before it reaches the canal. The existing sluice would be decommissioned.

From an engineering perspective there is not sufficient difference in level to route the river under the lined canal. The current river/canal level is at 82.54m and the river on the downstream side of the Marsh Benham sluice is at 81.065, giving a difference of 1.533m. The difference is not sufficient to fit a culvert without lowering the downstream river level. The water level would need to be lowered by approximately 1.5m which would dry out the downstream river where the channel has a depth of 1.5 to 2m. To maintain flow depth, the channel bed would need to be lowered by approximately 1.5m.

During the site visit on 1st March 2011 it was observed that the flow from the river, and the suction effect of flow over the sluice created a dominant flow across the path of the canal. At the interface between the canal water and the river water there was evidence of turbulent eddies where the faster flowing river water passed the slow flowing canal water. Discussion with Bob Preston (EA Fisheries Officer) suggested that during periods of increased algae/sediment in the canal it was possible to observe a clear difference in the colour of the water between the river and the canal; the implication was that the dominant flow pattern of the river water did not fully mix with the slow flowing canal water, in effect providing some natural separation limiting the potential for water quality impact.



100 0 100 200 300 400 500 (m)

Figure 12. Separation of the river and canal at the downstream location – taken from HR Wallingford (2007)

A survey of flow in the canal, in the river and where the canal and river are joined was undertaken at Marsh Benham Weir using an Acoustic Doppler Current Profiler (ADCP). The survey looked at flow velocities in a series of cross sections. Figure 15 shows the individual cross sections. The purple to blue end of the colour scale represents very slow current whilst the orange to red colouring is faster flow. The range of the scale associated with each cross section varies depending on the range of flows in an individual cross section but Figure 15 provides a conceptual representation of flow in the area. On the day of gauging (22/3/11), the discharge in the river only was 3.61 cumecs whilst discharge in the upstream canal only was 0.055 cumecs (leakage from the lock). At the downstream end of the section, once the majority of flow has gone over the Marsh Benham weir the flow in the canal is 0.31 cumecs.

The ADCP device measures both current speed and direction. At the point where the slow flowing canal water meets the faster flowing river water the ADCP shows turbulence occurring; a reverse flow is identified in part of the cross section on the left bank (Figure 14).

The ADCP survey also produces a cross sectional bed profile. Figure 15 shows clear evidence that the turbulence leads to erosion of the bed, and a hole of approximately 1m depth below the separate river and canal bed levels has been eroded. The suction effect of the undershooting Marsh Benham Weir also lowers the bed level of the combined river and canal in comparison to the separate channels. There is evidence for deposition at the point where the canal and the river meet which may result from the slow flowing canal water being checked by the faster river water or may be the result of the turbulence created where the two meet. The impact of turbulence at the join of the river and canal is also show in the long bed profile shown in Figure 13.

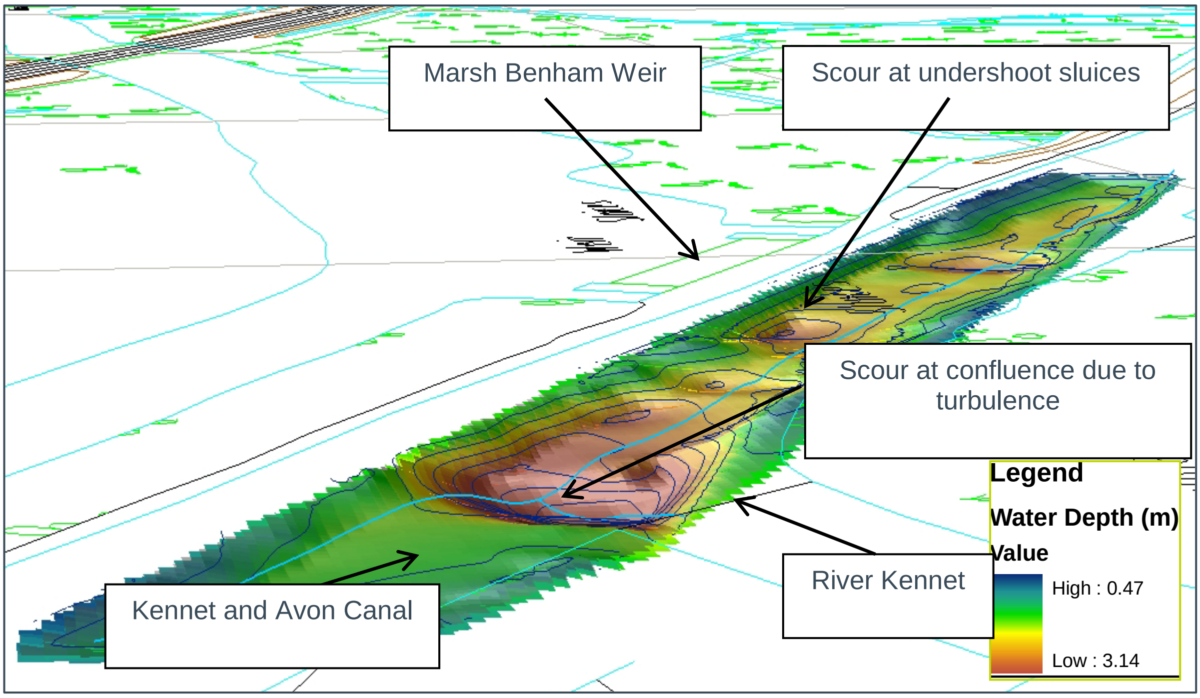


Figure 13. Bed survey interpolated from ADCP survey.

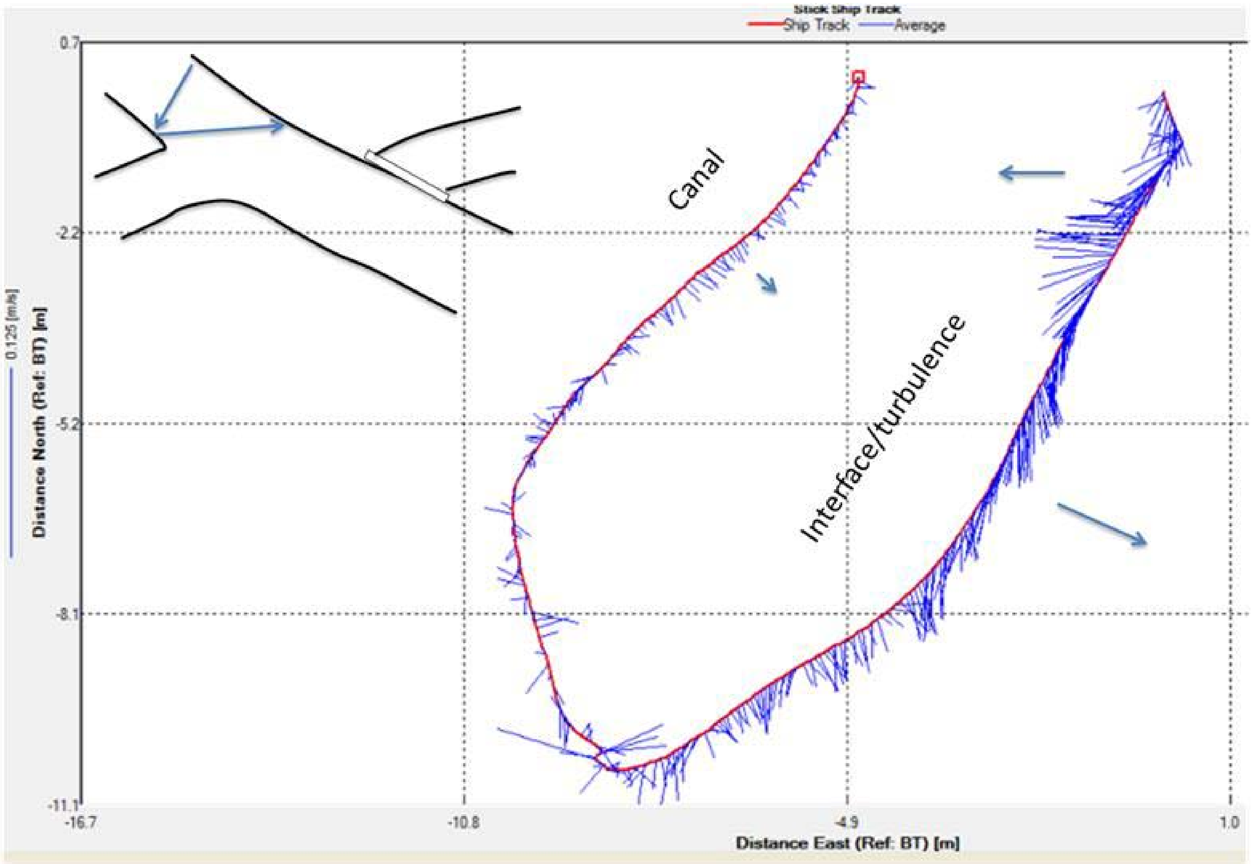


Figure 14. Path of the ADCP across the canal only, then through the interface between canal and river water. Blue lines point in direction of flow with length representing speed of flow.

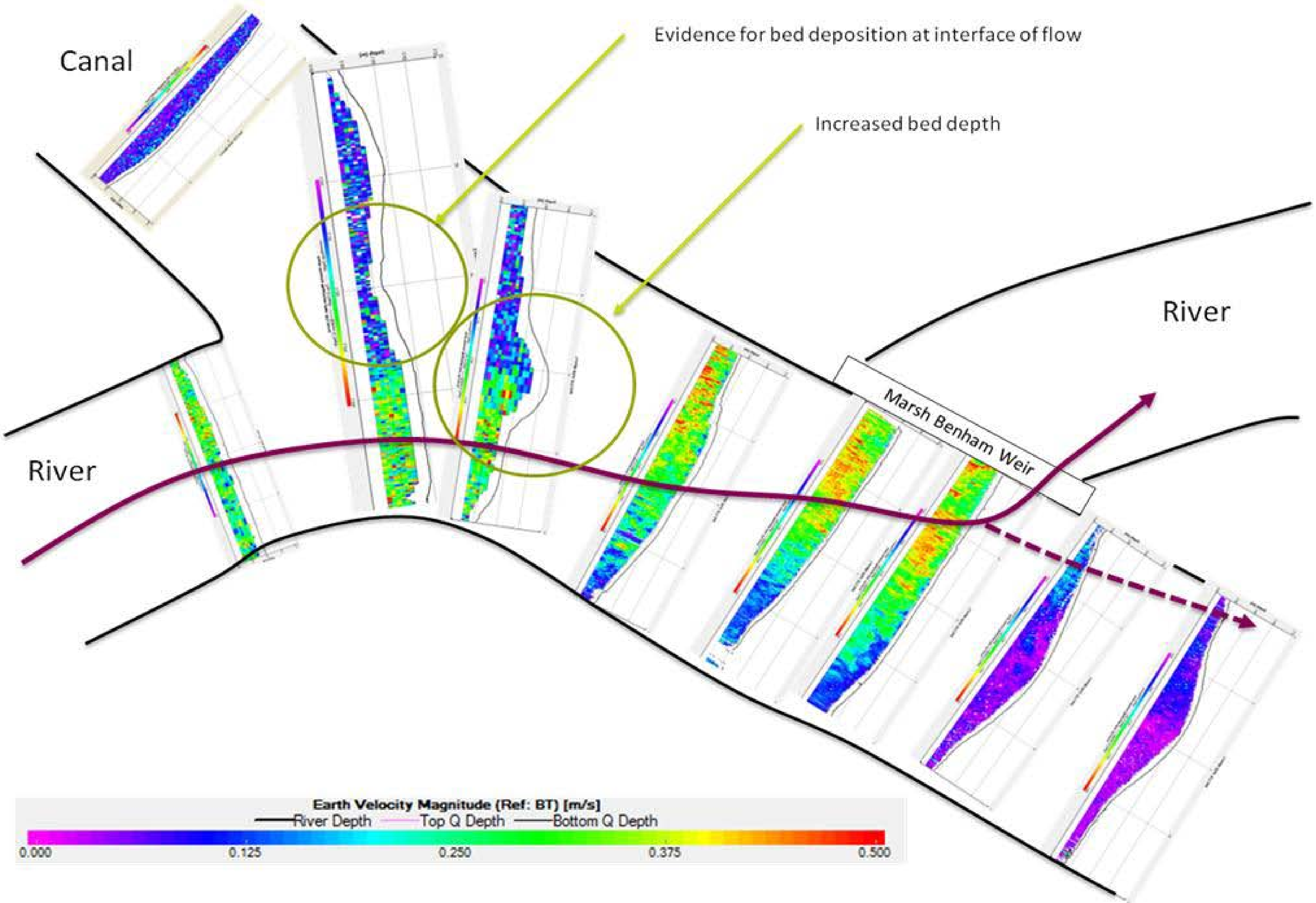


Figure 15. Integration of flow at the join of the river and canal close to Marsh Benham Weir

With the river fully separated from the canal at Copse Lock, there will be a greater difference in water quality between the higher quality river water and poorer quality canal water. Where the river flow crosses the canal it is possible that the poorer quality water may be held back in the canal channel by the turbulence at the interface of slow canal water and faster river water. The dominant flow from the river creates a turbulent boundary at the join which potentially creates a flow wall that prevents downstream canal flow from fully mixing with the river flow.

The costs of culverting the river under the canal are considerable and would involve lowering the downstream River Kennet river bed. It is recommended any works at the point where the canal and river rejoin are not undertaken until the initial separation at Copse Lock has been completed, and further observation is made to confirm whether the river and canal water mix or if the canal water is held back. The current situation is that the boundary separates water of similar quality. Once the river and canal are separated there will be an improvement in river water quality and deterioration in canal water quality making a clear distinction between the two water bodies. Further observation of the impact of boat passage at the interface will be required; some canal water may get mixed during boat passage but then washed downstream over the weir in the river by faster river flow. Similarly if the river water is proven to hold back canal water, then there are implications for the downstream canal water quality.

If the water is held back then it may not be necessary to culvert the river under the canal. The poorer quality water being held in the canal between Hamstead Lock and the rejoining point may need to be managed, notably to ensure that the channel is maintained for navigation. It is also worth noting that the held back poorer quality water will mean that the canal water downstream of the river – canal join may be of an improved quality.

2.9. Summary of engineering considerations

The assessment of each of the six options at this stage has considered if the topography of the area will allow the crossings and routes of the separation. The results of these assessments are summarised in Table 1.

Table 1. Summary of engineering considerations

Option	Route Feasible?	Levels feasible?	Option Feasible?	Comments
1. River diverted to north and culverted under canal at Hamstead Lock	Yes	Yes	Possible	To make space to culvert the river under the canal at Hamstead Lock lowering the downstream level at Craven Fishery will be required by approximately 2.5m
2. River diverted south of the canal and culverted under canal at Copse Lock	No, without excessive and expensive excavation	No, without excessive and expensive excavation	No	There is insufficient floodplain space for the proposed route which will require significant earth excavation
3. River diverted to north and siphoned under canal at Hamstead Lock	Yes	Yes	Possible	To achieve an equal river level upstream and downstream of the crossing at Hamstead Lock will require an embanked channel so as not to lower downstream water levels. It is unlikely fish will be able to progress upstream
4. River diverted south of the canal and siphoned under canal at Copse Lock	No, without excessive and expensive excavation	Yes	No	There is insufficient floodplain space for the proposed route which will require significant earth excavation
5. Copse Lock moved downstream. River culverts under new canal and follows the southerly route.	No, without excessive and expensive excavation	Yes	No	There is insufficient floodplain space for the proposed route which will require significant earth excavation.
6. Canal crosses over the river. Copse Lock moved downstream after crossing. Northerly route along floodplain	Yes	Yes	Possible	This option is technically possible but will require significant elevated embankments and landscape impact. Acceptability of impact needs to be agreed with stakeholders

3. Effectiveness Considerations

The proposal to separate the river and canal is based on an assumption that this will lead to improved water quality in the river by removing the detrimental input by the canal.

3.1. Water Quality Baseline Assessment

3.1.1. Review of key previous studies

A number of past studies have reviewed information on the water quality of the Kennet and Avon Canal and the River Kennet, in the vicinity of Copse Lock. These include the following key documents:

- A publication by Neal et al. (2010) which focused on the reduction in phosphorus concentrations in River and Canal due to changes in sewage treatment work (STW) processes and subsequent effects on the water quality dynamics of the whole system.
- An MSc dissertation by Martin (2008), which included analysis of continuous monitoring (2007), spot sampling data and field observations on the system.
- A report by Halcrow (2007), which incorporated analysis of continuous monitoring (2005-2006) and spot sampling (June and November 2006) from several locations along the system, as well as information from a site visit and study of aerial photographs.

Important points from these studies in relation to the baseline water quality of the River Kennet and the Kennet and Avon Canal in the vicinity of Copse Lock are provided below. Note the sections below simply report the findings of previous studies, without assessing consistency between studies or comparing with the outcomes of this study,

3.1.1.1. Neal et al. (2010)

Neal et al. (2010) note that a step reduction in soluble reactive phosphorus (SRP) in effluent discharging into the River Kennet has been observed since the mid 2000s. This has resulted in over halving of SRP concentrations in the River Kennet; however, chlorophyll concentrations (an indicator of algal concentrations) have not decreased accordingly.

Monitoring results revealed that chlorophyll concentrations in the Kennet and Avon Canal are an order of magnitude higher than in the river. The authors suggest that this is due to the long residence times and the higher temperatures in the canal, which promote algal growth. The study found that SRP in the canal was higher in the autumn/winter compared to the spring/summer, reflecting the higher algal growth and nutrient uptake rates during the spring/summer.

The effect of boat movements and lock usage at Copse Lock was examined. The authors state the canal acts as a point source of sediment, algae and total phosphorus to the river, especially during the summer months, when boat traffic peaks, bottom sediments are disturbed and the locks are often opened. The peak in boat traffic corresponds to the time when dilution is lowest and hence the river is ecologically most vulnerable. However, the study also found that patterns in suspended solids (SS), SRP and chlorophyll concentrations in the canal were 'erratic' and not always linked to boat movements, indicating variable sources. The authors note the need for a change in monitoring strategy to be of sub-daily time-step and high spatial resolution.

The study goes on to address three questions relating to interactions between the Canal and the River Kennet:

- 'What is the source of contamination of phosphorus within Wilton Water[2] that contaminates the canal?'
    - o It is concluded that the key source of high SRP in the reservoir is STW effluents; the potential for lowering these SRP inputs to Wilton Water was examined.

[2] Wilton Water is the main source of water and SRP to the Kennet and Avon Canal (Neal et al., 2010). It is located approximately 9 km to the SW of Hungerford.

- 'What can be done to reduce the problem?'
    - The issue of reducing SRP inputs to Wilton Water is first considered. The possibility of separating the canal from the river is then examined. The authors state that there would remain significant issues of the 'highly unsightly' Wilton Water and the potential for transferral of the problem further down to the River Thames, potentially resulting in accumulation of sediment in the canal at Reading.
- 'Does the input of algae from the canal at Copse Lock affect algal development and concentrations within the River Kennet, further downstream?'
    - The authors state that the canal may indeed be discharging chlorophyll into the river. There is also the potential that the canal inoculates the river with biologically active algae, with a population then able to grow in the river.

3.1.1.2. Martin (2008)

This dissertation was completed by E. Martin, following placement with he Environment Agency, as part of the requirements for an MSc at King's College, London. Ecological data, water quality survey data and observations on lock operations were considered in the study. Additionally, the following continuous monitoring data for 2007 (a high flow year) were analysed (Figure 16):

- Wilderness (River Kennet), a reach managed as a trout fishery;
- Hungerford Farm (Kennet and Avon canal), monitored following a fish kill in 1998;
- Copse Lock (Kennet and Avon Canal), where the canal enters the river. The channel downstream of this location is canalised;
- Craven Fishery (River Kennet); downstream of Copse Lock, but at a point where the river is separated from the canal by an aeration weir.

The aim was to assess seasonal patterns and understand the interactions between the two watercourses under different weather conditions. Data analysis included graphical analysis in Excel and statistical analysis (Excel and SPSS for non-parametric analyses). Note that the automatic ammonia record was found to contain a number of gaps and was not further analysed.

Key conclusions from the report included the following:

- At Wilderness (river) overall chlorophyll and turbidity levels were low, while healthy DO% and low ammonia levels were recorded. No rise in chlorophyll was seen at Wilderness or Craven Fishery during a spring algal bloom in the canal.
- In the canal, turbidity and chlorophyll concentrations were high, while DO% levels indicated supersaturated conditions. Phosphorus concentrations were low, due to high algal growth and hence elevated nutrient uptake rates.
- Turbidity and chlorophyll levels at Craven Fishery (river, downstream of Copse Lock) were significantly higher than at Wilderness (river, upstream of Copse Lock) and significantly lower than at Copse Lock (canal).
- Sources of turbidity in the system were thought to be phytoplankton and bed material mobilised by boat activity.
- It is not yet understood how canal phytoplankton responds to conditions in the river (Love, A., personal communication; as quoted in Martin [2008]). Algae adapted to the conditions in the canal may not be suited to survive in the turbulent river. However, the higher phosphorus concentrations in the river may encourage algal growth.
- The data indicated that the canal and river interact more in summer than in winter, due to increased boat traffic (and hence increased lockage operations).
- The report concluded that the Kennet and Avon Canal 'does increase levels of turbidity and phytoplankton in the River Kennet at Copse lock and to a lesser extent at Craven Fishery'. The impacts of the interaction between the two watercourses at Copse Lock were described as localised, but further investigation was recommended to consider downstream impacts.

3.1.1.3. Halcrow (2007)

The Halcrow (2007) report considered continuous monitoring data from four sites: Wilderness (representative of the river, upstream of the canal influence), Copse Lock (representative of the canal), Craven Fishery (representative of the combined canal/river section), and Newbury Wharf (also representative of the combined canal/river water quality, but further downstream than Craven Fishery). The continuous data indicated that:

- Turbidity readings at Newbury were higher than those at Wilderness during summer months.
- Turbidity at all stations showed a diurnal variation, during certain parts of the record.
- The magnitude of the diurnal variation was largest at Copse Lock, while a ‘damped version’ of this diurnal cycle can be seen at Craven Fishery. The magnitude of the daily cycle in turbidity at Copse Lock decreased with the onset of autumn/winter.
- At Copse Lock, a sharp increase in turbidity was observed typically around noon, in the summer months only. Due to the location of the logger at Copse Lock, which meant that the monitor was not exposed to direct sunlight until later in the day, the timing of the turbidity peak may be attributed to movement of algae through the water column.
- The seasonal variation in turbidity at all stations was linked to changes in water temperature; at Copse Lock; the diurnal variation in turbidity appeared to be linked to the diurnal variation in chlorophyll.
- A weekly cycle was not apparent in turbidity readings at any of the stations. If changes in turbidity were due to boat movements, one would expect turbidity to increase on weekends, when boat traffic peaks.
- Increases in turbidity at all stations were also clearly linked to rainfall events. The magnitude of the increase in turbidity following rainfall events was larger at Copse Lock than at other locations, potentially reflecting the influence of Peartree Bottom Stream.

Halcrow (2007) also considered the results of water quality spot sampling (June and November 2006) carried out in the canal just upstream of Copse Lock, in the river upstream of Copse Lock, and in the combined river/canal section). Conclusions of the report included:

- Results for SS, chlorophyll and orthophosphate (OP) indicated that the canal is ‘the only significant influencing factor’ responsible for the change in the water quality of the river downstream of Copse Lock.
- SS concentrations showed good correlation with chlorophyll, suggesting that elevated SS levels are due to the presence of algal material rather than inorganic sediment.
- Based on SS measurements, the sediment transport in the Canal was estimated at $1m^3$ / 10 days. The SS concentration would need to be raised by an order of magnitude above the measured value in order to become a major factor regarding sediment accumulation in the canal.

Finally, following observations during a site visit (24/08/2006; Halcrow, 2007) it was reported that the poor water quality at Copse Lock was due to ‘progressive deterioration in water quality along the canal’. Examination of aerial photos suggested disturbance of bed sediment by boat movements in the canal upstream of Kintbury and Hungerford and algal proliferation at Wilton Water, which feeds the canal.

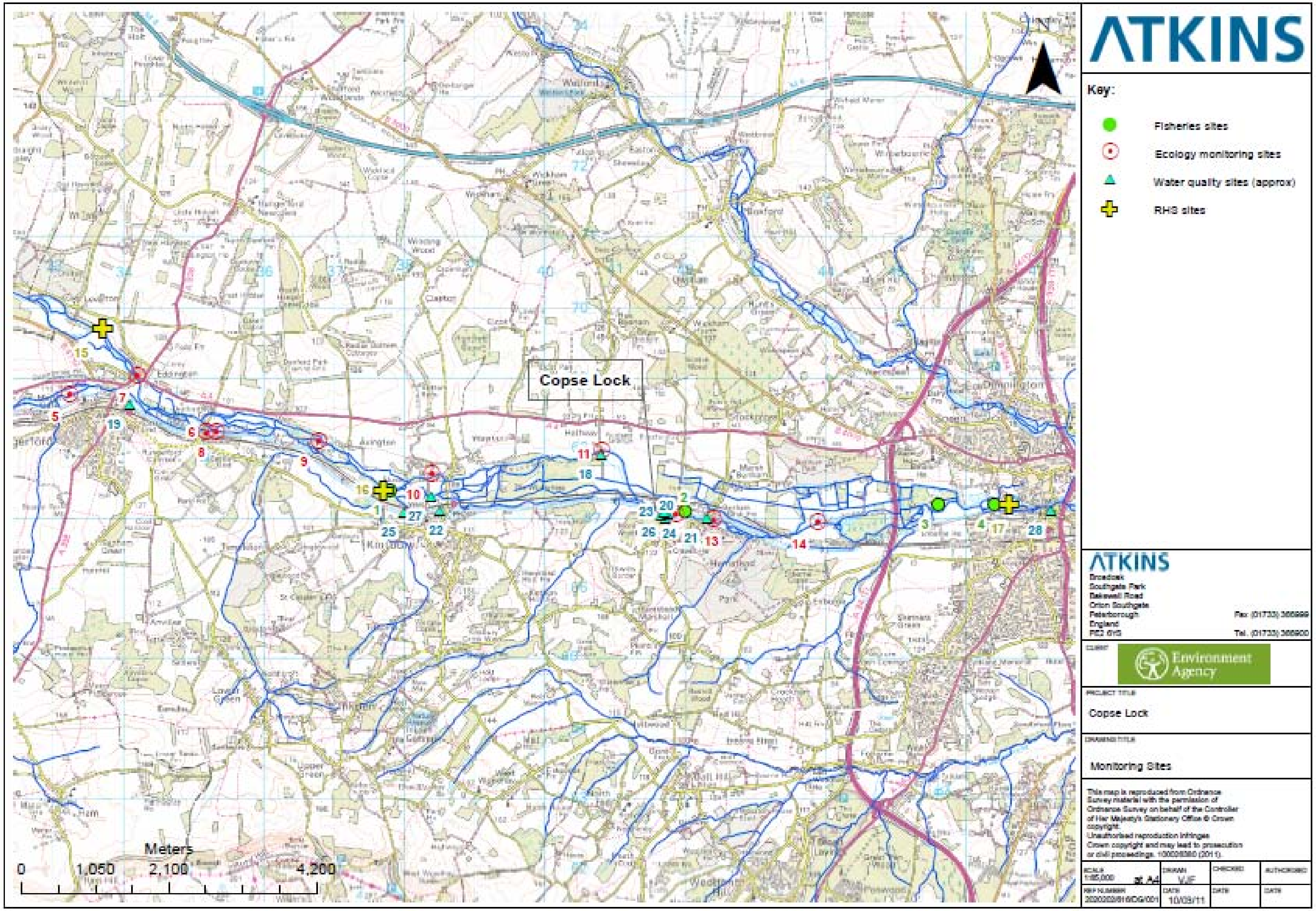


Figure 16. Map of continuous monitoring (locations; Martin, 2008; Halcrow, 2007 and Section 3.1.2.2 of this document) and for spot sampling data sets considered in Section 3.1.2.3 of this report (site reference numbers in Table 2).

Table 2. Site ID numbers referred to on the map (Figure 16)

Site name	Type of monitoring	Map ID number
Willow Stream, Barton Court	Fisheries	1
Marsh Benham, Hamstead Marshall	Fisheries	2
Speen Moor	Fisheries	3
Northcroft	Fisheries	4
River Dun upstream of Berkshire Trout Farm	Ecology	5
River Dun downstream Berkshire Trout Farm	Ecology	6
River Kennet upstream River Dun	Ecology	7
River Kennet downstream River Dun	Ecology	8
Below Hungerford STW	Ecology	9
Barton Court	Ecology	10
Wilderness	Ecology	11
Copse Lock (below Kennet and Avon Canal)	Ecology	12
Craven Fishery	Ecology	13
Benham Estate	Ecology	14
KENNET	RHS	15
KENNET	RHS	16
KENNET	RHS	17
River Kennet, Wilderness	Water Quality	18
Kennet and Avon Canal, Hungerford	Water Quality	19
Kennet and Avon Canal, Copse Lock	Water Quality	20
Craven Fishery	Water Quality	21
Kennet and Avon Canal at Kintbury Bridge	Water Quality	22
Kennet and Avon Canal just above Copse Lock	Water Quality	23
River Kennet just above Copse Lock	Water Quality	24
Kennet and Avon Canal, Kintbury	Water Quality	25
Kennet and Avon Canal, Copse Lock	Water Quality	26
River Kennet, Kintbury	Water Quality	27
Newbury Wharf	Water Quality	28

3.1.2. Baseline data analysis

3.1.2.1. Data sets considered in this study

As mentioned above, the water quality of this area has been the subject of numerous studies over many years. Some additional data analysis was carried for this study, aiming to complement the outputs of previous investigations. The focus was on the following key questions:

- Would separation of the Canal and the River at Copse Lock bring significant water quality benefits?
- Would any such benefits be apparent throughout the year or would they only be seasonal?

The following data sets were analysed, representing key locations along the system (Table 3):

- Automatic monitoring data collected by the Environment Agency at Hungerford (canal), Wilderness (river), Copse Lock (canal) and at Craven Fishery (river) during 2005-2008, hence containing in part more recent automatic monitoring data than those reviewed in Halcrow (2007) and a longer period than that considered in Martin (2008)[3].
- Spot sampling conducted by the Environment Agency at sites on the Kennet and Avon Canal at Kintbury (2008-2010), Kennet and Avon Canal just above Copse Lock (2006), and River Kennet just above Copse Lock (2006);
- Spot sampling conducted as part of the Environment Agency-Centre for Ecology and Hydrology (CEH) monitoring scheme on the Kennet and Avon Canal at Kintbury (2000-2009), on the River Kennet at Kintbury (2000-2002), on the Kennet and Avon Canal at Copse Lock (2008-2009).

Data for selected important water quality indicators were considered; background information on key indicators is provided below. Note that data were not available for all the determinands below in both the automatic and spot sampling record.

- **Water temperature**, and in particular changes in water temperature, have a critical impact on aquatic life, as biochemical reactions commonly experience a doubling in reaction rate with a rise of 10°C. Additionally, key constituents of water either change their form (as in the ionisation of ammonia) or alter their solubility (as with dissolved oxygen) when temperature changes.
- **Dissolved oxygen % saturation** (DO%) levels in the water provide an excellent indicator of the general water quality of the system. Sufficient dissolved oxygen is crucial for a healthy ecosystem, as fish kills are often due to asphyxia when concentrations fall to very low levels as a result of organic pollution. If levels persist around zero, anaerobic or septic conditions yield products, such as methane or toxic un-ionised ammonia.
- **Ammonia** is present in all natural waters in very small amounts; levels in excess of 0.1 mg N/l can be indicative of some sewage or industrial contamination. It is generally measured as total ammonia, which accounts for two aqueous forms: ammonium ions (NH4+) and un-ionised ammonia (NH3). Their relative abundance changes with pH and temperature. High levels of un-ionised ammonia are toxic to invertebrates and fish, causing respiratory stress, conditions such as gill hyperplasia and reduced resistance to parasites and disease.
- **Phosphorus** is also an important nutrient for algal growth in aquatic environments and likely to be the limiting nutrient in fluvial environments. The primary sources of phosphorus to watercourses are agriculture and human effluent. High concentrations of phosphorus in the water can lead to eutrophication. SRP represents a key part of the phosphorus pool in terms of bioavailability. SRP usually consists largely of ortho-phosphate (OP) and the terms are often used inter-changeably. However, SRP is a measurement of all the phosphorus in filtered samples (without digestion), while orthophosphate refers specifically to inorganic orthophosphate (PO_4).

[3] Eleanor Martin had edited the automatic monitoring data sets analysed in this report, as part of her MSc placement with the Environment Agency, but due to time constraints only data for 2007 were presented in her MSc dissertation. The full automatic dataset (2005-2008 including several gaps) which had been edited by Eleanor Martin has been considered in this report. The focus of the analysis here (Section 3.1.2.2) is on differences between sites (overall and during different seasons). Also, the automatic monitoring ammonia data set was not analysed in Martin (2008), whereas it has been considered in Section 3.1.2.2 of this report.

Table 3. Summary of water quality data sets considered in this report. *This record contained several gaps.

Site Name	Data collected by	Spot sampling /automatic monitoring	Period of sampling	Approximate frequency of monitoring	Representative of water quality in
River Kennet, Wilderness	Environment Agency	Automatic monitoring	2005-2008*	Every 30 min to hourly	River upstream of canal influence
Kennet and Avon Canal, Hungerford	Environment Agency	Automatic monitoring	2005-2008*	Every 15 min to hourly	Canal upstream of river influence
Kennet and Avon Canal, Copse Lock	Environment Agency	Automatic monitoring	2005-2008*	Every 15 min	Canal just upstream of confluence
Craven Fishery	Environment Agency	Automatic monitoring	2005-2008*	Every 15 min	Combined river/canal part of the system
Kennet and Avon Canal at Kintbury Bridge	Environment Agency	Spot sampling	2008-2011	Monthly	Canal upstream of river influence
Kennet and Avon Canal just above Copse Lock	Environment Agency	Spot sampling	2006	Weekly	Canal just upstream of confluence
River Kennet just above Copse Lock	Environment Agency	Spot sampling	2006	Weekly	River just upstream of confluence
Kennet and Avon Canal, Kintbury	Environment Agency - CEH	Spot sampling	2000-2002 and 2008-2009	Weekly	Canal upstream of river influence
Kennet and Avon Canal, Copse Lock	Environment Agency - CEH	Spot sampling	2008-2009	Weekly	Canal just upstream of confluence
River Kennet, Kintbury	Environment Agency - CEH	Spot sampling	2000-2002	Weekly	River upstream of canal influence

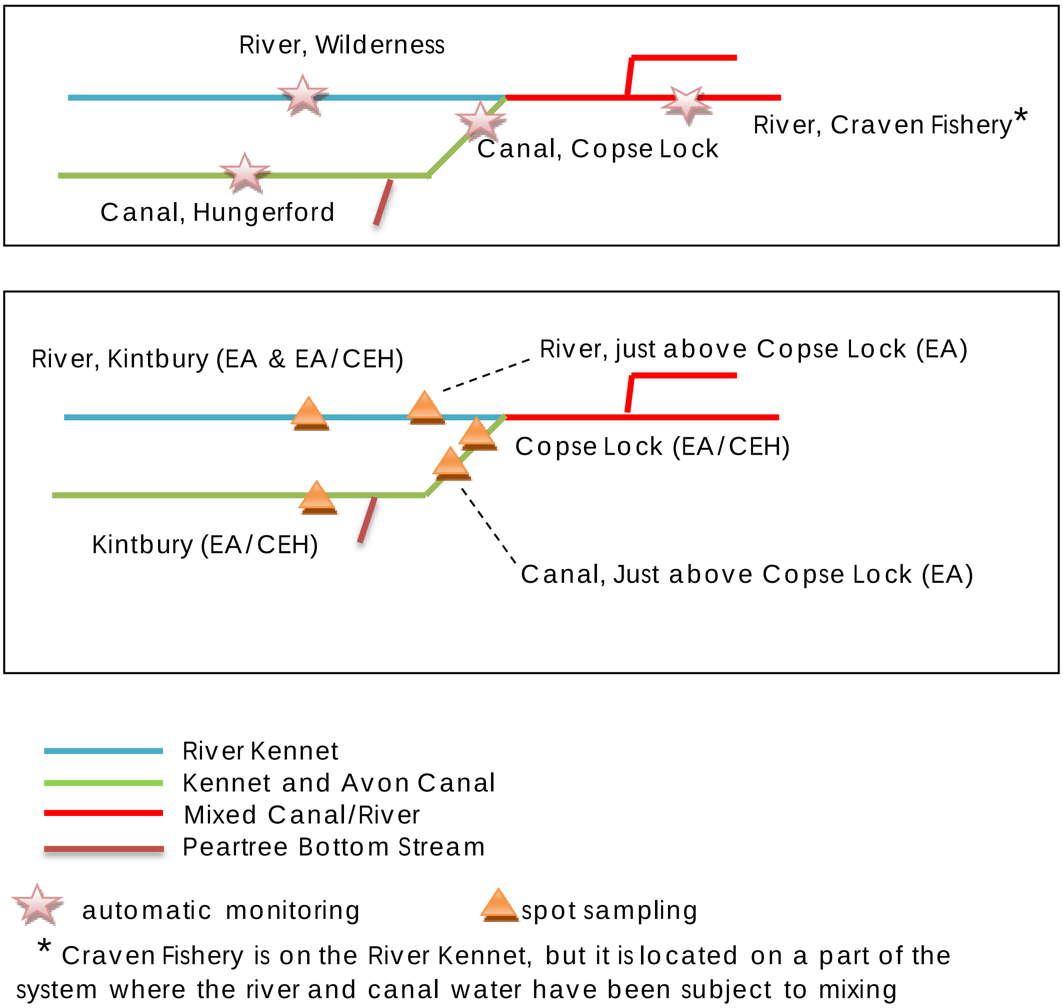


Figure 17. Schematic of sampling locations considered in this report. This schematic is not to scale. Automatic monitoring data and two spot sampling data sets were analysed (Environment Agency [EA] and EA/Centre for Ecology and Hydrology [CEH]).

3.1.2.2. Automatic data set - Analysis of Variance

Analysis of Variance (ANOVA single factor) was carried out on the automatic monitoring data sets to establish whether the water quality of river and canal sites was statistically significantly different (at the 95% confidence level; the full analysis of variance outputs are provided in Appendix A). Statistical analysis was carried out based on daily averages at each site, as different records contained readings of different frequency (for example 15 min or 1 hour readings). Additionally, records at each location covered different periods of time and contained a number of gaps, so the analysis was only carried out on overlapping periods of time, after matching dates between records. The analysis of variance was carried out to examine differences:

- between the automatic monitoring data sets at Wilderness and Hungerford, hence on the River and the Canal, respectively, upstream of any interaction between the two watercourses; and
- between the automatic monitoring data sets at Copse Lock and Craven Fishery, hence just upstream of the confluence of the two watercourses and then at location where canal and river water have been subject to mixing.

The statistical results indicated that temperature, chlorophyll, dissolved oxygen saturation (DO%), turbidity and ammonia levels were significantly different between Wilderness and Hungerford. Average levels for all five determinands were higher in the canal than the river. Chlorophyll and turbidity averages, in particular, differed by an order of magnitude between the two data sets. Average DO%, temperature and ammonia showed smaller differences between the two locations. These results are in agreement with the conclusions of previous studies, indicating that water quality of the canal is significantly different to that of the river, upstream of any interaction between the two watercourses. The elevated chlorophyll and DO% saturation levels suggest that water quality issues in the canal are largely due to algal activity.

The analysis of variance also showed a statistically significant difference between the Copse Lock and Craven Fishery data sets for chlorophyll, DO%, turbidity and ammonia, but not for temperature. Average levels of the four determinands (i.e. excluding temperature) were higher at Copse Lock than at Craven Fishery. However, differences were small, with the exception of chlorophyll concentrations, which were an order of magnitude higher at Copse Lock than at Craven Fishery. These results indicate that the poorer quality canal water at Copse Lock is 'diluted' with better quality water from the river, resulting in an overall small improvement in water quality when the two watercourses are mixed further downstream the system.

The analysis of variance was then repeated, separating each data set into autumn/winter (assumed to cover October to March) and spring/summer (assumed to cover April to September) to try and establish whether differences in water quality of the canal and the river are seasonal.

Results indicated that temperature, chlorophyll-a, DO%, turbidity and ammonia levels were significantly different between Wilderness and Hungerford when considering both the autumn/winter and spring/summer periods separately. Differences for most determinands (temperature, DO% saturation, ammonia) were much smaller in the autumn/winter compared to spring/summer, despite being statistically significant throughout the year. Levels of chlorophyll, DO%, turbidity and ammonia were higher in the Canal than in the river both in the spring/summer and autumn/winter. The average temperature was higher in the canal than in the river in the spring/summer, but lower in the autumn/winter. This most likely reflects the different nature of the two watercourses. The river's main source is groundwater, expected to result in 'buffered' temperature variations throughout the year; in contrast, the canal, which has some spring sources but significant surface water sources, and long water residence times, is expected to show larger temperature variations throughout the year.

The analysis of variance results for Copse Lock and Craven Fishery when considering the autumn/winter and spring/summer data sets separately differed for some determinands to the results of analysis on the whole data set. Chlorophyll, turbidity and ammonia levels were statistically different between the two data sets in October – March, but temperature and DO% were not. When considering the spring/summer data only, temperature, chlorophyll, DO% and turbidity were significantly different, but ammonia levels were not. These results indicate that differences between the quality of canal water just upstream of confluence and the water in the combined canal/river part of the system are less pronounced for some determinands in the autumn/winter compared to the spring/summer. However, chlorophyll and turbidity differences remain evident in data from both seasons, as well as in the yearly data set.

Note that analysis based on averages can be misleading with regards to DO%, which shows large diurnal variation in environments with high algal growth rates. The 10^{th} percentile of DO% measurements was therefore calculated for all four automatic monitoring locations to check whether very low DO% is observed at any point in the diurnal cycle, despite the average high levels. The 10^{th} percentile DO% for all four continuous monitoring data sets was > 83%, indicating that DO% remains high throughout the diurnal cycle.

A summary of the analysis of variance results is shown in Table 4.

Table 4. Summary of analysis of variance results on automatic monitoring data sets.

T=temperature, Chl=chlorophyll, DO%= DO% saturation, turb=turbidity.✓ indicates the two data sets were significantly different; × indicates the two data sets were not significantly different.

Site name	Average - All months									
	T		Chl		DO%		turb		NH_4	
Kennet and Avon Canal, Hungerford	12.4	✓	35.2	✓	115.2	✓	37.7	✓	0.24	✓
River Kennet, Wilderness	11.6		2.5		102.9		7.9		0.16	
Craven Fishery	11.6	×	4.6	✓	99.8	✓	15.6	✓	0.19	✓
Kennet and Avon Canal, Copse Lock	11.7		15.7		101.4		29.2		0.27	
	Average -Autumn/winter									
	T		Chl		DO%		turb		NH_4	
Kennet and Avon Canal, Hungerford	7.7	✓	26.1	✓	104.6	✓	28.4	✓	0.25	✓
River Kennet, Wilderness	8.5		2.9		101.4		8.7		0.19	
Craven Fishery	8.7	×	3.7	✓	96.5	×	.49	✓	0.21	✓
Kennet and Avon Canal, Copse Lock	8.4		7.5		97.0		12.4		0.27	
	Average -Spring/summer									
	T		Chl		DO%		turb		NH_4	
Kennet and Avon Canal, Hungerford	16.1	✓	42.1	✓	123.0	✓	44.8	✓	0.23	✓
River Kennet, Wilderness	14.1		2.2		104.1		7.3		0.13	
Craven Fishery	14.5	✓	5.4	✓	102.9	✓	20.4	✓	0.18	×
Kennet and Avon Canal, Copse Lock	15.2		24.0		106.3		45.8		0.25	

3.1.2.3. Spot samples – analysis against environmental quality standards

The suite of determinands in the Environment Agency and Environment Agency – CEH spot sampling records was slightly different to that in the automatic record and the means of measurement were also different (laboratory analysis rather automatic loggers). Data for SS, chlorophyll, SRP/OP and ammonia were considered.

The spot sampling data set consisted of weekly or monthly readings, hence a limited number of data points. Also, each record reflected different time periods depending on the sampling location (no spot sampling data were available for the combined canal/river section). It was therefore deemed that this data set was best suited to graphical/visual interpretation, rather than statistical analysis. Data were analysed in terms of averages over the whole record, but also separated into measurements made in the autumn/winter (October – March) and spring/summer (April – September), and then compared against relevant environmental quality standards (EQS).It is important to note that the EQS generally apply to a specific length of data record (e.g. annual record or a three-year sampling cycle), while the results discussed in this report represent a limited number of spot samples. EQS are hence referred to here in order to put the results into context, rather than assess compliance. The EQS employed for each determinand were as follows:

- **SS:** Freshwater Fish Directive (FFD) Imperative EQS of 25 mg/l; Natural England (NE) SSSI target of 10 mg/l[4] (Natural England, 2008)
- **SRP/OP:** Water Framework Directive (WFD) thresholds - e.g. High Status (50 mg/l) and Good Status (120 mg/l)
- **Chlorophyll:** No suitable EQS exists for chlorophyll levels in rivers, hence the Organisation for Economic Development and Co-operation (OECD, 1982) EQS for trophic categorisation of lakes was applied to the Canal sites; e.g. 2.5 - 8 µg/l chlorophyll for "mesotrophic", 8 - 25 µg/l chlorophyll for "eutrophic", and >25 µg/l for "hypertrophic". (note these OECD standards were also applied in Neil et al., 2010).
- **Ammonia:** FFD Guideline Salmonid[5] EQS of 0.04 mg NH_4/l; FFD Guideline Cyprinid EQS of 0.2 mg NH_4/l; FFD Imperative EQS of 1 mg NH_4/l.

Average suspended solids (SS) concentrations at the canal sites were higher than those recorded in the river (Figure 18). In the canal, year-round, spring/summer and autumn/winter average SS concentrations were above the NE SSSI target. With regard to the FFD EQS, canal year-round average SS concentrations were near or above the threshold, autumn/winter concentrations were below the threshold and spring/summer concentrations exceeded the threshold (in some cases significantly). In the river, year-round and autumn/winter average SS concentrations were just above the NE SSSI target, while spring/summer average concentrations were below the NE SSSI target. Year-round, autumn/winter and spring/summer average SS concentrations were below the FFD EQS in the river.

Chlorophyll spot sample readings (Figure 19) were only available at some of the monitoring locations considered in this report. The average chlorophyll concentration at Kintbury was equal to the OECD eutrophic threshold in the autumn/winter; the average year-round and spring/summer concentrations were well above the eutrophic threshold, hence classified as hypertrophic. Average concentrations at Copse Lock were above the OECD eutrophic threshold when considering the year-round, autumn/winter, spring/summer average levels (hypertrophic). Chlorophyll concentrations in the river (just above the canal) were an order of magnitude lower than those in the canal, corresponding to a mesotrophic OECD classification. These measurements are in agreement with the average chlorophyll concentration reported for the River Kennet (1997-2001) in Neal et al. (2010), which also corresponded to the mesotrophic OECD classification.

SRP (or OP) concentrations were relatively low at all spot sampling sites considered, remaining within the WFD Good Status classification (Figure 20). SRP (or OP) levels were overall higher in the river than in the canal, which may reflect greater algal uptake in the canal as suggested by other investigations. At the canal sites, average concentrations were below or just above the WFD High Status threshold in the autumn/winter and lower than the WFD High Status threshold in terms of the year-round and spring/summer averages. The exception to this was the Environment Agency site just above Copse Lock (note, however, this data set included data for 2006 only- see Table 3), where the average SRP concentration recorded was above the WFD High Status threshold (year-round, spring/summer and autumn/winter). At Kintbury (river) concentrations were above the WFD High status threshold (year-round, autumn/winter and spring/summer averages). Just above the confluence with the canal, the year-round and autumn/winter average concentrations were above the WFD High Status threshold, while the summer/spring average concentrations were below the threshold.

Average ammonia concentrations were much lower than the FFD Imperative EQS at all spot sampling sites considered (Figure 21). The highest ammonia concentrations were recorded at Kintbury (canal) in spring/summer and at Copse Lock (canal Environment Agency data set and Environment Agency-CEH data set) in autumn/winter. Average concentrations (year-round, autumn/winter and spring/summer) for the remaining sites were either below the FFD Guideline Salmonid EQS or between the FFD Guideline Salmonid and Cyprinid thresholds. Ammonia measurements did not show a clear seasonal signal along the system, as was evident for other determinands. At Kintbury on the canal, ammonia concentrations were higher in the spring/summer than in the autumn/winter, but the reverse was true at Copse Lock. For both river sites (Kintbury and just above Copse Lock) ammonia levels were higher in the autumn/winter than in the

[4] Target to be refined using actual data (Natural England, 2008). Other conditions include: no unnaturally high loads, bed should be visible to at least a depth of 1 m.
[5] Parts of the River Kennet and the Kennet and Avon Canal are designated as Salmonid Waters (Defra, 1998), including: the Kennet and Avon Canal Benham Reach; the River Kennet from Hungerford STW to Newbury STW and from Newbury STW to Aldershot Stream.

spring/summer. This pattern indicates complex ammonia dynamics, which may include ammonia inputs into the system at different locations from STW. Ammonia may be taken up by algal blooms at Copse Lock (hence resulting in reduced levels in the spring/summer), while further upstream the canal and in the river, elevated levels in the spring/summer may reflect external ammonia inputs (e.g. Kintbury STW) and a smaller degree of dilution. Note that previous studies have generally assumed that phosphorus is the limiting nutrient in this system (e.g. Zeckoski, 2010) have focused on phosphorus dynamics; however investigation of ammonia dynamics can also reveal important sources and processes in the system.

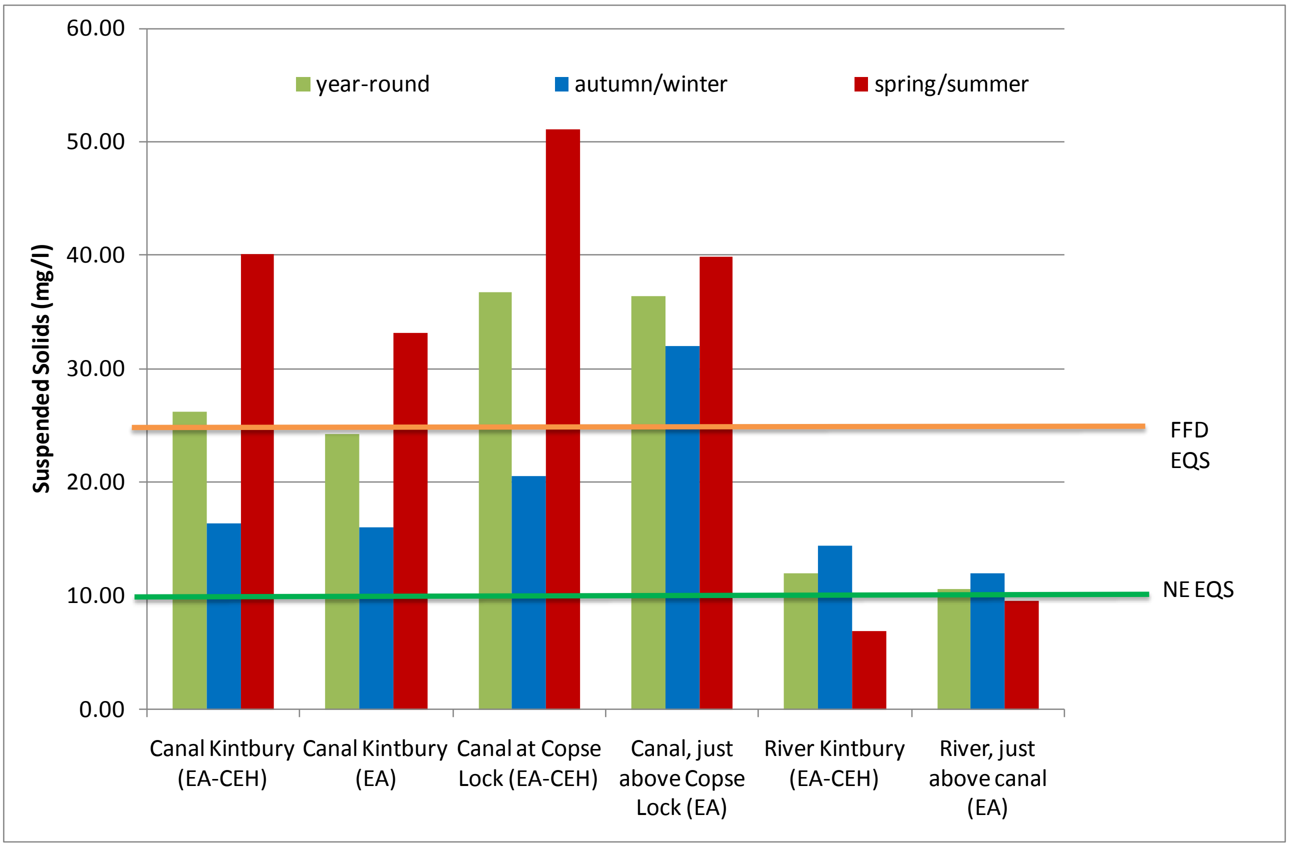


Figure 18. Average suspended solids concentrations (spot sampling record). FFD=Freshwater Fish Directive. NE =Natural England. EA= Environment Agency record. CEH= Environment Agency-Centre for Ecology and Hydrology record.[6]

[6] EQS generally apply to a specific length of data record (e.g. annual record or a three-year sampling cycle), while the results discussed in this report represent a limited number of spot samples. EQS are hence referred to here in order to put the results into context and help provide and indication of water quality, rather than assess compliance.

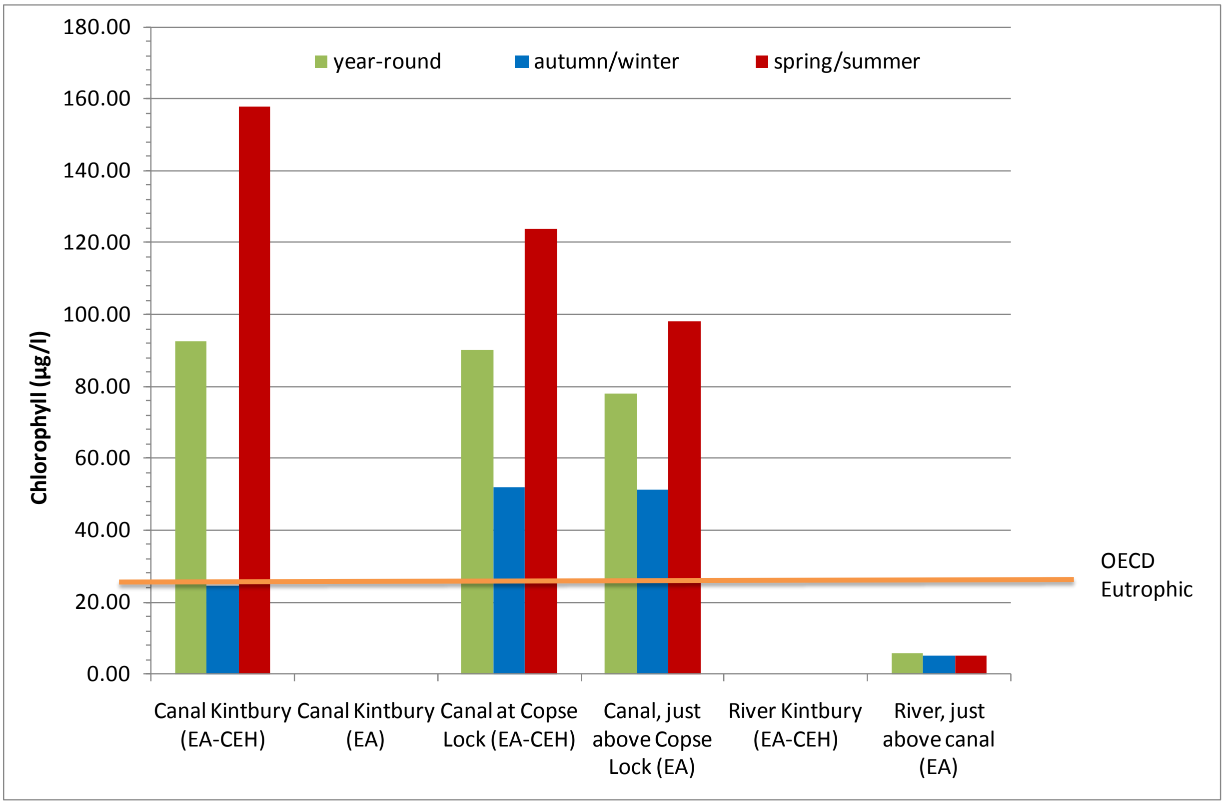


Figure 19. Average chlorophyll concentrations (spot sampling record). OECD=Organisation for Economic Co-operation and Development. A= Environment Agency record. CEH= Environment Agency-Centre for Ecology and Hydrology record. [6]

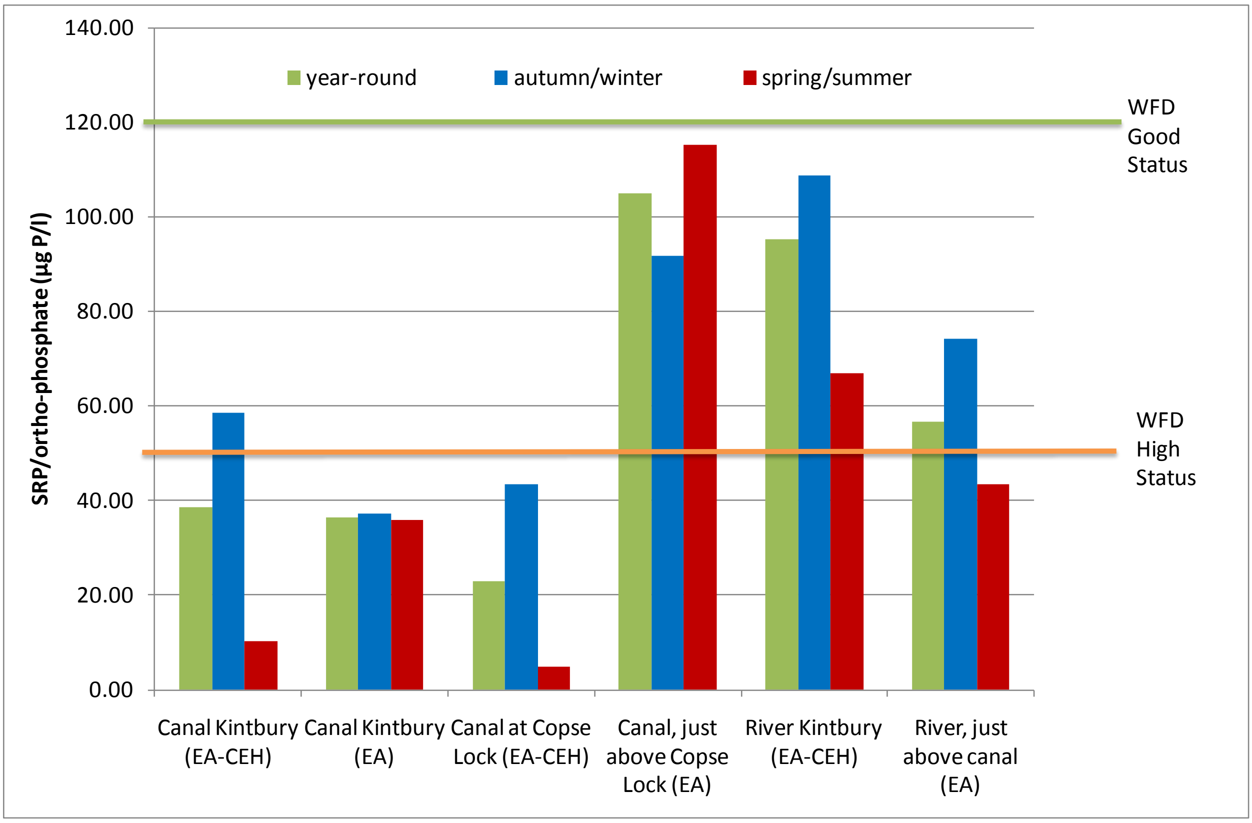


Figure 20. Average Soluble Reactive Phosphorus (SRP) or ortho-phosphate (OP) concentrations (spot sampling record). WFD-Water Framework Directive. A= Environment Agency record. CEH= Environment Agency-Centre for Ecology and Hydrology record. [6]

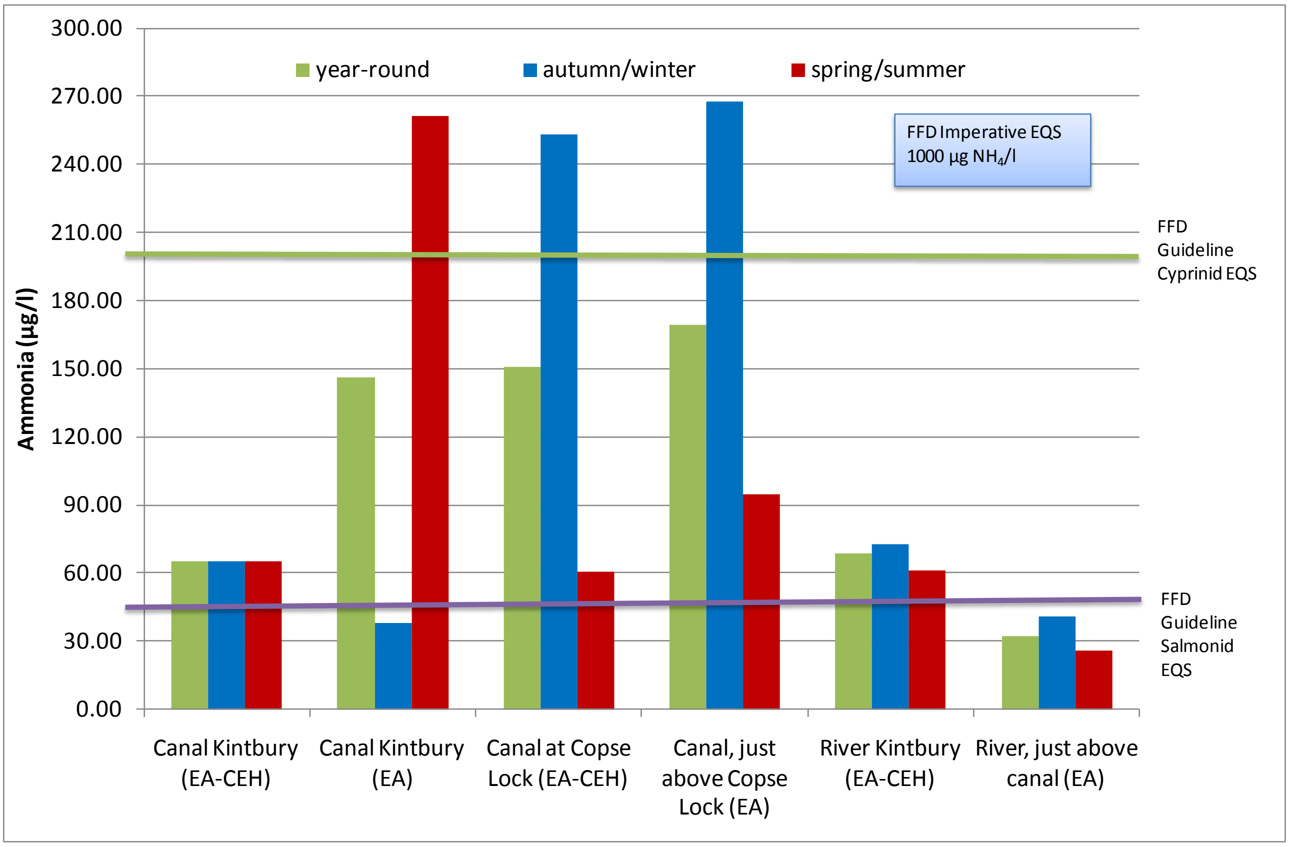


Figure 21. **Average ammonia concentrations (spot sampling record). FFD=Freshwater Fish Directive. A= Environment Agency record. CEH= Environment Agency-Centre for Ecology and Hydrology record.** [6]

3.1.3. Conclusions

The following key points arise from the review of previous studies and analysis of monitoring data sets:

- The data analysed in this report generally support previous observations and studies, in showing that the water quality of the canal is significantly different to that of the river with regard to a number of water quality indicators, such as suspended solids, chlorophyll and DO%.
- The differences in water quality between the canal and river are less pronounced in autumn/winter than in spring/summer, due to the seasonal cycle in photosynthetic activity (algal growth).
- It is important to note that the water quality of the canal is considered poor with regard to measures of water clarity (turbidity/suspended solids), but not with respect to nutrient levels (ammonia and SRP concentrations are relatively low) or DO% (saturation levels are high throughout the year).
- Poor water clarity in the canal appears to be linked to photosynthetic activity, as evident by the high chlorophyll concentrations and seasonality in phosphorus levels. Neal et al. (2010) and Zeckoski (2010) also refer to boat movements and lock operation as an important potential factor in controlling nutrient/algal dynamics in this system. However, Halcrow (2007) reported that a weekly cycle was not apparent in turbidity readings, as would be apparent if changes in turbidity were due to an expected pattern of boat movements.

Based on the above, the following preliminary conclusions can be drawn:

- Separation of the Kennet and Avon Canal and the River Kennet at Copse Lock is likely to result in a localised decrease in chlorophyll concentrations for the river. This would bring localised benefits to the water quality of the river just downstream of Copse Lock, primarily with regards to water clarity (suspended solids).
- SRP levels may increase in the river, due to the absence of low SRP water from the canal and, perhaps more significantly, because nutrient uptake rates would be expected to reduce due to a smaller algal population in the river water compared to the canal water. Ammonia levels may

decrease, as the river has overall lower ammonia levels than the canal[7]. Having said this, separation of the canal and the river may lead to changes in the ecological balance of the system, potentially leading to a higher or lower nutrient uptake rate than currently observed. Such changes will need to be considered during further investigations, including water quality modelling. Changes relating to nutrient status are also likely to vary between seasons.

- DO% levels in the river are likely to decrease due to the localised decrease in photosynthetic activity. However, levels are very high overall in the river and the canal (10th percentile >83%; based on the automatic monitoring data sets), so potential impacts on water quality arising from the change in DO% are likely to be small. Further assessment will be required to look at the impact any changes may have on macrophytes, such as *ranunculus* growth, and the resultant impact on DO.

A summary of the baseline assessment and preliminary conclusions regarding changes in water quality that may result from separation of the canal and the river is provided in Table 5.

Table 5. Summary of baseline assessment and preliminary conclusions regarding potential changes to water quality (in the river just downstream of Copse Lock) resulting from separation of the canal and river at Copse Lock.

Water quality indicator	Current water quality of the combined Canal/River just downstream of Copse Lock	Preliminary* assessment of potential water quality changes in the river just downstream of Copse Lock
Suspended solids/turbidity	Poor	Moderate
Chlorophyll	Poor	Moderate
SRP	Moderate	Poor (see note above)
Ammonia	Moderate	Good (see note above)
DO% saturation	Good	Good (no change)

* These results will have to be confirmed and examined further by water quality modelling to reliably inform any decisions regarding the proposed scheme. In addition, changes to nutrient (ammonia and SRP) levels, in particular, may be affected by ecological changes (and subsequent changes to nutrient uptake rates) and may vary between seasons.

3.2. Proposed further investigation of effectiveness with regard to water quality

3.2.1. Proposed modelling approach

As biogeochemical interactions are complex and are affected by a number of environmental factors, the above preliminary conclusions on predicted water quality after separation on the canal and the river at Copse Lock would need to be confirmed and examined further by water quality modelling to reliably inform any decisions regarding the proposed scheme. We suggest maximising the use of existing models, which have already been calibrated especially for the River Kennet and Kennet and Avon Canal. The most appropriate models for this application are thought to be at present:

- A canal model developed by Zeckoski (2010; for sediment, algae and TP);
- An INCA-P river model, developed by the University of Reading (WRA, 2007; for SRP, TP, macrophytes and sediment).

The models have been developed separately. One approach, which would involve joining the two models, is likely to be too complex and time-consuming at this stage. We propose instead to first run the canal model, and then use the output of the canal modelling as an additional 'discharge' or boundary to the River Kennet INCA-P model, which would be run to a downstream point at Newbury. This approach would, therefore, involve the following two steps:

[7] Any associated change in un-ionised ammonia concentrations in the river, dependent on pH and temperature, should be investigated if this scheme is to be taken forward

- First running the canal model; then using the output of the canal model as an input to the INCA-P (river) model. The river model would require some re-calibration at this stage, as currently it does not explicitly include the influence of the Kennet and Avon Canal on the River Kennet. The output of this model run would form the **baseline**.
- A **scenario** model run simulating separation of canal and the river would then be carried out. This would involve removing the canal input from its location in the baseline run and adding it further downstream, where the canal would re-join the river if the proposed scheme was to go ahead.

Scenario results would be compared against the baseline and a percent predicted change in the concentration of key determinands would be calculated. Interpretation could focus on different time periods within each model run, which would reflect different environmental conditions, such as:

- Summer conditions (increased day length, higher temperatures);
- Winter conditions (shorter day length, lower temperatures);
- Storm conditions (elevated nutrient load and flow inputs from the catchment into the river);
- Dry weather conditions (decreased dilution of pollutants in the river and the canal); and

Changes would be considered downstream of the location of the separation to see the impact at Newbury as well as the localised changes for the Craven Fishery.

All modelling results will be analysed further in the context of the available information on this system and in collaboration with the ecologists and other specialists. Water quality impacts in the stretch immediately downstream of Copse Lock will be considered, but also impacts further downstream should be examined (see Neal et al, 2010).

Further background information on the Zeckoski (2010) and INCA-P (WRA, 2007) models is provided below. Note that the Canal model has been calibrated for the period 1997-2005 and validated for the period 2006-2009. The INCA-P river model has been calibrated for the period 1997-1998. There is hence a two-year period of overlap in the calibration periods of the two models, and so both models could be run in the current state for this common period without the need to collect further input data. If a longer period is desired then additional data for the INCA-P model should be obtained including:

- Hydrology
    - Daily time series of Soil Moisture Deficit (mm), Hydrologically Effective Rainfall (mm/day), Air Temperature (°C) and Actual Precipitation (mm/day). These data are usually obtained from the MORECS model (Met. Office) or via the Met Office MOSES system.
    - Base flow index
- Land management practices - namely estimates of growing season for different crop and vegetation types, and fertiliser application quantities and timings which are estimated from the Fertiliser Manufacturers‘ Association (1994) and local knowledge, respectively.
- Time-series of sewage effluent flow rates and SRP concentrations. Also, flow and water quality data for validation or re-calibration (primarily TP and SRP spot samples taken at various points in the river).

3.2.2. Canal model

A water quality model of the Kennet and Avon Canal has been produced by R. Zeckoski, as part of recent doctoral work at the University of Cambridge. A brief overview of this model is presented below, based on the information provided in R. Zeckoski's thesis document (Zeckoski, 2010).

Development of the model involved construction of a canal model, incorporating for example: water and solids flow occurring with lockages/weirs, water and solids flow associated with overtopping lock gates, sediment disturbance caused by boat propellers, biological solid generation by algal growth, deposition of sediment along the length of a reach, external influences on water and solids. The model assumes that phosphorus is the limiting nutrient in the system.

After initial successful testing, the model was applied to the Kennet and Avon Canal. The study considered the part of the system extending from Copse Lock, 21 km eastwards. The system was simulated in a series of reaches, within which solids are assumed to be completely mixed. The model included four state variables: water storage, cohesive sediment storage, non-cohesive sediment storage and algal storage. All inflows and outflows within each reach were based around these four variables. It was assumed that the primary sources of sediment within each reach are boats and upstream canal reaches. The model was verified against observed hydrological data, suspended solids and chlorophyll data and found to be adequately representing processes in the Kennet and Avon Canal. The final part of the study involved testing of scenarios relating to management of the water quality of the canal. The following scenarios were tested:

- Do minimum, hence dredging of the canal reaches near Copse Lock;
- Diverting surface flow;
- Installing on-line canal filtration of the canal flow, assuming a 30% reduction in P loads through use of reedbeds;
- Reducing the volume of poor water quality water from the Canal into the River;
- Controlling effluent discharges in the catchment;
- Treating the canal water, assuming the biological or chemical treatment of the water to reduce sediment and algal concentrations by 90%).

As this was a canal model, separation of the canal and river could not be tested. The study concluded by recommending that a water quality management scenario will need to address water quality problems restricting algal growth and minimising sediment disturbance. The model tested a range of options for water quality management and suggested that filtration or other treatment of water in the canal near the confluence with the river is the best management option to remove algae and sediment from the water.

The author noted that the canal model code and algorithms are freely available to any interested party and may be incorporated into other models. The possibility of combining the Kennet and Avon Canal model to the INCA model of the River Kennet is also noted in the thesis.

3.2.3. INCA-P model

The INCA (Integrated Catchment) Model is the result of several NERC, EA and EU funded projects over the past 10 years (Whitehead et al, 1998; Wade et al, 2002a; Wade et al, 2002b) and is a dynamic computer model that predicts water quantity and quality in rivers and catchments. The primary aim of INCA is to represent the catchment topography and the complex interactions and connections operating at a range of scales. INCA is process- based so it can address the scaling-up issue that often limited the potential of most water quality models. Separate models are available for nitrogen, phosphorus, carbon and metals. The INCA models have been designed to investigate the fate and distribution of water and pollutants in the aquatic and terrestrial environment. The models simulate flow pathways and tracks fluxes of pollutants in the land and in aquatic ecosystems.

The model INCA-P focuses on phosphorus dynamics, but also includes plant and sediments. An INCA-P model of the River Kennet has been constructed and calibrated by WRA. Details of the model are outlined in WRA (2007) and a summary of key information contained in this report is outlined below.

The INCA-P model is a process-based representation of factors and processes controlling phosphorus dynamics in the land and in-stream components of river catchments. It aims to investigate the transport and retention of phosphorus in the terrestrial and aquatic environment and impacts of phosphorus loads on in-system macrophyte biomass. Following on from the application of INCA-P to the upper part of the River Kennet catchment, the application was extended to include all of the Kennet catchment by the Environment Agency (Paul Simmons).

Development of the model included weekly water chemistry sampling at seven sample points in the Kennet system upstream of Knighton, analysed for example for total phosphorus, SRP, boron[8] and SS concentrations. The model was found to be able to reproduce the observed in-stream total phosphorus and SRP dynamics. However, the authors note that results represent a ‘worst-case’ scenario in terms of in-stream SRP concentrations, due to an over-estimation of flows from Knighton to Newbury, which result in an over-estimation of SRP in these reaches. The current model does not explicitly include the influence of the Kennet and Avon Canal on the River Kennet either in terms of flow or water quality.

[8] Boron acts is a tracer of STW inputs.

4. Ecology and Fisheries Assessment

4.1. Ecology

4.1.1. Context

The River Kennet is designated a Site of Special Scientific Interest (SSSI) from below Marlborough to Woolhampton as a chalk river. Although the Kennet catchment is dominated by chalk it shows a downstream transition to a lowland clay river as it crosses Tertiary sands and gravels, London Clay and silt (Natural England, 1995). Through the reach between Hungerford and Newbury, the River Kennet comprises a number of carriers and channels associated with former water meadow systems, which flow through areas of marshy grassland, wet woodland and reedbeds (Natural England, 1995).

Natural England (1995) notes the following as being of particular note within the River Kennet:

- Species rich and diverse flora: the flora is considered to be intermediate in character between the classic chalk rivers of the south and the oolitic rivers to the north and shows a clear downstream succession reflecting the geology and flow pattern. Stream water-crowfoot *Ranunculus penicillatus,* starwort *Callitriche obtusangula* and watercress *Rorippa nasturtium-aquaticum* dominate the upper Kennet and river water-crowfoot *R. fluitans* occurs below Newbury where there is less chalk influence and more water. The nationally scarce river water-dropwort *Oenanthe fluviatilis* has been recorded in the mid to lower Kennet.
- Abundant macroinvertebrates: The River Kennet is noted for its large numbers of mayflies including *Ecdyonorus insignis* and *Ephemerella notata,* which have a very local distribution. Two nationally scarce species are noted as occurring along the River Kennet; *Molophilus niger* and *Ylodes conspersus.*
- Good bird populations: kingfisher, grey wagtail, sedge warbler, reed warbler, mute swan and little grebe. Common sandpiper and redshank use the river on passage.
- Mixed self-sustaining fishery: wild brown trout, grayling, perch, chub, dace, roach, pike, gudgeon and bullhead.

The River Kennet SSSI is currently in unfavourable: no change condition; the 2008 condition assessment reports the following (Natural England, 2011):

- Biological GQA class: all units meet target
- Chemical GQA class: all units meet target
- Un-ionised ammonia: all units well below target
- Suspended solids: fails target – levels mostly around target but with peaks well above
- Total reactive phosphorus: fails target – annual mean below target but with peaks well above
- Morphology: fails target – needs more work on river restoration

The conservation objectives (Natural England, 2008) include targets for the ecological and fisheries functioning of the river. The key relevant targets that any proposal for separating the river and canal channels should aim to meet include:

- Vegetation – species composition to be relevant for the river type, fine sediment should not prevent *Ranunculus* growth; characteristic species to be supported: *Oenanthe fluviatile, Schoenoplectus lacustris, Callitriche* spp., *Ranunculus fluitans, R. pseudofluitans, Sparganium emersum, S. erectum.*
- Channel form – river morphology should be characteristic of the river type; widening, deepening and reinforcement are indicators of unfavourable condition
- Fisheries – population structure of characteristic fish species including brown trout, grayling and bullhead indicates healthy natural recruitment; no artificial barriers impairing characteristic migratory species from essential life-cycle movements; no significant impacts on native fish populations from fishery management
- Water quality – Biological and Chemical GQA class of A or B

The assessment of impacts on the river ecology of the proposed diversion of the River Kennet away from the Kennet and Avon Canal at Copse Lock draws on existing data collected by the Environment Agency. Data has been analysed previously in Martin (2008) and Environment Agency (2011) therefore extensive reanalysis of data has not been undertaken. Instead, the analyses and conclusions drawn from the studies have been used to determine the existing baseline and from that to identify what could reasonably be expected to be present in a new river channel and the potential impacts further downstream of the proposed separation of the river and canal channels.

4.1.2. Ecological baseline

4.1.2.1. Macroinvertebrates

Martin (2008) undertook a review of the historic dataset resulting from Environment Agency monitoring for the whole of the River Kennet between 1990 and 2007, focussing on years where more than 15 samples were collected. The analysis showed a significant downward trend in BMWP scores at Hambridge Road, Newbury and at Fobney, Reading over time but no significant trends in ASPT, indicating no significant changes in water quality (organic enrichment). Greater distinction between sites was observed in ASPT than BMWP. No analysis was made of trends between sites although visual inspection of the data suggests that there are no clear spatial trends although Hambridge Road, Newbury consistently achieves amongst the highest ASPT and the site above River Thames is consistently amongst the lowest.

Environment Agency (2011) reports the findings of a study of the River Kennet (and River Dun) between Hungerford and Newbury. The study includes samples from autumn 2009 and spring and summer 2010 taken from ten sites. The study concludes that this stretch of the River Kennet is not impacted by organic pollution or flow stress and that the reach achieves at least Good Ecological Status (except for River Dun upstream Berkshire Trout Farm) based on 2010 spring and summer macroinvertebrate data (Table 6).

This assessment was made using the River Invertebrate Classification Tool (RICT), the WFD classification tool for macroinvertebrates in rivers designed to detect the impact of organic enrichment. It may also detect the impact of other pressures or combination of pressures. Macroinvertebrates are used to assess the ecological status of a water body based on the number of scoring taxa (NTAXA) and ASPT. RICT compares observed data with those expected from reference (near pristine) sites to assess the degree of impact.

Table 6. The summary of the overall status for each site based on spring and summer 2010 data and the Minimum of Number of Taxa and ASPT (MINTA)

Site	Ecological status
Dun upstream Berkshire Trout Farm	poor
Dun downstream Berkshire Trout Farm	good
Kennet upstream river Dun	high
Kennet downstream river Dun	high
Kennet downstream Hungerford STW	high
Kennet at Barton Court	high
Kennet at Wilderness	good
Kennet at Copse Lock	good
Kennet at Craven Fishery	good
Kennet at Benham Estate	good

Figure 22 and Figure 23 show the spatial and temporal changes in ASPT and Number of Scoring Taxa (NTAXA) respectively focussing on the interaction of the Kennet and Avon Canal on the River Kennet; Barton Court and Wilderness represent the River Kennet upstream of Copse Lock before any influence of the Kennet and Avon Canal, the Copse Lock site is on the combined channel, Craven Fishery is located on the river after it has been separated from the combined channel Benham Estate is located downstream of where the river crosses the canal. When interpreting macroinvertebrate data from the canal site it should be noted that the methodology used does not provide a sample representative of the whole site. At Copse Lock, macroinvertebrates are sampled from the shallower margins only, rather than proportionally accounting for the deeper canalised habitat. These figures combine the data from Martin (2008) from Wilderness and Copse Lock and the recent survey data from Environment Agency (2011).

The figures tend to show a reduction in indices at Copse Lock from Wilderness. Continuing downstream, autumn 2009 and spring 2010 samples show an increase at Craven Fishery after the river has separated again from the canal; however this is not apparent in the summer 2010 sample. The two datasets combined (Martin 2008 and Environment Agency 2011) show ASPT is over five for all but one sample at Copse Lock, indicating the site is not generally impacted by organic pollution. Both ASPT and NTAXA are generally lowest at Copse Lock compared to upstream and downstream sites, except for spring 2010 when the sample from Benham Estate was lowest. Of note, NoT at Copse Lock improves dramatically between autumn 2009 and spring 2010.

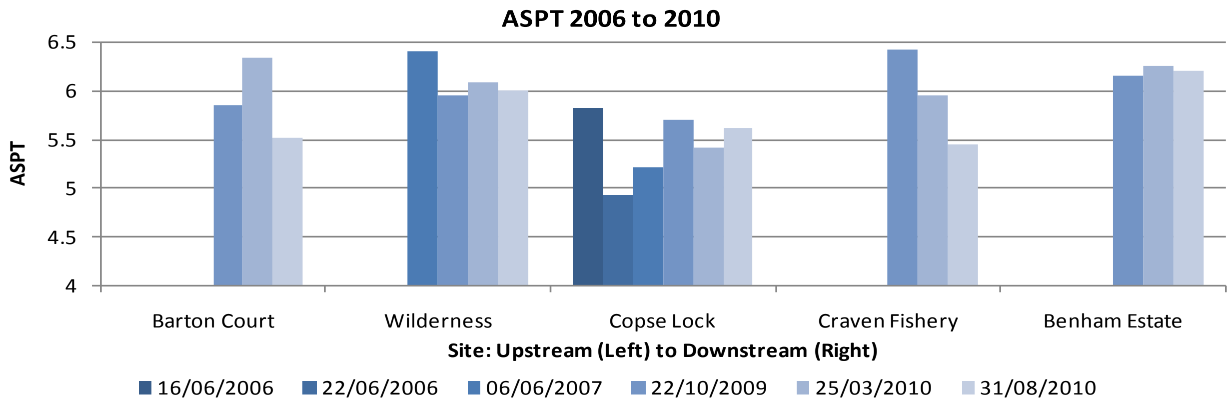


Figure 22. Kennet ASPT upstream and downstream of Copse Lock from 2006 to 2010

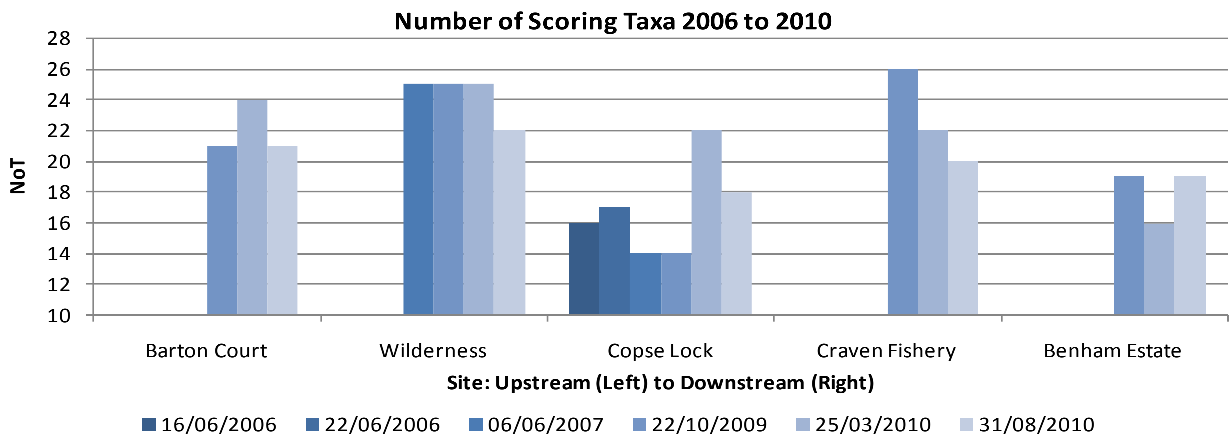


Figure 23. Kennet Number of Scoring Taxa upstream and downstream of Copse Lock from 2006 to 2010

Figure 24 shows the detail of the composition of a single sample from Wilderness and Copse Lock with respect to BMWP scoring taxa. These samples were used for detail as the species lists were available from Martin (2008). It shows a reduction in the most sensitive taxa at Copse Lock compared to the upstream site at Wilderness but it should be noted that Copse Lock does support sensitive species. The number of scoring taxa at Copse Lock on this sampling occasion was just over half that recorded at Wilderness and is likely to be associated with habitat conditions at the canal site.

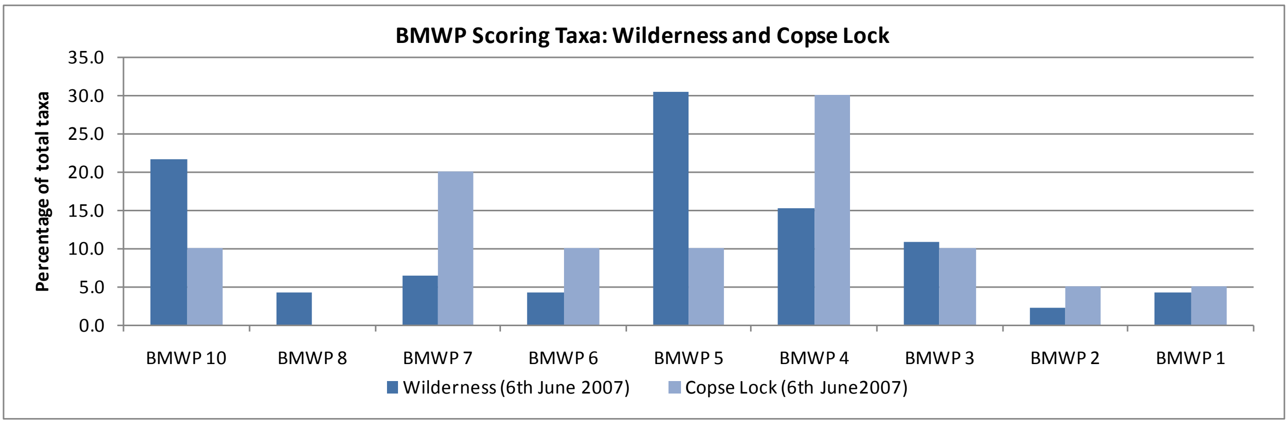


Figure 24. Proportion of BMWP Scoring Taxa within a Sample from Wilderness and Copse Lock

Figure 25 shows the LIFE scores (family and species LIFE) from the five sites upstream and downstream of Copse Lock and the influence of the canal on the river. LIFE scores are lowest at Copse Lock but all scores are over 7 and, as reported by Environment Agency (2011) do not indicate flow stress. Using the species lists from Martin (2008), Figure 26 shows the composition of a single sample from Wilderness and Copse Lock. Both sites are dominated by taxa within LIFE Flow Group 2; however Copse Lock lacks any taxa from the highest flow group indicating the relatively slower velocities expected from a canalised section. It should be noted however that LIFE flow group 1 taxa are associated with rapid flows, usually associated with upland and riffle sites and LIFE flow group 2 taxa associated with moderate to fast flows. Therefore, the similar composition of LIFE flow group 2 at the two sites suggests that flows in the canal are still relatively high, and as noted above the LIFE scores do not indicate that the macroinvertebrate community is subject to flow stress.

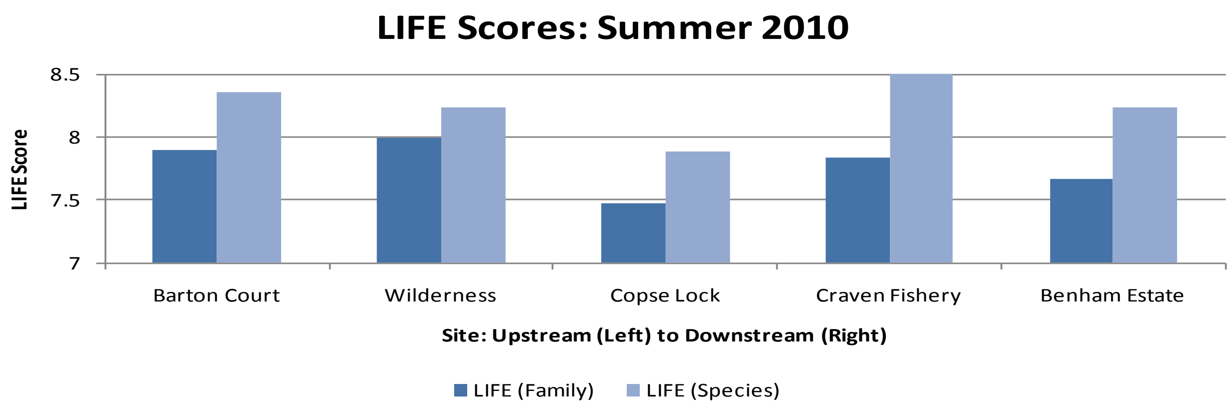


Figure 25. Kennet LIFE scores upstream and downstream of Copse Lock, summer 2010

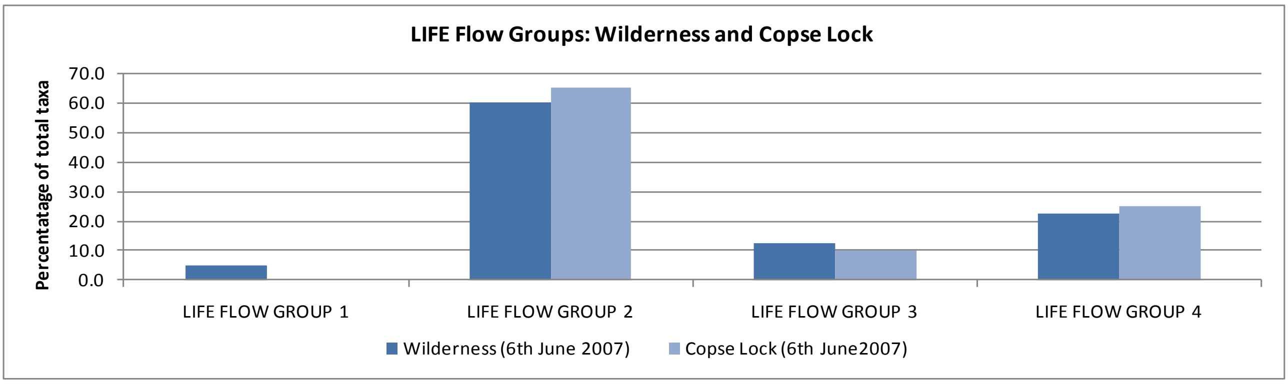


Figure 26. Proportion of LIFE Flow Group Taxa within a Sample from Wilderness and Copse Lock

4.1.2.2. Macrophytes

Martin (2008) assesses the macrophyte survey data, which concludes the River Kennet is ‘at risk of eutrophication’ based on Holmes *et al* (1999). Environment Agency (2011) recommends macrophyte surveys be undertaken as these surveys have not been included in the current study. The species list for Copse Lock from 2007 shows the site to be dominated by yellow water lily *Nuphar lutea* and common club-rush *Schoenoplectus lacustris*, which are typical of relatively deep, slow flowing water as would be expected in a canalised river. The 2007 data also indicates a variety of marginal vegetation.

Vegetation cover recorded as part of the macroinvertebrate survey reported in Environment Agency (2011) suggests a lower diversity of vegetation types at Copse Lock, where only emergent reeds, rushes and sedges were recorded, compared to the river sites. These are only incidental records and not the results of specific macrophyte surveys and cannot be used to draw firm conclusions on comparative macrophyte communities.

4.1.2.3. Diatoms

Diatom surveys were undertaken during 2009 and 2010 and reported in Environment Agency (2011). The data from Copse Lock and the sites immediately upstream and downstream (Wilderness and Craven Fishery) indicate impacts of high nutrients. The Tropic Diatom Index (TDI3) is used as a measure of nutrient enrichment where increasing scores indicate increasing nutrient impacts. The autumn 2009 and spring 2010 results show a peak in nutrient enrichment at Copse Lock when compared to the upstream and downstream sites. However, the summer 2010 results indicate decreasing nutrients with progression downstream. The River Kennet at Wilderness shows the least seasonal variation of the three sites, indicating the possible influence of the canal on seasonal variability in nutrient conditions.

The percentage of motile taxa (diatoms that can move independently) is used to assess the influence of pressures other than nutrients on diatom communities, such as sedimentation. Results from Wilderness (river) and Copse Lock (canal) indicate greater seasonal variation than between the two sites. At Craven Fishery data from the three seasons indicates that the proportion of motile taxa increases from spring through summer to autumn (it should be noted however that this is based on autumn 2009 and spring and summer 2010 data).

4.1.2.4. River Habitat Survey

River Habitat Survey (RHS) data is available for three sites on the River Kennet: upstream of Hungerford (1996), upstream of Barton Court (2003) and upstream of Newbury Wharf (1995). The results (Table 7) show a range of modifications with upstream of Hungerford being the least modified with resectioning or reprofiling recorded on one bank. The site upstream of Barton Court is subject to the greatest modification of the three sites with extensive bank and channel resectioning or reprofiling and being realigned and over deepened through more than one third of its length.

Table 7. River Habitat Survey Summary Data

Site location	Habitat Modification Score (HMS) / Habitat Modification Class (HMC)	Modification features
Upstream of Hungerford	280 / HMC3 Obviously modified	Extensive resectioning/reprofiling on one bank
Upstream of Barton Court	3960 / HMC5 Severely modified	Extensive resectioning/reprofiling and reinforcement, over deepened, realigned, culverts, bridges, weirs/sluices
Upstream of Newbury Wharf	920 / HMC4 Significantly modified	Major bridge and weir/sluice, outfalls/intakes, extensive bank reinforcement

4.1.2.5. Summary

In the summary, the key ecological baseline conditions are:

- Macroinvertebrate communities throughout the reach are not impacted by organic or flow stress;
- A less diverse macroinvertebrate community is present at Copse Lock than at other sites, likely due to habitat conditions within the canalised section;
- Incidental vegetation type data suggests that macrophyte diversity is lower where the two channels are combined at Copse Lock ; however further surveys are required to confirm this;
- The results of the diatom surveys indicate that the River Kennet and Kennet and Avon Canal are impacted by nutrients and other factors affecting the presence of motile taxa. Seasonal variation appears to be greater than that between the river and canal;
- The River Kennet has been modified to differing degrees throughout the reach varying from ‘obviously modified’ to ‘severely modified’, even where the channel is not in a canal.

4.2. Fisheries

4.2.1. Rationale

An assessment of the fisheries population of the River Kennet, Kennet and Avon Canal and associated streams has been undertaken in support of the investigation of ecological outcomes associated with engineering options (detailed in Section 2.2 to 2.7) to remove the connectivity between the River Kennet and the Kennet and Avon Canal at Copse Lock and downstream works at the Marsh Benham Weir Junction (see Section 2.8). These works are proposed to address the negative impacts associated with mixing of waters from the Kennet and Avon Canal and the River Kennet at Copse Lock on ecological communities (HR Wallingford 2008). As a result of these proposed options there is potential for impacts (both negative and beneficial) on the fisheries populations in the Kennet and Kennet and Avon Canal. These include:

- Effects arising from alterations in water quality as a result of hydrological regime change e.g. removal of canal and river water mixing.
- Creation of habitat through provision of diversion channels.
- Long terms effects of culvert/siphon construction and fish ladder provision on fish passage.

In order to assess the likely ecological outcomes of the options this section draws on fisheries data from routine surveys undertaken by the Environment Agency (between 2004 and 2010) and includes the investigation of spatial and temporal population trends. The assessment centres around fisheries data collected at four survey sites in the middle and upper section of the lower reach of the River Kennet (Figure 16). Fisheries survey site details and survey methodologies are provided in Table 8 (sites are ordered in an upstream to downstream direction) and maps of each survey location provided as Figure 27.

The survey sites include two locations downstream of Copse Lock on the main River Kennet at Speen Moor and Northcroft as well as one site below Copse Lock in the Kennet and Avon Canal at Marsh Benham. The Marsh Benham site therefore provides information on the fish population immediately downstream of the point of mixing between the River Kennet and the Kennet and Avon Canal. In addition, fisheries data is presented for the Willow Stream, a feeder stream flowing adjacent to the river Kennet near Avington, this site is considered to be unaffected by stocking and therefore provides a truer reflection of the expected natural fish population of the middle Kennet i.e. fish population data for the main river Kennet upstream of Copse Lock are strongly influenced by historic stocking strategies in the provision of game fishing sport.

Table 8. Summary of fishery survey sites

Site name and (code)	Location details	Survey details
Willow Stream (KTA7)	Middle reach (SU 37820 67378)	Willow Stream at Barton Court. A carrier stream of the River Kennet. Fished between sluices by upstream electro-fishing, wading, 3 anodes and 2 nets.
Marsh Benham (KTA2)	Middle reach (SU 42095 67041 to SU 41732 67037)	River Kennet/Kennet and Avon Canal. (combined) located upstream of Hamstead weir at River Kennet/canal confluence. Fished using DUC Boat with two anodes. Up and down margins. Catch per unit effort for 42 minutes.
Speen Moor (unknown)	Upper section of lower (SU 45226 67152)	River Kennet at Speen Moor. Fished using DUC Boat with two anodes. Up and down margins.
Northcroft (KTA1)	Upper section of lower (SU 46205 67173 to SU 46816 67112)	River Kennet at Northcroft Recreation Centre to Westmills swing bridge. Fished using DUC boat, with two anodes and two nets.

Key:

Kennet feeder stream (i.e. not main river).	
River Kennet and Kennet & Avon Canal mixed.	
River Kennet.	

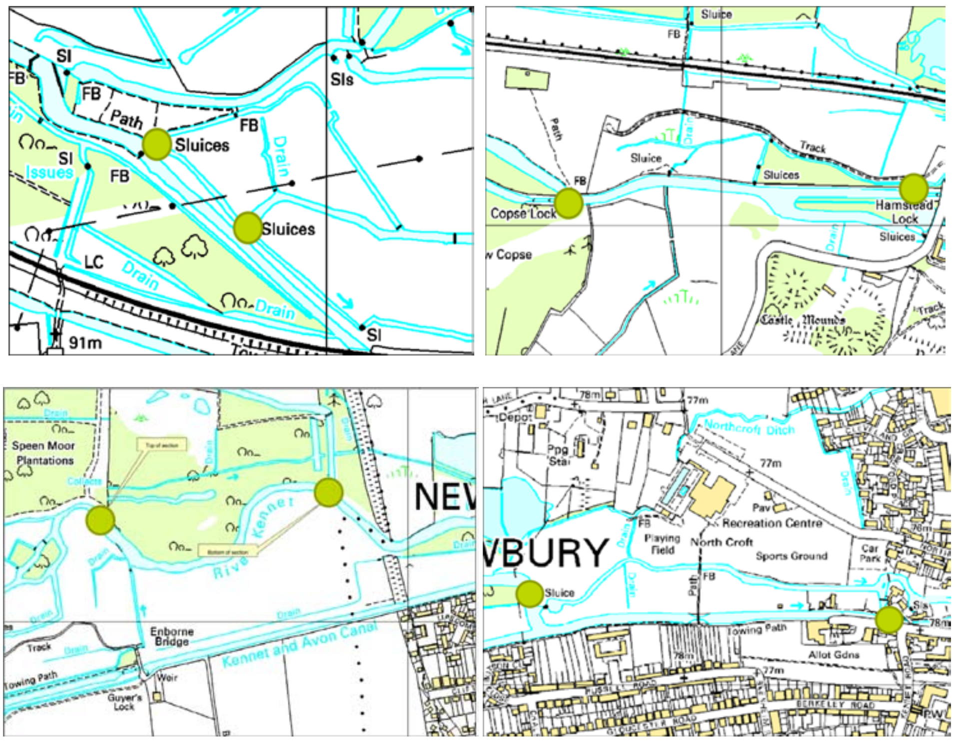


Figure 27. Location of fish survey reaches. Clockwise from top left, Willow Stream; Marsh Benham; Speen Moor and Northcroft. Survey conducted between green markers.

4.2.2. River reach background

The Kennet and Pang Fisheries Action Plan (FAP) describes the middle reach of the Kennet as being delimited by Eddington Bridge at Hungerford, to the new A34 bypass to the west of Newbury. The fishery here is identified as being a mixed trout and coarse reach and includes the survey sites on Willow Stream and on the combined canal and river flow section at Marsh Benham. Degradation of the coarse fish community has historically arisen from the removal of coarse fish to allow the development of game fishing in this reach. Water Framework Directive classification of the middle reaches from Marlborough to Newbury identified this reach as being "moderate" for fish in 2010 (Bob Preston, pers. com., March 2011).

The lower reach is described as being located from the A34 bypass to the confluence of the Kennet with the River Thames and includes, in its upper section, the survey sites at Speen Moor and Northcroft. The lower reaches provide a coarse fishery known for its large barbel (*Barbus barbus*), chub (*Leuciscus cephalus*) and silver fish e.g. roach (*Rutilus rutilus*) and bream (*Abramis brama*). The FAP reports evidence of fisheries change with a reduction in the abundance of silver fish and recruitment problems in the chub and barbel populations. Water quality issues (e.g. high turbidity) and concomitant losses of typical chalkstream plant communities (e.g. *Ranunculus*) in this reach are identified as reasons for this decline.

In addition to the water quality concerns relating to the impact of canal and river water mixing there are a number of additional factors that could influence the fish assemblages observed at each of the survey site. These include, but are not necessarily limited to:

- Habitat quality and complexity
    - Availability and range of suitable adult and juvenile fish habitat
    - Availability and quality of spawning habitat
    - Suitable refuge from high flow events e.g. presence of back waters and off main channel habitat
- Influence of stocking and non-native species
    - Resource competition and displacement as a result of fish introductions on natural fish populations.
- Habitat severance
    - Influence of barriers to fish movement e.g. weirs, interrupting seasonal migration patterns and recruitment.
- Fish population dynamics
- Influence of the natural temporal variability in recruitment, growth and mortality of fish populations.

4.2.3. Fisheries data and data analysis

Summary fish species population metrics (e.g. number of species, density and biomass) are provided for each survey site and sampling period in Table 9. Fisheries data detailing individual species biomass and density estimates is included as 7.Appendix B.

Table 9. Fisheries data summary metrics

Site name and (code)	2004	2005	2006	2007	2008	2009	2010
Willow Stream	Sampled in March	Sampled in March	Sampled in March	Not sampled	Sampled in March	Sampled in March	Not sampled
Number of species	8	8	8	-	7	7	
Salmonids reported	BT, RT, G	BT, RT, G	BT, RT, G	-	BT, G	BT, G	-
Total density (no. m^{-2})	0.086	0.036	0.069	-	0.154	0.116	-
Total biomass (g m^{-2})	33.81	15.75	22.14	-	19.68	26.544	-
Marsh Benham	Sampled in October	Sampled in October	Sampled in October	Not sampled	Sampled in November	Sampled in November	Sampled in (??)
Number of species	5	7	7	-	9	7	7

Site name and (code)	2004	2005	2006	2007	2008	2009	2010
Salmonids reported	RT	BT	-	-	BT	-	-
Total density (no. min^{-1})	3.59	3.71	5.09	-	5.23	1.88	5.09
Total biomass (g min^{-1})	1411.47	389.22	567.00	-	519.19	343.27	567.00
Speen Moor	Sampled in October	Not sampled	Not sampled	Not sampled	Not sampled	Sampled in November	Not sampled
Number of species	9	-	-	-	-	7	-
Salmonids reported	-	-	-	-	-	BT	-
Total density (no. min^{-1})	2.80	-	-	-	-	1.77	-
Total biomass (g min^{-1})	1252.31	-	-	-	-	1420.00	-
Northcroft	Sampled in October	Sampled in October	Sampled in November	Not sampled	Sampled in November	Sampled in November	Sampled in (??)
Number of species	9	6	9	-	8	9	8
Salmonids reported	BT	-	-	-	-	-	-
Total density (no. min^{-1})	7.52	5.56	3.71	-	6.54	5.85	7.50
Total biomass (g min^{-1})	516.64	555.46	366.73	-	422.50	640.91	546.02

Notes: BT = Brown trout, RT = Rainbow Trout, G = Grayling

The total number of species recorded at each site during the survey period of 2004 to 2011 is as follows:

- Willow Stream = 10
- Marsh Benham = 13
- Speen Moor = 10
- Northcroft = 11.

These data show that all four survey sites exhibit similar species richness although spatial and temporal variability in the range and number of individual species is considerable. In general cyprinid species dominate the fish assemblages although salmonids have been recorded at all sites. Salmonid numbers are highest in the Willow Stream, the only site shown to support grayling, with brown trout recorded during each survey. Infrequent records of brown trout are observed at the sites downstream of Copse Lock and of particular note are the 13 Atlantic salmon parr recorded at Marsh Benham in 2010; it is assumed that these fish were introduced. Other records of introduced species include rainbow trout (*Oncorhynchus mykiss*) at Willow Stream and Marsh Benham.

The adoption of the same semi-quantitative fish survey methodology and survey period at Marsh Benham, Speen Moor and Northcroft allows a comparative analysis of fish biomass (grams per minute of survey) and fish density (numbers per minute of sampling) values. Mean biomass and density values for the sites are:

- Marsh Benham = 568 g min^{-1} and 4.1 no. fish min^{-1}
- Speen Moor = 1336 g min^{-1} and 2.3 no. fish min^{-1}
- Northcroft = 508 g min^{-1} and 6.1 no. fish min^{-1}

Although the habitat quality and the specific nature of the habitats sampled will strongly influence these metrics these data indicate that both Marsh Benham and Northcroft are able to support broadly similar standing crops and fish population densities, whereas Speen Moor supports fewer, but proportionally larger fish species.

4.2.3.1. Analysis of spatial and temporal population dynamics

Fisheries density data has been used to assess both temporal and spatial differences in fisheries population for the individual survey sites. Density data have been standardised to take into account differences within and between data sets, such as the sampling methodology adopted, the timing of individual surveys and differences in physical habitat quality as identified by variations in habitat modification scores (see Table 7).

This allows a comparative analysis to be undertaken. These data have been used, together with water quality findings in this report, to provide an assessment of the ecological outcomes associated with the proposed work.

For each site and sampling period the species recorded have been broadly grouped into one of three Tolerance Groups. These grouping indicate the relative tolerance of the individual freshwater fish species to varying levels of environmental disturbance e.g. poor water quality, habitat degradation and results in the species being described as having:

- Low tolerance
- Medium tolerance, or
- High tolerance.

This grouping draws on that used in the Fisheries Classification Scheme for the assessment and classification of rivers in accordance with the requirements of Article 8; Section 1.3 of Annex II; and Annex V of the Water Framework Directive (2000/60/EC). It is important to note that only 23 of the most prevalent fish species in England and Wales (Annex 1) are used within this assessment and therefore the tolerance data presented here is based on the presence of these indicator species only. Species listed under each tolerance category are provided as 7.Appendix B.

Figure 28 to Figure 31 presents the proportional change in the density (numbers per minute or number per m^{-1}) of fish belonging to each of the Tolerance Groups for Willow Stream and sites on the Kennet at Marsh Benham, Speen Moor and Northcroft.

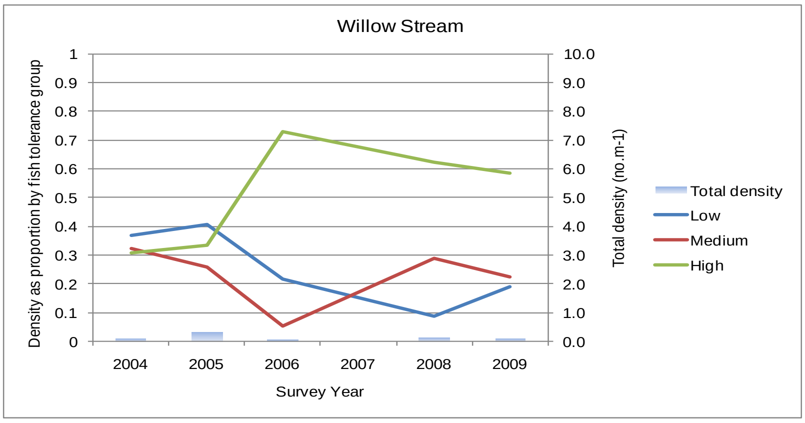


Figure 28. Proportional change in fish tolerance group density at Willow Stream

The analysis for the Willow Stream shows:

- For records between 2004 and 2011 there is evidence of a general trend towards an increase in the proportion of indicator fish species belonging to the high tolerance to environmental disturbance group (see 7.Appendix B).
- The most recent survey (2011) shows that the proportion of the population belonging to the high, medium and low tolerance groups is 0.73, 0.15 and 0.12, respectively. i.e. 73 percent of the assemblage, as measured by the relative density of indicator species is composed of species classified as being of high tolerance to environmental disturbance.
- This site consistently contains the highest proportion of species intolerant to environment disturbance e.g. brown trout and grayling (*Thymallus thymallus*), although there is a general trend towards a reduction in the numbers of these species since 2004.
- Since 2008 the recorded density of the indicator species has remained relatively constant at between 0.1 and 0.2 no. m^{-2}.

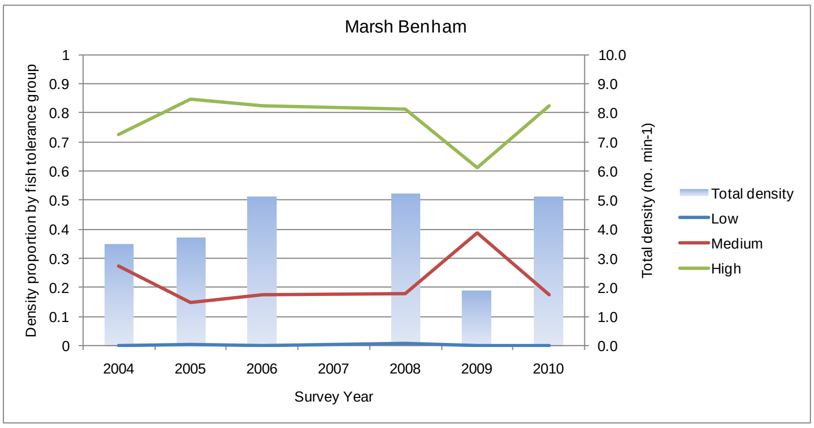


Figure 29. Proportional change in fish tolerance group density at Marsh Benham

The analysis at Marsh Benham shows:

- For records between 2004 and 2010 it is evident that the fish assemblage at Marsh Benham is dominated by species belonging to the high tolerance grouping.
- The most recent survey (2010) shows that the proportion of the population belonging to the high group is 0.83.
- Roach and perch (*Perca fluviatilis*) were particularly abundant during the most recent survey conducted in 2010.
- The mean proportions of high and medium tolerance species groups throughout the available record period is 0.76 and 0.21, respectively, with little variation across the years exhibited.
- Salmonid species belonging to the low tolerance group were recorded in the 2008 and 2009 survey only.
- Total indicator fish densities are relatively constant except for the lower than average values observed in 2007 and 2009.

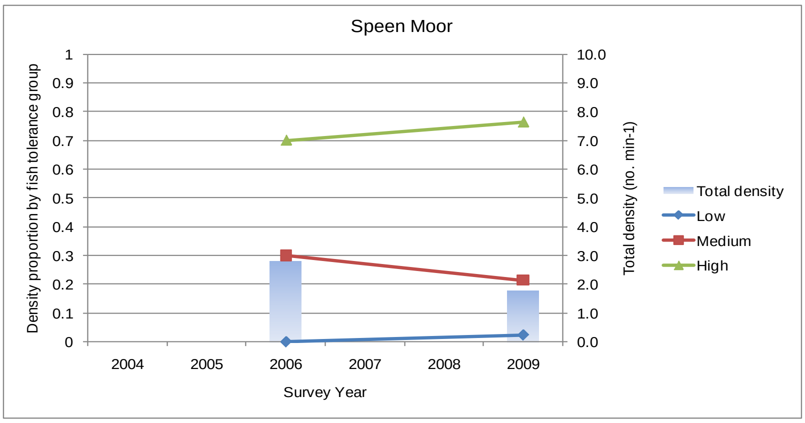


Figure 30. Proportional change in fish tolerance group density at Speen Moor

The results for Speen Moor show:

- Fisheries data is available for only two years at this site (2006 and 2009). In common with Marsh Benham, this River Kennet site exhibits a high proportion of high tolerance group species (average proportion of 0.73) and has a negligible occurrence of salmonids belonging to the low tolerance grouping.
- The proportion of both high (0.73) and medium (0.26) tolerance group is broadly similar to that observed at Marsh Benham.
- High variability in the fish population assemblage is evident from the switch in dominant species between 2006, when bleak (*Alburnus alburnas*) and roach were abundant, to 2009 when bream and

perch dominated the population. This stated the proportion of high to medium tolerance groups remained similar.
- In general the total densities of fish were lower than those observed at either Marsh Benham or Northcroft.

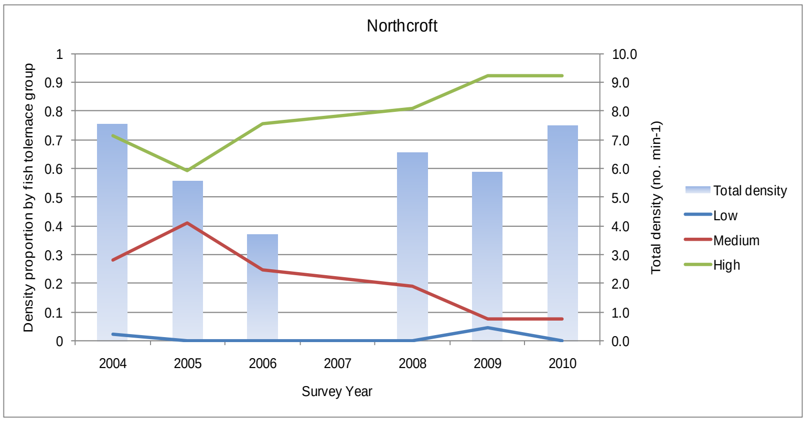


Figure 31. Proportional change in fish tolerance group density at Northcroft

The data for Northcroft show:

- Fisheries data is available annually for this site between 2004 and 2010. Species data shows that since 2004 there has been a temporal change in the assemblage, with a strong increase in those species belonging to the high tolerance group. This potentially indicates an increase in the level of environmental disturbance at this site over time e.g. deterioration in water quality.
- Examination of the 2010 survey data show that the proportion of high, medium and low tolerance groups was 0.92, 0.08 and 0.00 respectively, in comparison to 0.71, 0.28 and 0.02 in 2004.
- Total fish densities are consistently higher at Northcroft than those observed at either Marsh Benham or Speen Moor. This potentially indicates that habitat quality is suitable for the high tolerance species observed at this site such as perch, roach and dace that tend to form large shoaling groups.

4.2.3.2. Summary

With the exception of Marsh Benham, there has been a general increase in the proportion of high tolerance species within the river system since 2004, this indicates at an increase in the level of environmental disturbance as reflected by proportional changes in fish density measured at each survey site. At Marsh Benham, on the Kennet and Avon Canal, the proportion of species exhibiting high tolerance to environmental disturbance has remained relatively constant throughout the survey period; with on average ¾ of the fish populations surveyed composed of high tolerance indicator fish.

It is clear that, although described as a mixed coarse / salmonid fishery, the survey site immediately downstream of Copse Lock (Marsh Benham) is dominated by cyprinid species, many of which are characteristic species of slow flowing / lentic systems e.g. bream, perch, roach. The absence of salmonids is considered likely to be a reflection of in appropriate flow and habitat conditions the presence of weirs / structures and poor water quality episodes relating to canal and river water mixing.

At sites with limited / no significant influence from canal water mixing or fish stocking e.g. Willow Stream, a mixed fishery is present in which good numbers of trout and grayling are observed.

4.2.4. Option appraisal: ecological outcomes of varying options

The following tables identify the potential outcome of the various options identified to separate the influence of the canal from the River Kennet at Copse Lock and Marsh Benham Weir for existing fish, macroinvertebrate and macrophyte populations / assemblages and habitat quality elements. This assessment draws on the baseline information compiled for the individual receptors. For each assessment the relevant options and generic changes that will arise from those options are identified.

A "traffic light" system has been used to provide an overall measure of the outcome for each element, where:

- Red = Likely deterioration in element.
- Medium = No discernable change expected.
- Green = Likely improvement in element.

Table 10. Impact of separating the canal and river on ecology and fisheries

Element	Current quality downstream of Copse Lock	Preliminary assessment of potential change and reason
Fisheries (Options 1,2,3,4,5)	Kennet and Avon Canal: No evidence of deterioration in recent years although proportion of fish with a high tolerance to disturbance is high as recorded at Marsh Benham.	Potential reduction in fisheries quality of Kennet and Avon Canal due to removal of river flow inputs from Kennet through river diversion.
Fisheries (Options 1,2,3,4,5)	Craven Fishery: No baseline fisheries data	Potential improvement in fisheries quality of River Kennet at Craven fishery due to removal of canal water influence.
Fisheries (Option 6)	Kennet and Avon Canal: No evidence of deterioration in recent years although proportion of fish with a high tolerance to disturbance is high as recorded at Marsh Benham.	Potential improvement in fisheries quality of Kennet and Avon Canal due to removal of canal water influence. Improvements in water quality in existing Kennet an Avon Canal system will result, but poor habitat quality limits fishery potential even though influence of canal mixing are removed.
Fisheries (Option 6)	Craven Fishery: No baseline fisheries data	Potential improvement in fisheries quality of River Kennet at Craven fishery due to removal of canal water influence.
Macroinvertebrates	No evidence of flow stress or impacts of organic pollution; low species diversity at Copse Lock likely due to poor habitat conditions	Potential deterioration in Kennet and Avon Canal due to reduced water quality.
Macroinvertebrates		Potential improvement at Craven Fishery from improved water quality.
Macrophytes	Macrophyte community typical of deep, slow – moderate flowing channel	Potential improvement at Craven Fishery, although insufficient data to assess change; likely no significant change in canal community.
Habitat quality	Modified channel being a canalised section of river with little habitat diversity	No change in habitat quality in the canal unless option includes habitat improvements.

Table 11. Impact of new channel habitat created by separating the river and canal

Element	Current status of new excavated channels	Preliminary assessment of potential change and rationale
Fisheries (Options 1,3,5)	Limited fisheries value along proposed river diversion route. Fisheries value limited to undesignated ditch systems present on floodplain along river diversion route.	Improvement in fisheries quality through creation of additional fisheries habitat receiving waters from the Kennet only i.e. no influence from canal water input. Expected to result in habitat capable of supporting salmonid populations (similar to that observed at Willow Stream) due to improvement in water quality combined with good habitat design in new river cut.
Fisheries (Options 2,4)	No current fisheries value along proposed river diversion route.	Canal: Increase in extent of fisheries habitat although quality of new canal will be limited by the current water quality issues on site.
		New river channel: Expected to result in habitat capable of supporting lentic species only with high tolerance to environmental disturbance.
Macroinvertebrates	Unknown	Could expect an invertebrate community approximate to Wilderness or Barton Court within the new channel, potentially more like Wilderness due to the opportunity to maximise habitat.
Macrophytes	Unknown	As for invertebrates, could expect macrophyte community typical of the river type through appropriate channel design; potential for Ranunculus.
Habitat quality	Unknown	Channel can be designed to maximise habitat diversity; may require installations of structures such as weirs/sluices.

Relevant Options = 1, 2, 3, 4 and 5

Table 12. Downstream impacts of separating the river and canal

Element	Current status of Kennet downstream of Marsh Benham Weir junction	Preliminary assessment of potential change and rationale
Fisheries	Fish survey sites downstream of junction at both Speen Moor and Northcroft showing recent signs of deterioration as reflected by increasing proportion of high tolerance fish species.	Improvement expected through improvements in water quality as a result of closure of existing weir and provision of fish ladder. Extent of improvement limited in part by existing habitat quality downstream of weir junction to Newbury. Also, discussion with Bob Preston (EA Fisheries Officer) suggested that during periods of increased algae/sediment in the canal it was possible to observe a clear difference in the colour of the water between the river and the canal; the implication was that the dominant flow pattern of the river water did not fully mix with the slow flowing canal water, in effect providing some natural separation limiting the potential for water quality impact.
Macroinvertebrates	No evidence of flow stress or impacts of organic pollution	Potential improvement by removing interaction with canal resulting in improved water quality
Macrophytes	Insufficient data	No significant change although removal of weir may result in some localised improvement
Habitat quality	Presence of major weir contributes to modification of the channel	Improvement from removal of weir.
		Potential reduction as weir will be replaced by other structure(s).

Relevant Options = All

Investigation is also required to assess the impact of the river re-joining the canal downstream at Newbury. At present there is insufficient water quality information to understand the implication of re-joining, and consequently it is not possible to fully assess the impact on ecology and fish. Section 2.8 suggests that poorer quality water may get retained under the new junction between the cleaner river water and the canal water at Marsh Benham Weir, leading to downstream improvement at Newbury. However, if this in not the case, a reduced dilution of canal water resulting from the separation of the cleaner river water may have a downstream impact on quality where the canal and river rejoin.

4.2.5. Fish pass implications

Associated with the channel diversion works identified under each of the options is the need to construct either culverts, siphons or build over existing canal / river systems. The construction of such structures is identified as having potential to affect fish passage through the reach. There are a number of legislative drivers pertaining to fish passage in freshwater systems these include:

- The Water Framework Directive (2000/60/EC)
  - Identifies the risk of failing to achieve “good ecological status” as a result of barriers to fish migration.

- The Eel (England & Wales) Regulations 2009
  - Part 4 of the Regulations provide the Environment Agency with new powers to serve notices requiring:
    - Provisions for passage of eels through dams and other obstructions.
    - Placement of screens over some intakes and outlets to protect eels.

- Environment Act 1995
  - The Environment Agency has a statutory duty to 'maintain, improve and develop salmon fisheries, trout fisheries, freshwater fisheries and eel fisheries.

- Habitats Directive (92/43/EEC)
  - Lists a number of fish species of relevance to the River Kennet as being subject to management measures e.g. lampreys, bullhead and salmon.

- Water Resources Act 1991
  - Responsibility on flood defence such that 'due regard shall be had to the interests of fisheries, including sea fisheries.

- Land Drainage Act 1991
  - Where land drainage consent is required for a structure, the consent should not be issued if the structure would impede fish migration.

This section identifies the likely impact of the options on fish passage. The assessment does not take into account wider fish passage in the River Kennet and Kennet and Avon Canal i.e. it considers the direct impact of any new structures on fish passage in the River Kennet in isolation.

It should be note that at this stage it is not possible to ascertain the change in flow conditions that will result from the construction of individual structures. Hydraulic modelling will be required to determine flow velocities through the individual structures to provide a more robust assessment of impacts on individual fish species passage in relation to their swimming ability.

Table 13. Impact of options on fish passage

Fish pass element	Preliminary assessment of potential change in fish passage and reason
Culvert under canal (Options 1, 2 and 5)	Culverts can impede fish passage due to the habitat severance they create. Considered that extent of culverting required under these option will not provide a significant impedance to fish movement within the River Kennet.
Siphon under canal (Option 3 and 4)	Siphons required under these options will impede fish passage through the River Kennet as a result of hydraulic jump created by the structure.
Divert canal over River Kennet (Option 6)	Diversion of canal over the River Kennet is not considered to create significant barrier to fish passage in the River Kennet although shading impacts on existing macrophyte community (and associated macroinvertebrates) will result.
Culvert and fish ladder at Marsh Benham Weir junction. (All options)	Considered to improve fish passage and improve habitat connectivity over existing weir and sluice arrangement.

Note: This preliminary assessment

5. Overall Options Appraisal

5.1. Option Costs

The costs proposed in the HR Wallingford (2007) report for each of the options are shown in Table 14. Since it is proposed that any downstream works where the river and canal currently rejoin are undertaken as a second phase once the flow interaction has been investigated further, we have separated the costs to those for separating the river and canal, and those for keeping the river separate at the downstream location.

Table 14. Option Costs (based on Halcrow 2007)

	Upstream Works	Downstream Works	Notes
Option 1 and 3. River diversion to the north of the canal	£1.2M	£1.2M	No costs have been included for the ongoing maintenance required for the siphon in particular or for the required channel lowering through Craven Fishery. Based on the volume of bed material needed to be removed an additional cost of £0.5M (disposal on site) to £1M (disposal off site) could be expected
Option 2 and 4. River diversion to the south of the canal	£2.1M	£1.3M	Difference in downstream cost from other options is as reported by HR Wallingford (2007) The costs for land excavation are potentially low. The detailed topography suggests a cost of £2M* rather than the £0.5M; both do not include optimisation bias. Incorporating the difference increases total cost to £4.6M No costs have been included for the ongoing maintenance required for the siphon in particular
Option 5. River diversion to the south and relocating Copse Lock	£3.9M	£1.2M	£2.5M of the upstream works is for relocating Copse Lock. As above, the cost of excavation may be considerably under estimated. Total cost would rise to £6.4M with extra excavation included
Option 6. Canal diversion to the north and relocating Copse Lock	£5.5M	£1.2M	£2.5M of the upstream works is for relocating Copse Lock

Note: Costs are rounded to match the costs reported in the HR Wallingford (2007) report

* Based on Spon's price book cost of excavation, movement of the material to an appropriate landfill and disposal

The costs presented include the required construction works, fixed percentages for management and preliminaries, and a 40% contingency. The key difference in the costs between the different options is the degree of engineering required.

5.2. Multi-criteria analysis

Sections 2, 3 and 4 have considered each of the options put forward based on engineering considerations, effectiveness considerations for changing water quality and impact on ecology and fisheries. The engineering considerations considered each of the individual options from a technical viability. The water quality, ecology and fisheries assessment assumed that each option will deliver the same outcome since they are just different ways of separating the river from the canal. The assessment of options therefore differentiates between options on the basis of engineering considerations only (Table 15).

At this initial feasibility stage we have not fully considered implementation considerations such as detailed flood risk modelling, water resource implications or visual impact assessment. We have however applied professional judgement to score these elements in order to incorporate them into the multi-criteria analysis since they will vary between the different options.

Table 15. Copse Lock Multi Criteria Analysis

	Criteria Group	Implementation/Delivery				Engineering/Technical					
	Group weighting	0.6				0.8					
	Individual weighting within group	1	0.9	0.9	0.4	1	1	1	0.8		
	Criteria	**Compliance with Statutory Stakeholders (EA; NE; BDC; NCC)**	**Agreement with Non-statutory Stakeholders (NACA; owners; occupiers)**	**Water resource**	**Human Environment: Archaeology; landscape; recreation**	**Technical Feasibility & practicality**	**Geomorphic form & function**	Flood Risk	Climate Change & sustainability	Total Raw Score (max 16)	Total weighted score (max 9.92)
	Individual weighting factor =	0.6	0.54	0.54	0.24	0.8	0.8	0.8	0.64		
Option No.	Option										
1 River diversion north of canal	Raw score	1	1	0	1	-1	1	1	1	**5**	
	Weighted score	0.6	0.54	0	0.24	-0.8	0.8	0.8	0.64		**2.82**
2 River diversion south of canal	Raw score	0	1	0	-1	-1	0	0	0	**-1**	
	Weighted score	0	0.54	0	-0.24	-0.8	0	0	0		**-0.5**
3 River diversion north of canal	Raw score	-2	1	0	1	-1	1	1	1	**2**	
	Weighted score	-1.2	0.54	0	0.24	-0.8	0.8	0.8	0.64		**1.02**
4 River diversion south of canal	Raw score	0	1	0	-1	-1	0	0	0	**-1**	
	Weighted score	0	0.54	0	-0.24	-0.8	0	0	0		**-0.5**
5 River south diversion and move Copse Lock	Raw score	-1	1	0	-1	-1	0	0	0	**-2**	
	weighted score	-0.6	0.54	0	-0.24	-0.8	0	0	0		**-1.1**
6 Canal north diversion and move Copse Lock	Raw score	-1	1	0	-2	0	1	1	1	**1**	
	weighted score	-0.6	0.54	0	-0.48	0	0.8	0.8	0.64		**1.7**
Total Score		-2.6	-5.8	8.24	0	-4.72	-8	4.4	4.4	3.92	

Score	**Description**
2	High Relevance
1	Low Relevance
0	Neutral
-1	Low Detriment
-2	High Detriment

5.3. Summary Cost – Benefit Assessment

Each of the options has been considered for their engineering feasibility and for the potential benefits that will be gained by separating the River Avon from the Kennet and Avon Canal at Copse Lock. The costs have been considered too. Technically four options can be dismissed either due to level constraints or due to the environmental impact required. Two options are possible from an engineering perspective; extending the canal to the north or creating a new river channel to the north and culverting under the canal at Hamstead Lock.

There will be some benefit to water quality from separating the river and canal but further work is required to fully understand the impact on nutrient levels, and in particular phosphorous in the newly separated river. From a fisheries perspective, the improvement in water quality is likely to be a benefit for all options; however, the option to siphon the river under the canal will cause a barrier to upstream fisheries movement.

The assessment of the feasibility of the options is summarised in Table 16.

Table 16. Summary of feasibility of each option

<table>
<tr><th></th><th colspan="6">Option</th></tr>
<tr><th></th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th></tr>
<tr><td>Engineering</td><td>Levels require downstream level lowered, and channel is physically altered by 2.5m through Craven fishery</td><td>Significant environmental impact due to excessive earth excavation</td><td>Technically possible without changing existing river level</td><td>Significant environmental impact due to excessive earth excavation</td><td>Significant environmental impact due to excessive earth excavation</td><td>Technically possible without changing existing river level</td></tr>
<tr><td>Water quality</td><td colspan="6">Potential for reduced algal activity in the river but phosphorus levels may rise</td></tr>
<tr><td>Ecology</td><td colspan="5">Habitat can be designed into new river channels although engineering required will mean a semi-natural habitat with potential weir, culvert or siphon structures</td><td>Physical habitat is unlikely to change but water quality will</td></tr>
<tr><td rowspan="4">Fisheries</td><td colspan="5">Potential reduction in fisheries quality of Kennet and Avon Canal due to removal of river flow inputs from Kennet through river diversion.</td><td>Improvement in Kennet and Avon Canal.</td></tr>
<tr><td colspan="6">Potential improvement in fisheries quality of River Kennet at Craven fishery due to removal of canal water influence.</td></tr>
<tr><td colspan="5">Improvement in fisheries quality through creation of additional fisheries habitat receiving waters from the Kennet only i.e. no influence from canal water input.</td><td>Increase in extent of canal but with limited fisheries value.</td></tr>
<tr><td>Fish passage issues addressable</td><td>Fish passage issues addressable</td><td>Fish passage likely to be affected.</td><td>Fish passage likely to be affected.</td><td>Fish passage issues addressable</td><td>Fish passage issues addressable</td></tr>
<tr><td>Implementation</td><td>Downstream levels lowered</td><td>Large landscape impact</td><td>Unlikely to comply with environment objectives</td><td>Large landscape impact</td><td>Large landscape impact</td><td>Large landscape impact</td></tr>
<tr><td>Cost</td><td>£1.2M*</td><td>£2.1M*</td><td>£1.2M</td><td>£2.1M*</td><td>£3.9M*</td><td>£5.5M</td></tr>
<tr><td>Cost with extra excavation</td><td>£1.7M to £2.2M</td><td>£4.6M</td><td>£1.2M</td><td>£4.6M</td><td>£6.4M</td><td>£5.5M</td></tr>
</table>

* Cost for excavation potentially under-estimated.

6. Conclusion and Recommendations

The overall assessment of the six potential options put forward in the HR Wallingford (2007) report has identified that two options are feasible and can be considered further in detailed phase 2 feasibility. The options are:

- Option 1. Divert the river to the north of the canal and then culvert under the canal at Hamstead Lock
- Option 6. Divert the canal to the north of the river

The topographical levels associated with the options mean that for option 1 the River Kennet channel will need to have its bed lowered by 2.5m in places through to the Craven fishery, and for Option 6 the new stretch of canal will need to be raised above the current floodplain by up to 4m in places.

Both options will benefit water quality in the river by separating it from the canal and removing mixing with algal rich water, although further work is required to quantify the changes to nutrient levels. Fish passage in the river will be maintained for both options, although fish passage in the canal may be reduced where it is separated from the river. The ecology of the new channel for option 1 can be designed to give benefit to the river whilst the ecology of the river for option 6 will be unchanged, but will benefit from improved water quality.

Investigation of flow dynamics at the point downstream of Craven Fishery where the canal and river re-join suggest that the proposed option to culvert the river under the canal may not be necessary because the turbulence created by faster flowing river water meeting slow flowing canal water creates a flow wall that holds water in the canal. This will need to be confirmed once the river and canal have been separated.

Detailed design is recommended for a phase 2 feasibility studies of options 1 and 6. A geotechnical investigation will be required to look at the feasibility of lowering the river Kennet through the Craven Fishery section, and a full landscape impact assessment required for the extending of the canal. The full benefits to water quality from these options will need further investigation by water quality modelling.

7. References

Defra, 1998. Schedule 2. Freshwaters in England and Wales to which Classification SW applies http://www.defra.gov.uk/environment/quality/water/waterquality/fwfish/98f-sch2.pdf

Environment Agency (2011) Results from an ecological survey of the River Kennet, Hungerford to Newbury. Unpublished draft.

Holmes, NTH, Newman, JR, Chadd, S, Rouen, K, Saint, L and Dawson, FH (1999) Mean Trophic Rank: A User's Manual. R&D Technical Report E38. Bristol: Environment Agency

OECD. Eutrophication of waters; monitoring, assessment and control. Paris: OECD; 1982. Tech. Report F 52/11.50, 153 pp.; as quoted in: Water & Wastewater Branch Nova Scotia Environment, 2010. Darrell Taylor-Project Lead. Water quality survey of ten lakes in the Carleton River watershed area Yarmouth and Digby Counties, Nova Scotia.
http://www.gov.ns.ca/nse/surface.water/docs/Yarmouth.Area.Lakes.Water.Quality.Assessment.2010.pdf

Fertiliser Manufacturers' Association, 1994. British Survey of Fertiliser Practice: Fertiliser use on Farm Crops. HMSO, London.

Halcrow, 2007. Kennet Chalkstream Restoration Project, Kennet Canal/River Interaction Scoping, Final Report.

Martin, E., 2008. Impacts of a working canal on the turbidity of a lowland chalk stream. A report on a placement with the Environment Agency in fulfilment of the requirements of the MSc. in Aquatic Resource Management of King's College London.

Natural England (1995). River Kennet SSSI Citation. 1 November 1995.

Natural England (2008) Conservation Objectives and Definitions of Favourable Condition for the River Kennet SSSI. Consultation Draft March 2008

Natural England (2011)
http://www.sssi.naturalengland.org.uk/special/sssi/unit_details.cfm?situnt_id=1027151

Neal, C., Martin, E., Neal, M., Hallett, J., Wickham, H.D., Harman, S.A., Armstrong, L.K., Bowes, M.J., Wade, A.J., Keay, D., 2010. Sewage effluent clean-up reduces phosphorus but not phytoplankton in lowland chalk stream (River Kennet, UK) impacted by water mixing from adjacent canal. Science of the Total Environment, 408: 5306-5316.

Wade, A. J., Durand, P., Beaujouan, V., Wessel, W. W., Raat, K. J., Whitehead P. G., Butterfield, D., Rankinen, K. & Lepisto, A. (2002a) A nitrogen model for European catchments: INCA, new model structure & equations. Hydrol. Earth System Sci., 6, 559–582.Whitehead et al, 1998.

Wade, A.J., Whitehead, P.G. and Butterfield., D. , 2002b. The Integrated Catchments model of Phosphorus dynamic (INCA-P), a new approach for multiple source assessment in heterogeneous river systems: model structure and equations. HESS, 6 (3):583-506.

Whitehead, P. G., Wilson, E. J., Butterfield, D. and Seed, K., 1998b. A semi-Distributed Integrated Flow and Nitrogen Model for Multiple Source Assessment in Catchments (INCA): Part II Application to large River Basins in South Wales and Eastern England. Sci. Total Env., 210/211, 559-583.

WRA, 2007. Thames Water. Impacts of phosphorus removal from effluent on the water quality of the Kennet and Lambourn SSSIs (Version 1.0).

Zeckoski, R., 2010. Water quality modelling for the Kennet and Avon Canal, a navigational canal in an inland catchment. University of Cambridge, PhD Thesis.

Appendix A. Water quality - Analysis of Variance (ANOVA) single factor results

A.1. Kennet and Avon Canal, Hungerford and River Kennet, Wilderness

A.1.1. All data

turbidity

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Hungerford	509	19202.35511	37.72564855	2732.15898
Wilderness	509	4006.597742	7.871508333	310.4653181

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	226828.1356	1	226828.1356	149.1003248	4.27961E-32	3.850627526
Within Groups	1545653.143	1016	1521.312149			
Total	1772481.279	1017				

ammonia

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Hungerford	433	102.0119055	0.235593315	0.023543153
Wilderness	433	67.17558099	0.15513991	0.003310377

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.401350469	1	1.401350469	104.3699284	3.29102E-23	3.852243933

Within Groups	11.60072469	864	0.013426765
Total	13.00207515	865	

A.1.2. October-March

temperature

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Hungerford	222	1720.399624	7.749547854	7.149559542
Wilderness	222	1876.492876	8.452670614	3.721845291

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	54.87635929	1	54.87635929	10.09554149	0.001590502	3.86258298
Within Groups	2402.580468	442	5.435702416			
Total	2457.456827	443				

chlorophyll

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Hungerford	222	5793.354096	26.09618962	3481.062217
Wilderness	222	651.0470152	2.932644212	43.16314965

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	59557.03179	1	59557.03179	33.79865111	1.17239E-08	3.86258298
Within Groups	778853.806	442	1762.112683			
Total	838410.8378	443				

DO% saturation

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Hungerford	222	23223.15516	104.608807	314.2205178
Wilderness	222	22519.65585	101.4398912	32.03133021

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1114.665035	1	1114.665035	6.438464033	0.011510152	3.86258298
Within Groups	76521.65841	442	173.125924			
Total	77636.32345	443				

turbidity

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Hungerford	222	6301.721109	28.38613112	2021.656061
Wilderness	222	1924.441405	8.668654976	70.09298394

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	43154.45407	1	43154.45407	41.26159797	3.44687E-10	3.86258298
Within Groups	462276.5389	442	1045.874522			
Total	505430.993	443				

ammonia

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Hungerford	166	40.840613	0.25	0.039770784
Wilderness	166	32.23542051	0.19	0.00237635

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.223040174	1	0.223040174	10.58388335	0.001258809	3.869791671
Within Groups	6.954277093	330	0.021073567			
Total	7.177317267	331				

A.1.3. April-September

temperature

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Hungerford	290	4655.936567	16.05495368	11.17823657
Wilderness	279	3938.443855	14.11628622	6.105313135

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	534.4370728	1	534.4370728	61.49328176	2.21557E-14	3.85791111
Within Groups	4927.78742	567	8.690983104			
Total	5462.224493	568				

chlorophyll

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Hungerford	290	12216.29227	42.12514577	512.2540971
Wilderness	287	626.8931859	2.184296815	1.241388524

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	230111.6809	1	230111.6809	891.6264346	5.2137E-119	3.857681486
Within Groups	148396.4712	575	258.0808195			
Total	378508.1521	576				

DO% saturation

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Hungerford	290	35656.45485	122.9532926	535.8786086
Wilderness	277	28840.28262	104.1165438	109.9145933

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	50269.73566	1	50269.73566	153.3562681	2.48848E-31	3.857969535
Within Groups	185205.3456	565	327.7970719			
Total	235475.0813	566				

turbidity

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Hungerford	290	12990.34233	44.79428391	3140.166036
Wilderness	287	2082.156337	7.254900129	496.4183386

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	203272.3744	1	203272.3744	111.3705941	6.41057E-24	3.857681486
Within Groups	1049483.629	575	1825.188921			
Total	1252756.004	576				

ammonia

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Hungerford	270	62.28379251	0.23	0.013539194
Wilderness	267	34.94016049	0.13	0.002358968

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.337594457	1	1.337594457	167.6093747	1.53067E-33	3.858898508
Within Groups	4.269528694	535	0.007980427			
Total	5.607123151	536				

A.2. Kennet and Avon Canal, Copse Lock & Craven Fishery

A.2.1. All data

temperature

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Craven Fishery	707	8191.997324	11.58698348	15.66753689
Copse Lock	684	7974.310239	11.6583483	20.06318971

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.770584705	1	1.770584705	0.099309421	0.75270727	3.848162134
Within Groups	24764.43962	1389	17.82897021			
Total	24766.2102	1390				

chlorophyll

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Craven Fishery	707	3261.174863	4.61269429	44.92700405
Copse Lock	684	10733.05013	15.69159375	2184.823667

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	42671.86538	1	42671.86538	38.89307601	5.92877E-10	3.848162134
Within Groups	1523953.03	1389	1097.158409			
Total	1566624.895	1390				

DO % sat

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Craven Fishery	707	70547.9647	99.78495714	100.62882
Copse Lock	684	69327.36119	101.3557912	199.7912978

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	857.8453699	1	857.8453699	5.7423574	0.016692129	3.848162134
Within Groups	207501.4033	1389	149.3890593			
Total	208359.2487	1390				

turbidity

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Craven Fishery	704	10992.16612	15.61387233	739.5456545
Copse Lock	684	19960.25524	29.1816597	3886.446213

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	63864.18182	1	63864.18182	27.88474528	1.49333E-07	3.848176662
Within Groups	3174343.359	1386	2290.291024			
Total	3238207.541	1387				

ammonia

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Craven Fishery	693	134.0195714	0.193390435	0.022558374
Copse Lock	656	174.6777682	0.266277086	0.619143022

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.790280626	1	1.790280626	5.726019955	0.016851596	3.848371431
Within Groups	421.1490743	1347	0.312657071			
Total	422.9393549	1348				

A.2.2. October-March

temperature

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Craven Fishery	364	3160.403	8.682426	5.265414
Copse Lock	363	3046.924	8.393731	7.574954

ANOVA

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	15.14783	1	15.14783	2.359994	0.124919	3.854317
Within Groups	4653.479	725	6.418591			

Total	4668.627	726

chlorophyll

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Craven Fishery	365	1335.109	3.657834	80.64049
Copse Lock	364	2746.495	7.545316	40.98492

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2754.252	1	2754.252	45.27043	3.48E-11	3.854281
Within Groups	44230.67	727	60.83998			
Total	46984.92	728				

DO % sat

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Craven Fishery	365	35215.32	96.48032	38.47266
Copse Lock	364	35303.08	96.98648	67.07909

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	46.69185	1	46.69185	0.885049	0.347135	3.854281
Within Groups	38353.76	727	52.7562			
Total	38400.45	728				

turbidity

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Craven Fishery	365	3417.64	9.363398	66.46241
Copse Lock	364	4502.336	12.36906	320.9782

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1646.44	1	1646.44	8.506744	0.003647	3.854281
Within Groups	140707.4	727	193.5452			
Total	142353.8	728				

ammonia

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Craven Fishery	365	75.16716	0.205937	0.018603
Copse Lock	364	98.83147	0.271515	0.03183

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.783751	1	0.783751	31.09228	3.47E-08	3.854281
Within Groups	18.32566	727	0.025207			
Total	19.10942	728				

A.2.3. September-April

temperature

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Hungerford	290	4655.936567	16.05495368	11.17823657
Wilderness	279	3938.443855	14.11628622	6.105313135

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	534.4370728	1	534.4370728	61.49328176	2.21557E-14	3.85791111
Within Groups	4927.78742	567	8.690983104			
Total	5462.224493	568				

chlorophyll

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Hungerford	290	12216.29227	42.12514577	512.2540971
Wilderness	287	626.8931859	2.184296815	1.241388524

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	230111.6809	1	230111.6809	891.6264346	5.2137E-119	3.857681486
Within Groups	148396.4712	575	258.0808195			
Total	378508.1521	576				

DO% saturation

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Hungerford	290	35656.45485	122.9532926	535.8786086
Wilderness	277	28840.28262	104.1165438	109.9145933

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	50269.73566	1	50269.73566	153.3562681	2.48848E-31	3.857969535
Within Groups	185205.3456	565	327.7970719			
Total	235475.0813	566				

turbidity

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Hungerford	290	12990.34233	44.79428391	3140.166036
Wilderness	287	2082.156337	7.254900129	496.4183386

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	203272.3744	1	203272.3744	111.3705941	6.41057E-24	3.857681486
Within Groups	1049483.629	575	1825.188921			
Total	1252756.004	576				

ammonia

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Hungerford	270	62.28379251	0.23	0.013539194
Wilderness	267	34.94016049	0.13	0.002358968

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.337594457	1	1.337594457	167.6093747	1.53067E-33	3.858898508
Within Groups	4.269528694	535	0.007980427			
Total	5.607123151	536				

Appendix B. Fish Data

B.1. List of species (indicators) used for the Fisheries Classification Scheme

Low tolerance

Salmon (*Salmo salar*)

Brown and sea trout (*Salmo trutta*)

Grayling (*Thymallus thymallus*)

Lamprey (*Lampetra planeri, Lampetra fluviatilis, Petromyzon marinus*)

Bullhead (*Cottus gobio*)

Medium tolerance

Stone loach (*Barbatula barbatula*)

Barbel (*Barbus barbus*)

Spined loach (*Cobitis taenia*)

Pike (*Esox lucius*)

Gudgeon (*Gobio gobio*)

Ruffe (*Gymnocephalus cernuus*)

Chub (*Leuciscus cephalus*)

Dace (*Leuciscus leuciscus*)

Minnow (*Phoxinus phoxinus*)

Rudd (*Scardinius erythrophthalmus*)

High tolerance

Bream (*Abramis brama*)

Bleak (*Alburnus alburnus*)

Eel (*Anguilla anguilla*)

Common carp (*Cyprinus carpio*)

3-spined stickleback (*Gasterosteus aculeatus*)

Perch (*Perca fluviatilis*)

Roach (*Rutilus rutilus*)

Tench (*Tinca tinca*)

B.2. Fish species, biomass and density data

Willow stream fisheries data

	2004		2005		2006		2007		2008		2009		2010		2011	
Species	Biomass (g m^{-2})	Density (n m^{-2})	Biomass (g m^{-2})	Density (n m^{-2})	Biomass (g m^{-2})	Density (n m^{-2})	Biomass (g m^{-2})	Density (n m^{-2})	Biomass (g m^{-2})	Density (n m^{-2})	Biomass (g m^{-2})	Density (n m^{-2})	Biomass (g m^{-2})	Density (n m^{-2})	Biomass (g m^{-2})	Density (n m^{-2})
Chub					0.3	0.001							5.28	0.01	1.87	0.01
Barbel																
Dace	0.324	0.011	0.2	0.005	<0.1	0.001			0.7	0.033	0.5	0.014	0.44	0.00	0.42	0.01
Bleak																
Gudgeon	0.2	0.010	0.1	0.003					0.0	0.001	0.0	0.002	0.07	0.00		
Roach	0.9	0.009	<0.1	0.001	0.6	0.014			3.5	0.072	2.5	0.047	1.58	0.02	4.19	0.08
Common bream													4.69	0.00	1.21	0.00
Roach x bream																
Perch	7.0	0.017	2.5	0.010	11.3	0.036			5.4	0.025	3.4	0.021	2.07	0.03	5.88	0.03
Ruffe																
Pike	7.1	0.006	1.0	0.001	0.3	0.001			5.5	0.010	5.7	0.010	5.28	0.00	4.46	0.00
Tench																
Common carp																
Brown trout	14.9	0.020	10.3	0.011	7.7	0.011			3.7	0.009	12.2	0.015	2.83	0.00	8.33	0.01
Rainbow trout	1.5	0.002	0.8	0.001	1.0	0.001							0.92	0.00		
Atlantic salmon																
Grayling	2.0	0.011	0.8	0.003	0.8	0.004			0.8	0.005	2.1	0.007	3.00	0.04	0.97	0.01
Total	33.809	0.086	15.752	0.036	22.135	0.069			19.681	0.154	26.544	0.116	26.158	0.123	27.339	0.154

Marsh Benham

	2004		2005		2006		2007		2008		2009		2010	
Species	Biomass (g min^{-1})	Density (n min^{-1})	Biomass (g min^{-1})	Density (n min^{-1})	Biomass (g min^{-1})	Density (n min^{-1})	Biomass (g min^{-1})	Density (n min^{-1})	Biomass (g min^{-1})	Density (n min^{-1})	Biomass (g min^{-1})	Density (n min^{-1})	Biomass (g min^{-1})	Density (n min^{-1})
Chub			2.15	0.05	2.8	0.10			3.0	0.04	10.8	0.080	6.4	0.060
Barbel														
Dace	2.45	0.29	10.17	0.48	2.3	0.28			29.2	0.63	13.0	0.290		
Bleak									0.5	0.02			10.1	0.340
Gudgeon					0.1	0.03			0.6	0.04	2.0	0.120	0.0	0.020
Roach	52.90	0.67	125.43	2.55	186.9	3.10			198.3	3.52	44.7	0.840	10.0	3.580
Common bream					0.1	0.03			21.9	0.02				
Roach x Bream hybrid														
Perch	709.69	1.86	110.17	0.57	171.2	1.07			106.4	0.68	46.3	0.290	13.0	0.280
Ruffe											0.03	0.020		
Pike	573.59	0.67	9.21	0.02	203.6	0.48			122.2	0.23	226.4	0.240	110.5	0.420
Tench														
Common carp			111.09	0.02										
Brown trout			21.00	0.02					37.1	0.05			21.8	0.020
Rainbow trout	72.84	0.10												
Atlantic salmon													7.4	0.260
Grayling														
Total	1411.470	3.590	389.220	3.710	567.000	5.090			519.190	5.230	343.270	1.880	179.260	4.980

Speen Moor

	2004		2005		2006		2007		2008		2009		2010	
Species	Biomass (g min^{-1})	Density (n min^{-1})	Biomass (g min^{-1})	Density (n min^{-1})	Biomass (g min^{-1})	Density (n min^{-1})	Biomass (g min^{-1})	Density (n min^{-1})	Biomass (g min^{-1})	Density (n min^{-1})	Biomass (g min^{-1})	Density (n min^{-1})	Biomass (g min^{-1})	Density (n min^{-1})
Chub					67.6	0.24					71.8	0.10		
Barbel					110.7	0.04								
Dace					4.1	0.32					2.4	0.08		
Bleak					5.2	0.40								
Gudgeon														
Roach					35.6	1.00					15.1	0.33		
Common bream					170.9	0.28					962.8	0.65		
Roach x bream														
Perch					87.7	0.24					55.7	0.37		
Ruffe														
Pike					660.0	0.24					309.5	0.20		
Tench														
Common carp					110.7	0.04								
Brown trout											2.6	0.04		
Rainbow trout														
Atlantic salmon														
Grayling														
Total					1252.310	2.800					1420.000	1.770		

Northcroft

	2004		2005		2006		2007		2008		2009		2010	
Species	Biomass (g min^{-1})	Density (n min^{-1})	Biomass (g min^{-1})	Density (n min^{-1})	Biomass (g min^{-1})	Density (n min^{-1})	Biomass (g min^{-1})	Density (n min^{-1})	Biomass (g min^{-1})	Density (n min^{-1})	Biomass (g min^{-1})	Density (n min^{-1})	Biomass (g min^{-1})	Density (n min^{-1})
Chub	111.06	0.86	219.35	0.52	84.7	0.29			26.9	0.12	172.8	0.100	64.8	0.050
Barbel														
Dace	6.25	0.22	8.64	0.52	2.9	0.13			9.7	0.58	3.1	0.140	7.5	0.280
Bleak	1.51	0.11			2.9	0.16							4.1	0.120
Gudgeon	6.27	0.84	13.91	1.22	4.4	0.47			4.8	0.34	1.5	0.100	1.3	0.120
Roach	211.27	4.65	177.53	2.91	88.1	1.82			191.6	4.46	140.6	3.670	301.3	5.140
Common bream	22.62	0.22			2.1	0.02			15.8	0.08	43.4	0.310	18.5	0.210
Roach x Bream hybrid			12.94	0.04										
Perch	25.88	0.38	123.09	0.35	102.4	0.71			26.3	0.74	91.1	1.370	69.4	1.460
Ruffe														
Pike	106.95	0.19			25.9	0.02			125.3	0.20	118.4	0.100	79.2	0.120
Tench					53.3	0.09			22.2	0.02	53.4	0.040		
Common carp														
Brown trout	24.83	0.05									16.6	0.020		
Rainbow trout														
Atlantic salmon														
Grayling														
Total	516.640	7.520	555.460	5.560	366.730	3.710			422.500	6.540	640.910	5.850	546.020	7.500

Contact name
Peter Stone
Atkins Limited
The Hub, 500 Aztec West, Park Avenue, Almondsbury, Bristol BS32 1RZ

Email: peter.stone@atkinsglobal.com
Telephone 0117 9538934